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ENERGY CONSERVATION IN FEDERAL AND FEDERALLY ASSISTED BUILDINGS

HEARINGS

BEFORE THE

SUBCOMMITTEE ON BUILDINGS AND GROUNDS

OF THE

COMMITTEE ON PUBLIC WORKS

UNITED STATES SENATE

NINETY-FOURTH CONGRESS

FIRST SESSION

ON

S. 1392

A BILL TO ESTABLISH A DEMONSTRATION PROGRAM IN ENERGY CONSERVATION, USING PROMISING INNOVATIVE TECHNOLOGY TO THE MAXIMUM EXTENT POSSIBLE THROUGH RETROFITTING EXISTING BUILDINGS WITH ENERGY CONSERVATION EQUIPMENT AND SYSTEMS, AND FOR OTHER PURPOSES

S. 2045

A BILL TO INSURE THAT FEDERAL BUILDINGS AND CERTAIN BUILDINGS ASSISTED WITH FEDERAL FUNDS EMPLOY THE BEST PRACTICABLE ENERGY CONSERVATION AND MANAGEMENT PRACTICES, AND FOR OTHER PURPOSES

S. 2095

A BILL TO REQUIRE THAT BUILDINGS FINANCED WITH FEDERAL FUNDS UTILIZE THE BEST PRACTICABLE MEASURES FOR THE CONSERVATION OF ENERGY AND THE USE OF SOLAR ENERGY SYSTEMS

NOVEMBER 4 AND 5, 1975

SERIAL NO. 94–H27

Printed for the use of the Committee on Public Works

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ENERGY CONSERVATION IN FEDERAL AND FEDERALLY ASSISTED BUILDINGS

TUESDAY, NOVEMBER 4, 1975

U.S. SENATE,
COMMITTEE ON PUBLIC WORKS,
SUBCOMMITTEE ON BUILDINGS AND GROUNDS,
Washington, D.C.

The subcommittee met at 2 p.m., pursuant to call, in room 4200, Dirksen Senate Office Building, Hon. Robert Morgan (chairman of the subcommittee) presiding.

Present: Senators Morgan and Randolph.

Senator MORGAN. We will call the committee to order. There will be a vote in the Senate in just a few moments. Our distinguished chairman, Senator Randolph, also has another conference meeting afterwards.

Since he is the introducer of one of the three important bills that we are going to be considering, I would like to forgo my opening statement and yield to Senator Randolph with the hope that we can hear as much from him as possible about his bill prior to the vote.

Of course, after he has gone and we come back, he will have a representative here that we can talk to about it. But I am very much interested, as I am sure you are, in hearing as much from our chairman as possible.

So with that understanding, Senator Randolph, we will recognize you and be interested in hearing about S. 2045.

OPENING STATEMENT OF HON. JENNINGS RANDOLPH, U.S. SENATOR FROM THE STATE OF WEST VIRGINIA

Senator RANDOLPH. Thank you very much, Mr. Chairman. I appreciate your understanding of the scheduling problems which all of us have, and you are included in that group.

Mr. Chairman, and those persons who are intensely interested in this subject matter, and who are guests at this hearing, I think it is well known that there is a very real energy problem in America and that we must develop our resources to supply a greater portion of our needs from the resources which exist in our country.

But equally important, we must conserve our nonrenewable resources as we foster greater utilization of our vast energy resources, and as we think in terms of solar energy.

The February 1975 Congressional Program of Economic Recovery and Energy Self-Sufficiency sets forth comprehensive national energy policy. It identifies a series of actions designed to conserve the use of energy.

Federal agencies would be required to give energy conservation the highest priority in their actions. In recognition of the vital role that energy conservation can serve in the promotion of self-sufficiency, the first energy action by the 94th Congress was approval of our Senate Resolution 58 endorsing a voluntary national energy conservation crusade.

This resolution was cosponsored by the able chairman of the subcommittee. There were 44 Democrats and 25 Republicans who joined in this resolution that I presented.

This initiative on the energy conservation through voluntary action in part was endorsed by the President of the United States but it was never fully implemented by the administration.

I am not a carping critic, but I do believe that there has been a failure of the administration, as well as the agencies in the Government, to understand their obligations and their opportunities to conserve energy.

So this step was important because it indicated that the Federal Government could be a leader in energy conservation.

I did introduce after the action that has been mentioned, S. 2045, the Federal Facilities Energy Conservation and Utilization Act of 1975.

This measure requires the General Services Administration to develop and implement energy conservation practices in Federal building construction and in renovation and in refurbishing all of the opportunities which are there if they are studied carefully and they are utilized.

It also will commit our Federal Government to a policy of energy conservation in all Federal and federally assisted construction. The measure, Mr. Chairman, is modeled after similar legislation that was approved by the Senate and by the House in the 93d Congress.

Over 2 years ago the Senate passed S. 2176, which directed all Federal agencies to consider energy conservation in the construction of Federal facilities and federally insured buildings.

These provisions, Mr. Chairman, were subsequently incorporated by the Committee on Public Works into H.R. 11565, and that passed the Senate in December 1973.

Although a compromise measure was formulated between our two bodies, it did not receive final approval before the adjournment of the 93d Congress.

This was the measure introduced as S. 2045, which I am speaking about today, the Federal Facilities Energy Conservation and Utilization Act.

By publication of energy conservation guidelines, one for office buildings that are new ond one for office buildings that are now in use, the General Services Administration, I believe, has demonstrated a

certain substantial leadership in its efforts to conserve energy in Government facilities.

We must now expand on our knowledge and on our understanding, making energy conservation a permanent consideration in the widest range of our lives. This means that, among other facts, we must examine the programs which have been authorized by the Committee on Public Works.

Mr. Chairman, you, in your Subcommittee on Buildings and Grounds, are coming to grips with this matter in the hearings which begin today.

I commend you for this initiative and I assure you of my utmost cooperation. It doesn't necessarily have to be the bill on which I make the premise of these remarks. It will be my pleasure to work with you and with others in the development of legislation that can bring into being the goals which I have indicated are necessary.

We need really a crusade of conservation within the Federal structure. This does not seem to diminish that which has been done. It seems only to me to be encouraging to that which can and must be done.

Certainly, the example that we in the Federal Government can give to people in other political subdivisions can be of immeasureable value as we move forward in this important area of the conservation of fuels and energy thinking in terms not only of lessening the imports as we are trying to do now in the conference which is underway this afternoon; thinking in ways, of course, of the productivity of energy within our own country, but realizing that there also is the opportunity through creativity, through resourcefulness, for people within Government to do this job.

I thank you, Mr. Chairman, very, very much.

Senator MORGAN. Thank you very much, Mr. Chairman.

We will pursue your bill as we go along with the hearings. We have a vote on. We have 5 minutes to vote. So I will declare a recess and go vote and come back. Then maybe we can get on with the hearings.

[Brief recess.]

OPENING STATEMENT OF HON. ROBERT MORGAN, U.S. SENATOR FROM THE STATE OF NORTH CAROLINA

Senator MORGAN. We will come back to order.

I had an opening statement which I had proposed to make before we began the hearings. We have already heard from Senator Randolph. For the record, I think I will make it so that all of you here may know what we will be trying to do for the next 3 or 4 days.

We are here to discuss three bills that are now pending before this committee and these all propose methods to achieve reduced energy consumption in Government buildings.

There is S. 2045, which was introduced by the chairman of the parent committee, Senator Randolph, and you have heard him discuss that bill briefly.

S. 2095, introduced by Senator Gary Hart, of Colorado, and others. You will hear from Senator Hart shortly.

These two bills would try to reduce energy consumption through use of new analysis and design techniques. Both would authorize demonstration systems and encourage use of more efficient equipment.

S. 1392, which we will also be considering, that was introduced by Senator Tunney, provides for retrofitting existing buildings with energy saving equipment and materials.

Some 14 percent of all energy resources in this country are currently consumed by commercial and Federal office buildings. Progress has been made in the last 2 years to reduce this percentage by GSA and other agencies of Government working on their own initiative.

Mainly, this was done by cutting back on lights, heating, air conditioning, and operational practices that come under their control. This is primarily a matter of judicious budgeting and had resulted in a reduction of 20 to 30 percent below their previous needs which I think is extremely commendable.

Now the stage is set. We know, for instance, that savings can be made. These efforts have related mainly to buildings that are occupied, where various procedures could be tried and observed on a day-to-day basis.

Evaluations of the economy and efficiency could be made as they went along. Based on this, and with the help of outside consultants, GSA and others have developed and published workable guidelines that can affect substantial energy savings in existing buildings and also affect substantial energy savings in the design and construction of new buildings. I hope that we can discuss these later in more detail, and we will.

The three bills before us all have, as their major goal, the reduction of energy consumption in Federal and federally assisted buildings. They would mandate this legislatively, rather than have it proceed on a voluntary or strictly agency-oriented basis.

Advocates think it necessary in order to formulate a national standard, which they believe is essential. They feel some agencies might not be inclined to subordinate their individual efforts in this respect, and are concerned that no agency has jurisdiction over construction and procurement policies in any other.

Opponents feel that to legislate technical procedures is wrong and unnecessary in this case. They think it would inhibit efforts already underway to resolve the Nation's energy problems, as these pertain to Federal buildings.

To be frank, I am also concerned at this point, before hearing the testimony. These bills seem to have one thing in common and that is rather high cost. $300 million, which one of them would authorize, is a lot of money and I have doubts as to whether or not the budget can stand it.

Also, they all propose additional research, studies, and reports, and I wonder if these are necessary since much of this, including the publication of technical guidelines, already has been done.

It will be the purpose of this committee, during the course of the hearing, to try and pull together as much as possible all of the research

that has been done, and facts that are available so that when we come to voting on these bills, we can eliminate duplication wherever possible.

Further, each bill would assign responsibility for a Federal energy conservation program to different agencies. Each of these have diversified interests that may not be compatible with developing and enforcing an across-the-board national set of standards.

I wonder just how far we can go in setting up new materials and procurement regulations, or determining the merits of a proposal on the basis of how much energy was used in the manufacture and handling of construction materials.

Also, I wonder if life cycle cost projections can be relied upon in all cases, particularly where alterations or retrofit projects are concerned.

I am very much interested in the conference that is now going on at Harvard, concerning life cycle costing. I had the privilege of being there yesterday morning. I think it is going to be a rather challenging and enlightening program, and I look forward to seeing and hearing some of the results from that.

I also look forward to hearing the testimony that those of you who are present are going to offer. We will have some technical questions that were prepared by staff, and hope you can furnish us some answers and information.

And as a layman I will have many questions that may seem somewhat naive and simple, but unless I have a clear understanding of what you are talking about, I could not vote very intelligently.

One of the things I particularly want to do as we begin these hearings, is to make sure we have a clear understanding of each of the three bills, which will serve as a basis of understanding in the days to come.

You heard Senator Randolph give a résumé and statement on his bill, which I suggest we come back to shortly. It may be well, however, since we have Senator Hart here, to move our schedule ahead and hear from him.

Senator Hart, are you ready now?

Senator HART. Yes; I am.

Senator MORGAN. So rather than go further with the chairman's bill, S. 2045, let's discuss your S. 2095. We are very appreciative of your coming in and taking the time to present your bill.

I know you won't be able to stay long, but I hope you will have someone here from your staff, for to me the subject is one of the most crucial that I have ever had the privilege to participate in.

I talked to Senator Randolph and he agrees that we should not limit the hearings in any way until we have gotten all the information and facts that we can. So we welcome your statement today and anything further you have to offer as we go along. We need as much input from you as possible.

[The bills, S. 1392, 2045, and 2095 follow:]

94TH CONGRESS
1ST SESSION

S. 1392

IN THE SENATE OF THE UNITED STATES

APRIL 9, 1975

Mr. TUNNEY introduced the following bill; which was read twice and referred to the Committees on Commerce, Public Works, and Government Operations jointly by unanimous consent

A BILL

To establish a demonstration program in energy conservation, using promising innovative technology to the maximum extent possible, through retrofitting existing buildings with energy conservation equipment and systems, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Energy Conservation in Buildings Demonstration Act of 1975".

FINDINGS AND PURPOSE

SEC. 2. (a) The Congress finds and declares that—

(1) large amounts of fuel and energy are consumed unnecessarily each year in heating, cooling, ventilating,

providing hot water, lighting, and for other major energy uses in residential and commercial buildings because such buildings lack adequate energy-conservation features;

(2) substantial savings in fuel and energy could be accomplished by retrofitting such buildings with adequate energy-conservation features that would more than pay for themselves in reduced energy costs on a life-cycle basis; and

(3) the national interest will be best served by encouraging innovative technology and approaches so that a wide diversity of geographic and technological circumstances may be treated with a maximum of cost effectiveness.

(b) It is the intent of Congress to institute a demonstration program for retrofitting selected existing Federal, State, and municipal buildings for energy conservation, using promising innovative technology to the maximum extent possible, and to disseminate the results of that experience in order to promote this type of conservation nationwide.

DEFINITIONS

SEC. 3. DEFINITIONS.—As used in this Act—

(a) "Administrator" means the Administrator of the Federal Energy Administration.

(b) "Director" means the Director of the National Bureau of Standards.

(c) "Panel" means the Awards Panel as defined in section 4.

(d) "Governor" means a Governor of one of the fifty States.

(e) "Municipality" means a town, city, or other district in the United States which is not a State, which has powers of local self-government, and which owns at least ten buildings.

(f) "Executive" means mayor of a city or town, executive officer of a county or other municipality who has authority to contract for retrofitting of buildings which belong to that municipality.

DUTIES OF ADMINISTRATOR

SEC. 4. (a) Within ninety days after the enactment of this Act, the Administrator, in consultation with the Director of the National Bureau of Standards shall establish procedures for identifying existing buildings as candidates for retrofitting with energy conservation equipment and systems for the purpose of decreasing the cost of supplying such buildings with energy for climate-conditioning, water-heating, lighting, and other major uses of energy. In developing such procedures the Administrator and the Director shall consult with other Federal agencies and appropriate professional architectural and engineering societies as required to insure a broad perspective and maximum utilization of professional expertise.

(b) The Administrator shall establish and convene on a timely basis, as required, an Awards Panel for the purpose of awarding grants to States and municipalities under section 6 of this Act. The Panel shall consist of the Administrator or his designate, the Director or his designate, and one other person to be chosen by the Administrator. The Administrator shall designate one member of the Panel as Chairman.

(c) The Administrator shall publish in the Federal Register procedures established under (a) of this section, along with the provisions of this Act and necessary procedures for applicants, and shall also transmit a copy of same to the Administrator of the General Services Administration.

FEDERAL PROGRAM

SEC. 5. (a) On the basis of procedures established in section 4 the Administrator of the General Services Administration shall, within six months after the date of enactment of this Act, select no fewer than forty federally owned buildings as candidates for retrofitting with energy conservation equipment and systems. The buildings shall be selected so as to offer a wide range of geographic and technological circumstances and opportunities for implementation of energy conservation measures which can be justified on a life-cycle cost basis.

(b) The Administrator of the General Services Administration shall, within six months after the date of enact-

ment of this Act, solicit proposals for retrofitting each building identified in subsection (a) of this section with energy conservation equipment and systems. On the basis of the proposals received in response to his solicitations, the Administrator of the General Services Administration, in consultation with the Administrator and the Director, is authorized to award contracts for the design and installation of energy conservation equipment and systems in any or all of the federally owned buildings identified in subsection (a) of this section. In addition to the cost and estimated effectiveness of the proposal in achieving energy conservation, the potential for a novel and innovative approach to be of particular value in wide application shall be a factor in awarding contracts.

(c) Grants for Federal buildings shall be for the full cost of the contract, within the limit of funds available, but not to exceed $1,000,000 for any one building.

STATE AND MUNICIPAL PROGRAM

SEC. 6. (a) Governors of the fifty States and executives of municipalities may submit requests for grants for retrofitting of buildings owned by their respective States or municipalities. Requests for grants shall be submitted to the Panel, through the Administrator, and shall include, in accordance with procedures published by the Administrator in the Federal Register, a description of their State or municipal awards

panel, the criteria and procedures by which it will select proposals for awards, and an identification of the State or municipal buildings for which grants are to be sought.

(b) The Panel is authorized to allocate grants to States and municipalities from funds appropriated for those purposes, in accordance with criteria established by the Panel for State and municipal programs.

(c) Grants to States and municipalities shall be on a 3-to-1 Federal to State or municipality matching basis and may not be used for any other purpose. Grants may not exceed $10,000,000 Federal share for any one State nor $6,000,000 Federal share for any one municipality out of one year's appropriation under this Act.

ADMINISTRATIVE PROVISIONS

SEC. 7. (a) The Administrator of the General Services Administration, Governor or executive responsible for the administration of a grant under this Act shall file with the Administrator in such form as he may prescribe, reports or answers in writing to such specific questions, surveys, or questionnaires as may be necessary to enable the Administrator to carry out his function under this Act and to evaluate the effectiveness of the program in promoting energy conservation.

(b) The Administrator of the General Services Admin-

istration and the Governors and executives administering grants under this Act shall keep such records as the Administrator may prescribe in order to assure an effective audit of the disposition of the funds provided under this Act.

(c) The Administrator and the Comptroller General of the United States, or any of their duly authorized representatives, shall have access, for the purpose of audit and examination to any books, documents, papers, and records of any State or municipality which receives a grant under this Act that are pertinent to the grant received.

REPORT TO CONGRESS AND DISSEMINATION OF INFORMATION

SEC. 8. (a) The Administrator shall, not later than one year after the enactment of this Act, submit a report to the President and to the Congress presenting the results of this program. A second report shall be submitted not later than two years after enactment of this Act.

(b) The Administrator shall disseminate to the public, in such form and in such manner as he deems most effective, results of this program which promise to further promote conservation of energy on a wide scale. Each grantee shall be required, as a condition of the grant, to make available to any interested person the complete breakdown of cost information incurred in his project.

AUTHORIZATION OF APPROPRIATIONS

SEC. 9. There are authorized to be appropriated such sums as may be necessary to carry out the provisions of this Act, not to exceed $30,000,000 for the Federal program, $60,000,000 for the State program, and $60,000,000 for the municipal program for each of the fiscal years ending June 30, 1976 and June 30, 1977, to remain available until expended.

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94TH CONGRESS
1ST SESSION

S. 2045

IN THE SENATE OF THE UNITED STATES

JUNE 27 (legislative day, JUNE 6), 1975

Mr. RANDOLPH introduced the following bill; which was read twice and referred to the Committee on Public Works

A BILL

To insure that Federal buildings and certain buildings assisted with Federal funds employ the best practicable energy conservation and management practices; and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Federal Facilities Energy Conservation and Utilization Act of 1975".

FINDINGS AND PURPOSES

SEC. 2. (a) The Congress finds that—

(1) the consumption of energy in buildings, including Federal buildings and federally assisted buildings, has a significant impact on the United States' use of energy;

(2) the energy conservation practices adopted for the design, construction, renovation, and operation of these buildings will have a beneficial effect on the United States overall supply of energy;

(3) energy utilization over the economic life of these buildings must be considered, in addition to the initial cost of such buildings; and

(4) the design of these buildings must take into consideration the efficient use of energy over the economic life of the building.

(b) The Congress declares that it is the policy of the United States to assure that the best practicable energy conservation and utilization practices are employed in Federal and federally assisted buildings.

DEFINITIONS

SEC. 3. As used in this Act, the term—

(a) "Federal agency" means an executive department, a Government corporation, or an independent establishment in the executive branch;

(b) "Federal building" means any building which is constructed or renovated by a Federal agency, or which is leased by a Federal agency and more than 66 per centum of the net assignable area of which is used by a Federal agency;

(c) "major building" means any building of twenty-five thousand or more square feet of usable floor space;

(d) "major Federal building" means a major building which is constructed or renovated by a Federal agency, or which is leased by a Federal agency and more than 66 per centum of the net assignable area of which is used by a Federal agency;

(e) "federally assisted building" means a building constructed in whole or in part, other than by a Federal agency, with Federal funds or with funds guaranteed or insured by a Federal agency;

(f) "federally assisted major building" means a major building constructed or renovated in whole or in part, other than by a Federal agency, with Federal funds or with funds guaranteed or insured by a Federal agency;

(g) "existing building" means a building (other than a privately owned residential structure) which is owned by the United States or which is leased by a Federal agency and more than 66 per centum of the net assignable area of which is used by a Federal agency on or after the date of the enactment of this Act or on behalf of the United States;

(h) "initial cost" means the cost of construction,

and, in the case of a major building the cost of construction or renovation;

(i) "economic life" means the projected useful life of a building; and

(j) "initiated" means, with respect to construction or renovation, that offers or proposals for the construction or renovation work have been solicited or invited by the responsible Federal agency or its grantee, or the lessor in the case of a building leased by a Federal agency.

ENERGY CONSERVATION GUIDELINES

SEC. 4. (a) The Administrator of General Services, in consultation with the Administrator of the Federal Energy Administration, the Secretary of Defense, the Secretary of Commerce, acting through the Director of the National Bureau of Standards, the Secretary of Health, Education, and Welfare, the Secretary of Housing and Urban Development, and the Administrator of Veterans' Affairs, shall, not later than one year after the date of the enactment of this Act, publish energy conservation guidelines (including energy management guidelines) for use in the design, construction, renovation, and operation of certain residential, office, commercial, institutional, and other buildings: *Provided, however*, That the United States Postal Service shall, not later than one year after the date of the enactment of this Act,

publish such energy conservation guidelines for those Federal buildings, including major Federal buildings, under the custody or control of the United States Postal Service and may at periodic intervals thereafter amend its guidelines. Such guidelines shall take effect with respect to Federal buildings, federally assisted buildings, major Federal buildings, and federally assisted major buildings on which construction or renovation is initiated after the effective date of the guidelines, but such effective date shall be within one hundred and eighty days after the issuance of such guidelines.

(b) The guidelines published pursuant to this section by the Administrator of General Services and the United States Postal Service shall include information on those variable factors which may affect energy conservation and utilization, including—

(1) architectural features and site orientation of buildings to make the most efficient use of sunlight and other natural phenomena;

(2) building configuration and composition (including the usage of glass and insulation), illumination levels, electrical distribution systems, and the elimination of excessive fenestration;

(3) wasteful energy consumption practices in heating, ventilation, air-conditioning, and service water systems;

(4) new techniques for energy supply, generation, and transmission; and

(5) to the extent feasible, the energy expended in the development, processing, manufacture, and transportation of basic materials used in the construction, renovation, and maintenance of such buildings.

(c) The Administrator of General Services may, in consultation with the Administrator of the Federal Energy Administration, the Secretary of Defense, the Secretary of Commerce, acting through the Director of the National Bureau of Standards, the Secretary of Health, Education, and Welfare, the Secretary of Housing and Urban Development, and the Administrator of Veterans' Affairs, at periodic intervals amend or revise the guidelines published pursuant to this section, and such amendments or revisions shall take effect as determined by the Administrator.

(d) In the development of energy conservation guidelines pursuant to this section, the Administrator of General Services is authorized to consult with and utilize the services of private individuals, institutions, and organizations, including, but not limited to, professional engineering and architectural societies, private standard-setting bodies, trade associations, and consumer interest organizations.

ENERGY ECONOMIC AND UTILIZATION ANALYSES

SEC. 5. (a) Each Federal agency shall follow the guidelines established pursuant to section 4 of this Act.

(b) (1) Each Federal agency having authority over the construction of any Federal building or federally assisted building or the construction or renovation of any major Federal building or any federally assisted major building shall require the preparation of an energy utilization analysis and an energy-economic analysis for such building: *Provided, however,* That in the case of Federal buildings and federally assisted buildings, each Federal agency may for a category or type of building, including residential buildings, determine that the energy conservation benefits to be derived from an energy utilization analysis or an energy-economic analysis do not justify the expense for either, or both, such analysis, in which such analysis shall not be required under this subsection. In the case of residential buildings that determination shall be made taking into consideration the size of the residential development involved.

(2) Energy utilization analysis performed pursuant to this subsection shall consist of an evaluation of the efficiency of the energy consuming systems and components by demand and type of energy, including the internal energy load imposed on a building by its occupants, equipment, and com-

ponents, and the external energy load imposed on a building by climatic conditions. Such energy analysis shall include—

(A) an evaluation of two or more energy system alternatives;

(B) the simulation of each energy system over the anticipated range of operation of the building for a year's operating period considering the variable occupancy and operating levels of the building, including illumination levels;

(C) the evaluation of the energy consumption of component equipment in each energy system considering the operation of such components at both full and part load conditions as well as rated outputs; and

(D) the consideration of energy management procedures.

(3) Energy-economic analysis shall include consideration of—

(A) the economic aspects of the energy utilization analysis performed for such building pursuant to paragraph (2) of this subsection;

(B) the initial cost of each energy-consuming system being compared and evaluated;

(C) the cost of maintaining and operating each energy-consuming system including the cost of all utilities;

(D) the average replacement cost for each energy consuming system for the economic life of the building;

(E) the coordination and positioning of the building on its physical site; and

(F) the building composition and configuration, including the amount and type of fenestration and the amount of insulation incorporated in the building.

(c) The energy consuming system or combination of systems shall be selected for each major Federal building and each federally assisted major building, taking into consideration the energy-economic analysis performed for such building under this section.

(d) Estimates of the utilization, including specific data relating to the consumption, efficiency, and cost, of energy for a building shall be included in any prospectus submitted by a Federal agency to the Congress, including any prospectus submitted by the Administrator of General Services to the Committee on Public Works of the Senate and House of Representatives under section 7 of the Public Buildings Act of 1959, as amended.

(e) In the selection of locations for new Federal and federally assisted buildings the Administrator of General Services and Federal agencies shall consider the proximity of such buildings to existing and planned mass transit facilities.

(f) Nothing in this Act shall preclude the demonstration of experimental energy systems.

FEDERAL PROCUREMENT

SEC. 6. The Administrator of General Services, in consultation with the Director of the Office of Federal Procurement Policy and the Administrator of the Federal Energy Administration, is directed to make a study and survey of all Federal agency procurement in excess of $10,000, from the viewpoint of energy conservation, and report not later than one year after enactment of this Act to the President and to the appropriate committees of the Congress the results of such study and survey, together with such recommendations as he may have of measures to assure that energy conservation is a major consideration in Federal agency procurement policies and practices.

REPORTS

SEC. 7. (a) The Administrator of General Services shall prepare and submit an annual report to the Congress on his activities under this Act. Each such report shall include a description of equipment, methods of construction, and operating practices used to achieve energy conservation, and shall also include comparisons of energy consumption and costs for buildings in which such equipment, methods, or practices are and are not used.

(b) Each Federal agency shall conduct an inventory

and examination of buildings under its custody or control and report to the Congress, not later than one year after the date of enactment of this Act, on improvements that can be or are being made to assure that such buildings will utilize the best practicable energy management practices for the conservation of energy: *Provided, however,* That the Administrator of General Services may coordinate such inventory and examination of buildings and prepare a consolidated report to the Congress pursuant to this subsection.

AUTHORIZATION

SEC. 8. There is authorized to be appropriated to carry out the purposes of this Act not to exceed $7,500,000.

94TH CONGRESS
1ST SESSION

S. 2095

IN THE SENATE OF THE UNITED STATES

JULY 10, 1975

Mr. GARY W. HART (for himself, Mr. PHILIP A. HART, Mr. HATHAWAY, Mr. HUMPHREY, Mr. JAVITS, Mr. MCINTYRE, Mr. NELSON, Mr. PELL, Mr. RANDOLPH, and Mr. SPARKMAN) introduced the following bill; which was read twice and referred to the Committee on Public Works

A BILL

To require that buildings financed with Federal funds utilize the best practicable measures for the conservation of energy and the use of solar energy systems.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Conservation and Solar Energy—Federal Buildings Act of 1975".

FINDINGS AND POLICY

SEC. 2. (a) The Congress hereby finds—

(1) that federally owned and federally assisted facilities have a significant impact on the Nation's consumption of energy;

(2) that energy conservation practices adopted for the design, construction, and utilization of these facilities will have a beneficial effect on the Nation's overall supply of energy, and the procurement of solar heating and cooling units for use in Federal buildings in connection with demonstrations of solar energy applications on such buildings under this Act should help to create a market for such units generally;

(3) that the cost of energy consumed by these facilities over the life of the facilities must be considered in any analysis of their energy use, in addition to the initial cost of constructing the facilities;

(4) that the cost of energy is significant and facility designs must be based on total life cycle cost, including (A) the initial construction cost, and (B) the cost, over the economic life of the facility, of the energy consumed and of the operation and maintenance of the facility as it affects energy consumption; and

(5) that the total costs and benefits accruing to the Nation from the use of solar energy systems and conservation technology can be assessed in terms of a total national value beyond the direct economic tradeoffs of the life cycle cost analysis, with the determination of this value including (but not being limited to) such considerations as the energy-related values of competing

energy sources, the preservation of material resources, the reduction of pollutants, the export market potential, and the reduction of imports of oil (taking into account both economic and national security values).

(b) The Congress declares that it is the policy of the United States to insure that energy conservation and solar energy technology utilization be employed in the design and construction of every facility to which sections 4 and 5 are specifically applicable and, to the maximum extent feasible, in the design and construction of all other Federal and federally assisted facilities.

DEFINITIONS

SEC. 3. (a) For purposes of this Act—

(1) the term "solar energy" means direct and indirect solar radiance and intermediate solar energy forms, as further defined in Public Law 93–409 and Public Law 93–473;

(2) the term "Federal agency" means an executive agency (as defined in section 105 of title 5, United States Code), and also includes a military department (as defined in section 102 of such title) and the United States Postal Service;

(3) the term "new building" means any building (other than a privately owned residential structure)—

(A) which (i) is constructed or acquired by

or on behalf of the United States on or after the date of the enactment of this Act, or (ii) is leased by or on behalf of the United States on or after such date, after construction or alteration in accordance with Federal plans and specifications, under a long-term contract pursuant to the terms of which substantially all of the premises are to be used by or on behalf of the United States,

(B) the development of plans and specifications for which is initiated on or after the date of the enactment of this Act, and

(C) the net cost of which to the United States (for construction or acquisition or for total charges under the lease) exceeds or will exceed $10,000;

(4) the term "existing building" means any building (other than a privately owned residential structure)—

(A) which (i) is owned by the United States on the date of the enactment of this Act or is leased by or on behalf of the United States on such date under a long-term contract pursuant to the terms of which substantially all of the premises are used by or on behalf of the United States, or (ii) is constructed or acquired by the United States, or so leased by or on behalf of the United States, after

such date but pursuant to plans and specifications the development of which was initiated before such date, and

(B) the fair market value of which on the date of the enactment of this Act (or, in the case of a building described in subparagraph (A) (ii), the net cost of which to the United States determined as of the date on which ownership or possession by the United States begins) exceeds $10,000;

(5) the term "energy use analysis" with respect to any building means the evaluation of the building's heating, ventilating, and air-conditioning systems, lighting system, and all other major energy-consuming systems and components, by demand and type of energy, including the internal energy load imposed on the building by its occupants, equipment, and components and the external energy load imposed on the building by climatic conditions. Such analysis shall include (but not be limited to)—

(A) a detailed analysis of the life cycle energy costs of the building;

(B) a separate analysis of the total energy requirements of the building taking into consideration—

(i) the interior and exterior design of the

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building, including the insulation, fenestration, site orientation, and shape, that will make the most efficient use of sunlight and other natural phenomena,

(ii) the heating, cooling, ventilating, plumbing, electrical, and lighting systems of the building,

(iii) the construction materials used with respect to the building, including the extent to which such materials reduce the energy requirements of the building and the amount of energy required to produce and transport such materials,

(iv) the site of the building and the accessibility of the building (particularly by public transportation) to persons using its facilities,

(v) a comparison of two or more energy system alternatives,

(vi) new techniques for energy supply, generation, and transmission, including on-site total energy systems,

(vii) the projection of the operating costs of each system over the entire range of operation of the building,

(viii) the evaluation of the energy consumption of component equipment in each system considering the operation of such components at other than full or rated outputs, and

(ix) any other relevant information with respect to the design and site of the building;

(C) an identification and quantification of sources of heat loss or heat gain with respect to the building;

(D) in the case of a proposed acquisition of a building, recommendations for the improvement of its thermal efficiency; and

(E) in the case of a proposed alteration of a building, an estimate of the impact of such alteration on its energy requirements; and

(6) the term "life cycle energy costs" with respect to any building means the energy-related costs of such building, including the items referred to in paragraph (5) (B) and including (i) the initial energy-related cost of the building and (ii) the cost, over the economic life of the building, of the energy consumed and of the operation and maintenance of the building as it affects energy consumption.

(b) The life cycle energy cost analysis included in the

energy use analysis with respect to any building under subsection (a) (5) shall provide but not be limited to the following information:

(1) the initial cost of each energy consuming system being compared and evaluated;

(2) the annual and projected cost of all energy utilities and how this would affect the long-term comparative costs of the systems being evaluated;

(3) the annual and projected cost of maintaining each energy consuming system;

(4) the average replacement cost for each system expressed in annual terms for the economic life of the building;

(5) an estimate of future inflation rates, based on historical economic trends; and

(6) an estimate of the future costs of depletable resources.

(c) If discount rates are employed in calculating the life cycle energy costs with respect to any building, the assumed rate shall take into account both the current Federal prime interest rate as determined by the Federal Reserve Board and the best available estimates of future inflation rates.

ENERGY GUIDELINES FOR FEDERAL BUILDINGS

SEC. 4. (a) The Administrator of the General Services

Administration (hereinafter in this Act referred to as the "Administrator") and the Secretary of Defense (hereinafter in this Act referred to as the "Secretary") shall, in consultation with each other, develop, publish, and from time to time update guidelines designed to assure that the most effective and efficient measures for the conservation of energy and the use of solar energy systems are incorporated in—

(1) the design, construction, and renovation of Federal and federally assisted buildings, and

(2) the procurement of goods and services for such buildings and for other Federal purposes.

The guidelines developed by the Administrator and those developed by the Secretary shall be fully consistent with each other (subject only to the need for specific variations to meet particular conditions and circumstances) and with the purpose and provisions of this Act; and such guidelines shall be developed in accordance with the energy-related studies and findings of the Energy Research and Development Administration and the Federal Energy Administration.

(b) The guidelines developed by the Secretary shall apply with respect to all new and existing buildings, and related procurement, under his jurisdiction and control (or under the jurisdiction and control of the military departments); and the guidelines developed by the Administrator

shall apply with respect to all other new and existing buildings as defined in section 3(a) (3) and (4) and with respect to related procurement activities. Each Federal agency shall comply with the requirements of the applicable guidelines in all of its design, construction, operation, and procurement activities to which such guidelines are applicable under the preceding sentence, and shall in addition, to the maximum extent feasible, follow such guidelines in all of its other activities (including activities involving leased property not specifically covered under section 3(a) (3) or (4)) with respect to buildings which are held or used by the United States under laws or programs administered by such agency.

SPECIFIC ENERGY REQUIREMENTS RELATING TO FEDERAL BUILDINGS

SEC. 5. (a) The Administrator and the Secretary shall each—

(1) submit to the Congress, as part of and in accordance with his normal procedures relating to construction and procurement, an energy use analysis with respect to the construction, acquisition, or leasing of any new building to which guidelines developed by him under section 4 are or will be applicable, and incorporate the findings of such analysis (including the optimum system or combination of systems based on its life

cycle energy cost analysis) into the plans and specifications for such building; and

(2) submit to the Congress within one year after the date of the enactment of this Act an inventory and energy use analysis of all existing buildings under his jurisdiction and control, indicating the improvements which should be made in such buildings to insure that they utilize the best practicable measures for energy conservation and the use of solar energy systems, and setting forth detailed plans and specifications for incorporating such improvements in those buildings.

(b) The energy use analysis required by this Act with respect to any building under his jurisdiction or control shall be included by the Administrator in any prospectus submitted (with respect to such building) to the Committee on Public Works of the Senate and the Committee on Public Works and Transportation of the House of Representatives under section 7 of the Public Buildings Act of 1959 (40 U.S.C. 606).

(c) (1) Each Federal agency shall make, and submit to the Administrator or the Secretary (as may be appropriate) for use in carrying out this Act, a detailed life cycle energy cost analysis of any building to be constructed, acquired, or leased by it or for its use.

(2) No major component of a heating, ventilating, air-

conditioning, lighting, or other energy-consuming system for any building, and no other item or equipment having as one of its primary purposes the generation, utilization, or conservation of energy in or for any building, shall be purchased from any person by any Federal agency unless such person has submitted, along with or prior to the execution of the purchase contract, a detailed life cycle energy cost analysis with respect to such component, item, or equipment.

INCREASED COST LIMITATIONS TO ACCOMMODATE ENERGY EQUIPMENT IN FEDERAL AND FEDERALLY ASSISTED BUILDINGS

SEC. 6. (a) (1) In determining the maximum dollar amount of any Federal assistance for the construction or major rehabilitation of a residential, commercial, or other building, or the maximum per unit or other cost or floor area limitation of any federally owned building, where the applicable Federal law specifies such a maximum dollar amount or limitation and the building involved is or will be furnished with solar energy equipment or other special energy equipment in accordance with regulations prescribed under subsection (c), the maximum amount or limitation so specified which would otherwise be applicable to the building shall be deemed to be increased by the amount by which (as determined in to be increased by the amount by which (as determined in accordance with such regulations) the price, cost, or floor

area of the building including such equipment (taking into account design as well as actual construction or rehabilitation, and all related items) exceeds the price, cost, or floor area of the building with such equipment replaced by conventional energy equipment.

(2) In addition, any excess of price or cost permitted under paragraph (1) with respect to a building shall be fully taken into account in determining the value or cost of the building for purposes of applying any statutory provision specifying maximum loan-to-value or -cost ratio, in such manner as will minimize downpayments or other initial costs to the person or agency constructing or rehabilitating the building.

(b) As used in subsection (a)—

(1) the term "Federal assistance" includes any federally assisted mortgage loan within the meaning of section 13 (b) of the Solar Heating and Cooling Demonstration Act of 1974, and any grant, loan, or financial assistance in any other form which is provided or made available under a Federal law or program; and

(2) the term "federally owned building" includes a new building as defined in section 3 (a) (3) of this Act, federally constructed housing within the meaning of section 13 (c) of the Solar Heating and Cooling Demonstration Act of 1974, and any other building (of

any kind) constructed by the United States or a Federal agency or constructed with assistance provided or made available under a Federal law or program.

(c) The Administrator and the Secretary shall jointly prescribe such regulations (including regulations specifying the types of energy equipment which will qualify a building for the benefits of this section and regulations providing for the computation of the extent to which maximum dollar amounts and limitations on maximum per unit, cost, or floor area limitations may be increased on account of such equipment) as may be necessary or appropriate to carry out this section in a manner consistent with the guidelines developed under section 4.

APPROPRIATIONS

SEC. 7. There are authorized to be appropriated such sums as may be necessary to carry out this Act, not exceeding in the aggregate $ for purposes of section 4, $ for purposes of section 5(a)(1), $ for purposes of section 5(a)(2), and $ for the other purposes of this Act.

STATEMENT OF HON. GARY W. HART, U.S. SENATOR FROM THE STATE OF COLORADO

Senator HART. Thank you very much, Mr. Chairman. I am joined by my staff member, Mike McCabe, and will be joined by others who are present in support of this piece of legislation for your questions at the conclusion of the introductory statement.

I want to thank you for this opportunity to discuss with you and present to you the intent and provisions of S. 2095, the so-called Conservation and Solar Energy—Federal Buildings Act of 1975.

Last July, on the day I introduced this legislation, I sponsored with Senator Gaylord Nelson and Representatives Dick Ottinger and Gilbert Gude, an exhibit of solar energy equipment that was currently available for installation.

The exhibit accomplished what the sponsors had hoped—it assembled on the grounds of the Nation's Capitol, functional, operating solar energy systems which were ready for use now and not sometime in the distant future.

Even though the summer sun may have faded since July, the energy problems that can be addressed by the use of solar energy and energy conservation measures has not diminished in its intensity.

The legislation I am here to discuss today can apply some of the vast resources of our Federal Government to these technologies and fully develop them as weapons in the arsenal against the critical energy shortage which faces our Nation.

The Conservation and Solar Energy—Federal Buildings Act of 1975, S. 2095, requires that a building financed with Federal funds utilize the most economically and technically practicable measures for energy conservation and use of solar energy.

This is to be accomplished by means of an energy use analysis which will evaluate the energy requirements and comparative costs of energy-saving systems over the economic life of a Federal building. The findings from this analysis must be incorporated in the plans and specifications for the design, construction, and renovation of a Federal building and must be submitted to Congress as part of normal procurement procedures.

Included in the energy use analysis is a requirement for the evaluation of life cycle energy costs of a building. It is important to stress the adjustments to the total costs when evaluated in light of the life cycle basis, for herein lies the key to promoting the competitive benefits of energy conservation measures and the use of solar equipment.

Life cycle costs are assessed to incorporate the total costs and benefits of the use of solar energy systems and energy conservation measures versus conventional heating and cooling systems over the entire economic life of a building.

As stated in this bill, the assessment should include such variables as rising energy costs; comparative energy systems; equipment replacement and maintenance costs; the integration of energy-related factors into the structural design; and future inflation rates.

When these variables are taken into account and compared with conventional construction and energy use practices, conservation measures and solar energy equipment become economically competitive.

The problem with building construction in the past, when energy was both abundant and cheap, was that energy alternatives and conservation were ignored. The new conditions which now face us have necessitated a curb to the waste that has been integrated into building design.

These factors have direct economic trade-offs which become apparent when evaluated in the energy use life cycle energy cost analyses of this bill. But above and beyond these mesurable elements there are values which are difficult to quantify, yet are nonetheless of vital importance to our Nation.

The benefits and costs derived from these intangible values include the preservation of material resources; the reduction in pollutants; export market potential; and the economic and national security values which would be derived from a reduction in imports of oil. These values are often of more significance than the direct economic trade-offs traditionally used as the basis for cost comparisons.

The legislation also calls for an energy inventory to be conducted of all existing Federal buildings. This inventory, accompanied by energy use analysis, is to be followed by detailed plans and specifications for incorporating energy conservation measures and solar energy into buildings under Federal control.

The Government currently owns and operates over 400,000 buildings which total 2.5 billion square feet of space to be heated, cooled, and lighted. The energy inventory assures that this tremendous resource is fully utilized.

The bill does not require that any specific energy conservation or solar energy technology be applied. It does, however, require that these technologies be utilized where technically feasible and cost effective.

In order to assist in this evaluation, the responsibility to provide relevant energy data is placed on the manufacturer of major energy-consuming equipment before a purchase agreement can be executed. This requires the submission of a detailed life cycle energy cost analysis of the system before the purchase.

The bill also specifies that guidelines for optimal energy use and implementation of the required energy use analysis be developed by the General Services Administration and the Department of Defense in consultation with each other and in accordance with relevant energy-related findings of the Federal Energy Administration and the Energy Research and Development Administration.

In order to assure that Federal buildings utilize the most effective and efficient measures for the conservation of energy and the use of solar energy where practicable, these guidelines must be updated periodically.

In drafting the bill, the guidelines were intentionally left without rigid definition because the appropriate agencies can better arrive at a formula for applying the purposes set forth in this legislation than could Congress.

However, merely because the guidelines are not spelled out, there should be no question that they should be binding and comprehensive. Once developed, these guidelines should be of such quality so as to be of benefit to the private sector as well.

Using the most effective and efficient means of energy conservation and solar energy technologies will require higher initial costs than with conventional building design. For this reason, section 6, subsection (a) addresses the adjustments that must be made in procurement procedures to accommodate the increased initial costs accrued through utilization of non-conventional energy-saving design or equipment.

This is an important feature of the bill, for it is fundamental to the new orientation that must be given to building procurement policies.

If we remain tied to the old philosophy that initial costs are the sole basis of cost comparisons for building construction, then by default we exclude energy use analyses based on the benefits and costs of long-term life cycle costing.

It is only over the economic life of a building that the advantages of energy conservation measures and the use of solar energy will prevail over low initial cost conventional systems.

The appropriations section of the bill was intentionally left blank so as to allow the committee maximum flexibility in determining dollar figures recommended by testimony. I have no specific suggestions for these figures but I would encourage the committee to be generous in its recommendations so that the objectives of this legislation can be aggressively pursued.

Several agencies have already developed factual data to support this Federal buildings program. In testimony before the House Committee on Science and Technology this May, FEA Administrator Frank Zarb stated that a government buildings project should be implemented which requires an assessment of the feasibility of using solar heating and cooling.

This assessment, he said, should be made on the basis of a life cycle analysis and, where appropriate, substantial numbers of solar heating and cooling systems should be purchased and installed on new and existing buildings.

Mr. Zarb went on to state that the same type of energy use analysis called for in this legislation would cost less than 0.1 percent of the total cost of construction. This small percentage could be easily recouped by application of energy conservation measures alone.

An FEA working paper on the subject states that the use of solar energy systems in Federal buildings could result in energy savings of 20,000 barrels per day by 1980. And I understand that FEA has now developed a comprehensive implementation plan for Federal buildings as part of its Federal energy management project.

I am sure that Mr. Sant, of FEA, will testify regarding the details of this project in hearings scheduled for tomorrow.

Other agencies are also interested in applying the most efficient means of energy use to Government buildings. The General Services Administration has recently revised a handbook published in 1974 to assist architects and engineers in designing energy-saving measures for Federal buildings. And this year GSA published a similar handbook which would apply to existing buildings.

The Department of Defense, which has jurisdiction over the largest number of federally owned buildings, is in the process of revising construction criteria along the same lines as the GSA handbook. Whether these guidelines would meet the intent of Section 4 of the bill

is not yet determined, but the actions by these agencies show their willingness to pursue the goals of energy conservation.

Both GSA and DOD are in the process of making existing buildings less energy intensive through energy conservation retrofit programs and, in some cases, they are experimenting with solar energy equipment. This bill would be a logical progression to the full-scale adoption of energy conservation and solar energy in buildings under their control.

Most importantly, the effect of this legislation is not that buildings owned and operated by the Federal Government would be using conservation measures and solar equipment and saving money as a result, but that activity on the part of the Government would stimulate the market base for energy conservation technology and solar energy systems. This would be of particular benefit to the solar industry, now in the very basic stages of development.

The solar energy industry is looking for buyers to promote mass production capacity, and the large-scale procurement power of the Federal Government could provide the impetus needed to develop that industrial capability.

Once the cost of solar collectors are substantially reduced through mass production, not only will they be far more economical than conventional energy systems but will be more attractive to the consuming public.

The purchase of solar energy equipment by the Federal Government not only would provide the foundation for a dispersed market for these systems, but would also make information available to the private sector on installation procedures, maintenance techniques, architectural design and construction methods.

Solar heating and cooling systems would be given wide national exposure and the operation and installation of this equipment would provide commercial capability for involved technical services.

I will not dwell on the benefits that could be accrued to our Nation as a result of this program. I will let the testimony of the experts invited here supplement what I have briefly outlined.

I would only hope that the committee sees fit to pursue the kind of aggressive formula embodied in this legislation. The Federal Government must take an active role of leadership in showing the way to applying solar energy and energy conservation technology to all buildings.

It is this kind of commitment that must be undertaken nationally, in both public and private sectors, if we are to make a significant contribution to the resolution of our energy, environmental, and economic crises.

I am encouraged to see that this committee is holding hearings on legislation which relates to these issues and I am sure that you will act quickly on this important legislation. I would be glad to answer any questions you might have on this bill.

I might add, Mr. Chairman, that coming from one of the States of the Union which has developed more national leadership and more experimentation in both the public and private sector than almost any other part of the country, I feel very strongly about the future of solar technology for our Nation.

I am hopeful that we in the Federal Government can do all we can, as this bill intends to encourage the initiative and industry that is being demonstrated by individuals, not only in my own State, but across the country, to bring this sources of energy to the American people.

I would be glad to try to answer any questions you might have.

Senator MORGAN. Thank you very Senator Hart, for your very clear and concise explanation of the bill. I don't know how much time you have. I have a good many questions. Those that we can't get to, we will discuss with your staff.

I would quite frankly be interested, Senator, in knowing of some of the solar heating systems that may be working in Colorado. I have heard and read a lot about them, but everything seems to be in the abstract. Are there solar heating operations in the State of Colorado that are working?

Senator HART. Senator Morgan, I had a rare opportunity several months ago to help dedicate what I believe is the first commercial facility anywhere in the country to be primarily heated and cooled by solar energy. It is the Gump Glass Co. in Denver, opened in July.

This exemplifies that people are not only experimenting with their own homes, but business people, who have to make a profit are now seeing that over a long period of time they can, in fact, save money. Life-cycle costing is a fundamental principle in this piece of legislation. For it is this type of costing—amortizng the cost of the equipment over the life of a building—that can save money because of the increased fuel costs that now face this Nation.

We also have the Air Force Academy, as you know, in the State of Colorado just outside of Colorado Springs. The Superintendent of the Academy, General Allen, tells me they have a home at the Academy where cadets are using an experimental residential unit heated and cooled with the use of solar energy. They are very excited about the opportunity this presents the Academy.

We have a great deal of experimentation and development going on, on other campuses, particularly Colorado State University, and the University of Colorado. Prof. George Löf, of CSV, is one of the international experts and pioneers in the area of solar technology.

We have architects and other people around the State who have put solar units on their homes. I have visited many of them.

I promised the use of solar technology in my own campaign and, in fact, held a reception for former Secretary of Interior Stewart Udall, in a solar house.

So, in my State alone, individuals have demonstrated as was demonstrated on the Capitol steps several weeks ago, that this is technology which is here now. It is not something we have to wait for—people have conquered the technology. Now it is just a question of creating a mass market.

Senator MORGAN. In order to sell the idea, are we going to have to take into consideration the life-cycle costing of a building to justify it?

Senator HART. That is a crucial element as I mentioned in my prepared remarks. If you look at the cost of solar equipment versus conventional heating and cooling equipment now, there is no question that the solar equipment is more expensive.

However, what has to be taken into account are all of the cost factors integrated into the life of a building and including the savings in energy realized from using solar energy. It is also important to include in your decisions about this legislation, and other related legislation, the related benefits that I have mentioned such as a reduction in pollution and the financial and social costs that pollution causes in our country.

Also, the increased national security realized from less reliance on imported oil and preservation of fossil fuels. All of these elements, though difficult to quantify are factors we have to think about in solving the energy problems of this country.

Senator MORGAN. If you have the time, let me go over what I consider to be a summary of your bill. I think it is important as we consider these bills that we keep in mind what each one will do. If we don't have time for the questions we have prepared for you today, we will work out a time for you to come back.

The first thing I understand your bill does is it directs the Administrator of GSA and the Secretary of Defense in consultation with each other to develop and to publish consistent guidelines, assuring that the most effective and efficient energy conservation measures are incorporated into the design, construction, renovation, and operation of not only Federal buildings, but federally assisted buildings.

So your bill involves the GSA Administrator and the DOD Secretary. Is that correct?

Senator HART. That is correct.

Senator MORGAN. When you say federally assisted buildings, Senator Hart, how far does that go?

Senator HART. On one hand, we are talking about leased buildings, particularly buildings under long-term lease where the amount of financing involved makes sense for the Federal Government to consider energy conservation measures in negotiating a lease.

We are obviously not talking about short-term rentals or anything like that. But it is my understanding that the Federal Government does involve itself in considerable long-term leasing.

If the effect of that lease is over a long enough period of time, it makes financial sense to look at energy conservation measures.

Senator MORGAN. You are talking about buildings that are also not only federally assisted but will also be federally occupied?

Senator HART. Yes, sir, that is correct.

Senator MORGAN. So we can't read into it, that because the Federal Home Loan Bank Board may assist through loans, we are talking about this kind of thing?

Mr. MCCABE. Mr. Chairman, in certain instances—for example, on university campuses where a large portion of a building is funded by the Federal Government—the terms of Federal assistance in this act would apply. We would want these buildings to be included under the provisions of this legislation.

Senator MORGAN. In other words, if we get a medical center funded at some university, primarily through Federal funds, the building might be covered. I don't know whether that is spelled out or not, but by raising the question, the staff will work on that.

That is the first point as I see it. The second point is that guidelines shall be developed in accordance with the energy-related studies and

findings of ERDA and the Federal Energy Administration. So it involves not only DOD and GSA, but also the two agencies that are primarily concerned with energy, FEA and ERDA.

Senator HART. That is correct, in that they can contribute through their ongoing studies in energy conservation measures and solar energy. What we want to do is mesh the findings of the purchasing agencies of the Government with those studies being conducted by the energy research agencies.

Senator MORGAN. By directing that these guidelines be developed together, you intend to eliminate this duplication that might come in.

Senator HART. Absolutely.

Senator MORGAN. The third point, as I see it, is it directs that these guidelines incorporate the use of solar energy systems into the design, construction, and renovation of such buildings.

Senator HART. Yes; that is correct.

Senator MORGAN. I assume you are saying that we should incorporate these. Suppose you determine that a solar system in a given building at a given location might not be practical. What would be the result?

Senator HART. Obviously, the legislation would not mandate its use. It is only where it makes sense in the long-term costing of the building. The costs of heating and cooling that building and whether it would be feasible to install solar equipment would be considered in the design and procurement phase.

If, according to the guidelines to be developed, it made no sense for one reason or another, it wouldn't be mandated. For example, if it were in a part of the country where there was not enough sunlight, or ample thermal units could not be generated by the use of solar energy, it wouldn't be practicable to have solar equipment in that area.

Senator MORGAN. So the use of solar equipment wouldn't be mandated there.

Senator HART. It would not.

Senator MORGAN. Have you been back to the building that was dedicated in Colorado, to see how it was working?

Senator HART. I haven't, but I am going to go back this winter and see how it works in the Colorado cold.

Senator MORGAN. Are you going to carry an overcoat with you?

Senator HART. No. I think they knew what they were getting into because they are very practical business people.

Senator MORGAN. I am very interested because I know that many people are working on them. A friend of mine in this area has developed a home system.

I agree with you. I think the Government is going to have to show some interest and give some help before we can ever make it economically feasible.

Now we get down to the third part. It directs that guidelines developed by the Defense Department shall apply to all new and existing buildings and related procurement activities under the jurisdiction of the Secretary and appropriate military departments.

I take it you intend to make sure they don't just do it with new buildings but with all facilities they have anything to do with.

Senator HART. Yes. That is correct. As I said in my opening remarks, one of the reasons we targeted the Defense Department is that they

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have jurisdiction over more square footage than any other governmental agency. That is the principal reason why they are emphasized in this legislation.

Senator MORGAN. It directs that the guidelines developed by GSA shall apply to all new and existing buildings and related procurement activities under the Administrator's jurisdiction.

Senator HART. Yes.

Senator MORGAN. That is self-explanatory. It directs that each agency shall, to the maximum extent feasible, follow such guidelines in all of its other activities including those involving leased space. I believe you made that clear.

Senator HART. Yes; that is correct.

Senator MORGAN. Point 7 directs the Administrator of GSA and the Secretary of DOD to submit to the Congress, as a part of every prospectus, an energy use analysis with respect to the construction, acquisition, or leasing of any new building to which proposed guidelines are applicable, and to incorporate the findings in the plans and specifications.

In other words, before they come before this committee with a prospectus, the members must have access to an energy use analysis.

Senator HART. That is correct.

Senator MORGAN. I think that is good. It directs that an inventory and energy use analysis be made of all existing buildings under GSA and DOD jurisdiction, indicating improvements that should be made to utilize the best energy conservation methods, and also the use of solar energy systems. I assume that would take a long time?

Senator HART. I think it would. Mr. Chairman, I don't think that we have calculated within exactly what period of time that would have to be done or could be done feasibly.

Senator MORGAN. I think maybe that is something we may want to develop as we listen to the witnesses in the next few days.

It directs that each Federal agency proposing to construct, acquire, or lease a building shall submit a detailed life cycle energy cost analysis to GSA or DOD.

Senator HART. That is right.

Senator MORGAN. Would that include the U.S. Postal Service, too?

Senator HART. Yes; it would. In fact, one section of the bill, section 3(a)(C) has a figure of $10,000 which seems extremely low. This is a figure that I, as the primary sponsor of the legislation, feel is negotiable.

One of the reasons that the figure is so low is to make sure that we include new post offices being constructed. It is my understanding that most post office buildings cost less than $150,000. These are obviously very small buildings, but we want a figure which would bring most of those buildings under the provisions of the act.

Senator MORGAN. Point 10 directs that no Federal agency may purchase any item or equipment having as its purpose the generation and utilization of conservation of energy unless a detailed life cycle energy cost analysis of such item is submitted.

Senator HART. Yes.

Senator MORGAN. This again is to make sure that every agency is concerned about cost.

Point 11 provides that where a construction or rehabilitation cost limitation may be or has been established by law or otherwise, this maximum may be increased if installation of solar energy or other special energy equipment is proposed.

I assume that will take some studying to figure ways and means of finding the money. The idea is not to let energy saving methods be cut off because of spending ceilings.

Senator HART. That is right.

Senator MORGAN. It provides that any excess cost permitted due to installation of solar or special energy devices shall be taken into account in determining the value of the building with respect to all future transactions. I think that is fairly self-explanatory.

It directs GSA and DOD to jointly specify regulations, specifying types of energy equipment that will qualify a building for these benefits and also procedures for computing extra dollar value. I think that is self-explanatory unless you have something.

Senator HART. No; I can't add to that.

Senator MORGAN. It directs that provisions of the act shall apply to federally assisted buildings we talked about, including those involving mortgage guarantees and also postal service buildings and leased space.

I think something we have to decide is how far we plan to go. That is a question we can talk about as we go along.

Point 15 would authorize funds to carry out various provisions of the act but does not, as you stated, give any specific dollar amounts. Maybe later on, during the course of the hearings we may be able to get some better idea.

Senator HART. Yes. I think after hearing additional testimony, particularly from the agencies involved, we could discuss that.

Senator MORGAN. Are there any other provisions that come to mind that we might have left out?

Senator HART. I don't think so, Senator Morgan. Here today are two individuals I would like to introduce because they have valuable testimony and are willing to appear in whatever order you wish to take them.

They are here on behalf of this bill, S. 2095. They are the legislative director and research director of the Sheet Metal Workers' International Association, Mr. Frank Scaduto and Mr. Bernard Monigle.

The Association they represent recently commissioned two important studies by the Stanford Research Institute and the Mitre Corp., which detailed the positive effect a solar heating and cooling industry can have on their profession and our economy in general. They are also familiar with the provisions of this legislation and can contribute valuable information from their technical perspective to your deliberations on this bill.

By way of this introduction and their brief statement, I would like to present them to you. I am happy to have them here in support of this legislation.

Senator MORGAN. Do you plan to sit in at these hearings even though Senator Hart may have to leave?

Mr. SCADUTO. Yes, we do.

Senator MORGAN. Then I would appreciate it, if you will let me get all three bills before the committee first. I think we can follow them better, but I don't want to inconvenience you. If you are going to be here and can come in later to testify, I think that would be most helpful to us.

Senator HART. It is my understanding that these gentlemen have just very brief statements and then are going to present the bulk of their evidence for the record. Is that correct?

Mr. SCADUTO. Yes.

Senator HART. We may be talking about a very brief period of time.

Senator MORGAN. If you wish, then we will do that. As I have mentioned many times, my training is in math and chemistry. You have to start with 1, 2, 3 for me. It is hard for me to start in the middle.

Senator HART. I would like your indulgence to be excused to make another appointment. Thank you for your time. I appreciate it.

Senator MORGAN. Gentlemen, since your statement will be short, suppose you go ahead and give it now, provided you will be available for questioning later on.

STATEMENT OF FRANK SCADUTO, LEGISLATIVE DIRECTOR, AND BERNARD MONIGLE, RESEARCH DIRECTOR, SHEET METAL WORKERS' INTERNATIONAL ASSOCIATION

Mr. MONIGLE. Thank you. I would like to submit the statement for the record and make a few brief comments at this time. (The statement appears at p. 49.)

The Sheet Metal Workers' International Association has become active in energy conservation and solar energy not only because it makes sense for America's energy needs, because even figuring conservatively, energy saving modification work could put all unemployed sheet metal workers back to work.

At the present time one sheet metal worker in five is unemployed. Many more are working less than full time.

A Federal program to promote energy conservation and the use of solar energy will not only aid in achieving energy independence, but it will help to put Americans back to work. Dollars now being spent on expensive fossil fuels from abroad would be better spent, reducing joblessness by harnessing less expensive, inexhaustive energies at home.

As a result of our union's interest in energy conservation, we have taken several steps:

We are educating our membership to the possible impact of energy conservation and solar energy. In the August conference of our union's business agents we devoted nearly 2 days to energy developments and solar energy development and the part our union can play.

Our national training fund, recognized as one of the best of apprenticeship programs, is now conducting a survey to determine if additional courses are needed for the construction of solar hardware.

We commissioned the Stanford Research Institute and the Mitre Corp. to make studies of the impact on the sheet metal industry of solar development and energy conservation.

We have supplied your committee with copies of these reports. We hope that you will find them useful in your work on energy conservation and solar development.[1]

In conclusion, Mr. Chairman, I would like to say the Sheet Metal Workers' International Association strongly supports S. 2095. Its passage will help achieve the goals of fossil fuel conservation, solar energy development, and new job opportunities for America.

Thank you.

Senator MORGAN. Thank you very much. We will insert your entire statement in the record.

Mr. SCADUTO. I would briefly like to refer to the Mitre study. Also in connection with that study, one circumstance that is of great interest to the Sheet Metal Workers' International is that the emphasis so far has been very heavily on hydraulic systems rather than heated air systems.

We realize that in gathering the data and doing all the research that is going to be necessary in solar energy that you do want to come up with the most effective and the least expensive system.

We would certainly appreciate it if your committee would give serious consideration to what these studies bring forth in connection with solar, air heating and cooling systems.

Thank you very much.

Senator MORGAN. Thank you. Later on, you may add further comments and join in discussions, if you wish.

Mr. SCADUTO. Thank you.

[The prepared statement from the Sheet Metal Workers' International union follows:]

STATEMENT OF THE SHEET METAL WORKERS' INTERNATIONAL ASSOCIATION

The energy crisis of the last three years, and the spiraling fuel costs which characterize it, have demonstrated the need for energy conservation and solar energy. The current imbalance between the domestic supply and the demand for fuels and energy is likely to continue unless a federal effort is made to test, utilize and promote conservation measures and new forms of energy.

Twenty-four percent of all the energy used in the United States and Canada is consumed in the industries in which Sheet Metal Workers are employed—heating, ventilating, air-conditioning systems and related systems in space heating. The modification of these systems can be accomplished at relatively low cost and make a huge dent in the nation's energy consumption. The Project Independence Blueprint estimates that the equivalent of almost half a billion barrels of oil per year can be saved by 1985 through an accelerated energy conservation program in residential and commercial buildings. Among the energy conservation options:

Exchangers to transfer heat from exhaust air, before it goes outside, to incoming fresh air in schools, hospitals, and other buildings where health considerations require a heavy air turnover.

Replacement of constant-volume air circulation systems (which vary temperature, to provide constant comfort level) with variable volume systems (which hold air temperature constant, and vary volume to maintain comfort levels).

Installation of heat pumps to perform both the heating and cooling functions at a considerable savings of electricity.

Solar energy is nonpolluting, inexhaustible and can become inexpensive. However, the full potential of solar energy will not be realized until the cost of solar hardware is reduced through mass manufacturing. To increase public demand for solar hardware a program of Federal assistance is necessary. This assistance should include, but not be limited to, income tax credits and loans for homeowners and builders who purchase and install solar equipment, the use of solar equipment

[1] The reports referred to may be found in app. A, p. 227.

in buildings financed with Federal funds, direct subsidies to assist in the purchase of solar equipment, and Federal grants and contracts to the research community and manufacturers for the development of solar technology.

The Sheet Metal Workers' International Association has become active in energy conservation and solar energy not only because it makes sense for America's energy needs but because even figured conservatively, energy-saving modifications work could put all unemployed sheet metal workers back to work. At the present time, one sheet metal worker in five is unemployed. Many more are working less than full time.

Energy conservation and the use of solar energy can have a large impact on unemployment. It has been estimated by the Stanford Research Institute that one-fourth of the dollars invested in solar heating and cooling will go to the labor costs of installation. In addition, there will be many jobs created fabricating the collectors, storage tanks, ducting and allied equipment necessary for a solar installation.

A Federal program to promote energy conservation and the use of solar energy will not only aid in achieving energy independence but it will help to put Americans back to work. Dollars now being spent on expensive fossil fuels from abroad would be better spent reducing joblessness by harnessing less expensive, inexhaustive energies at homes.

As a result of our interest in energy conservation our union has taken several steps:

We are educating our membership to the possible impact of energy conservation and solar energy. At an August Conference of our union's business agents we devoted nearly two days to energy developments and the part our union can play.

Our National Training Fund, recognized as one of the best of apprenticeship programs, is now conducting a survey to determine if additional courses are needed for the construction of solar hardware.

We commissioned the Stanford Research Institute and the Mitre Corporation to make studies of the impact on the sheet metal industry of solar development and energy conservation.

We would like to present each member of the committee with copies of these reports.

The Sheet Metal Workers' International Association strongly supports S. 2095, "The Energy Conservation and Solar Energy Federal Buildings Act of 1975". The passage of S. 2095, will help achieve the goals of fossil fuel conservation, solar energy development and new job opportunities for Americans.

Senator MORGAN. Mr. Dennis Bridges? For the record, I believe you have been serving as a consultant to Senator Randolph in the development of his bill.

I am told you are accompanied by Mr. James Wolf, manager of the Washington office of the Trane Co. Are you also with the Trane Co., Mr. Bridges?

Mr. BRIDGES. Yes.

Senator MORGAN. Mr. Bridges, would you care to proceed with an explanation of S. 2045?

STATEMENT OF DENNIS BRIDGES, MANAGER, MARKET DEVELOPMENT, THE TRANE CO., LA CROSSE, WIS., ACCOMPANIED BY JAMES WOLF, MANAGER, THE TRANE CO. WASHINGTON OFFICE

Mr. BRIDGES. My name is Dennis Bridges, manager of market development, and with me is James Wolf.

The Trane Co. is a major manufacturer of heating and air-conditioning equipment. We also provide architects and engineers with design support through training, publishing of technical design materials, and more recently, through computer product selection programs, computer design systems, and in computer programs for energy and economic analysis.

I would like to discuss sections 4 and 5 of S. 2045, particularly concerning the availability of computer programs to accomplish the evaluation called for in section 5, to illustrate the state of the technology needed to accomplish section 5 by giving our experience.

I am not in a position to discuss sections 6, 7, and 8 of this bill.

Senator MORGAN. Mr. Bridges, if I may interrupt, would you please tell us what section 5 provides so we will know what we are talking about?

Mr. BRIDGES. OK. I think, if I might, in general, I will tell you what I see the whole bill doing and I will talk about section 5.

In general, this bill would establish a policy that would stimulate energy conservation in the private sector by requiring the Federal Government to provide leadership in developing and implementing energy conservation techniques in building construction and renovation.

These techniques would be employed on Federal and federally assisted facilities. Agencies of the Federal Government would be required to prepare energy utilization and energy economic analyses for all new facilities 25,000 square feet or larger.

The analyses would consider the major energy consuming systems including the heating, ventilating, lighting, and air-conditioning systems over the economic life of these buildings. The energy savings of such a policy is significant. The technology necessary to accomplish these savings is available.

As a point of interest, four States—New York, Florida, North Carolina, and Washington—have adopted legislation covering State owned and leased buildings that require almost identical analyses to those contained in S. 2045. So, in effect, it is working in those States.

Section 4 of this bill requires GSA and other agencies to publish energy conservation guidelines.

We have a major area of concern contained in section 4(b)(5). This requires "the energy expended in the development processing, manufacture, and transportation of basic materials used in the construction, renovation, and maintenance of such buildings."

Right at this present time, this is beyond the scope of present technology to estimate those costs. For that reason, we recommend that section be deleted.

Senator MORGAN. I am not sure I follow you. Would you repeat that?

Mr. BRIDGES. Section 4 of the bill, 4(b)(5) asks that information be supplied concerning energy expended in the development, like the development of a product; the processing of products in a manufacturing plant; the manufacturing, for example, like the welding energy; and the transportation of the basic materials. In other words, the aluminum to the plant, the steel to the plant, and then the product to the f.o.b. site.

The costs, a way of calculating that is not presently available under present technology. What I want you to understand is what we can do presently and what we can't do presently. That aspect we can't do.

Senator MORGAN. The bill requires that this information be furnished with regard to materials supplied for the use of a building that is being constructed?

Mr. BRIDGES. Right.

Senator MORGAN. In other words, if you are going to supply brick, you have got to find out what the energy expended was. In working on this bill, was this problem discussed, or do you know?

Mr. BRIDGES. Yes.

Senator MORGAN. You don't think it can be done?

Mr. BRIDGES. At the present time we haven't got a procedure on how that can be done easily. It is very important that we try to calculate it because it is basically an energy utilization in building.

I think we recognize that. The point I am making is the fact that the way to calculate that precisely is not available at the present time.

Senator MORGAN. In your opinion, was this so that materials specified must use less energy in their construction?

Mr. BRIDGES. Yes.

Senator MORGAN. I can see the point of it, but also can see us getting into a maze nobody would ever be able to overcome. Excuse me, I didn't mean to interrupt. But we must try to understand as we go along.

Mr. BRIDGES. Section 5 requires each Federal agency to prepare an energy utilization analysis and an energy economic analysis. The essential elements of these two things are, one, the evaluation of two or more energy system alternatives for the building; the simulation of each of these systems for a year's operating period; then the evaluation of the energy consumption of each of the components in each of these systems.

Senator MORGAN. Let me get it straight again. Section 5 requires a utilization analysis and an economic analysis?

Mr. BRIDGES. That is right, and an energy economic analysis.

Senator MORGAN. Tell me again the difference between the two.

Mr. BRIDGES. The utilization analysis would tell you how much energy is going to be used in the building for a certain set of design parameters. This would give you the amount of energy that is going to be used in the building.

The economic analysis would allow you to then determine what would be the cost of applying a certain set of design parameters to that building. The way this works is you would run several good designs alternatives for the building that would employ different energy systems and they would be analyzed for the whole year operating period to find out how these different designs utilize energy.

The energy economic analysis would then decide which of those are the best from the owner's economic standpoint.

Senator MORGAN. What else does section 5 require?

Mr. BRIDGES. That is the basis of section 5.

Senator MORGAN. I believe this is the one you are going to direct most of your remarks to.

Mr. BRIDGES. That is right.

Senator MORGAN. When we recognize that we are going to get involved in all kinds of energy-use analyses, and when this is added to environmental impact studies and all the other things Government requires, are we ever going to get any more buildings built?

Mr. BRIDGES. What I hope to show you today is the fact that energy utilization analysis is being used on a lot of buildings today, even Federal buildings. It is technology that is being employed by the Federal agencies to do some of the things we were talking about

previously in reducing energy consumption in the buildings. It is a technique being used today. It is described within this bill.

Senator MORGAN. I didn't mean to interrupt you. Go ahead.

Mr. BRIDGES. Section 5(b)(3) calls specifically for the energy economic analysis and that requires data from the energy utilization analysis; that is, how much energy is being used in making the energy economic study and section 5(b)(3) discusses the energy economic study.

The energy economic analysis is more limited than the commonly referred to life-cycle costing because it includes only the energy-consuming or related items that affect the energy cost of the building.

Senator MORGAN. What else would life-cycle costs include for the building?

Mr. BRIDGES. The life of the carpeting, the life of the paint on the walls, the life of the fixture that holds the light bulb.

The thing we are trying to address is just the energy consumption of the building, not in the broad scope of life-cycle costing.

Senator MORGAN. I am not trying to make it complicated, but can the carpeting on the floors really have something to do with the energy economics, too?

Mr. BRIDGES. Yes, sir, it can.

You make a good point. The different things we use in the building are not necessarily the air-conditioning and heating systems; obviously, the outside wall, the glass, all have a function in the energy usage of the building.

So you have to study all of those. Life-cycle costing causes difficulty when people try to calculate the cost of all the internal furnishings of a building which is not really directly related to the energy consumption of the building. The energy economic analysis addresses just the energy cost effect.

For instance, this would allow the building owner to have all the economic information about the building from the energy cost, for example, not only the air conditioning system, but the maintenance of that system, the replacement of that system, all the economic data concerning that particular energy system; including, for instance, the study of whether or not energy cost is going to escalate in the future.

Certainly, we know that energy is not going to remain at a stable rate of cost and you must inflate energy costs. In fact, you can inflate energy costs to the point that you can distort the real meaning of the study because the inflation factor becomes so important. However, it is just a small point.

If, for instance, you just use energy at the present cost and you don't escalate it, by using this technique and this technology, you can save energy in buildings.

The energy economic analysis is very comprehensive and provides a way an owner can get all the data he needs to make an economic decision.

This type of analysis provides, I feel, a big step forward in design of buildings because it gives the owner all these costs.

Section 5(c) requires that the system shall be selected considering the energy economics analysis essential to insure that the proper economic decisions are made while saving energy.

Section 5(b) provides for the energy analysis and 5(c) says that the system shall be selected, considering this energy economic analysis.

Senator MORGAN. It doesn't say that the system has to be selected that is the most economical, according to the analysis. It just has to be considered?

Mr. BRIDGES. No, just considered. We feel a lot of judgments have to come in there by the design people, depending on how they use the building.

We feel the application of present technology to accomplish the requirements of section 5 offers a good potential for energy savings in new and existing Federal buildings averaging at least 25 to 30 percent per building.

The procedures involved are well established and now through the use of computers we have a practical means to employ it. The technology applied successfully requires these steps:

First, the architect and engineer have to make a comparison of building designs;

Second, they have to—well, in going into detail on that, for instance, they have to select different wall constructions, different type of glass construction, different mechanical systems, heating and air-conditioning systems, and compare these. There is no clear set of parameters to design a building that will give you the lowest energy consumption.

You can narrow those down, but there are always options that there is a question which is best.

In the past the work was very difficult because of the extensive hand calculations to determine which option had the lowest energy. As a result, few buildings were analyzed in depth for energy consumption.

It probably was based on the fact that there was a certain design time factor required, plus there was a deterrent because of the design fees. It just didn't allow enough money for the professionals to do the job that they had to with hand calculations.

Particularly, Federal buildings fell prey to that where maximum design fees are established.

To make a manual hand calculation of energy in a building requires, roughly, 16 million calculations. At 30 seconds a calculation that is more than 60 years of work.

Senator MORGAN. Please repeat that.

Mr. BRIDGES. To make an energy utilization analysis by hand calculation, say, using a slide rule, requires 16 million calculations; putting numbers into a formula, getting answers. At 30 seconds a calculation that is 60 years of work.

Senator MORGAN. Before computers we just didn't much worry about it.

Mr. BRIDGES. This illustrates why in-depth energy analyses have not been made in the past because of the extensive calculations required.

The Trane Co., working with the computer, developed a program in 1973 called TRACE, which is available to architects and engineers and the Federal Government to perform this function. Other computer programs are also available by others.

The current cost for a computer analysis, to make this building utilization analysis, not including any consultants' fees, varies from about $500 to $2,000, depending on building size.

To illustrate the potential energy savings, this could result by using the requirements in the technology of section 5 and I would like to cover three quick examples. The first consists of a survey of 26 buildings. These buildings were located throughout the United States, consisting of office buildings, schools, hospitals, a factory, a post office, a chapel, and a shopping center.

The energy consumption varied from 302,000 Btu's per gross square foot per year in an office building in Hartford, Conn., to a low of 63,000 Btu's per gross square foot per year in an office building here in Washington, D.C.

In a sample of the 26 buildings there were two other office buildings located in Washington. One had 129,000 Btu's per gross square foot per year. The other had 116,000 Btu's per gross square foot per year. The statement we submitted contains the data in all 26 buildings.

The average consumption, energy consumption in these 26 buildings is 133,000 Btu's per gross square foot per year. The average of the lowest 25 percent, take the lowest 25 percent, the average of that is 72,000 Btu's per gross square foot.

If all 26 of those buildings could be reduced to the 72,000 or the average of the low 25 percent, it would achieve a 47-percent reduction in the energy in these buildings.

GSA says that it should be possible to reduce existing buildings to 75,000 Btu's per gross square foot and new buildings to 55,000 Btu's per gross square foot. And GSA is demonstrating this capability in recent designs using the technology and the technical analysis made available in section 5.

Particularly, for instance, I know of the Manchester, N.H., Federal Office Building that was designed and it has an energy consumption around 55,000 Btu's per square foot and, incidentally, TRACE was used in the energy utilization study for that particular project.

The second example is a new 20-story, 300,000-square-foot office building that underwent an energy utilization analysis like that called out in section 5(b)(2).

The air-conditioning system was changed and actually, in this case, the air-conditioning system chosen, was actually less first cost than the original air-conditioning system that was the base design.

The air conditioning equipment was changed. The amount of glass was reduced in the building. The type of glass was changed to a heat-reflective type of glass. The lighting intensity was dropped. The amount of insulation was increased in the walls and the orientation of the whole building was changed to favor the direction of the sun.

All of these changes were made that are consistent with good design practices as we know them today, that as GSA would be using in new buildings.

The total energy cost reduction per year reduced from $122,000 per year down to slightly more than $50,000 per year. It is a 58.5 percent savings in energy costs.

For that particular building, the computer energy utilization analysis cost $3,000 excluding consultant fees.

The first two examples illustrate potential for energy reduction in new Federal, commercial and institutional buildings of at least 40 percent using these new technologies.

The third and last example is an existing building. It is a 200,000-square-foot office building. It was built in 1967. It is a very modern design. It is located in La Crosse, Wis., and it is the international headquarters of the Trane Co.

This building underwent an energy utilization analysis like section 5 calls for. The computer simulation of the energy cost compared to the actual energy cost showed very close estimates could be made.

The actual heating cost was $63,000 per year. The simulated cost using the TRACE program was $61,000 per year; a difference of 2.6 percent.

The actual electric cost was $89,000 per year and the simulated cost was $84,600 per year, a difference of 6 percent. Subsequently, this data led us to discover there was a system malfunction causing an energy waste of $4,000 a year.

Consequently, the correlation became closer. It was really around 2 percent.

The computer simulation systems of design and operational changes predicted a savings of $93,500 for this building per year because we reduced the energy using some operational and system changes within this building using technology as called out under section 5, that reduced the cost of energy in this building $93,500 per year.

It was a reduction of 61 percent. The changes were made according to the results of the energy utilization analysis and the actual saving measured was 61.2 percent. The total cost to these modifications to this building was $20,000 of which $4,000 was this computer expense.

The investment was recovered in 5 months.

In summary, I would like to say clearly there is a tremendous potential for energy savings in new and existing buildings. Our experience in analyzing over 1,000 buildings has been that, normally, the design alternatives for a new building with the lowest energy consumption is the same design that yields the lowest total cost for the building over its projected life.

The total costs are the initial investment, operating cost, including the cost of energy consumed over the life of the building, plus maintenance and replacement costs.

There is an urgent need to stimulate effective energy conservation in Federal Government, commercial and institutional buildings. Willingness by both the Federal Government and the private sector to purchase buildings designed for higher energy efficiency will provide the incentive for development of products and systems with higher energy efficiency.

When this is demonstrated by decisions based upon energy and economic evaluations, manufacturers will respond with equipment that permits even further energy savings.

Architects and consulting engineers must react to the change in energy economics and shift from the comparison of first cost to that of total costs for the life of the building. The owner can make a proper decision only when he is given all the economic facts.

The Federal Government can provide leadership in energy conservation by requiring all Government owned and assisted projects to be budgeted and approved based upon the total costs for the projected life of the building.

The energy and economic evaluation concepts contained in section 5 will provide the basis for better design decisions that insure Federal Government buildings are energy conserving.

We would be pleased to respond to any questions from the committee.

Senator MORGAN. Thank you very much, Mr. Bridges. I think your discussion has been helpful. We may have gotten a little ahead of ourselves at times. But to keep it clear in my mind, and for those who are trying to follow it, since you are directly interested in this bill, let's briefly go through it step by step to see what it does.

Then we will also be able to compare it with Senator Hart's bill, S. 2095.

Correct me if I am wrong, but briefly summarized, it first directs the Administrator of GSA, after consulting with the Federal Energy Administrator and the Department of Defense, with HUD, VA, and the Bureau of Standards, to publish energy conservation and management guidelines within 1 year for use in the design, construction, renovation and operation of buildings for which these agencies are responsible.

If I could make a distinction for the record, or draw an analysis, this bill puts the sole responsibility on the Administrator of GSA to promulgate guidelines for all of these agencies after consulting with them, whereas Senator Hart's bill puts the responsibility on the Administrator of GSA and the DOD together.

Is that a distinction that you see?

Mr. BRIDGES. Yes.

Senator MORGAN. Here the GSA has the responsibility of promulgating the guidelines after consulting with the others, whereas in the Hart bill the DOD and GSA do it together. If you differ with me, please note it and tell us about it later, so we will understand what we are doing.

Further, it directs the Postal Service to publish separate energy conservation guidelines within 1 year, for buildings under their control.

We may want to consider this question, even though the Postal Service may be a separate agency. It would seem that if we have the authority to require them to do this, we may also have the authority to put them under the same guidelines as GSA. Do you have any comment on that?

Mr. BRIDGES. It is appropriate.

Senator MORGAN. Point 3: It directs that such guidelines shall include information on all factors that may affect energy conservation and utilization such as architectural features, site orientation, building conservation, and consumption practices, new techniques, and energy expended in manufacturing and handling the basic materials in construction, repair, or maintenance of such buildings.

In other words, it specifies the things that must be taken into consideration in preparing the background.

Fourth: It authorizes GSA to utilize outside services in the development of energy conservation guidelines. I assume this will allow GSA to draw from the vast source of information that private industry may have.

It requires agencies to prepare an energy utilization analysis and an energy economic analysis for each building to be constructed, repaired, or maintained under their supervision.

This is the section you and I talked about, that differs between utilization and economic analysis.

It directs that energy utilization and cost data be indicated in prospectuses submitted for approval. This is the line of the Hart bill.

It directs that, in selecting building sites, agencies consider the proximity of existing and planned mass transit facilities.

Mr. BRIDGES. To go back to paragraph (d), I think we should understand that the estimate that is called for in paragraph (d) is not the same function as called out in paragraphs (b) and (c).

Senator MORGAN. What is the distinction there?

Mr. BRIDGES. Mr. Chairman, the information required for (b) and (c) is the data that would be used in the actual design sequence of the building. The estimate required in (d) is not the same information. It is—hate to use the word ball park, but it is an estimate based on experience from similar energy analyses that have been performed on similar types of buildings.

The point here to be clarified is the fact that the energy utilization analyses and the energy economic analyses are derived during the actual design of the building; in other words, the actual preparation of the specifications and the blueprints.

Paragraph (F) refers to the giving an estimate of how much energy the building is expected to take. GSA, for instance, designs the buildings to try to meet a guideline of 55,000 Btu's per gross square foot per year.

As their success in that unfolds, they will have a feeling of about how much energy they will be using in a building. They will be using past data as an estimate instead of a precise number that they will generate in the actual design of a building

Senator MORGAN. I think I may be lost when you refer to paragraph (d) and the other paragraph. Let me see if I can summarize it in my own words. It requires agencies to prepare an energy utilization analysis and an energy economic analysis, whenever a building is to be constructed, repaired or maintained under their supervision.

Does this mean the agency that is going to use the building? Is this the distinction you are making? GSA or whoever designs the building will actually make the utilization and economic analysis?

Mr. WOLF. Mr. Chairman, the agency that would prepare the analyses would either be the agency that is occupying the building or the agency that would be responsible to provide the facilities such as the case where GSA would construct a building, but it would be occupied by one of the other agencies.

The distinction here is that the requirement for the energy utilization and energy economic analyses is to be completed during the design and that data evaluated before construction commences so that the energy utilization and the total cost of the building are known and

a decision is made based on that information; whereas the estimate of the utilization of the energy and the cost could be based on past experience of similar type buildings or could be based on a modified or, if you will, a shortcut estimate of that building.

The difficulty here is that to complete an energy utilization or energy economic analysis at the prospectus stage can be difficult, considering the stage of the concept when it comes to Congress, and it may not be necessary for the budgeting aspects with the history that would be developed; whereas before you go to construction, the objective of the bill is to insure that energy isn't wasted and the total cost is considered.

Senator MORGAN. I still am not sure I fully understand it, but maybe after I read the bill again I will. If not we will come back to it.

The point 6 requirement of the bill directs that energy utilization and cost data be indicated in all prospectuses submitted for approval. This does not differ from the Hart amendment.

Point 7, it directs that when selecting building sites, agencies must consider the proximity of existing or planned mass transit systems.

Point 8, it directs that demonstration and experimental energy systems shall not be precluded.

Point 9 directs that GSA consult with FEA and the Office of Federal Procurement Policy, to survey all Federal procurement in excess of $10,000 from the viewpoint of energy conservation, and report to the President and Congress, recommending improvements.

Point 10 directs FEA to submit an annual report to Congress, of their activities under this act, and also that each agency examine their buildings and report to Congress on improvements that could be made. It would authorize $7.5 million to carry out the purposes of this act.

Are these essentially the requirements of this bill?

Mr. BRIDGES. Yes.

Senator MORGAN. Gentlemen, a 15-minute rollcall already has been going on for several minutes, and I must be there. I just want to know now who is next.

Mr. Bridges, we do have a lot more specific questions. How inconvenient would it be for you to come back later on?

Mr. BRIDGES. Yes; I can come back.

Senator MORGAN. Mr. Meisen, you are supposed to be up next. I've got to go vote and take care of one other matter. Shall we go as far as we can this afternoon along these lines or try to make it as convenient as we can for everybody who is here now? We can't stop the Senate from running, but will you be able to come back tomorrow?

Mr. MEISEN. Yes; I will be here tomorrow. I will stay as long tonight as you wish; whatever is your pleasure.

Senator MORGAN. Dr. Willenbrock, I believe you are leaving the country tomorrow?

Dr. WILLENBROCK. Yes.

Senator MORGAN. Let us recess until 4:15 p.m. We will try then to hear you. Can you stay this afternoon?

Dr. WILLENBROCK. Yes; I can.

Senator MORGAN. Let us try to make it back here by 4:15 p.m. That will give me time to get over there and get back.

[Brief recess.]

[Mr. Bridges' complete statement follows:]

THE TRANE COMPANY

S.2045, A BILL TO INSURE THAT FEDERAL BUILDINGS AND CERTAIN BUILDINGS ASSISTED WITH FEDERAL FUNDS EMPLOY THE BEST PRACTICABLE ENERGY CONSERVATION AND MANAGEMENT PRACTICES.

SENATE COMMITTEE ON PUBLIC WORKS,
SUBCOMMITTEE ON BUILDINGS AND GROUNDS
NOVEMBER 4, 1975

STATEMENT BY
DENNIS BRIDGES, MANAGER,
MARKET DEVELOPMENT
THE TRANE COMPANY
LA CROSSE, WISCONSIN

The Trane Company statement on S.2045.

Mr. Chairman and members of the committee, The Trane Company appreciates the opportunity to present our views on this energy bill. My name is Dennis Bridges and I am Manager of Market Development for The Trane Company, headquartered in La Crosse, Wisconsin. With me is James Wolf, Manager of Government Relations for Trane.

The Trane Company is a major manufacturer of air conditioning, refrigeration, and heat transfer equipment. We also provide architects and engineers with design support through training, publishing of technical design materials, and more recently, computer product selection, system design, and energy and economic analyses programs.

I would like to make specific comments on sections 4 and 5 of this bill and to discuss the availability of computer programs to accomplish the evaluation requirements of these provisions. To illustrate the state of the technology needed to perform energy and economic evaluations I will present our experience with The Trane Company's computer program. I am not in a position to discuss sections 6, 7, and 8.

Before discussing sections 4 and 5 I would like to make a few general comments about S.2045. This bill would establish a policy that would stimulate energy conservation in the private sector by requiring the Federal Government to provide leadership in developing and implementing

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energy conservation techniques in building construction and renovation. These techniques would be employed on Federal and federally assisted facilities. Agencies of the Federal Government would be required to prepare energy utilization and energy-economic analyses for all new facilities 25,000 square feet or larger. The analyses would consider the major energy consuming systems including the heating, ventilating, lighting and air conditioning systems over the economic life of these buildings. The energy savings of such a policy is significant. The technology necessary to accomplish these savings is available. As a point of interest, four states - New York, Florida, North Carolina, and Washington - have adopted legislation covering state owned and leased buildings that require almost identical analyses to those contained in S.2045.

Section 4 requires the General Services Administration with assistance from other agencies and the United States Postal Services to publish energy conservation guidelines for use in design, construction, renovation and operation of certain buildings. The past efforts by GSA in developing their energy conservation guidelines for new and existing buildings is a major step toward accomplishment of this goal.

There is one major area of concern contained in section 4(b)(5). It is the requirement that the guidelines include information on "--The energy expended in the development, processing, manufacture, and transportation of basic materials used in the construction, renovation, and maintenance of such buildings". This is beyond the scope of present

available technology and possibly would not significantly contribute to energy conservation in buildings. It is recommended that this section be deleted.

Section 5. requires each Federal agency to prepare an energy utilization analysis and an energy-economic analysis for any Federal building or federally-assisted building 25,000 square feet or more of usable floor space, leased facilities that are more than 66% occupied by a Federal agency, and smaller buildings based on the energy conservation benefits of such analyses. The energy utilization analysis requirement contained in section 5(b) (2) would accomplish an accurate estimate of the energy used in a building. It would consider the external, primarily weather, and internal energy load requirements including the efficiency of the energy consuming systems. The essential elements for this analysis are an evaluation of two or more energy system alternatives, simulation of each system for a year's operating period, and evaluation of the energy consumption of component equipment. This analysis can be accomplished with current computer technology at a reasonable cost to the government.

The data developed in the energy utilization analysis is essential to accomplishment of the energy-economic analysis requirement contained in section 5 (b) (3). This energy-economic analysis is more limited than the commonly referred to life cycle cost concept. It includes only those energy consuming or energy related items affecting the

energy cost of the facility. This analysis considers not only the initial cost of each system but also the cost of utilities, cost of maintaining each system, and the average replacement cost for the projected useful life of the building.

The economic data such as replacement cost and utility cost are dependent on projections of energy cost increases, including inflation, for the life of the building. These projections are made by the building owner and can be any amount including no increase in cost. This capability of the owner to select the variables insures a valid projection of the total cost of the building for its economic life.

This type of analysis provides a new dimension in building design enabling the owner to consider not only the initial cost of construction but also the important cost of owning the building. An owner presented with this type analysis has the information to make a decision based on comparisons of initial costs and energy savings.

The requirement in section 5 (c) that the system shall be selected considering the energy-economic analysis is essential to insure that proper economic decisions are made while striving to save energy. The application of present technology will enable the Federal government to accomplish the requirements in section 5. The performance of these evaluations, and only to the extent that they are economically justified, offers a potential for energy savings in new and existing Federal

buildings averaging at least 25 to 30 percent. The technology to obtain these savings is available. The engineering and design procedures involved are well established and now practical means to employ them, through the use of computers, are available.

To apply this technology successfully, a building designer must compare many architectural and air conditioning options to select the optimum design for each building based on its geographic location and many other variable factors. Historically, evaluations of this type were laborious, if not impossible, and approximations at best. Consequently, in an effort to reduce building design time and operate within traditional design fee structures, few buildings have been analyzed in-depth from a total energy-consumption standpoint. This has been particularly true for Federal Government buildings where maximum fees are established.

To make an accurate energy and economic prediction for a building following the criteria in this bill and by using manual (slide rule) procedures, our engineers estimate that approximately 16 million calculations would be required. If calculations are made at the rate of 1 each 30 seconds it would take in excess of 60 man years. This illustrates why in-depth energy analyses have not been made in the past by the Federal government or the private sector.

The Trane Company, working with the computer, developed a program called Trane Air Conditioning Economics (TRACE) which is available

to the Federal government, architects, and engineers to perform this function. Other computer programs, which make a similar type analysis, are available from other sources. The cost to use these programs is nominal when compared with the tremendous potential economic benefits that they can provide. The current cost for a computer analysis, not including the consultants fee, is based on the building size and can range from $530 to over $2000.

Building Size Square Foot	Price for Specified no of alternatives 2	3	4
Up to 60,000	$530	$600	$670
60,001-90,000	630	700	770
90,001-120,000	730	800	870
120,001-150,000	830	900	970
150,001-180,000	930	1000	1070
180,001-210,000	1030	1100	1170
210,001-240,000	1130	1200	1270
240,001-270,000	1230	1300	1370
270,001-300,000	1330	1400	1470
300,001-330,000	1430	1500	1570
330,001-360,000	1530	1600	1670
360,001-390,000	1630	1700	1770
390,001-420,000	1730	1800	1870
420,001-450,000	1830	1900	1970
Above 450,000	Contact The Trane Company		

To illustrate the potential for improved efficiency, and hence energy conservation in new and existing buildings, here are data on 26 commercial and institutional buildings including 16 office buildings located all over the nation. Each of the buildings, now under design or construction, has been analyzed using the TRACE Computer Program.

BUILDING LOCATION	TYPE BUILDING	BTU/GSF/YR	BUILDING LOCATION	TYPE BUILDING	BTU/GSF/YR
Hartford, Conn.	Office	302,252	Cincinnati, Ohio	Office	76,803
Jacksonville, Fla.	Office	245,680	Tyson's Corner	Office	66,163
Collegeville, Pa.	Office	228,670	Washington, D.C.	Office	63,358
Raleigh, N.C.	Office	159,847	Tallahasee, Fla.	University	172,161
Jackson, Miss.	Office	153,353	Milwaukee, Wi.	Gymnasium	94,360
Roanoke, Va.	Office	150,247	La Peer, Mi.	School	69,296
Washington, D.C.	Office	129,055	Kansas City, Mo.	Hospital	202,997
Washington, D.C.	Office	116,264	East Orange, N.J.	Hospital	163,780
San Rafael, Calif.	Office	111,169	Springfield, Mass.	Hospital	75,635
Baltimore, Md.	Office	97,527	Kettering, Ohio	Factory	100,439
Orlando, Fla.	Office	95,261	Sacramento, Calif.	Post Office	154,558
Detroit, Mi.	Office	88,907	Sacramento, Calif.	Chapel	133,369
Roanoke, Va.	Office	81,933	Lawrence Township, N.J.	Shopping Ctr.	121,074

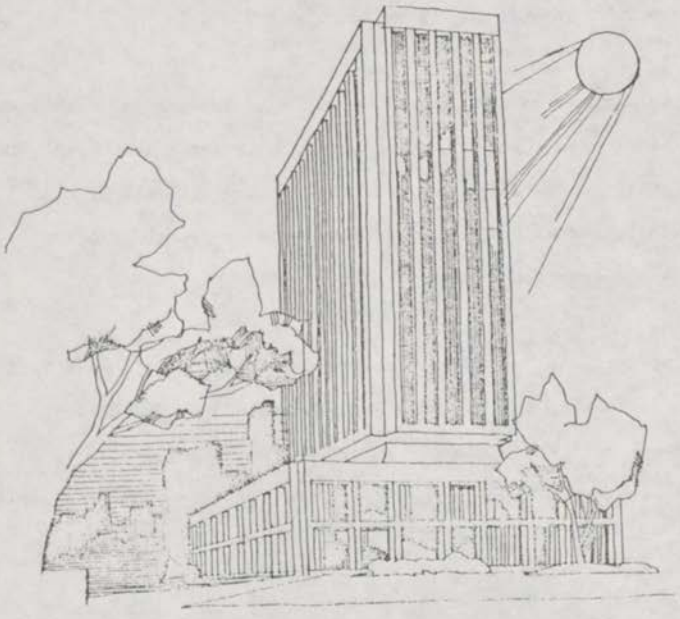
These figures ranging from 63,358 to 302,252 represent the estimated total energy consumption for a typical year, expressed in BTU's per gross square foot of building floor space per year.

According to a study by the General Services Administration, a reasonable target for office building energy consumption is approximately 55,000 BTU's per gross square foot per year. Comparison with the figures shown for these actual buildings indicates the tremendous disparity that exists based on the designs.

For example, note the two office buildings in this area, one at Tyson's Corner and another in the District of Columbia. They are predicted to require about 65,000 BTU's per year. At the other extreme is an office building in Hartford, Connecticut that would consume approximately

300,000 BTU's. The average for these buildings is about 133,000 BTU's. If each of the office buildings were reduced to 72,000 BTU's, the overall weighted reduction in energy usage for all 16 buildings would be 47%.

To illustrate how a computer analysis can be used to evaluate design alternatives and to meet the requirements of section 5, consider this case study. This is an architectural rendering of a typical office building which is 20 stories high and contains 300,000 square feet of floor space. The base design used gas for heat and electricity for cooling.

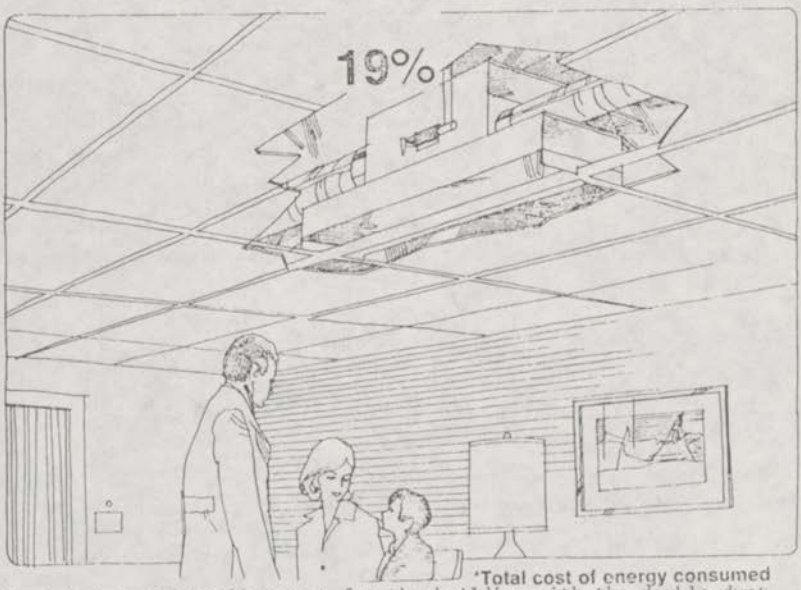


This building was analyzed for 7 design alternatives compared with an initial design commonly used today. The cost of energy for the initial design was $.41 per square foot per year. This was below the average for all U.S. office buildings last year.

In this first alternative two popular types of air conditioning systems were evaluated, double-duct and variable air volume.

DOUBLE DUCT* **$122,428**

VAV ..... **$ 98,354**



*Total cost of energy consumed

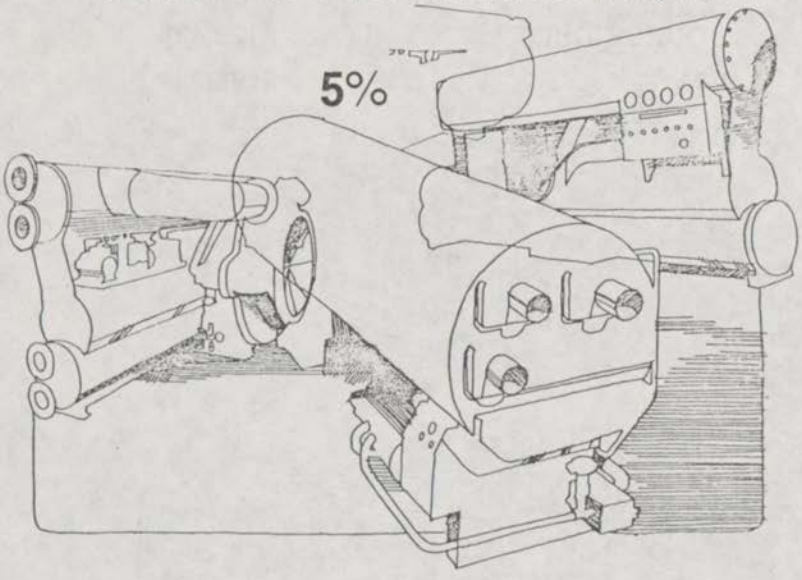
The total annual utility cost for the building with the double-duct system was projected at $122,428. When changed to variable air volume, the energy consumption dropped to $98,354, a 19% reduction.

In the next alternative use of centrifugal versus absorption water chillers was compared, in each case using a variable air volume system.

EQUIPMENT

CENTRIFUGAL ..... $ 98,354

ABSORPTION ..... $ 93,473



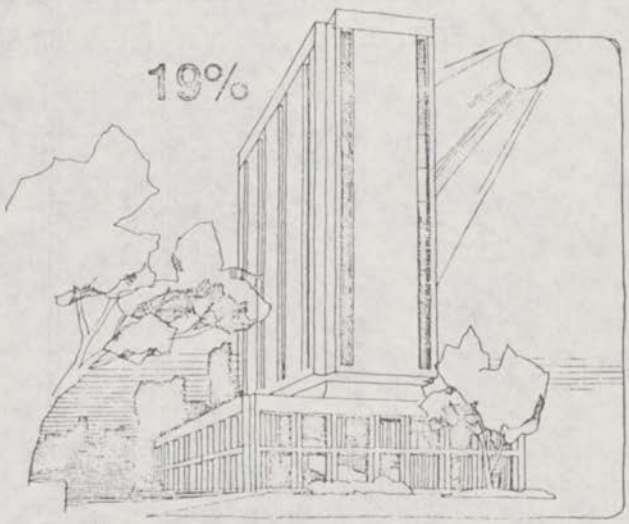
With gas heat, the centrifugal required $98,354 in annual energy consumption. With oil heat, the absorption required only $93,473, a reduction of 5%.

Next, the amount of insulated clear glass in the building was reduced from 50% to 20%.

AMOUNT OF GLASS

50% GLASS ..... $ 93,473

20% GLASS ..... $ 75,442



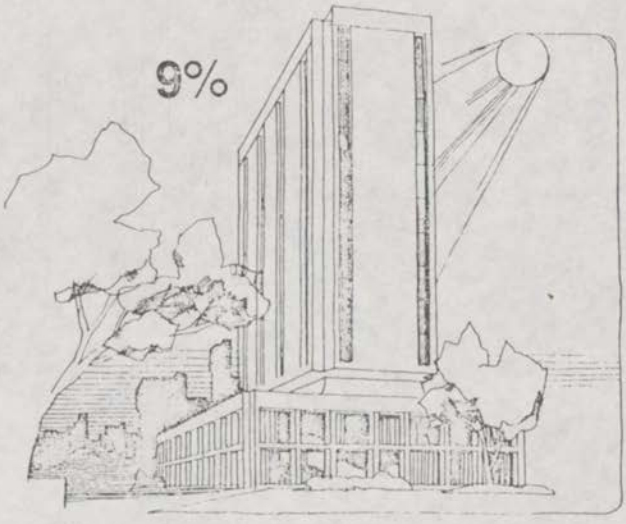
This prompted a further utility cost reduction from $93,473 to $75,452, a 19% drop in energy consumption.

Then, retaining 20% glass but changing the type from insulated clear to reflective glass resulted in a further reduction in estimated annual utility expense of 9% to a level of $68,692.

TYPE OF GLASS

CLEAR ..... $ 75,442

REFLECTIVE ..... $ 68,692

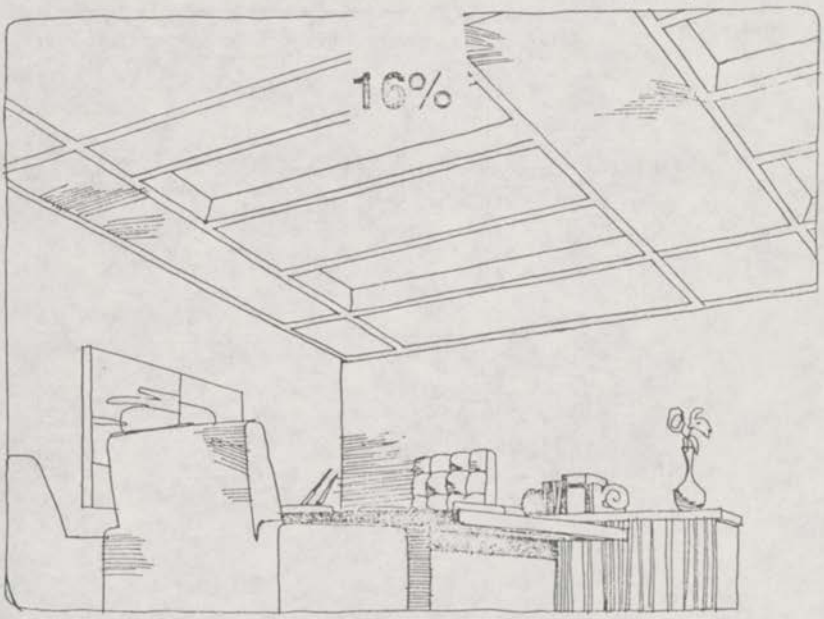


The fifth alternative involved a reduction in lighting intensity from 4 to 3 watts per square foot.

LIGHTING INTENSITY

4 WATTS ..... $ 68,692

3 WATTS ..... $ 57,624



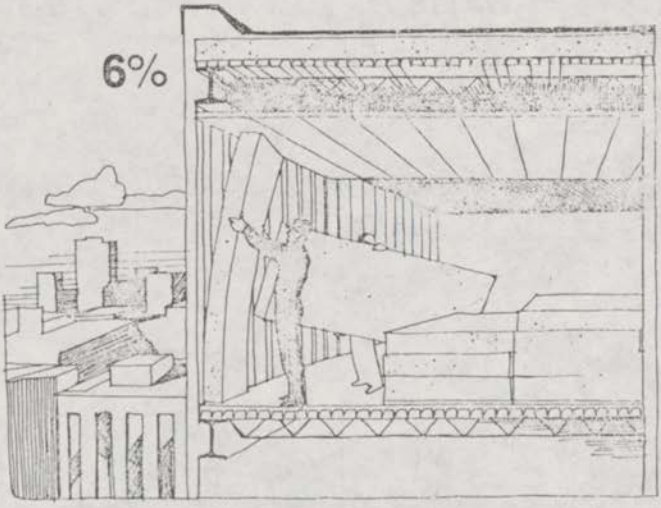
This produced an additional 16% drop in annual energy consumption to a level of $57,624.

The sixth alternative involved doubling the thickness of insulation.

INSULATION

3 INCHES ..... $ 57,624

6 INCHES ..... $ 54,275



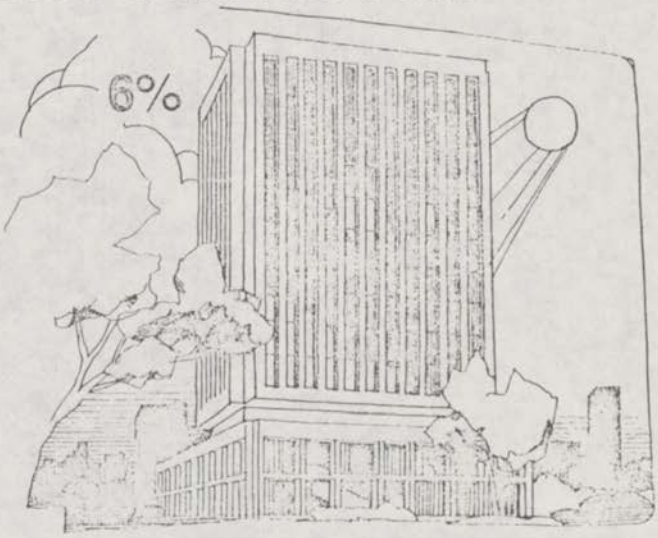
This produced an estimated reduction in annual energy consumption of 6% based on total annual utility cost at $54,275.

The seventh and final alternative involved building orientation. The office building tower was rotated 90 degrees so that the primary glass exposure was north-south instead of east-west.

ORIENTATION

EAST/WEST ..... $ 54,275

NORTH/SOUTH ..... $ 50,780



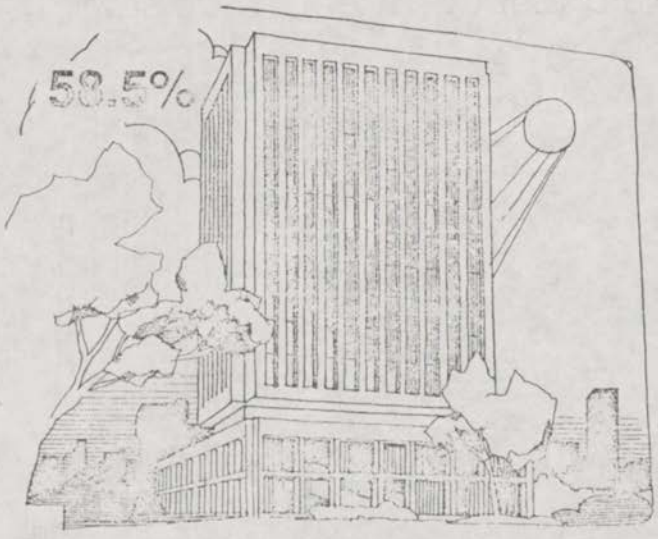
This produced an additional 6% drop in energy consumption to a final projected level of $50,780.

In total, the annual energy cost was reduced from $122,428 to $50,780, a 58.5% reduction in energy consumption.

TOTAL

ORIGINAL $122,428

CHANGED ..... $ 50,780



Obviously, some of the alternatives illustrated are not possible on every building. Each change must be considered individually in view of comparative first cost and other considerations. Nevertheless

most options of this type are normally acceptable and carry a high level of economic justification.

Clearly, this illustrates the tremendous effect that alternative building designs have on energy consumption. Incidentally, this computer analysis, excluding consultant fees, cost about $3000.

This example, along with the data presented earlier on 26 buildings, illustrates a potential for energy reduction in new Federal government, commercial, and institutional buildings of at least 40%. The next obvious question, then, is whether there is sizable potential for energy reduction in existing buildings. The answer is yes. Here is an example.

The Trane Administration Building located in La Crosse, Wisconsin, constructed in 1967, contains approximately 240,000 square feet. The building is conditioned with conventional room fan coil units and a terminal reheat system. The large interior area served by this reheat system, typical of many large office buildings today, was the key to the majority of the savings we achieved.

Here is a summary of actual heating fuel bills from July 1, 1972 through June 30, 1973.

HEATING FUEL UTILITY COSTS
(Dollars By Month)

ACTUAL UTILITY EXPENSE (JULY '72 THRU JUNE '73)

J	A	S	O	N	D	J	F	M	A	M	J	TOTAL
5156	6825	6421	4942	3091	1927	8008	5308	5217	5178	5005	6538	63,527

TRACE SIMULATION OF EXISTING BUILDING

7441	6340	5448	4938	4476	4307	4357	3851	4379	4749	5610	6092	61,988

A TRACE analysis, using a weather tape for this location and this same period showed close correlation between the actual utility expense of $63,527, and the computer prediction of $61,988, a difference of 2.6%. As recently as 3 years ago, it would have been impossible to simulate building energy consumption with this degree of accuracy.

A second TRACE analysis was made to simulate turning off the reheat system on the interior of the building at 5 p.m. and turning it back on at 7 a.m. This resulted in a projected heating fuel cost of $24,630, a reduction of $37,358 or 61% annually. We also analyzed use of an air side economizer which, fortunately, because of the system design, could be incorporated with very little change. The computer simulation indicated an additional 9% fuel cost reduction to $18,837. Combined, the computer analysis indicated a potential for heating conservation in the neighborhood of 70%.

Next, we analyzed electric utility costs on the same basis.

ELECTRIC UTILITY COSTS
(Dollars By Month)

ACTUAL UTILITY EXPENSE (JULY '72 THRU JUNE '73)

J	A	S	O	N	D	J	F	M	A	M	J	TOTAL
7778	8007	7657	7635	7468	7241	7111	7325	7325	7091	7518	7460	89,616

TRACE SIMULATION OF EXISTING BUILDING

8212	8209	7224	6620	6403	6465	6541	6149	6799	6427	7544	7911	84,604

Again, we compared actual electric utility bills totalling $89,616 with the computer simulation of the building at $84,604. Analysis of the $5,012 differential, or about 6%, led to the discovery of a system malfunction causing a waste of approximately $4,000 per year. Consequently, the correlation was really within 2%.

Computer simulation of the system operational changes predicted an electric expense reduction of about 52%.

In total, between heating fuel and electric utility costs, the annual predicted savings was $93,590, or 61%. Incidentally, we have confirmed that the changes actually produced savings that matched the computer predictions within 3%. The actual expenses to make these changes, including the computer analyses cost of $4000, was about $20,000. Therefore, the added investment was recoverable in about 5 months based on savings - - <u>after</u> taxes.

A similar analysis, conducted on our Lexington Manufacturing Plant, produced a savings of 31%. But, a plant at another location showed little potential for justifiable savings. This illustrates why a computer analysis is needed on each building to determine what energy cost savings can be justified. Overall, our experience indicates that energy consumption in existing buildings can be reduced at least 25%.

Clearly, there is tremendous potential for energy savings in new and existing buildings. Our experience in analyzing over 1000 buildings has been that, normally, the design alternatives for a new building with the lowest energy consumption is the same design that yields the lowest total cost for the building over its projected life. The total costs are the initial investment, operating cost, including the cost of energy consumed over the life of the building, plus maintenance and replacement costs.

There is an urgent need to stimulate effective energy conservation in Federal government, commercial and institutional buildings. Willingness by both the Federal government and the private sector to purchase buildings designed for higher energy efficiency will provide the incentive for development of products and systems with higher energy efficiency. When this is demonstrated by decisions based upon energy and economic evaluations, manufacturers will respond with equipment that permits even further energy savings.

Architects and consulting engineers must react to the change in energy economics and shift from the comparison of first cost to that of total costs for the life of the building. The owner can make a proper decision only when he is given all the economic facts.

The Federal Government can provide leadership in energy conservation by requiring all government owned and assisted projects to be budgeted and approved based upon the total costs for the projected life of the building. The energy and economic evaluation concepts contained in section 5 will provide the basis for better design decisions that insure Federal government buildings are energy conserving.

We would be pleased to respond to any questions from the Committee.

Senator MORGAN. Dr. Willenbrock, since you must leave town, we will hear from you now. You are Director of the Institute for Applied Technology, National Bureau of Standards? And accompanied by Dr. Richard Wright, Director of the Center for Building Technology?

STATEMENT OF DR. F. KARL WILLENBROCK, DIRECTOR, INSTITUTE FOR APPLIED TECHNOLOGY, NATIONAL BUREAU OF STANDARDS, U.S. DEPARTMENT OF COMMERCE, ACCOMPANIED BY RICHARD N. WRIGHT, DIRECTOR, CENTER FOR BUILDING TECHNOLOGY, NATIONAL BUREAU OF STANDARDS

Dr. WILLENBROCK. That is correct, Mr. Chairman.

Thank you, very much.

We welcome this opportunity to present the comments of the National Bureau of Standards with respect to S. 1392 and S. 2045.

My name is F. Karl Willenbrock, Director of the NBS Institute for Applied Technology. With me this morning is Dr. Richard N. Wright, Director of NBS' Center for Building Technology. NBS has an active interest and program in energy conservation with a particular emphasis on energy conservation in buildings.

INTRODUCTION

Energy used in buildings accounts for one-third of the total energy consumed in the United States. Thus, energy conservation in buildings can have a major effect in reducing the Nation's total energy consumption. Energy conservation is the most effective short-range approach to mitigate the Nation's shortage of energy. Conservation will continue to be an important factor in the long-range. The Federal Government can and should provide leadership for energy conservation in buildings.

NBS, which serves as a technical resource for over 30 Federal agencies concerned with direct and federally assisted programs for building construction, can provide the technical base for an effective energy conservation program for both new and existing buildings.

Both S. 1392 and S. 2045 address energy conservation in Government buildings. S. 1392, "The Energy Conservation Buildings Demonstration Act," would establish a demonstration program in energy conservation by using innovative technology to retrofit existing buildings with energy conservation equipment and systems.

Under this legislation, the Federal Energy Administration (FEA) and NBS would establish procedures for identifying existing Federal, State and municipal buildings as candidates for retrofitting with energy conservation equipment and systems. Using these procedures, the General Services Administration (GSA) would select 40 Federal buildings as candidates for retrofitting based on life-cycle considerations. Also, States could submit grant requests for retrofitting selected State and municipal buildings.

The purpose of S. 2045 is to insure that federally owned buildings and buildings constructed with Federal assistance employ the best energy conservation and management practices. This bill directs GSA in consultation with various Federal agencies including the National

Bureau of Standards, to develop energy conservation guidelines for use in the design and construction of Federal buildings. This bill also directs that each Federal agency shall require the reparation of energy economic and utilization analyses for Federal buildings.

Both these bills are concerned with promoting the efficient use of energy in buildings. Although the objectives of S. 2045 and S. 1392 are commendable, neither of these bills is necessary. The Federal Energy Administration is currently addressing energy conservation retrofit measures in existing Federal buildings. We defer to the Federal Energy Administration and the General Services Administration for discussion of the policy and programmatic implications of these bills.

Since both bills require advances in technology, I should like to address the technical problems involved. The problems fall into two categories: (1) The development and implementation of design standards for new buildings and, (2) the development of retrofit procedures for existing buildings. I will describe the technically distinct approaches required for new buildings and for existing buldings.

STANDARDS FOR NEW BUILDINGS

The National Bureau of Standards, with its own resources and with the support from the Department of Housing and Urban Development (HUD), for many years worked on the development and implementation of energy conservation standards for all types of new buildings. More recently, FEA and the Energy Research and Development Administration (ERDA) have also provided us with financial support for this program.

With respect to new buildings, it is important to note that while guidelines provide the general intent and direction for attaining energy conservation, they do not provide a means for measuring the results of or enforcing regulatory requirements. Guidelines suggest a variety of opportunities for energy conservation without specifying any required minimum level of performance.

On the other hand, standards are minimum requirements stated in terms suitable for adoption in building codes. As an example of an energy-conservation standard for new buildings, I cite ASHRAE Standard 90–75, issued by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers in October 1975.

It is the Nation's first, comprehensive energy conservation standard which is applicable to all types of new buildings. With the permission of the chairman, I would like to submit a copy of this for the record.[2]

The history of the development of the standard is of interest. ASHRAE 90–75 is based on a research report published by NBS in February 1974, entitled "Design and Evaluation Criteria for Energy Conservation in New Buildings."

In July 1973, the National Conference of States on Building Codes and Standards, an organization of building regulatory officials from State and local governments, requested the National Bureau of Standards to develop an interim standard for energy conservation in new buildings which could be used by the States as a basis for energy-conserving building codes.

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[2] Retained in committee files.

This request arose from the desire of the conference to avoid the adoption by State legislatures of differing code requirements which could fragment the market for building materials and systems and add unnecessary costs to the building construction process.

NBS responded to this request promptly and in 7 months produced this report, a copy of which, with your permission, Mr. Chairman, I should like to submit for the record.[3]

This report was turned over to ASHRAE in February 1974, with the recommendation that it be processed by ASHRAE and the American National Standards Institute (ANSI) as a national consensus standard. At the same time, the National Fire Protection Association (NFPA) was asked to add energy-conserving provisions to the National Standard for Mobile Homes, A119.1. NBS staff have participated actively with ASHRAE and NFPA in the development of both of these national standards.

The ASHRAE standard was completed and published last month. Currently, the mobile home requirements are in the form of a tentative interim amendment being considered by the NFPA committee for inclusion in the mobile home standard. The Department of Housing and Urban Development has also included provisions based on the NFPA and the NBS work in its proposed Mobile Home Construction and Safety Standard.

We do not feel that our work on the develoment of energy conservation standards is finished. We are now working on the development of an energy budget approach. An energy budget is the maximum amount of energy required per year to operate a building. It depends on the size, location, and use of the building. A properly developed budget can lead to greater savings of energy, greater freedom for the designers to meet design objectives, and more cost-effective use of materials, systems, and construction procedures.

We also need to develop techniques for predicting the performance of buildings throughout the useful life of the building. With a life-cycle performance prediction capability, we would be in a position to minimize the life-cycle operating costs of a building. Such a minimization could lead to the best possible choice of energy conserving building technology.

The effective implementation of energy conservation standards is not a trivial task. Few building designers or building regulatory (building code) officials have experience with the design and construction of buildings to meet an energy conservation standard.

With the support of ERDA, HUD, and FEA, we are working with the American Society for Testing and Materials, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, the American Institute of Architects, the Council of American Building Officials, the National Conference of States on Building Codes and Standards, and other representatives of the building community in the development of sound procedures and techniques for the application of the present and future energy conservation standards.

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[3] See app. B, p. 461.

The Federal Government is in a unique position in its construction of new buildings to demonstrate the application of the best available standards and to test and evaluate concepts for improved standards. Advanced concepts for energy conservation in buildings are being explored at the GSA demonstration office building in Manchester, N.H.

NBS assisted GSA in the selection of the energy conservation options to be used; designed instrumentation and data collection systems to evaluate the performance of this building and the energy conservation options selected; and is planning with the support of ERDA to evaluate the future potential of the techniques employed. There should be, in each demonstration project, careful evaluation of the results of the experiment. Then those results which are both technically and economically feasible sould be transferred to the building community.

RETROFIT OF EXISTING BUILDINGS

Turning now to the problem of energy conservation in existing buildings, we start with the recognition that an average life-span of a building is about 50 years. The Nation's tremendous inventory of existing buildings is being replaced at the rate of about 2 percent per year.

The technical challenges that face us with existing buildings are different than those encountered in developing standards for new buildings. No single set of procedures or techniques can address the great diversity of characteristics which existing buildings possess. They differ in types of construction, heating, ventiliating equipment, fenestration, air leakage, and in many other aspects. Many of the existing features in these buildings are often expensive to change, while some are easy.

A rational methodology must be available to examine each building as a specific case. Thus, improved technical procedures, methodologies, and measurement techniques are required to permit us to design, develop, and carry out cost-effective retrofit programs.

A thorough understanding of the thermal performance of materials and components, as well as the ability to predict their performance, is essential if we are to carry out effective retrofit programs of existing buildings. NBS has carried out several experiments related to the retrofit of residential buildings.

For example, at its site in Gaithersburg, Md., a 2,054 square foot wood-frame house constructed in the early 1950's has been retrofitted over the past several years. By staging the various retrofit phases, that is, adding insulation in selected places, adding storm doors and windows, studying air leakage, we were able to check out our computer-based calculation procedures. We were able to reduce energy requirements 52 percent and came within 10 percent of our predicted results.

We have also studied the thermal characteristics of a four-bedroom townhouse, first in our environmental chamber and then outside under the prevailing weather conditions in Gaithersburg. Again, we validated our computer-based dynamic load simulation program to within

8 percent. More recently, this townhouse has been equipped with solar panels, and we are evaluating a solar heating and cooling system. Again, we will compare these experimentally obtained results with our theoretical predictions.

In a recent NBS publication, Building Science Series 64, entitled "Retrofitting Existing Housing for Energy Conservation: An Economic Analysis," we presented an economic analysis for retrofitting existing housing for energy conservation. This document has received widespread distribution and acceptance in the building community. It has also been simplified into a document for the homeowner, entitled "Making the Most of Your Energy Dollars in Home Heating and Cooling." This document provides the homeowner with the means to evaluate the most effective way to invest limited dollars in a retrofit program to attain maximum energy conservation savings. With your permission, Mr. Chairman, I will submit copies of both of these reports for the record.[4]

While we have made considerable progress on retrofit techniques for residential occupancies, our efforts also are being directed toward research for larger buildings. Again, I can give an example from our own experience at the NBS facilities in Gaithersburg. We decided to use our own extensive facilities as an experimental base.

Our site contains 2¼ million square feet of building area, and uses, on the average, 115 million kWh of electricity and 780 billion Btu of heating fuel annually. As a result of modifying our operating procedures, we reduced our energy use between fiscal year 1973 and fiscal year 1975 by 20 percent. This energy savings translated to a dollar savings of approximately $888,000 in utility bills.

In addition to this low investment cost immediate impact program, we also are involved in a long-range major retrofit program which includes the installation of a computerized automatic central control system in one of our general purpose laboratory buildings. This control system will control the heating, ventilating, and air-conditioning systems, and also will monitor all 10 air-conditioning zones and energy flows. It is presently under construction. We are predicting that with this system, we will be able to operate our Gaithersburg facilities with 40 percent less energy than we used in fiscal year 1973. We estimate the payback period to cover the cost of computer equipment will be less than 3 years.

NBS is working with an ad hoc industry committee and the Building Owners & Managers Association (BOMA), in developing a survey to inventory the characteristics of existing buildings. This survey will give us data needed to provide rational methodologies for retrofitting. We have had much experience in studying characteristics of existing buildings.

At present, we are working with GSA support on a study on fire and live loads of office buildings. Previously, we have evaluated existing structures for their ability to withstand wind and seismic forces. In these studies, the individual characteristics of buildings selected are examined in a scientific manner with statistically valid sampling

[4] The reports may be found in appendix B, pp. 572–666.

techniques. Applying such techniques to the energy requirements of existing buildings should enable us to develop procedures for various categories of buildings.

Despite these and other projects, practical, technical procedures are not yet available to develop in a systematic way a comprehensive retrofit program for all types of existing buildings. Techniques need to be developed to categorize existing buildings. After a reasonable number of categories have been identified, analystical and experimental methods need to be developed to identify those modifications which will be technically feasible and cost-effective.

The Federal Government, in dealing with its large inventory of existing buildings, can and should play a leadership role in a retrofit research program. Federal buildings provide a unique and important means for obtaining feedback on retrofit demonstrations and for carrying out technical evaluations of the retrofit projects. In addition, institutional mechanisms and training programs must be developed for design professionals and building regulatory officials, if retrofit programs are to be successful.

Building upon the many years of experience in developing the technical bases for energy conservation activities, NBS is committed to supporting the development of improved energy conservation design standards for new buildings. We are also committed to providing the necessary technical data for cost-effective retrofit of existing buildings.

While we concur in the intent of the subject legislation, it is important to note that there is no reason for treating Federal buildings differently than similar buildings in the public and private sector. We need energy conservation standards for all buildings. The Federal Government has an opportunity to display leadership in implementing standards for energy conservation in new buildings and in developing sound technical approaches for retrofitting existing buildings.

I will be happy, Mr. Chairman, to respond to questions.

Senator MORGAN. First of all, tell me about the National Bureau of Standards. Is it a separate agency? Where does it fit into the overall Federal structure?

Dr. WILLENBROCK. The National Bureau of Standards, which develops standards and measurement technology, is an agency within the Department of Commerce. As part of its charter, NBS has been authorized to work for other Federal agencies in the development of technical standards and technical information. A rather large part of our activities in the building area is in support of work of other Federal agencies.

Senator MORGAN. What other Federal agencies?

Dr. WILLENBROCK. For example, we work with HUD, GSA, FEA, ERDA, HEW, and VA. In fact, we work for practically all of the more than 30 Federal agencies which have building construction programs.

Senator MORGAN. So you have been consulting with all of these agencies that have been referred to in these bills all along. Is that true?

Dr. WILLENBROCK. Yes. We work directly with them.

Senator MORGAN. Are there any that you have not been working with and consulting with?

Dr. WILLENBROCK. I can't think of any right offhand. It would be difficult for me to go through the entire 30 today.

Senator MORGAN. Are you sharing and exchanging the information you have and are there any problems in that?

Mr. WILLENBROCK. We regularly run, Mr. Chairman, a series of Federal building technology workshops. These workshops were initiated at the request of the Office of Management and Budget to transfer building standards, criteria, and test methods among Federal agencies. We run these workshops on more than a monthly basis. A number of these have been in the energy conservation area, as well as in other technical areas.

Senator MORGAN. You are carrying out these experiments at Gaithersburg? Is GSA aware of them? Have they participated, especially in the huge building that you mentioned?

Dr. WILLENBROCK. Yes, sir. We have worked closely with GSA on the Manchester Federal office building project. For example, we have participated in the design of the experiment, and as I indicated in my testimony, we already have provided instrumentation and plan to do the measurements with GSA.

Also, GSA has supported us in a number of other technical areas in which we have a joint interest.

Senator MORGAN. How many other agencies are doing the same sort of research now?

Dr. WILLENBROCK. Within the Federal Government, we do not think there are any other agencies that are doing the same research that we are. Other agencies involved would not pay us to do research if the work were duplicated. We work on a reimbursable basis for most of these agencies, and therefore, there is a direct tie to their own programs.

As far as comparing National Bureau of Standards research with building research in the country at large, we have in our estimation the most comprehensive building research capability within the country located in National Bureau of Standards Center for Building Technology. Individual manufacturers have the capability for in-depth research in their product areas, but we believe we have the most comprehensive program in the United States.

Senator MORGAN. But you are doing all that now on a reimbursable basis from other agencies?

Dr. WILLENBROCK. Not entirely. Roughly one-third of our program in building technology is supported by direct appropriation from the Congress, and the other two-thirds is funded by reimbursement from other agencies.

Senator MORGAN. Once you get this information, you hold seminars? Are there other ways of disseminating information, making sure it is being used properly, or is it being put on the shelf with a lot of other Federal studies that aren't being used?

Dr. WILLENBROCK. We feel, Mr. Chairman, that we have very good mechanisms for delivering the information to the entire building community. For example, we advise HUD on the Federal Housing Administration's Minimum Property Standards, and our technical input goes directly into the Minimum Property Standards used by FHA.

As I indicated, we have worked closely with GSA, FEA, ERDA, and other agencies who use our input very directly.

Senator MORGAN. Do I understand you to say that in your opinion, none of these bills are necessary?

Dr. WILLENBROCK. We feel that the Federal agencies have existing authorities to carry out these activities.

Senator MORGAN. They have the existing authority, but is it mandatory? As I recall, these bills before us could mandate action. Is that not your recollection?

Dr. WILLENBROCK. Yes, I believe they do mandate it.

Senator MORGAN. Knowing the Federal bureaucracy, unless there is some kind of mandate, do you think this information you are digging out is going to be used anywhere?

Some will, I am sure, but you know Atlanta and Houston are a long way from Gaithersburg. What is going to happen if standards aren't mandated?

Dr. WILLENBROCK. My position on that, Mr. Chairman, is to defer to the lead agencies in the legislation to tell you whether they will or will not use our standards, if they are not mandated.

Senator MORGAN. Is it fair to say that you can do the research necessary, but not put it in action?

Dr. WILLENBROCK. Yes. I would defer to the other agencies which have the operating responsibilities to comment on that point.

Senator MORGAN. What are you doing about solar research?

Dr. WILLENBROCK. Mr. Chairman, we had some particular responsibilities designated in the Solar Heating and Cooling Demonstration Act and we delivered to HUD in January of this year a document on interim performance criteria for solar heating and combined heating/cooling systems and dwellings.

Also, we are carrying out, as I indicated in my statement, experimental programs on solar heating and cooling equipment. We are making experimental measurements now in some of our facilities in Gaithersburg. We are in close touch with some of the university solar energy programs. Progress is being made to bring solar technology into a more practical stage.

Senator MORGAN. As the Director of the Institute of Applied Technology, I think you are in a position to observe solar research and what has been done. What do you foresee for the future with regard to solar energy in heating residential and other types of buildings?

Dr. WILLENBROCK. It is my opinion that solar heating and cooling technology is a very practical technology which can have a major impact in the United States.

Senator MORGAN. How soon?

Dr. WILLENBROCK. I am not in a position to say exactly how soon. I feel it is very important for the demonstration projects to be carried out and the technology evaluated carefully from the standpoint of length of life, maintenance requirements, and reliability. Those demonstration projects are an important step before launching on a major program in which many people install equipment. Solar technology must be sufficiently tested and approved.

Senator MORGAN. Would the same thing be applicable to public buildings or other large buildings, with respect to solar heat?

Dr. WILLENBROCK. It is my opinion, as I indicated in my statement, that it is highly desirable for the Federal Government to use its own building programs as an experimental base.

Besides the work that GSA is doing at Manchester, to which I referred, GSA has a building in Saginaw, Mich., which is using solar heating. I think these two GSA projects are exactly the right directions for the Federal Government to go. The Federal Government should prove the technology within its own building program.

Senator MORGAN. You know, I think this sort of study and experimentation should be done by industry, in the normal course of events, but we are now in a crisis situation.

Is there something we can do in Government to expedite such experimentation that might benefit the homebuilder for example? Or should the Government participate simply because we want to see if it really works?

I would hate to advise my neighbor to invest $5,000 in solar heat, and yet I don't know whether we have the time to go on experimenting winter after winter.

Are there ways we can expedite this sort of experimenting?

Dr. WILLENBROCK. The best way that I know to expedite the experimentation, Mr. Chairman, is via the demonstration projects. I personally would like to see more demonstration projects carried out in a systematic way, with the results evaluated, and the information made available as quickly as possible.

I think the evaluation, the demonstration and the evaluation procedure are essential activities for the very reason you indicated, that you would not like to recommend to your neighbor a $5,000 installation which only lasts for a few years.

Senator MORGAN. How many experimental projects are there in existence? You have some. I assume GSA and ERDA have some, and that FEA probably has also. Do you know about them?

Dr. WILLENBROCK. In addition to these programs, the National Science Foundation is supporting quite a few programs at universities. There has been much activity in this area.

In general, we keep close contact with the work of ERDA and the others in the other Federal agencies through a variety of means. As I have indicated, we hold workshops regularly, and there are many other means. We keep in close contact with the agencies with active programs in solar technology.

As far as ERDA goes, we have assisted ERDA in developing their building energy conservation program. So I don't think there is unnecessary duplication of the work of these agencies.

Senator MORGAN. I don't think duplication is necessarily bad. Sometimes competition helps out. But it does seem to me we are going in a number of different directions. Is there any agency we should give oversight responsibility to?

For instance, do we simply tell the GSA Administrator to coordinate all of these? Would this expedite the matter? I think this is one of the things some Members of the Senate are concerned about. That is, trying to bring all of the projects together.

Today we are hearing from you and tomorrow it will be someone else. We are left with the feeling that everybody is going their own direction and may not know what the other is doing.

Could having a coordinating agency help?

Dr. WILLENBROCK. In the energy area, it has been our understanding that ERDA is the agency with the lead responsibility for energy research and development.

We have been operating with ERDA with that understanding. As far as the activities of other agencies, there are a large number of agencies which have responsibilities in the building area. It is difficult to know how best to organize the efforts to maximize the results of their work.

However, it is my perception that there is good coordination among a number of these agencies.

As I indicated, since we have two-thirds of our funding coming from these agencies, we have a close working relation with most of these agencies.

Senator MORGAN. You may be coordinating with them, but are they coordinating with each other? That is the thing that worries me.

Dr. WILLENBROCK. I don't feel I can comment on that, Mr. Chairman.

Senator MORGAN. Do you consider ERDA the lead agency?

Dr. WILLENBROCK. It is the lead agency as far as the energy research and development goes. We work very closely with them. As far as operating policies in regard to energy conservation in a number of other areas, such as industry, we work closely with FEA.

For a much longer period of time, we have worked with GSA in a number of areas: on energy problems, fire safety problems, structural problems, and many others.

Senator MORGAN. Let's go back to another matter. Weren't you talking about working with a home in Gaithersburg, to reduce the energy consumption by 20 percent?

Dr. WILLENBROCK. The frame building which was a 2,000-square-foot residence, which was already on the Gaithersburg site when the Federal Government bought that site for NBS. We reduced the energy consumption by 52 percent as a result of our retrofitting.

Senator MORGAN. You say you published a manual on that?

Dr. WILLENBROCK. Yes, sir. We have made an exhaustive study of the retrofitting of existing housing for energy conservation. This study to which you refer can tell you which cost-effective options you should choose for your own home.

Senator MORGAN. Who did that? Who knows most about it? If you wanted to send a witness down to tell this committee, who would you send?

Dr. WILLENBROCK. The author of this report is Steven Peterson. He is a research economist who works for Dr. Wright.

Senator MORGAN. Who paid for that report?

Dr. WILLENBROCK. This was a joint project of NBS and FEA.

Senator MORGAN. I would be interested in knowing about it. I might even be interested in hearing from the people who put it together. There seems to be a lot of material available if we only had time to sit down and study it.

Dr. WILLENBROCK. He could certainly be made available to you. I would also point out if you are not an economist or if you find this difficult to read, there is a simpler version to read which tells you how to use these ideas in your own home.

Senator MORGAN. You say the Bureau of Standards has done a solar home demonstration project?

Dr. WILLENBROCK. Yes. We have an ongoing solar heating and cooling home demonstration project by means of which we are now collecting data at Gaithersburg.

Senator MORGAN. Who is in charge of that?

Dr. WILLENBROCK. Dr. Wright is in charge of the overall program.

Senator MORGAN. Dr. Wright, would you be in a position later to tell us in detail how it is working?

Dr. WRIGHT. Yes. We began in the summer of this year to collect experimental data on the performance of the solar cooling systems. As the winter progresses, we will be getting data on the performance of the heating systems.

The major thrust of our program is to develop test methods to measure the performance of solar collectors and solar storage systems so that FRDA will have a uniform basis for assessing all the experiments and demonstration programs across the country. The results an investigator is getting in Colorado can then be compared with the results of a different investigator who is working in another area of the country.

Senator MORGAN. We may want to pursue that, and maybe even go out and look at it.

Dr. WRIGHT. We would certainly welcome you, sir.

Dr. WILLENBROCK. I think I can say we probably have the most thoroughly measured townhouse in existence in the world. We have measured it for a year and a half. We know all of its thermal characteristics in great detail.

Senator MORGAN. My chief adviser over here wants to know, and I do, too, whether its features are similar to those prescribed in ASHRAE standard 90–75?

Dr. WRIGHT. Is this the question about the townhouse? The study for the solar collectors is distinct from ASHRAE 90–75. This standard

does not apply directly to the performance of solar energy equipment.

However, the test methods which we have been developing for solar collectors and for solar storage units have been turned over to ASHRAE committees so that they might work on them in the development of ASHRAE standards for these items of building and mechanical equipment.

Senator MORGAN. Did you hear Senator Hart's testimony this afternoon?

Dr. WILLENBROCK. Yes.

Senator MORGAN. Are you familiar with the building project in Colorado he is talking about?

Dr. WILLENBROCK. I have not visited it, but I knew of its existence.

Senator MORGAN. Have you had any reports on the effectiveness of those projects, and how they are working?

Dr. WRIGHT. Not to my knowledge.

Senator MORGAN. Would you make some inquiry and try to give us some input? Apparently those are ongoing active projects. I would be interested to know the Bureau's evaluation.

I don't want to get you involved in controversy, but I don't necessarily want to avoid it either, because I think we need all the facts we can get.

Dr. WILLENBROCK. We will be happy to look into this project and report for you, sir.

Senator MORGAN. I think we have covered most of the things that Mr. Purinton, of my staff, is interested in. Do you have other comments?

Dr. WILLENBROCK. The point I would like to emphasize, one that I have made in my statement, Mr. Chairman, is that there is a great deal that can be done with improved technology in the area of energy conservation in buildings.

I think it is most appropriate for the Federal Government to play a leading role in the development of the technology needed for both energy-conserving new buildings and also for retrofitting old buildings. We welcome very much your interest in this area.

Senator MORGAN. Thank you for coming.

I want to add only one thought. The Senators who have introduced these bills want to expedite the use of this technology. They don't feel we have got a lot of time to waste.

So, I would appreciate it if you would follow the hearings as closely as you can, and be prepared to come forward if you have any further thoughts about it.

If we are going to come up with something we will need your help, and that of others.

Dr. WILLENBROCK. Yes, sir. We will have staff members here for the rest of the hearing, sir.

Senator MORGAN. Thank you very much.

We will stand adjourned until tomorrow morning at 10. Thank you very much.

[Whereupon, at 5:15 p.m., the subcommittee recessed, to reconvene at 10 a.m., Wednesday, November 5, 1975.]

[Mr. Willenbrock supplied the following additional information:]

62-963 O - 76 - 7

UNITED STATES DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

December 31, 1975

Honorable Robert Morgan, Chairman
Subcommittee on Buildings and Grounds
Committee on Public Works
United States Senate
4204 Dirksen Senate Office Building
Washington, D.C. 20510

Dear Mr. Chairman:

During the November 4, 1975, energy hearings of the Subcommittee on Buildings and Grounds, you requested that the National Bureau of Standards submit additional information for the record. After discussion with subcommittee staff, NBS has prepared background information in the following areas:

1. Summary of current and past activities on solar energy research at NBS.

2. Information on the use of solar energy heating and cooling systems in commercial buildings throughout the United States, including the Gump Glass Company in Colorado which was specifically mentioned at the hearings.

3. Discussion of interrelationships with other Federal agencies and the public and private sector and information on technical transfer activities within NBS.

4. List of energy conservation projects funded by other agencies and NBS.

5. Discussion of performance and prescriptive theory and a clarification of the difference between guidelines and standards.

The National Bureau of Standards would be glad to furnish the Public Works Committee with any other needed information on NBS programs.

Sincerely,

F. Karl Willenbrock

F. Karl Willenbrock, Director
Institute for Applied Technology

SOLAR ENERGY ACTIVITIES AT THE NATIONAL BUREAU OF STANDARDS

Current activities in solar energy at the National Bureau of Standards (NBS), are centered around four projects pertaining to the heating and cooling of buildings. One project involves developing techniques of testing and rating solar collectors and thermal storage units. The second involves evaluating what is felt to be a state-of-the-art residential solar heating and cooling system. The third involves evaluating a solar heating and cooling system installed in a large commercial office building. The fourth project involves participation in various phases of the Solar Heating and Cooling Demonstration Act of 1974.

These projects are being carried out by NBS with financial support from the Energy Research and Development Administration (ERDA) and the Department of Housing and Urban Development (HUD) [1].

Testing and Rating Components

Solar collectors and thermal storage units are two of the most important components in any solar heating and cooling system. Several different varieties and types of each device are, or have been, developed by research and industrial firms throughout the Nation. Even though much work is going on in the development of solar devices, there exists no uniform method or procedure for measuring or reporting on the performance of such devices. Thus, it is difficult to compare components, even though they are of the same general type. Consequently, NBS developed a standard method of testing both solar collectors and thermal storage devices. The first versions of the test procedures have been published [2,3] and experimental verification studies are beginning at the NBS site in Gaithersburg, MD.

State-of-the-Art Residential System

The second major project involves a four-bedroom house that has been at NBS for approximately four years. In order to study energy usage, the house was completely furnished, fully instrumented, and installed in a large environmental chamber. Over a period of a year and a half, it underwent tests with its conventional heating and cooling system (gas-fired furnace and central electrical air conditioning unit with a forced air distribution system). As a result of these tests, the thermal characteristics of the house were well defined [4] and a solar heating and cooling system was designed for the house.

With support from the Federal Energy Administration, a solar heating and cooling system was installed in the house. The system became operational in April 1975 and consists of 485 square feet of flat-plate collector mounted on the roof, 1500 gallons of water storage, and a modified 3-ton "gas-fired" absorption air conditioning unit. The existing forced air distribution system continues to be used and appropriate water-to-air heat exchangers have been installed. The primary objective of this project is to determine the solar system performance in a variety of operational modes for typical summer and winter conditions in Washington, DC.

Additional information on solar energy activities may be obtained from Robert D. Dikkers, Acting Manager, Solar Energy Program, National Bureau of Standards, Building 225, Room A-114, Washington, DC 20234; telephone (301) 921-3285.

Office Building

The third NBS project is related to a seven-story office building that the General Services Administration (GSA) is constructing in Manchester, New Hampshire. GSA has designated the building as a special energy conservation project. Construction is underway and the building will be completed and occupied in July 1976. NBS has been involved as a consultant during the design phase and will be responsible for doing experimental evaluation of the performance of the building and its systems for a three-year period. The building's mechanical systems will include approximately 5000 square feet of flat-plate solar collector whose output will be used for heating, cooling, and domestic hot water.

Demonstration Act

The Solar Heating and Cooling Demonstration Act of 1974 (P.L. 93-409) calls for ERDA and HUD to demonstrate the practical use of solar heating and cooling over a three to five-year period by installing and evaluating such systems in a sufficiently large number of residential and commercial buildings located in various geographical areas. Current NBS tasks in support of ERDA and HUD activities on the demonstration programs include:

(1) The preparation of plans defining the technical performance data to be collected during the residential and commercial demonstration programs. This task will ensure that an adequate technical data base is obtained for the development of performance criteria and standards.

(2) The development of intermediate standards for solar and domestic hot water and space heating systems that can be used in conjunction with HUD's Minimum Property Standards. As data become available from the residential demonstration program, HUD plans to modify or replace the intermediate standards with appropriate performance criteria or standards.

(3) The development of performance criteria for commercial buildings, similar to those already developed by NBS for HUD on dwellings [5]. The National Aeronautics and Space Administration (NASA) has prepared on "interim" performance criteria document for ERDA covering commercial solar systems and buildings.

(4) The development of a document for HUD containing conceptual designs and site planning concepts for residential buildings suitable for and adaptable to the installation of solar heating and cooling systems. This work is being carried out with contractual support from the AIA Research Corporation and the American Society of Landscape Architects Foundation.

Future tasks for NBS will include the technical monitoring of the design, testing and evaluation, construction, and operational phases of the demonstration programs as described in the National Program for Solar Heating and Cooling (Residential and Commercial Applications) [6].

References

[1] Hill, J. E., "Laboratory Based Activities in Solar Energy at the National Bureau of Standards," ASTM Standardization News, Vol. 3, No. 8, August, 1975, American Society for Testing and Materials, Philadelphia, PA.

[2] Hill, J. E., and Kusuda, T., "Method of Testing for Rating Solar Collectors Based on Thermal Performance," NBS Report NBSIR 74-635, Washington, DC, December, 1974.

[3] Kelly, G. E., and Hill, J. E., "Method of Testing for Rating Thermal Storage Devices Based on Thermal Performance," NBS Report NBSIR 74-634, Washington, DC, May, 1975.

[4] Peavy, B. A., Burch, D. M., and Powell, F. J., "Comparison of Measured and Computer-Predicted Thermal Performance of a Four-Bedroom Wood-Frame Townhouse," National Bureau of Standards Building Science Series 57, Washington, DC, 1974.

[5] "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings," prepared by NBS for HUD, January, 1975, available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402; Catalog No. C-13.6/2:S04.

[6] "National Program for Solar Heating and Cooling (Residential and Commercial Applications)," ERDA-23A, Energy Research and Development Administration, Division of Solar Energy, Washington, DC, October, 1975.

USE OF SOLAR HEATING AND COOLING SYSTEMS IN COMMERCIAL (NON-RESIDENTIAL) BUILDINGS

In response to the request of the Subcommittee on Buildings and Grounds, Senate Committee on Public Works for information on the use of solar heating and cooling systems in commercial buildings located in the United States, I am attaching summary descriptions of 27 projects. These summary descriptions have been excerpted from "Solar Heated Buildings--A Brief Survey," W. A. Shurcliff, 10th Edition, September 9, 1975.

The Gump Glass Company Building is described on page 31. The solar heating system became operational in April 1975. NBS has also received additional information on this project from the Soloron Corporation. This information is also attached.

Of the 27 solar commercial building projects described, three were built before 1960 (only one--page 85--is still in operation); seven were completed in 1974 (including four public schools--NSF projects); ten are scheduled to be completed in 1975; and seven projects are in the design or planning stage or are to be completed in 1976-77.

The summary descriptions are attached.

Attachments

Dr. William A. Shurcliff is an Honorary Research Associate in the Physics Department at Harvard University.

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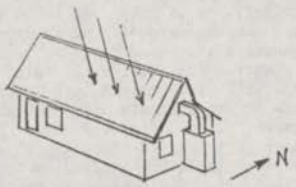
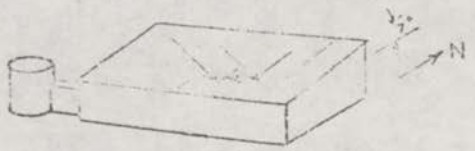
WAS 9/9/75

Arizona

Tucson — Univ. of Arizona Environmental Research Lab. Solar Test House 32° N. Dec. 1974.
Solar eng'g.: J. Peck et al. Construction: by Univ. or Arizona Env.Res.Lab. staff. Support: Univ. of Arizona, Pima County Government, Southern Arizona Home Builders Association.
Bldg.: One story, 20 ft x 20 ft lab. There is an attic but no basement. Two rooms. Floor area: 600 ft^2. Window area: small.
Collector: 200 ft^2(?), air-type, on steeply sloping roof. Absorber proper consists of 4 layers of copper screen. Single-glazed.
Storage system: 2000 gal. water in underground cistern.
(Ariz.Daily Star 9/5/74; also P-900).



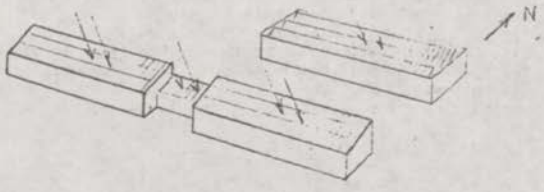
Tucson — Univ. of Arizona Solar-Energy Lab. 32° N. 1959.
Architect: W. Wilde. Solar engineer: R. W. Bliss.
One-story 1440 ft^2 solar-energy lab. on campus of Univ. of Arizona.
Collector: 1600 ft^2 of dark-green-painted copper sheets (with integral tubes) on roof sloping 7° from horizontal. No glazing.
Storage system: insulated, 4500 gal., vertical, cylindrical, steel tank 10 ft. dia., 9 ft high; tank is above ground, adjacent to bldg. Upper and lower halves of tank are separated by an insulating (but not watertight) septum. Upper half is for (solar-heated) hot water. (Lower half, in summer, is for cold water.) When rooms are cold, hot water from upper half of tank flows to ceiling panels (copper with integral tubes), circulation being provided by two pumps, ½-HP each. When necessary, 1½-HP heat-pump transfers energy from lower half of tank to upper half.
Summer cooling: water pumped to collector at night is cooled by convection and radiation and flows to lower half of tank, whence, during hot day, water flows to ceiling panels.
Performance: generally good. Percent solar heated: 85%. Collection efficiency in Jan.: 29%. Troubles: some leaks in panel tubes; occasional air-lock in tubes; occasional condensation on ceiling panels, and dripping, in hottest months. Termination: In about 1963 the bldg. was demolished to make room for a new bldg. (B-305 in U-400; R.W.B. ltr.)



California

Santa Clara (35 mi. SE of San Francisco)

Community Recreation Center 37° N. late 1975(?). 969 Kiely Blvd. Solar engineering and planning: Lockheed Palo Alto Research Lab. Funding: from NSF/ERDA: basic system $404,200; evaluation and proposals for widespread use of such system by public utilities: $101,000. Gen'l. supervision: Santa Clara City Manager (D. R. Von Raesfeld). Project Director: R. R. Mortenson, Dir. of Water & Sewer Utilities. Architect: D. C. Thimgan. Builder: Welch Constr. Co. Utility application: R. W. Beck & Assoc. and also Wilson Jones Morton & Lynch. Evaluation studies by Santa Clara Eng'g. School.
Bldg.: 27,000 ft. Community Recreation Center with great variety of large rooms etc. Bldg.was new in 1974 and 1975, but decision to include solar heating and cooling was made after general planning was nearly complete. Bldg. is in 52-acre city park. Is one story.
Collector: About 6500 ft^2 net. Water-type. Employs 270 panels, each 3 ft x 8 ft. Panel slope: 18 to 30 deg. Absorber consists of two copper sheets press-formed and brazed together to create integral passages for water flow. Selective black coating, formed by 2-step electrodeposition, consists of a bright nickel layer covered by a thin black nickel layer. $\alpha = 0.93$; $\epsilon = 0.10$ (predicted). Absorber sheets are supported by rigid insulation of sintered quartz powder. Double glazing consists of high-solar-transmittance "Crystal 76" glass (outer sheet) and float glass (inner sheet). Panels are grouped in three large arrays. Total flow-rate: 285 gpm, in closed pressure loop. In summer, water temp. will reach 230° F and will operate chiller (see below).
Storage system: 10,000 gal. tank underground, for hot water. Rooms heated by fan-coil systems.
Percent solar heated: 75%.(predicted).
Auxiliary heat: 1.2×10^6 Btu/hr gas fired boiler. Serves rooms or chillers, but not the storage systems (hot or cold).
Cooling in summer: Two 25-ton Arkla LiBr absorption chillers, powered by solar-heated hot water (180 to 230 °F) or by auxiliary heat source (boiler). When demand is low, the chillers cool the water in a separate,50,000 gal. cold reservoir, situated underground.
Percent solar cooling: 65% (predicted).
Cost: $1,000,000. Schedule: Bldg. completedJune '75. Solar heating and cooling system to be completed by end of 1975.
(Misc. NSF and Santa Clara releases)



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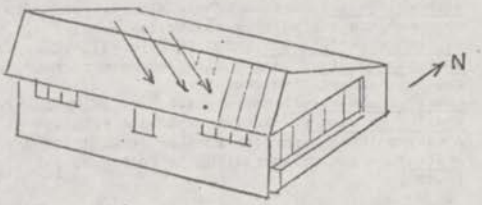
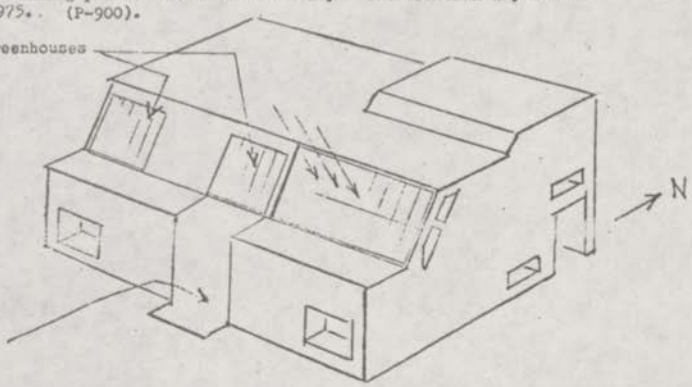
WAS 9/9/75

Colorado

Denver Crowther Retrofit House 40° N. Oct. 1974
Architect and owner: R. L. Crowther.
Bldg.: One-story, 1100 ft² house with full basement. Extensively remodeled for energy conservation and solar heating.
Collector: 380 ft² air-type collector sloping 53° from horizontal. Includes 24 Solaron Corp. 2 ft x 8 ft panels. Glazing: 2 sheets of 1/8-in. glass. Air is circulated at 700 cfm by 3/4 HP blower
Storage system: 20 cubic yards of rocks (3/4 in. to 1½ in. dia.) in old coal-bin (now insulated). Rooms heated by gravity convection of air from bin.
Percent solar heated: 85% (predicted). Carrythrough: 2 or 3 days (predicted).
Auxiliary heat: Gas furnace.
Cooling in summer: By (nighttime) gravity convection of cool outdoor air. (P-900)



Denver Crowther Solar Office Bldg. 40° N. 1975(est.)
Architect and owner: R. L. Crowther.
Bldg.: Three-level modern office building, 69 ft x 43 ft, with one level below grade (opening to below-grade courtyard). Total floor area: 7000 ft². Excellent insulation. Many energy conserving features. First floor view-window area: 180 ft² total; double-glazed; regressed.
Collector: 600 ft², flat-plate, air-type collector sloping 53° from horizontal. Double-glazed with tempered glass. Horizontal area at south edge of collector serves to direct more radiation toward collector. Ample servicing-access at rear of collector.
Storage system: 4000 gal. water. Water is in two insulated, concrete tanks in basement.
Percent solar heated: 80% (predicted).
Status: Funding problems have caused delay. Construction may start by mid-1975. (P-900).



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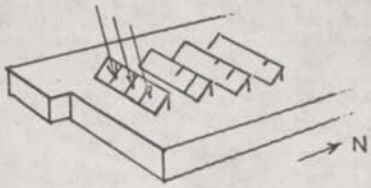
WAS 9/9/75

Colorado

Denver

Gump Glass Co. Bldg. 40° N. 1976(?). S. Broadway & Louisiana Ave. Designer & builder of solar heating system: Solaron Corp. Owner and occupant: Gump Glass Co.
Bldg.: Solar heating is being applied to a 7200-ft^2 wing (office and showroom space) of a new, one-story, 41,000-ft^2 office bldg. There is no basement or attic.
Collector: 1600 ft^2, air-type collector on horizontal roof. Consists of four arrays, each 10 ft x 44 ft, sloping 50° from horiz. Each array includes four Solaron Corp., 10 ft x 11 ft panels mounted side by side. Heart of panel is a non-selective black coating on a sheet of steel. The panel is double glazed. Behind the sheet of steel there is an airspace in which air is circulated by a blower to the storage system or directly to five separately controlled office-area zones. Slight positive pressure is maintained in the ducts.
Storage system: 60 tons of 1½-in.-dia. stones in an 8 ft x 8 ft x 16 ft cement-block bin adjacent to office area.
Percent solar heated: ~75% (predicted). Carrythrough: ~½ day (predicted).
Auxiliary heat: Five gas-fired burners on roof, each serving one of the above-mentioned five zones.
Domestic hot water: Not preheated by solar heating system.
Cooling in summer: Not accomplished with aid of solar heating system. A conventional vapor compression air-conditioner is used.
Status: Under construction in spring of 1975.
(P-900)



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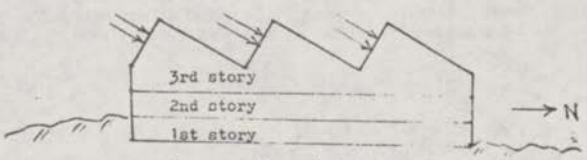
WAS 9/9/75

Colorado

Westminster (11 mi. N of Denver)

Community College of Denver, North Campus 40° N. Sept. 1976 (est.)
Solar engineers: Bridgers & Paxton. Architects: ABR Partnership; partner-in-charge: J. D. Anderson. Many assisting groups.
Funding: by Colorado State Legislature, which in April 1974 appropriated the additional funds (about $700,000) needed for equipping the bldg. with solar heating. Site: 160 acres.
Bldg.: Part has 2 stories, part has 3 stories. Bldg. is long and narrow (1200 ft x 170 ft) with main axis E-W. Bldg. occupies crest of long E-W ridge. Excellent insulation. Windows double glazed. Many energy-conserving features. Floor area: 300,000 ft^2. Bldg. will serve equiv. of 3500 full-time students. Shape of bldg. very complicated. Est.total cost of bldg, incl. solar heating system: $11,000,000.
Collector: Area: 50,000 ft^2 (el. larger than football field). Design: flat-plate, water-type collector comprising three long arrays sloping 60° from horizontal. The three arrays are mounted on steep south faces of three "teeth" of sawtooth roof (which also provides daylight and provides space for fans for forced ventillation). Fluid: water-plus-30%-ethylene-glycol, with heat exchanger between collector and storage tank. Type of collector plate not yet specified. Single glazing on collector. Black coating: non-selective.
Storage system: Two concrete tanks, underground, with 400,000 gal. total capacity.
Chiller-and-heat-pump system is to be used (a) in cold weather to transfer energy from storage tank to room-heating system; may reduce tank temp. to value as low as 50 °F in midwinter; (b) in hot weather to transfer energy from rooms to conventional cooling tower.
Supply of energy to rooms: via heating-coil-and-fan units.
Percent solar heated: ~100% (incl. elec. power to heat-pump)(est.).
Auxiliary heat source: none.
Cooling in summer: via chiller. See above.
(B-504, ABR Partnership brochure of 7/3/74, P-900)



Cross section, looking west

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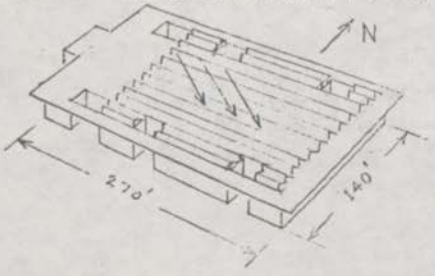
WAS 9/9/75

Georgia

Atlanta George A. Towns Elementary School 33½° N. July 1975.
Prime contractor for equipment for (a) solar heating of building, (b) solar heating of domestic hot water, (c) solar powering of air cooling system: Westinghouse Special System; R. T. Duncan, Project Manager. Solar-architectural design: P. R. Rittelmann of Burt, Hill, & Assoc. Mech. design: Dubin, Mindell, & Bloome, Assoc. Performance monitoring: S. C. Bailey et al of Georgia Inst. Tech. NSF & ERDA funding: $829,000 ($180,000 in mid-74 for design, $649,000 on 12/31/74 for constr.).
Bldg.: One-story, 32,000 ft² bldg. built in 1962. Horizontal roof. Used year round by 500 students. Winter heating load equals summer cooling load.
Collector: 10,000 ft², flat-plate, water-type. On roof. 576 PPG Industries, Inc., panels are used. They are in 12 rows. Slope of panel: 45°. Panel area: 34 in. x 76 in. Absorbing sheet is of aluminum (Olin Brass Co. Roll-Bond, with sheet thickness 0.060 in. in region between the integral passages for water; cross section of passage: 3/8 in. x 0.065 in. I.D.). Alcoa/black coating. Glazing: two layers of 1/8-in. PPG Herculite tempered glass in standard insulated frames. Fluid: water and special inhibitor; inhibitor will reduce aluminum corrosion rate to less than 0.0001 in./yr. No antifreeze; liquid will be drained at end of day and will be replaced by nitrogen. Reflector: Adjacent to each row of collector panels is an oppositely sloping (36° from horiz.) crude reflector which (1) directs additional radiation to collector and (2) helps shade the roof (important in summer). Reflector consists of sheet of aluminized mylar bonded between mylar sheets and supported by 1/8-in. sheet of Masonite. Total area: 12,000 ft². Reflectance: 0.74. Irradiation gain factor provided by reflector is near-unity in midwinter and near 1.7 in midsummer. Collection temp.: 140 °F in midwinter, 200 °F in midsummer.
Storage system: 45,000 gal. water. To be stored in three 15,000 gal. insulated underground steel tanks. All tanks store hot water in winter.
Percent solar heated: 60% (predicted). Carrythrough: 4 days (predicted).
Auxiliary heat: existing gas furnace.
Cooling in summer: 100-ton ARKLA LiBr absorption chiller, powered by water at 195 to 200 °F, heated by solar radiation (or, when that is insufficient, by auxiliary heat source). Note: In summer, one of the three tanks will contain chilled water and the other two will contain hot water. Expected percent solar cooling in summer: 60%.
Status: Constr. started in March 1975. Completion: July 1975 (predicted).
(NSF and Westinghouse releases; also D-900, P-900, W-159)



cross section of portion of collector

Maryland

Timonium (near Baltimore)

Timonium Elementary School 39½° N. May 1974.
Solar eng'g., design, construction, trial operation: AAI Corp.
Funding: $73,000 of own funds and $427,000 from NSF.
Bldg.: Existing, one-story, 3-wing, 60,000 ft² school. Solar heating & cooling applied just to 2nd (middle) wing. During daytime, most of the heat needed is supplied by lights, equipment, students' bodies.
Collector: 5000 ft² water-type collector installed on horizontal roof of middle wing. There are 180 panels, each 4 ft x 7 ft; they are arranged in 10 parallel arrays (rows), supported by steel trusses, and slope 45° from the horizontal. Double glazing is of double-strength low-iron glass, 1/8 in. Two aluminum honeycombs are used: one between two sheets of glass, other between inner sheet of glass and non-selective-black aluminum absorber sheet. Lower honeycomb is slotted to allow water to run down surface of absorber sheet. Assembly is bonded with epoxy. Rubber strip is applied to edges. Back insulation: 1½ in. polyurethane foam. Overall thickness of assembly: 2 3/8 in. Wgt.: 90 lb. Liquid: water. No antifreeze. No inhibitor; Culligan dionizer is used, produces pH 7.5 - 8.0. All piping is aluminum. Rubber tube connectors. Along edge of roof there is an 8-ft-high opaque fence impeding view of collector from ground and discouraging stone throwers.
Storage system: 15,000 gal. water in vertical cylindrical tank (16 ft.dia., 12 ft high) of welded 6061-T6 aluminum. Tank rests on reinforced concrete pad 35 ft N of bldg. Tank insulation: 4 to 6 in.; reduces heat loss to 1 °F/day. Pump & treatment house adjacent to tank. Water is fed to collector via a header tank and thence, by gravity, to collector. Main pipes insulated with 1½ in. polyurethane foam protected by black building paper. Heat distribution to rooms is via 20 specially installed fan-coil systems.
Percent solar heating of wing in question: Predicted: 100% in Nov., 50% in Dec. & Jan., 94% in Feb., 100% in March. Actual value for 60-day period March 14 - May 14, 1974: 91%. Carrythrough: 6 days, if tank initially at 150°F.
Elapsed time between sunrise and start of delivery of energy to storage system on typical sunny day in winter: 2 hrs (per Fig. 3-12, Ref. A-60).
Collection eff.(sunny windless Apr.29 noon, 250 Btu/(ft²h), T=80°F): 60%.
Auxiliary heat: From existing oil-fired steam boiler.
Fuel oil saving: Tot. saving, March 1 - May 15, 1974: 1200 gal.
Overall cost of entire system: $509,000. Same, but per ft² of collector: About $100. Same, but if work had been at reasonable (slower) pace: $85. Cost if system had been applied to a new, very favorably designed school: $23. Cost that would make such system economic: slightly below $5.
Historical note re solar heating system: Contract signed Jan. 14, 1974. Work nearly complete 60 days later. System now in routine use.
Cooling in summer: 50-ton absorption-type York cooling system installed in Dec. 1974. Powered by solar-heated water at temp. exceeding 180 °F.
Cooling consultant: A. B. Newton. (Sources: Sci. News 4/13/74, Mosaic spring 1974, York (Pa.) Daily Record 12/16/74, Ref. A-40(AAI rpt. for NSF))
For a vigorous criticism of this solar heating system, see B-310.

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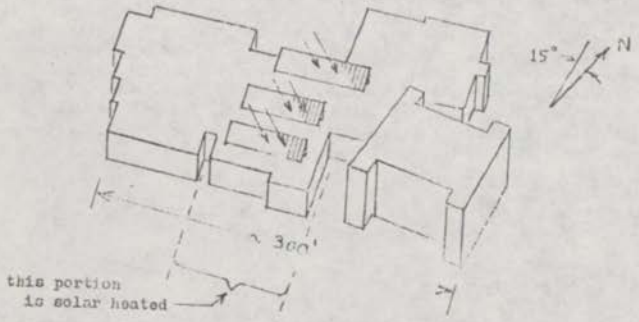
WA3 9/9/75

Massachusetts

Boston (Dorchester area)

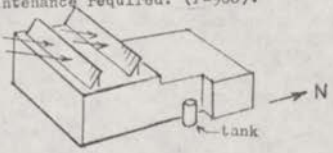
Grover Cleveland Middle School 42° N. 1974. 6000 deg-day location. Solar engineering, designer, builder: Gen. Elec. Co.,Space Div.; assisted by A-E firm of Ballinger Co. Funding: $359,000, from NSF.
Bldg.: Solar heating retrofitted to portion of existing 61,000 ft^2 2½-story conventional brick school, namely a 20,000 ft^2 central portion.
Collector: 4500 ft^2, water-type, on horizontal roof. Includes 144 panels in three large arrays, sloping 45° from horiz. Each panel, 4 ft x 8 ft, includes an Olin Brass Co. aluminum Roll-Bond sheet with internal aluminum passages. Black coating (3M 301-C10 Black Velvet paint, baked at 350 °F) is practically non-selective. Double glazing is of 0.08-in. Lexan, a polycarbonate plastic resistant to sunlight, hail, thrown rocks; the Lexan sheets were formed to have "ribs" that insured adequate space between sheets and to have edge, ½-in.-wide, bent over at 90° to house butyl sealant strip and engage extruded metal framing strip. Insulation on back: 2 in. polyurethane foam. Sealants: Kydex (acrylic polyvinyl-chloride) and RTV silicone. Each glazing sheet reflects about 7%, absorbs about 7%, of normally incident solar radiation. Liquid used: water (65%), ethylene glycol (35%); corrosion inhibitor included. Liquid carries energy to "...heat exchangers within two air handlers and a storage tank, all piped in parallel."
Storage system: 2000 gal. water in horizontal cylindrical steel tank (insulated; on roof). Rooms are heated by air-flow system served by heat exchangers.
Percent solar heated: ~6% of the indicated portion of school.
Carry-through: Very small.
Auxiliary heat: Large existing conventional system.
Cooling in summer: None provided.
Domestic hot water: Solar heating system does not contribute to this.
Performance in early trials: Max. energy collected on one day: 4,500,000 Btu. Max. collection rate: 169 Btu ft^{-2} h^{-1}. Max storage temp.: 214 °F. (NSF release; G.E. release; G-105, which is a 300-p. report, by G.E., describing system in great detail; P-900. Also B-310, a Feb. 1975 report criticizing the design and operation.)
In first year, some erosion, or corrosion, of some tubes of collector developed (FEA Energy Reporter, July 1975).



Massachusetts

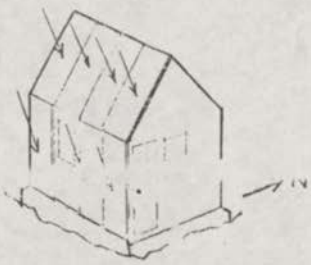
North Chelmsford (30 mi. NW of Boston)

New England Tel. & Tel. No. Chelmsford Bldg. 42½° N. Nov. 1974. Solar engineering advice from A. D. Little, Inc.; W. P. Teagan. Installation by P. A. Hayes, Inc. Financed and operated by New England Telephone and Telegraph Co.
Bldg.: Floor area: 3800 ft^2. Vol.: 50,000 ft^3. Most of bldg. was built in 1957 and 1964. Addition completed in mid-1974 had horiz. roof suitable for collector. Heat load:40,000 Btu per deg. day.
Collector: 400 ft^2, water-type, on roof. Collector consists of 20 panels arranged in two arrays. Panels slope 55° from horizontal. Some panels, made by Daylin, Inc., are 3 ft x 6 ft and employ a galvanized iron plate with selective black coating. Other panels, made by Revere Copper and Brass, Inc., are 3 ft x 7 ft and employ a copper plate with non-selective black coating. Fluid: water-and-ethylene-glycol. Glazing: single. Collection temp. expected to approach 200 °F when conditions are ideal.
Storage system: 500 gal. insulated steel tank situated outside the bldg. Heat is delivered to rooms via fan-coil system.
Percent solar heated: 50% (predicted). Carrythrough: 1 night.
Auxiliary heat: Existing oil-fired hot-air furnace.
Performance: In 1975 winter, system performed well. Saved 725 gal. oil. No maintenance required. (P-900).



Waltham (near Boston)

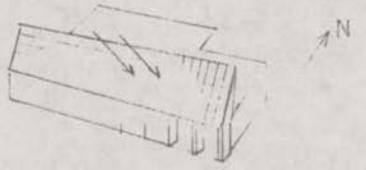
Solar Heat Corp. Test House 42½° N. Oct. 1974.
Solar eng'r.: M. Hyman. Architect: H. Russell. Owner: Solar Heat Corp. Bldg. is to be used in comparing different kinds of collectors and control systems --and to demonstrate feasibility of 100% solar heating in Mass.
Bldg.: One story, 12 ft x 12 ft. With basement. Insulation thickness: 8 in.
Collectors: 150 ft^2 net, water type. Seven panels are employed: 4 on 45°-sloping roof and 3 on vertical S face. Typical panel is 3 ft x 8 ft and includes a Roll-Bond aluminum plate with integral passages for water. Various kinds of black coatings are employed.
Storage system: 4000-gal. water in rectangular, waterproofed concrete tank in basement. Tank insulation: 8 in. plastic foam.
Percent solar heated: 100% in winter of 1975.
Auxiliary heat: None.
Cooling in Summer: None as yet.
Performance in winter of 1975: system performed well. (P-900).



WAS 9/9/75

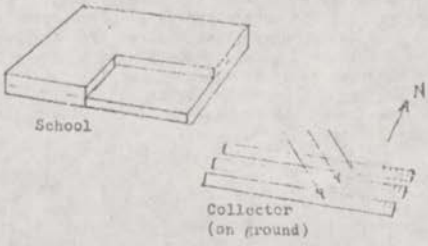
Michigan

Saginaw — Federal Bldg. 43½° N. (1977? Status uncertain. See below.)
Bldg.: One-story, 50,000 ft² bldg. to be used by eleven Federal agencies.
Collector: 8000 ft², water type. Covers 40 ft x 200 ft scaffold-face that is situated above the roof and slopes 55° from the horizontal.
Heat-pumps are used also.
Status: Uncertain. Bids far exceeded $5,400,000 estimate. Redesign underway. (Bldg. Design & Constr., Apr. '75)



Minnesota

Brooklyn Park (suburb of Minneapolis) — North View Junior High School 45° N. 1974. At 5859 69th Ave., near Interstate Highway 94, in Osseo School District. 155,000 ft². Solar engineering & construction: Honeywell, Inc., with many assisting groups. NSF funding: $358,000.
Collector: 5000 ft². Tilt: 55° from horizontal. Collector is on a plot of ground just SE of school. Collector consists of three long parallel arrays; each array includes 82 panels; each panel is 3 ft x 8 ft x ½ ft and is double-glazed with 3/16-in. tempered glass (outside) and 0.004-in. tedlar (inside). Fiberglass backing. Selective coating has a/ε ratio of ~10.
Fluid: water-and-ethylene-glycol. Collection temp.: 130 to 150 °F.
Storage system: 3000 gal. tank.
Percent solar heated: 6% (predicted).
(S.E.D. Mar. '74; NSF release; Honeywell release; P-900).



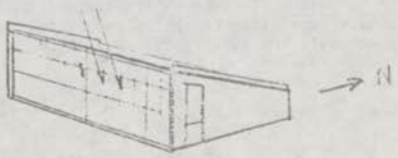
77

WAS 9/9/75

Nebraska

Mead (25 mi. west of Omaha)

Solar, Inc., Office Bldg. 41° N. Spring of 1975.
Solar eng'g: by Hanson, Lind, Meyer, Architects. Architect: J. Schoenfelder of that firm. Owner: Solar, Inc. (J. H. McLaughlin, President).
Bldg. Two stories high; but has open design and second floor space is small and consists of one room only, used for heat storage. Plan dimensions: 42 ft x 42 ft. Floor area: 1750 ft^2. There is a crawl space but no basement. Monoslope roof slopes downward toward north. Vertical south face is 42 ft x 21 ft and consists entirely (except for one small view-window area) of collector. Few windows on N, E, W. Insulation of walls: 4½ in. of Dylite bead board. Insulation of ceiling: lightweight concrete (Dycon) insulating roof tile (Perma-Tile). Vestibule (glassed in, with some plants growing) acts as buffer between outdoors and indoors.
Collector: 800 ft^2; air-type. Collector includes 36 panels, each vertical, each 3 ft x 7 ft. Double glazed. Absorber plate is of galvanized iron (18 gauge) and the black coating is non-selective. 2 in. behind this plate there is a second plate of galvanized iron. Air circulates in the 2-in. space between plates. The front (black) plate contains many small holes that were punched in such way that the displaced bits of metal remain and project toward the outdoors and slightly increase the area exposed to solar radiation and slightly discourage circulation of air between absorber plate and glass. The holes permit some interchange of air in the spaces in front of and behind the front plate. A 1-HP blower drives the air in the 2-in. space to the storage system, at 4000 cfm.
Storage system: 10,000 lb. of Glauber salt ($Na_2SO_4 \cdot 10\ H_2O$), plus nucleating and thickening agents as follows: (no info.)
The operating temp. (phase change temp.) of this combination is 95-110°F. The material is contained in plastic trays (of 1/16-in. plastic) that are 1 ft x 1 ft in area and 9/16 in. thick. Trays are stacked with 2-in.-thick intervening air spaces. The 5 ft x 6 ft x 7 ft housing, situated in second floor room at SE corner of bldg., is insulated with 6 in. of Dylite Perma-Foam (polystyrene bead board). When rooms need heat, air is circulated, by a separate, ⅔-HP blower, through storage system.
Percent solar heated: 90 to 100% (predicted). Carrythrough: 10 sunless Jan. days (predicted).
Auxiliary heat: electric furnace.
Domestic hot water: No provision for solar heating.
Cooling in summer: When outdoor air is hot, a conventional air conditioner is used. When outdoor air is cool, a 3/8 HP blower blows such air into bldg. to cool it and the air conditioner is not used. Design of bldg. is such that little outdoor heat, and little summer solar radiation, enters. (P-1066).



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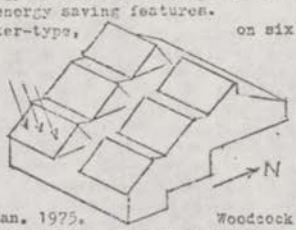
WAS 9/9/75

Nevada

Boulder City (25 mi. SE of Las Vegas)

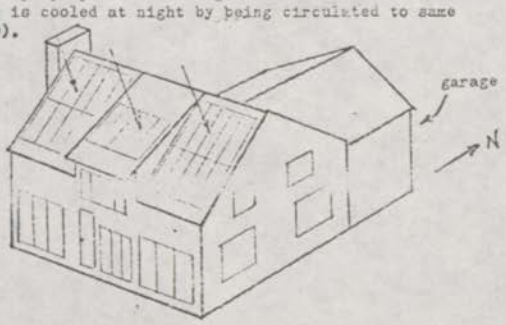
Desert Research Institute Lab.Bldg. at Boulder City 36° N. Planning stage. Planned by DRI of Univ. of Nev. early in '74. Will require ~ $1 M. Source of funds: Fleischmann Foundation, Mckd Family Trust, State of Nev. Architect: H.P.Wood of Jack Miller & Assoc. Feasibility: A.D.Little Inc. Bldg.: One-story, three-level, biology lab. on south slope of hill. Gross floor area: 10,000 ft^2. Many energy saving features.
Collector: 4000 ft^2, flat-plate, water-type, on six roof areas 36° from horizontal.
Storage system: water.
Performance expected: 100% solar heating, 60% summer cooling.
Status: Fund-raising underway. (A-704, P-900).



New Hampshire

Etna (near Hanover)

Sol-R-Tech Solar House #1 43½° N. Jan. 1975. Woodcock Lane. Off Trescott Rd. At south end of crest of 1000-ft-altitude hill. Solar engineer: J. DeVries of Sol-R-Tech. Builder: Quechee Construction Co., Inc. Owner: C. Weinberg.
Bldg.: 2 stories, 3 bedrooms, 2½ bathrooms. Heated area: 2100 ft^2. No basement. Excellent insulation. All windows double glazed. First story has concrete slab floor.
Collector: 600 ft^2 water-type collector on roof sloping 45° from horizontal (30° on dormer roof). Collector consists of 25 panels, each 3 ft x 8 ft, constructed by Sol-R-Tech. Each includes an Olin Brass Co. aluminum Roll-Bond plate with integral expanded channels. Black coating is non-selective. Liquid used: silicone oil. Glazing is double: outer sheet is of Alsunite fiberglass reinforced polyester; inner sheet is of Tedlar. Insulating backing on panel consists of 1-in.-thick fiberglass board.
Storage system: 4000 gal. water in main tank, which is of poured concrete, 10 ft x 10 ft x 8 ft, and 500 gal. auxiliary tank, of precast concrete. Both tanks are beneath floor slab. Two heat-pumps are used; they extract energy from tank water (as long as its temp. exceeds 45 °F) and deliver it to the rooms via forced hot air. Heat-pumps are York Triton pumps, DW-30H and DW-40H. Typical COP: ~3, per the manufacturer's specifications.
Percent solar heated (incl. heat-upgrading by heat-pumps): 100% (predicted). Carrythrough: 2 days (predicted).
Auxiliary heat: Electric heaters in ducts. Can handle 100% of load.
Domestic hot water: Preheated by solar heating system.
Cooling in summer: Heat-pumps provide cooling. Main tank is used as heat sink. Tank water is cooled at night by being circulated to same panels on roof. (P-900).



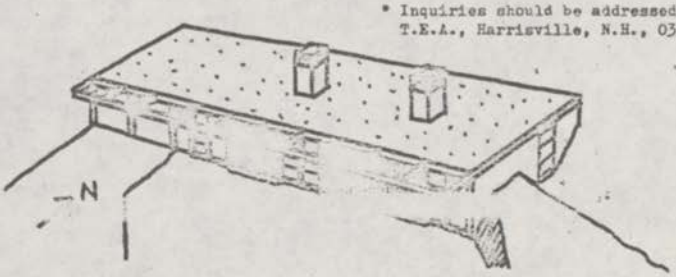
75
WAS 9/3/75

New Hampshire

Bedford (suburb of Manchester)

Tyrrell House 43° N. March 1975.
Solar engineers and building designers: Total Environmental Action* (asp. D. Coonley and B. Anderson). Owner and resident: K. Tyrrell.
Bldg.: One-story bldg., 24 ft × 80 ft, includes 3 bedrooms and 2-car garage. No basement or attic. Heated living area: 1300 ft². N wall is covered to full height with earth berm. E and W walls partly covered by berms. Ceiling insulation: 8 in. fiberglass. N, E, W walls insulated on exterior with 2 in. polyurethane foam. S wall is used for collecting and storing solar energy. Thickness of reinforced concrete floor slab: 4 in. (house) and 6 in. (garage).
Collector: Opaque part (~ 300 ft²) consists of a 12-in.-thick concrete wall, 8 ft high, behind 9-ft-high beadwall panels. S face of concrete wall is rough and has been coated with dark -- not black --non-selective paint. Wall serves both to absorb solar radiation and store the energy absorbed. Each Beadwall panel is 9 ft high and 4 ft wide; it includes two 0.040-in.-thick sheets of Kalwall Sun-Lite Premium (polyester reinforced fiberglass) spaced 2 3/4 in. apart and enclosed in a near-airtight frame; at night the space between sheets is filled with about one million tiny white polystyrene beads, which provide insulation approx. equivalent to an equal thickness of fiberglass. At start of sunny day, a 1/4 HP blower transfers the beads to drums (tot. vol. 120 gal.) situated in garage, at N side thereof. There is a 3½-in. airspace between Beadwall and concrete wall, and a gravity convection stream of air travels upward through this space, through holes at top of concrete wall, and enters room, warming it; return air flows via holes at base of concrete wall. (Dampers can be turned manually to stop such circulation.) North face of concrete wall has no insulation. Wall contributes heat to the rooms by radiation etc. Transparent part (90 ft²) consists of double-glazed Anderson windows and doors, which are covered at night by 1-in.-thick styrofoam shutters.
Storage system: The above-mentioned wall, and the house as a whole.
Percent solar heated: 60 to 80% (predicted). Carrythrough: 5 sunless Jan. days (est.) if total temp. swing of 15 F deg. is permitted.
Auxiliary heat: Two wood stoves, one of which is for cooking.
Domestic hot water: Preheated by passage along an array of 3-in.-dia. PVC pipes in thick concrete wall. Tot. vol. of pipes: 30 gal.
Cooling in summer: At night, space between thick wall and Beadwall is vented to outdoors, with the consequence that cool outdoor air is drawn into rooms via slots near north eaves. (P-900).

* Inquiries should be addressed to T.E.A., Harrisville, N.H., 03450.



Sketch courtesy of designers

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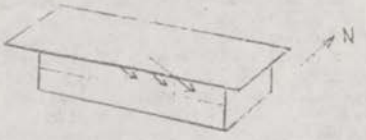
WAS 9/9/75

New Jersey

Princeton

Princeton Solar Lab. 40½° N. 1959.
Built by Curtiss Wright Corp. Architect: A. Olgyay.
Bldg.: One-story, 1200 ft^2. Flat roof with large overhang.
Collector: 600 ft^2 on vertical south wall. Air-type. Double glazed.
Storage system: 275 ft^3 eutectic salt.
Percent solar heated: 100%.
Auxiliary heat: none.
Performance: Estimated average collection efficiency in Dec. - Jan.: 47%.
Termination: After several years, ground was sold and building was demolished. (O-490, D-20, and misc. sources.)



WIC 9/9/75

New Mexico

Albuquerque

Bridgers-Paxton Office Bldg. 35° N. 1956-62; also 1974- .
215 Truman St., NE, Albuquerque, N.M. 87108. Solar engineers, architects, owners: F. H. Bridgers and D. D. Paxton.
Bldg.: One-story, well-insulated office bldg. in two portions (N, S), with collector on S face of N portion. Useful floor area: 4300 ft² (through 1962). Drafting rm. ceiling, behind collector, is 14 ft high.

Period 1956-1962

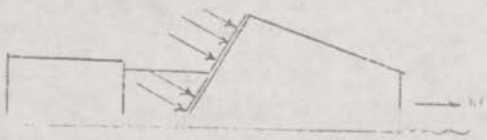
Collector: 750 ft² net, water-type, comprising 55 panels sloping 60° from horizontal. 26 of the panels are 22 in. x 9 ft; 26 are 22 in. x 7 ft; 3 panels are 22 in. x 5 ft. Each panel employs 3/16-in. aluminum sheets to the back of which ½-in.-dia. copper tubes (6-in.-apart on centers) have been soldered. Black coating (paint) is non-selective. Glazing: single; 1/8-in. double-strength glass. There is a 4-in. air-space between black surface and glass. Fluid: water (no anti-freeze; water is automatically drained when freezing condition is sensed in 4-in.-space.
Storage system: water-filled, 6000-gal., cylindrical, 5-ft-dia., steel tank (not insulated) buried in ground beside bldg. Carrythrough: 3 days.
Water-to-water heat-pump (actually an Arma 7½-ton water chiller) is used, when tank water is insufficiently hot, to transfer energy from tank water to water circulated to room-heating system. COP: 4.5 when input and output temperatures are 55 °F and 105 °F.
Auxiliary heat source: None.
Cooling in summer: By above-mentioned water-to-water heat-pump.
Performance: Generally good. On a few occasions the collector failed to drain completely and some water froze in some pipes.
Temporary termination: Use of solar heating system ceased in 1962.

Period 1962-1974

Bldg. was enlarged. Size approx. doubled. Furnace and boiler installed to heat bldg. Solar heating system not used.

Period 1974 -

Solar heating system put back into use. Collector fluid changed to water-and-ethylene-glycol; energy transferred to water-filled tank via heat exchanger. Five small water-to-air heat-pumps ("California heat-pump system"), collectively using 10 kW elec. power, are used to extract energy from water circulating through bldg. and deliver energy, via air-flows, to the rooms (five groups of rooms). Heat-pumps were made by American Standard (4 pumps) and American Air Filter Co. (1 pump); their COP's are 3 to 3.5, typically. Auxiliary heat is now available. 60%-portion of floor-area is 100% solar-heated. Performance being studied by S. F. Gilman of Penn State Univ. under NSF grant. (B-900, G-190, P-900, U-456m).



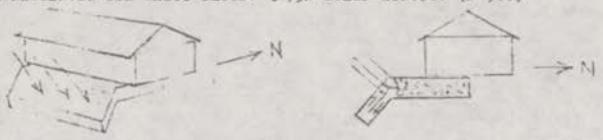
07

WAS 9/9/75

New Mexico

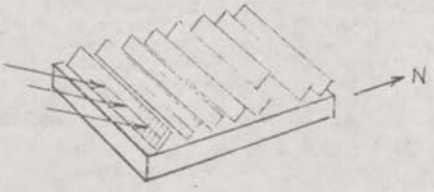
Corrales (suburb of Albuquerque)

P. Davis House 35° N. 1972. Solar eng'r.: Zomeworks (S.Baer et al). One-story house, 1000 ft². Gravity-convection air-type collector, 430 ft², on sloping ground. Store: 42 yd³ (~45 ton) fist-size stones in insulated bin under floor. ~ 75% solar heated. (P-900).



Las Cruces

New Mexico Dept. of Agriculture Bldg. 32° N. 1975. On NMSU campus. Solar engineering: Bridgers & Paxton. Architects: W.T.Harris & Assoc. Funding: by State Univ. of New Mexico. Est. total cost: 3½M.
Bldg.: One-story, rectangular, well-insulated, lab. bldg. for study of crop diseases & pesticides. Floor area: 25,000 ft² gross, 19,000 net. Small basement for mech. equipment only. Exhaust air from lab. hoods: 9500 cfm. Heat exchanger recovers energy from exhaust air.
Collector: 7000 ft², flat-plate, water-type (water-plus-ethylene-glycol) in 8 E-W arrays on horizontal roof. Arrays slope 30° from horizontal. In each of 7 arrays there are 26 panels, each 4 ft x 8 ft; 8th array has 23 panels. Double glazing used. Absorber plate (not yet specified) will have selective black coating.
Storage system: 30,000 gal. water. In two 15,000 gal., pressurized, insulated, steel tanks which are buried adjacent to (and communicating with) basement.
Cooling in summer: Absorption refrigeration system used. It is solar powered ordinarily, with energy from water at T>180 °F. Auxiliary energy source sometimes used.
Auxiliary heat: gas-fired boiler, mainly for cooling system.
Percent solar heated: ~100% (predicted).
Status: General design, and funding, completed by mid-1974. Bids received by Sept. '74. Construction to start late in 1974. Completion scheduled for end of 1975. (B-504, P-900).



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WAS 9/9/75

New Mexico

Los Alamos

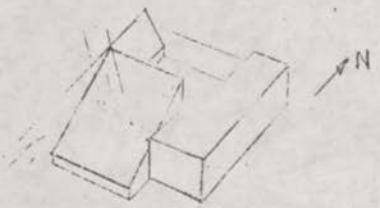
National Security and Resources Study Center Bldg. 36° N. Fall of 1976(?). Solar engineering: Los Alamos Scientific Lab. (of U. of Cal.), J.D. Balcomb et al. Solar energy consultant: J. Weingart. Architect: S. Burnett. Project Manager: Charles Luckman Assoc. Engineer: Ayers & Hayakawa. Contractor:_____. Owner, and source of funds: ERDA.

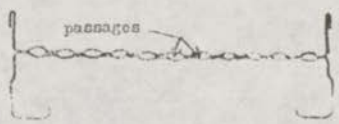
Bldg.: 3-story bldg. with 59,000 ft^2 heated space, 6600 ft^2 unheated utility space. To house National Study Center, also LASL main library;also a report library. Excellent insulation (U=0.07). Double glazing. Floating temp.-humidity setpoint. Heat recovery system. Other energy saving features. Annual heat load: 2.5 x 10^9 Btu. Est. cost: $4,600,000, of which $600,000 is attributed to solar heating and cooling system.

Collector: 8000 ft^2, liquid type. Rectangular planar array is 80 ft x 100 ft, slopes 35° from horiz., and is mounted on roof of a southerly part of bldg. There are 400 panels, each an integral part of roof --serving as roof. Each panel is of LASL design, is 2 ft x 10 ft, and consists mainly of ordinary (non-galv.) steel sheets. Two sheets are used; each is corrugated; the two are welded together in opposed orientation to provide many parallel passages for parallel flow of fluid.Passages are so thin that average thickness of liquid layer is only 0.035 in. and thermal capacity (and warm-up time) is short. Edges of sheets are bent upward and downward to form integral framing (which support -- below -- 3½ in. of fiberglass insulation and -- above -- metal strips holding 1 or 2 layers of 1/8-in. glass.) Frames of adjacent panels are clipped together to form a strong, water-tight array. Black coating on upper steel sheet will be of non-selective type on some panels and selective type (black chrome, α/ϵ = 0.95/0.1) on others. Fluid: a light paraffinic oil--either Shell Thermia 33 or Dowtherm HP. Flow rate: 420 gpm. Collector array is supported by horizontal steel I-beams 10 ft. apart.

Storage system: 15,000 gal. water in two tanks: 10,000 gal tank, at low pressure; 5000 gal. tank, at high pressure. There is a heat exchanger between collector fluid and tanks. Rooms are heated by forced hot air; fan-coil systems are used. There are two main heating zones, separately controlled.

Percent solar heated: 90% (predicted). Carrythrough: 2(?) days(predicted).
Auxiliary heat: Los Alamos Scientific Lab. central steam-supply system.
Domestic hot water: No information.
Cooling in summer: In summer the 10,000 gal. tank is used for cold storage (tank is cooled by conventional chiller which is backed up by a cooling tower). Rooms are cooled by forced cold air. (The 5000-gal. tank continues in use as hot storage.)
Instrumentation and Controls: Elaborate.
Status: Constr. started in mid-1975. Scheduled completion date: Aug. 1976.
Source of Info.: Various LASL pamphlets and reports. Also P-900.





Cross section of LASL fluid-type collector panel: steel sheets only. (glazing is installed above, insulation below.)

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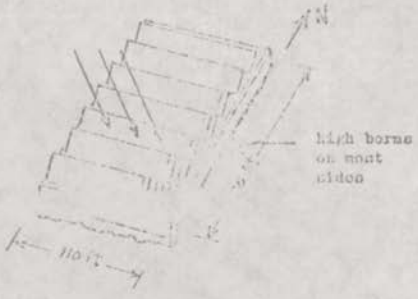
WAS 9/9/75

New York

Hillbrook (70 mi. N of N.Y.C.)

Cary Arboretum Bldg. 42° N. July 1976(?).
Solar engineer: Dubin et al. Architect: M. B. Wells. Owner: New York Botanical Garden. Funding: Mary Flagler Cary Charitable Trust.
Est. cost: $2,000,000 or somewhat more.
Bldg.: 35,000 ft² research, admin., and educational bldg. Two stories; no basement. (Lower story, flanked by high earth berms, could be regarded as basement. It contains library and mechanical rooms.) Few windows on E, N, W; 40% of area of S-side second story consists of windows. All windows are double glazed. S windows shaded by eaves in summer. Bldg. is well insulated. Heavy masonry walls are insulated on exterior side. Low-wattage elect. illumination system. Rainwater from roof is used for flushing toilets. Deep wells on property used in summer for cooling. Roof is of 60 deg. sawtooth type, has 7 teeth. A small energy collecting and conserving greenhouse is included just to the south of bldg.
Collectors: 6000 ft² areas. Flat-plate (water + 50% ethylene glycol). Selective black surfaces. Double glazing. Collector panels are on 50°-from-horiz. S-sloping facets of saw-tooth roof, with N-sloping facets reflecting additional radiation to the panels. Energy is delivered to storage system via heat exchanger.
Storage system: 50,000 gal. pure water, in a set of three tanks in basement. Each tank is of reinforced concrete, with bldg. foundation walls serving as portions of tanks. Tank exteriors have insulating coating of urethane. Tanks may be at different temperatures. Rooms heated by fan-coil system. Heat-pumps are used, and are of "double bundle condenser" type. They are used in winter to transfer heat from a hot tank to the coils of fan-coil systems.
Percent solar heated: No estimate available. Percent heated by solar heating system and heat-pumps: Very high percentage.
Cooling: Very little.
Auxiliary: Electric. Resistance heaters serving fan-coil-system water.
Remainder: Presumably heated by solar heating system.
Cooling: Summer cooling: forces cooling with cool water from deep wells. Supplementary cooling by conventional chiller driven by cooling tower.
Status: Groundbreaking occurred 4/26/75. Entire project expected to be completed by July 1976.
(Release of 2/11/74 by N. Y. Botanical Garden; NYT 2/12/74; release of March 1975 by Dubin et al. P-520.)

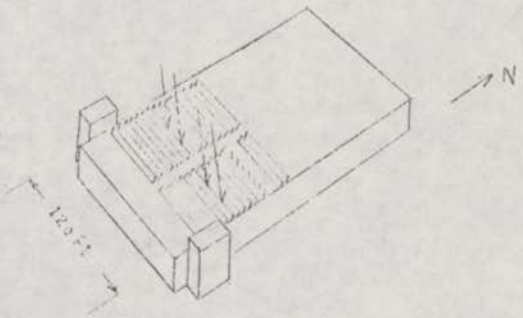


11C
WLS 9/9/75

Pennsylvania

Valley Forge (suburb of Philadelphia)

Gen.Elec. Co. Solar-Heated Bldg. 40° N. May 1975.
Designer, solar engineer, builder, owner, operator: Gen.Elec. Co.
Interested official: G. W. Van Citters.
Bldg.: Existing bldg. built in 1960. Solar heating system is intended to heat the 20,000 ft² cafeteria-and-kitchen area.
Collector: 4900 ft², water-type, on horizontal roof. Collector consists of 203 panels, each 8 ft x 3 ft, and 5 in. thick, tilted 45° from horiz. Heart of panel is a Series 1100 Roll-Bond aluminum sheet with 240 ft of integral passages. For comparison, three kinds of selective black coatings are used and several glazing schemes (employing the G.E. plastic Lexan). Insulated backing includes 0.001-in.aluminum foil, a layer of foam-type insulation, and, in addition, a thin layer of fiberglass. Fluid: 900 gal. of sol'n. consisting of water (70%) and ethylene glycol (30%) in a closed system; circulation is by a 5-HP centrifugal pump.
Storage system: 8000 gal. water. Water is in six tanks. Heat exchangers are used. Rooms are heated by fan-and-coil systems. When end of tank temp. reaches 210 °F, additional heat is "vented" to cold water.
Percent solar heating: 75% (predicted, for the bldg. portion in question).
Carrythrough: 2 days (predicted).
Auxiliary heat: Existing furnace.
Domestic hot water: Preheated by energy in storage tanks.
Cooling in summer: Solar heating system not used to provide cooling.
Instrumentation: Extensive.
Cost: $400,000 approx.
(S. E. I.R. Apr. 15, 1975. Also G. E. release of 4/9/75. Also P-900.)



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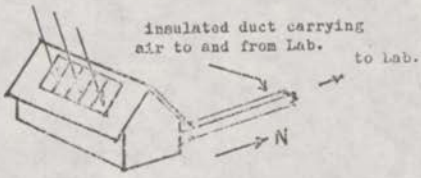
WAS 9/9/75

South Carolina

Cheraw (130 mi. N of Charleston)

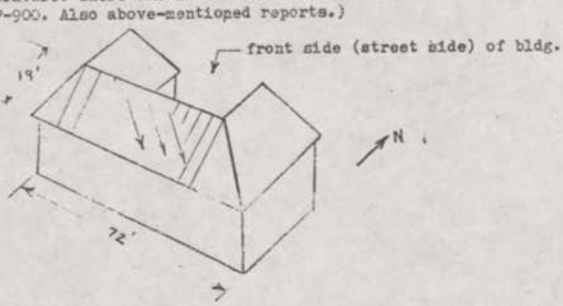
Chesterfield-Marlboro Technical College Solar Heated Lab. $34\frac{1}{2}^{o}$N. Spring 1975.
Solar engineers, builders: Thomas, R., and Smith, D.
Owner: Above-mentioned college.
Bldg.: The (partially) solar heated bldg. is a one-story, 40 ft x 40 ft lab. bldg., called the Air Conditioning, Refrigeration, and Heating Lab. It is well insulated.
Collector: This is on a nearby one-story shed, 14 ft x 12 ft in plan, with ridge roof. No attic or basement. Well insulated. Collector area: 125 ft^2; air-type; mounted on roof sloping 45^{o} from horizontal. Collector consists of five side-by-side panels, each consisting of a 3 ft x 8 ft black-painted metal sheet, or shallow trough, which is single glazed with 1/8-in. glass. A 1/3-HP blower circulates the air to the storage system.
Storage system: 20 tons of 3-in.-dia. stones in an uninsulated rectangular bin 4 ft x 10 ft in plan and 2 to 5 ft high. Bin occupies most of the space within shed. Hot air is sent (with the aid of the above-mentioned blower, and via an insulated, below-ground duct with 16 in. x 16 in. cross-section) to the Lab. Duct is made of fiberglass and plastic.
Percent solar heated: ~80%. Carrythrough: ~4 sunless Jan. days.
Auxiliary heat: Electric heaters in duct.
Cooling in summer: No attempt has yet been made to use solar energy to power a cooling system.
Performance: In 1975 winter, collector temp. as high as 235 ^{o}F was achieved.
Cost of materials: $1000.
(Cheraw Chronicle, 5/1/75; also P-900)



Vermont

White River Junction

Custom Leather Boutique Bldg. 43½° N. 1974.
Solar engineer: J. DeVries of Sol-R-Tech. Builder: Quechee Construction Co., Inc. Owner: J. Brown.
Bldg.: 1½-story building with two short N-S ells and concrete slab first-story floor. No basement. Floor area: 2100 ft^2. Thickness of fiberglass insulation: wall, 4 in.; roof, 6 in. All windows are double glazed. No windows on vertical S,E,or W walls.
Collector: 910 ft^2 net. Flat-plate, water-type collector consisting of 58 Sol-R-Tech panels on 45° roof. Each panel is 3 ft x 8 ft, and includes an Olin Brass Co. aluminum Roll-Bond plate (of Type 1100 aluminum) with integral expanded channels. The black coating is non-selective. Liquid used: water with 500 ppm chromate inhibitor (Na_2CrO_4) called Bartlet Chem.Co. Inhibitor C. No antifreeze is used. Liquid is drained into storage tank at night. Glazing: double, of 0.04 in. Kalwall Sun-Lite. Behind the collector there is 6 in. of fiberglass (in roof). Dekolabs, Inc.,differential controller used.
Storage system: 5000 gal. water in rectangular, concrete-block tank with epoxy waterproof coating on interior. Tank is under concrete slab. 3 in. of styrofoam applied to top of tank in 1975.
Heat-pumps: Heating is assisted by three York heat-pumps (Triton, DW-30H, water-to-air, 2½-ton capacity) which extract energy from tank water as long as this is at temp. exceeding 45 °F and deliver energy to rooms via forced hot air. Typical COP of heat-pump is 3 or slightly better, per mfr's spec. Output temp. of heat-pump: ~120 °F.
Percent solar heated: 50% (predicted). Note: This does not include the small additional amount of energy from heat-pump motor).
Auxiliary heat: Electric heaters in ducts. Can handle 100% of load.
Cooling in summer: Heat-pumps used in opposite manner, taking heat from rooms and delivering it to storage tank. Water from tank is cooled at night -- by being circulated to same panels on roof.
Performance: Measurements made by A. O. Converse of Thayer School of Engineering, Dartmouth College (with NSF support via Mitre Corp.) are reported in 35 p. reports of 3/31/75 and 7/30/75. Some conclusions are: With 700 of the 910 ft^2 of collector panels in operation, 30,000,000 Btu were collected between Jan. 1 and May 7, 1975. This provided 40% of the space-heat need of that period. Collection efficiency was 35 to 40% typically; occasionally higher; much higher during steady, high-level irradiation in early afternoon. The COP of the (intermittently operated) heat-pumps ranged from 2.0 to 3.0 typically, depending on tank temperature. There was no evidence of corrosion of collector panels. (P-900. Also above-mentioned reports.)



Virginia

Fairfax County (20 mi. W of Wash.D.C.)

Miller & Smith Townston Sales Office 39° N. Nov. 1974.
Not in any townships. Between Herndon and Reston. Off Fox Mill Rd. and Pine Crest Rd. In Townston subdivision.
Solar engineer: J. Cummings of Goodwin H.Tayler Co.
Builder and owner: Miller and Smith, Inc. Supervisor: K. Murphy.

Bldg. 1½ story, with basement. Heated living area: about 1500 ft^2. Fiberglass insulation: wall: 3 in. (U = 0.1); ceiling: 6 in. (U = 0.05). Windows are double-glazed (Thermopane).
Collector: 750 ft^2 gross area; trickling water type; on roof that slopes 60 deg. from horiz. Water trickles down valleys of Reynolds corrugated aluminum that has a non-selective black coating. Nominal rate of flow of water: 4 to 6 gpm. Distribution pipe runs along ridge of roof. Collector-pipe (gutter) runs along lower edge of roof. Glazing: one layer of double-strength glass. Power of water pump: 3/4 HP. (Or 1/3 HP?)
Storage system: 4000 gal. water in horizontal cylindrical steel tank (64 in. dia., 24 ft long) in basement. Tank is insulated with 2 in. polyurethane foam. Water is same water that is circulated to collector. No antifreeze is used. Calgon inhibitor is (or will be) used.
Rooms are heated by fan-coil system, supplied with hot water from tank.
Percent solar heated: 30 to 50% (predicted). Carrythrough: No info.
Auxiliary heat: 30 kW electric immersion heater insures that tank temp. remains above 95 °F.
Domestic hot water: Preheated by above-mentioned storage-system tank.
Cooling in summer: None provided.
Cost: Bldg. proper: about $50,000. Solar heating system: about $12,000 (Wash. Post 11/17/74; F-900).

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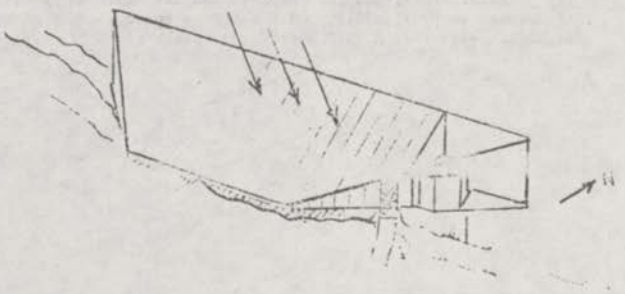
WAS 9/9/75

Virginia

Greenway (near Wash.,D.C.)

Madeira School Solar Energy Science Bldg. 39°N. July 1975(predicted).
Solar & Gen'l. eng'g.: Flack & Kurtz, Inc.
Architect: Arthur Cotton Moore Associates, esp. K. Abraham.
Builder: Commercial Industrial Construction, Inc. Funding: private.
Bldg.: 1½-story modern science bldg. housing biology, chemistry, and physics classroom-laboratories, a greenhouse, space for animals, and a basement photographic lab. Upper (main) story is trapezoidal; N wall is 201 ft, S wall 70 ft, bldg. width 47 ft.; floor area of main story: 6000 ft^2. N wall has windows, for view; S wall is adjacent to external corridor and walkway under collector overhang. Sliding partitions between main rooms permit flexible use. Lab. equipment is stored in portable cabinets hung on racks along N wall and transported by dollies. Abundance of conveniently placed water and sink stations, electrical outlets, safety equipment. Lower level is 50% crawl space and 50% useful area (3000 ft^2, consisting of mechanical rooms, printing shop, photo lab.) Some windows on N side; S side is below grade. Total useful floor area of bldg.: 9000 ft^2. Bldg. as a whole is a cedar-sided structure flanked by woods except on south. Bldg. is on downward-to-north slope. Winter temp. deficit: 4000 F deg. days.
Collector: 4000 ft^2 gross, covering trapezoidal wooden roof (waterproofed with silicone-base roof membrane) sloping 26° from horizontal. Collector consists of panels each of which employs a 27 in. x 104 in. Olin Brass Co. aluminum Roll-Bond sheet with integral passages for coolant liquid. Black coating is non-selective. Coolant is a heat transfer oil; probably Exxon Caloria HT-43 will be chosen. Single glazing. Pump drives liquid (at rate of 72 gpm) upward along passages in panels to a header pipe at ridge of roof, whence the liquid flows to storage system. Here, via heat exchanger, heat is imparted to water in tank.
Storage system: 10,000 gal. water in horiz. steel tank (8 ft dia.; insulated) in mechanical room. Tank temp.: typical, 130 °F; max.,180°F. Heat is delivered to rooms by hot water circulation.
Percent solar heated: (No estimate available). Carrythrough: 2 or 3 days.
Auxiliary heat: From steam boiler in adjacent bldg.
Cooling in summer: Not yet planned. Suitable space is available.
Swimming pool heating: Collector heats nearby swimming pool in spring and fall when bldg. heat requirement is small.
Status: 80% complete. Expected completion date: July 1975.
(S.E.D. July 1974; Wash. Post Feb. 15, 1974; P-900)

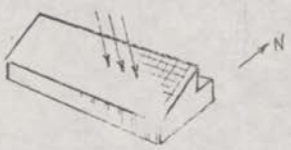


Virginia

Hampton NASA Eng'g. Bldg. 37° N. 1975(?)
Eng'g. bldg. for NASA's Langley Research Center.
Solar energy design: F. F. Simons and colleagues.
Floor area: 53,000 ft^2.
Collector: 15,000 ft^2. May employ evacuated glass tubes. May be situated on field adjacent to bldg. (S.E.D. Feb. '74)

Virginia

Richmond Phys.Sci. Museum & HQ of Sci. Museum of Virginia. 38° N. 1977(?)
Situated in Byrd Park. One of several bldgs. of statewide museum system.
Solar eng'g.: Rankins & Anderson, Inc. Architects: Glave, Newman, Anderson, & Assoc., Inc. (esp. R. B. Prud'homme). Support by Sci. Mus. of Va. Foundation, by Va. Elec. Power Co. and others; also by ERDA (re R&D); remainder by state.
Bldg.: Will house HQ staff and also Phys. Sci. Museum (incl. a tilted-dome planetarium). On 45-acre site. Bldg. includes several stories, with a total floor area of 59,000 ft^2. Large monoslope roof faces S. Wall area is 12% (double-glazed)glass windows. Good insulation: U-values 0.10(roof),0.13(walls).
Collector: 28,000 ft^2, water-type, on roof sloping 30° from horiz. Collector employs non-selective-black aluminum panels, each double glazed. (Two shapes of panel have been considered: 3 ft x 8 ft, and 110 ft x $\frac{1}{2}$ ft.) Liquid: water and inhibitor. No antifreeze; water will be drained & replaced by N_2 gas before freeze-up can occur.
Storage system: 150,000 gal. water in 8 insulated cylindrical steel tanks beneath ground at S side of bldg. Tank dia. & length: 10 ft, 34 ft. Plan calls for having various tanks at different temperatures, e.g., 120 or 140 °F in winter; 140 or 195 or 40 °F in summer. Rooms heated by ".. fin tube radiation and a terminal reheat system on the air conditioning system." Tank insulation: 1-in. sprayed-on polyurethane foam plus vapor barrier.
Percent solar heated: 75% (predicted). Carrythrough: 3 days.
Auxiliary heat: oil-fired boiler.
Domestic hot water: Preheated by condenser water; final heating by high-temp. storage tank and heat exchanger.
Cooling in summer: 125-ton absorption refrigeration system will be powered by hot (~190 °F) water from collector or storage tanks.
Also a 200-ton centrifugal chiller will be used; and rejected energy will be salvaged.
Cost of solar heating and cooling system and heat salvaging: Expected to exceed $750,000.
Status: Main funding not yet complete and not expected before 1976. In mid-75 NASA agreed to provide $174,000 for R&D re solar heating & cooling. Bldg. completion expected in 1977(?). (Eng'g. News-Record 7/25/74; also P-900)



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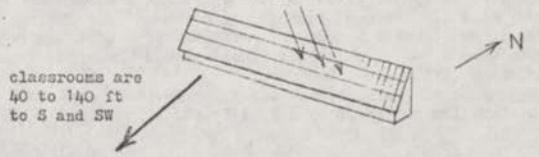
WAS 9/9/75

Virginia

Warrenton (60 mi.WSW of Wash. D.C.)

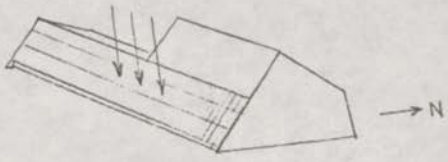
Fauquier County Public High School 39° N. April 1974. Intertechnology Corp., with own funds and $173,000 NSF funds, completed in March 1974 the design and installation of a solar heating system for a set of five separate classroom buildings, comprising a 4100-ft^2 portion of the school. Overall cost: $297,000.
Collector: 126 ft x 26 ft (2400 ft^2 net) water-type collector on 53°-from-horizontal scaffold adjacent to school. Double-glazed with 1/8 in. double-strength glass. Radiation strikes a chemically etched and black coating on face of Olin Brass Co. Roll-Bond aluminum sheet. Selectivity ratio: $\alpha/\varepsilon = 3$, per measurement. Water (with corrosion inhibitor) flows in the integral expanded channels in the aluminum sheet. No antifreeze is used, but liquid can be drained from collector into storage tank in 1½ min. There are 105 collector panels, each 3½ ft x 8 ft.
Storage system: Two separate, water-filled, underground, 5500 gal. tanks. Total capacity: 11,000 gal. Each tank (an electrical transformer bunker) is of reinforced concrete with L, W, H of 11½ ft, 8½ ft, 7½ ft. (R. W. Bliss's 4/10/75 rpt. discusses harmful water leaks --leaks which were stopped in Jan.1975).
Percent solar heated: 100% (for the five classrooms in question).
Carrythrough: 10 sunless Jan. days.
Sources of info.: Intertechnology final report "Solar Energy School Heating Augmentation Experiment", Rpt.090974 (also called NSF-RA-N-74-019) of 12/4/74; 80 p. Also NTIS PB-239 397/3WE "Design, Construction, and Initial Operation"

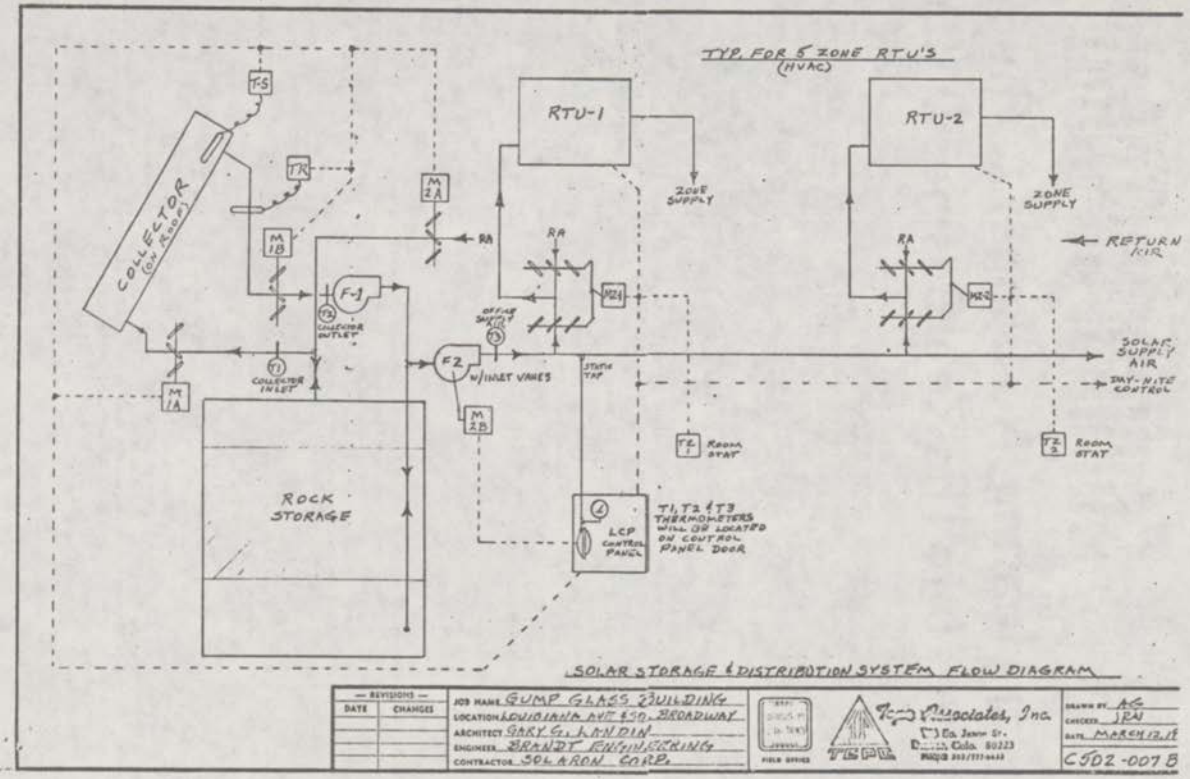


Wyoming

Lovell (N. central part of state)

Bighorn Canyon Visitors Center 45° N. 1976(?)
Designers: Wirth Associates. Solar consultant: G. O. G. Löf.
Funding and operation: National Park Service.
Bldg. Visitors center at entrance (near Lovell, Wyoming) to Bighorn Canyon National Recreational Area. Cost of bldg.: $1,300,000 (est.) Floor area: 9500 ft^2. Heat loss: 55,000 Btu per deg. day.
Collectors: Tentative design calls for 2500 to 2900 ft^2, air-type collector on roof sloping 48° from horiz. Collector consists of a large number of Solaron Corp. panels, each 12 ft x 2 or 3 ft x 5 in. Each is double glazed, with ½-in.-thick space for air-flow. Air is driven by a blower turned by a two-speed 5-HP motor; an air-flow of 5000 ft^3/min. at static pressure of 2 in. of water is achievable. (Less power when air is circulated from collector to rooms, rather than to storage system.) Panels can be "manifolded" side-by-side so that very few ducts and roof penetrations are needed.
Storage system: Bins of stones with total mass of order of 75 tons. Temp. stratification occurs in bin of stones, providing certain advantages. When rooms need heat and collector is not operating, room air is circulated through bins of stones in opposite sense. Bins may be located at corners of basement, basement walls forming parts of the enclosures. Each bin may be an 8-ft-cube, with vertical air-flow. Or it may be long and low, with horizontal flow.
Percent solar heated: 60 or 70% (predicted). Carrythrough: No info.
Auxiliary heat: Gas-fired, 400,000 Btu/hr furnace.
Domestic hot water: Heated via heat-exchanger in duct from collector.
Cooling in summer: Bins of stones cooled at night by stream of cool air from outdoors; water may be sprayed into air en route to bins to cool this air further. During day, cool air from bins is circulated to rooms, and (again) a spray of water may be used to enhance cooling effect. Note that each ton of stones, used through ΔT of 20 F deg., "stores" 2/3 of cooling, i.e., 8000 Btu.
Status: Nat'l. Park Service may issue invitations-to-bid by June 1975. Construction may start by end of Summer 1975. (L-379; ASET Jan.'75;P-900).




TYP. FOR 5 ZONE RTU'S (HVAC)
RTU-1
RTU-2
ZONE SUPPLY
ZONE SUPPLY
RETURN AIR
RA
RA
COLLECTOR (ON ROOF)
TS
TX
M 2A
M 1B
F-1
T2 COLLECTOR OUTLET
T1 COLLECTOR INLET
M 1A
OFFICE SPACE T
T3
F2 W/INLET VANES
STORE TYP
M 2B
SOLAR SUPPLY AIR
DAY-NITE CONTROL
TZ 1 ROOM STAT
TZ 2 ROOM STAT
ROCK STORAGE
LCP CONTROL PANEL
T1, T2 & T3 THERMOMETERS WILL BE LOCATED ON CONTROL PANEL DOOR
SOLAR STORAGE & DISTRIBUTION SYSTEM FLOW DIAGRAM
— REVISIONS —
DATE
CHANGES
JOB NAME GUMP GLASS BUILDING
LOCATION LOUISIANA AVE & 2ND. BROADWAY
ARCHITECT GARY G. LANDIN
ENGINEER BRANDT ENGINEERING
CONTRACTOR SOLARON CORP.
FIELD OFFICE
TCPA
Associates, Inc.
Co. Denver St.
Colo. 80223
DRAWN BY AG
CHECKED JRN
DATE MARCH 12, 19
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APRIL 28, 1975

Commerce Today

Solar Heating, No Longer A Theory, Moves Into The Real Business World

What is believed to be the nation's first full-fledged solar heating system designed for use in a commercial building has been installed in Denver, Colorado.

Built by Solaron Corp. of Denver, the system was built into the $1 million headquarters of the Gump Glass Co.

Solaron is a publicly-held company organized for the sole purpose of developing, manufacturing, marketing and installing solar space heating systems. The same systems may be used for hot water heating and air-conditioning.

Gump Glass, a closely-held family corporation, becomes what they believe is the first commercial business in America to buy a solar heating system for practical use in its own establishment.

Presidents John C. Bayless of Solaron and Jerry Sigman of Gump Glass said the system's installed cost is estimated at $60,000. It includes 1,600 square feet of glass-covered metal solar collectors to be mounted on the roof of the one-story plant, ductwork, heat storage, and automatic controls.

The solar collectors, heat storage, controls, and air handling equipment accounted for about half of the total cost.

The collectors will save a projected 77 percent of annual fuel requirements for approximately 7,180 square feet of office and showroom space in the 41,000-square-foot structure.

Bayless and Sigman describe the project as a "major breakthrough in the practical application of solar heating technology in the commercial/industrial sector.

"Work in the field thus far has been limited largely to demonstration projects in a smattering of residences," Bayless said. "To our knowledge, the only previous commercial applications have been experimental in nature, or limited to heating hot water.

"In no way are we going into this for experimental or prestige purposes," Sigman said. "We are profit-oriented and economy-minded, and we view this as an eminently practical way to assure ourselves of an unlimited source of fuel for as long as we are in business.

"The front-end cost of installation is minimal in the light of sharply-rising costs of conventional energy sources, with every indication that such sources will become ever more scarce as time goes on.

"Not to be overlooked is the fact that we feel we are establishing a milestone in environmental quality control with the installation of a clean, non-polluting source of energy.

"Gump has been in the glass business in Denver for more than 50 years," Sigman added. "Since all solar heating systems depend on glass, we looked to Solaron in our own backyard when we began discussing the feasibility of solar heat for our new building.

"The Solaron system should have as long a life as the building itself, without any maintenance costs whatsoever," Jerry Sigman said. "We feel we are making a practical investment and, at the same time, we are contributing our little bit to the national need for conservation of dwindling fossil fuel resources."

Overnight change

Bayless said solar heating has moved "out of the laboratory and into the marketplace almost overnight" because of the soaring costs of conventional fuels.

"As a result, we have been able to make the transition from an R and D (research and development) to an operational mode long before our most optimistic projections," he said. "There really is nothing new about the principles and technology of solar heating; what is new is the price and scarcity of oil, gas and electricity, which almost without warning have made solar heating an attractive and economic alternative."

Solaron's system is based in large part upon the research and development work of Dr. George O. G. Lof, a civil engineering professor at Colorado State University, who in 1943 fitted a house in Boulder with a solar collector system as part of a Commerce Department-sponsored demonstration and, since 1957, has heated his own Denver home maintenance-free with a system he designed.

Now president of the International Solar Energy Society, Lof is a founder, vice president and technical director of the Solaron Corp.

Bayless said computer models of the solar heating system indicate it will save an average of 77 percent of the fuel needs of office and showroom on an annual basis.

A conventional gas-fired forced air heating system will provide supplemental heat to office and showroom areas, while gas space heaters will heat fabrication and warehouse areas.

During periods of normal, sunny weather, the solar heating system will provide up to 100 percent of heating needs. However, during prolonged cloudy periods, he said, the solar collectors may not receive enough solar heat to satisfy the building needs completely, in which case, the additional heating requirements will be supplied by the back-up conventional system.

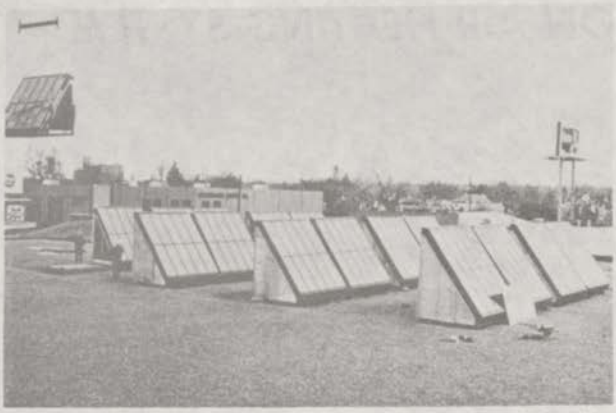
Bayless added that scientific means of adapting the system to other climates already exist, and that each system produced by Solaron is sized to projected weather conditions at the point of installation.

The solar heat collector system on the roof of Gump's headquarters consists of four rows of factory-assembled collector modules mounted facing south in order to receive the winter sun at all times of the day. The panels will be pitched at a 50 degree angle from the horizontal—a slope which Solaron's studies have shown provide the best entrapment of the sun's rays at Denver's geographical position.

The collector panels contain a metal absorber sheet, coated with a special, non-reflective, absorbent black paint, and covered by two panes of glass separated by an insulating layer of dry air.

Circulating air enters the collector panels at the bottom through a cold air manifold. It rises through a duct behind the hot absorber sheet, which heats it. At the top of the panels the heated air is gathered into an insulated duct which carries it into the building heating distribution system or to the solar heat storage unit located in the building's warehouse area.

This storage unit is a bin, eight feet wide, eight feet deep, and 16 feet long, containing about 50 tons of rounded pebbles of uniform size—a medium pro-



LAST OF THE FIRST—*The sixteenth, and final, solar energy collector is lowered into place on the roof of Denver's Gump Glass Co. The firm is believed to be the first commercial operation in the United States to rely on solar energy as its prime heating source.*

viding the most efficient heat storage, according to Solaron's research findings.

Automatic thermostatic controls regulate the flow of heated air from the collectors on sunny days, through ducts to the office and showroom as required. At other times, the air is drawn through the heat storage unit to be heated before distribution to the building.

Power plant design

Taking the solar process still further, the Energy Research and Development Administration is seeking proposals from industry for designs of a ten-megawatt solar power plant.

Responses are to be submitted by April 29. Over a period of about two years, the selected projects are expected to lead to several preliminary designs of the pilot plant. Then a final design will be selected for fabrication, construction and testing. The plant is expected to be in operation in four to five years in the Southwest.

This solar thermal power plant, which will use the central receiver concept, is considered one of the most economical approaches to production of electricity by solar thermal conversion. The collector field will consist of an array of controlled heliostats, or mirrors, which will continuously reflect solar radiation to an absorber-boiler atop a tall tower. Fluid in the boiler will be converted to a high-temperature vapor, such as steam, which will be expanded through a turbine to run electrical generators.

Excess collected energy in the form of hot fluids can be stored in an insulated tank for use when the sun is not shining.

Once in operation, the solar thermal pilot plant will be used to check the predicted performance and operating characteristics of the system and to project the economic viability of the larger, commercial-size power plants.

An upcoming FEA report covering all federal activities in the solar energy area between July 1973 and January 1975 says that "obstacles to the widespread utilization of solar energy include lack of incentives that would help defray capital costs and enable people to take advantage of the free fuel the sun makes available.

"It is estimated," the report states, "that the amount of solar energy falling on the continental United States is roughly 700 times our total energy consumption."

The National Science Foundation has recognized six different applications of solar energy: solar heating and cooling of buildings; photovoltaic electric power generation; wind energy conversion systems; ocean thermal gradient power generation; and bioconversion to fuels. The first three use solar energy directly whereas the last three use solar energy after it has been converted to a different medium. Each of these applications involves a different technology and they are related only by the original source of the energy.

To push solar energy development, 14 federal agencies have sponsored 171 solar projects at a cost of $25.2 million dollars during the 19-month period covered by the report which provides a summary of each project.

About half of this federal effort has been concentrated on demonstrations for the heating and cooling of buildings, with $17 million authorized for expenditure in this area duing fiscal year 1975.

Of the six applications noted above, several show promise of commercial viability by 1980 in special circumstances. Based on research supported by the NSF, solar heating and cooling of buildings is already competitive with electricity in certain regions of the country, and as the price of electricity goes up, the time required goes down for the savings in fuel costs to pay for the high initial cost for the solar energy system. Other solar energy systems which could be in some use by 1980 are photovoltaic electric power generation, wind energy conversion systems, and bio-conversion to fuel. Each of these has already been demonstrated on a small scale and the NSF has planned research and larger demonstration units to explore the commercial viability of these facilities. The Project Independence business-as-usual scenario estimates a savings of 50,000-barrels-per-day or 0.3 percent of petroleum demand in 1980 from these four solar energy applications. While this is not much, it is a necessary first step, in FEA's view.

One agency, the National Science Foundation, has been responsible for 80 percent of the 171 projects and 77 percent of all funds spent. The report shows that NSF's solar budget has grown by 4,000 percent, from $1.2 million in 1971 to an estimated $50 million in 1975.

Much of the federal effort in solar energy development, including that part administered by NSF, has been assumed by the newly-established Energy Research and Development Administration.

Minimal impact

In a related development, the Federal Energy Administration released results of a survey which shows U.S. manufacture of high-temperature solar energy collectors in 1974 was equivalent to only 56 barrels of crude oil per day.

The United States currently consumes about 17 million barrels of crude oil per day.

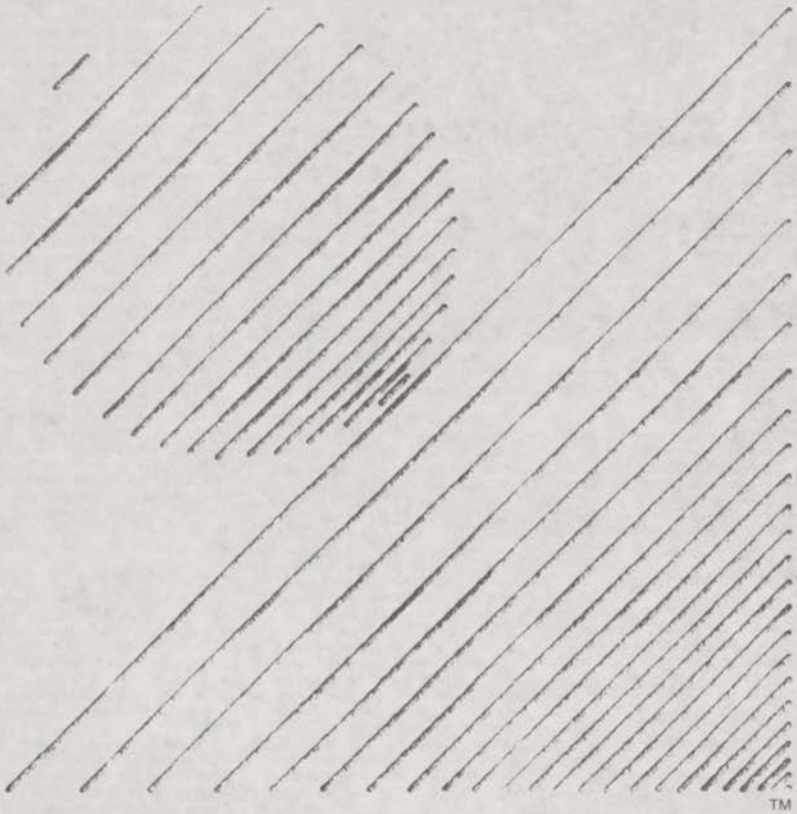
FEA's 56-barrel-a-day figure for the maximum petroleum energy equivalent of high-temperature solar collectors manufactured in the U.S. in 1974 came from the results of a survey conducted by the agency's Office of Energy Statistics.

A total of 170 firms were identified as possible manufacturers of solar collectors, and each was telephoned to determine square footage of high- and low-temperature solar collectors produced and sold in 1974. Only 39 were actively engaged in production. These produced a total of 136,540 square feet of high-temperature collectors in 1974. About 18,000 square feet of this was used to equip four public schools. If applied to space heating, the remaining square footage could provide power to heat about 220 houses.

FEA's Solar Report will be available to press and public in mid-May.

SOLARON CORPORATION STAPLETON FIELD INDUSTRIAL PARK 4850 OLIVE STREET DENVER COLO 80022
PHONE 303 / 289-2288

THE SOLARON AIR HEATING SYSTEM



SOLARON™
CORPORATION
SolarEnergySystems

The Solaron solar air heating system, based on over thirty years of research and development is now commercially available. It is designed for use with conventional forced air heating/cooling systems in both residential and commercial applications.

* The system will reduce fuel consumption by as much as eighty percent by utilizing solar energy for space heating.

* The system has proven safe, reliable, and virtually maintenance-free in over eighteen years of operation.

* The system, because of its simplicity, can be easily installed in both new and existing buildings.

Solar Home by ECO-ERA, Inc.
Ft. Collins, Colorado

ADVANTAGES OF THE SOLARON AIR SYSTEM

The Solaron air heating system, which uses air as the transfer medium, has several advantages over solar liquid systems.

1. Cost—Generally the installed cost of the Solaron air system is lower than systems using water or other fluid because of simplicity, use of less expensive materials and ease of adaptability to conventional heating systems.

2. Long Life—The Solaron air system, the result of over thirty years of development, is designed for ease of operation and long life. The prototype system has been in continuous operation for eighteen maintenance-free years. On the other hand, recent tests of solar liquid systems have uncovered corrosion and wear problems that simply don't occur with air systems.

3. Maintenance—The Solaron air system is remarkably maintenance-free. The only moving parts are standard dampers, blowers and motors. The liquid systems require a series of pumps and automatic valves that are subject to continuous corrosion and wear. The liquid system is charged with a solution that must be periodically tested and adjusted to prevent vaporization or freezing much like an automobile radiator.

4. Flexibility—The air system can readily accept conventional humidifiers, air conditioners, electronic air cleaners and other options. These accessories cannot be incorporated into a liquid system.

5. Safety—The Solaron air system cannot be damaged by freezing or boiling, nor can it cause water damage to the building or its contents. The glass used in the manufacture of the collectors is tempered to resist breakage.

THE SYSTEM INCLUDES THE FOLLOWING COMPONENTS:

Solaron provides the following proprietary products and services:

1. Solar Collectors—factory assembled solar air heating collectors that contain a flat absorber/heat exchanger and internal manifolding. It is sealed with two tempered glass plates for absorbing solar energy and converting it to useful heat energy.

2. Air Handling Module—an air handler that directs the flow of air through the system during the various operating modes. The module consists of a set of automatic dampers, blower, motor, and optional hot water heating coil. For residential applications a completely factory-assembled unit is provided. For commercial applications, the air handler is typically custom-engineered for on-site integration into the conventional HVAC system. All components are readily available for inspection and service.

3. Automatic System Controller—a control unit, activated by a conventional thermostat, that is designed to continually monitor and regulate the operating modes of the system. It includes the sensors and controls

necessary to automatically maintain the desired comfort level. For residential applications, a factory-assembled unit is provided. For commercial installations the controller is typically custom-engineered for the specific application.

4. Solar heat storage unit plans and specifications.

To complete the system installation, the local heating contractor provides the following services:

1. Installation of the standby heating system—a conventional forced air heating unit with the necessary duct system for proper distribution of air. Solaron will provide specifications for this system.

2. Installation of the solar heat storage unit—a concrete or wooden box properly insulated and filled with dry pebbles to serve as the storage medium for the solar system.

3. Installation of the solar system—this includes the installation of the collectors, air handling module, and automatic controller along with the necessary ducting and control wiring for a complete solar system integrated with the standby system. Solaron will provide complete installation instructions for this work.

SYSTEM OPERATION

As shown in the illustration on page 4, a Solaron equipped building is heated directly from the collector whenever heating is needed during sunny periods, as shown in Figure A. Air is circulated from the building to one end of the collector; as the air passes through the collector, it is heated by converted radiant energy. The optional hot water heat exchanger is in series with the collector to provide solar pre-heated water for domestic consumption.

The Solaron system utilizes the unique heat exchange and heat storage characteristics of dry pebbles, the most practical storage medium for use with air heating collectors. Solar heated air is routed through the storage unit as shown in Figure B, thereby heating the pebbles, and returns to the collector for reheating. Near perfect temperature stratification in the storage unit assures maximum heat recovery from the solar collector. Heat is delivered from the storage by circulating air from the building as in Figure C. Because of storage temperature stratification, this mode provides heat at nearly the same temperature as from the solar collector. The system automatically activates the standby system when solar heat is not available either from the collector or from storage.

The Solaron system is installed and operated in accordance with accepted heating, ventilating, and air conditioning engineering practice. The Solaron collector can be integrated into the building roof or wall, or it can be free-standing on the building structure to provide proper orientation and tilt for best winter heating performance.

SYSTEM WARRANTY

The Solaron Collector is warranted to be free of defects for a period of ten years from date of installation if installed in accordance with Solaron specifications. If in this period the collector unit fails in any manner, Solaron will provide the necessary replacement parts at no charge. This warranty does not include glass breakage.

The air handling module and automatic controller are guaranteed for a period of one year from installation.

HOW TO OBTAIN MORE INFORMATION ABOUT A SOLARON SYSTEM

Contact your local heating and air conditioning contractor, mechanical engineering firm, architect, or Solaron directly. Solaron will provide the necessary hardware and engineering services. Your local contractor will install the system.

Solaron's trained engineering staff is available to assist architects and engineers in feasibility studies, system arrangement and installation approaches. Direct your inquiries to Solaron Marketing Services, Solaron Corporation.

With the rapidly escalating costs of conventional heating fuels, now is the time to consider a Solaron heating system. With today's rising fuel costs, a Solaron residential system is clearly cost effective. In commercial applications where additional tax incentives are available, the payback period can be as short as six years, depending on alternative energy costs.

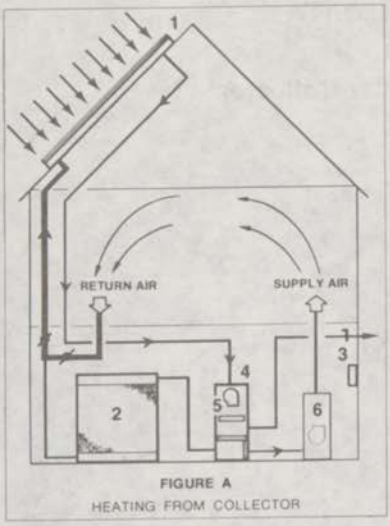


FIGURE A
HEATING FROM COLLECTOR

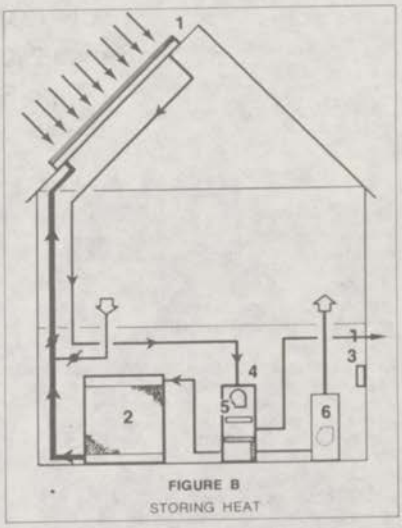


FIGURE B
STORING HEAT

LEGEND

1. SOLAR COLLECTOR
2. HEAT STORAGE UNIT
3. CONTROL UNIT
4. AIR HANDLING MODULE
5. OPTIONAL HOT WATER UNIT
6. AUXILIARY HEATING UNIT

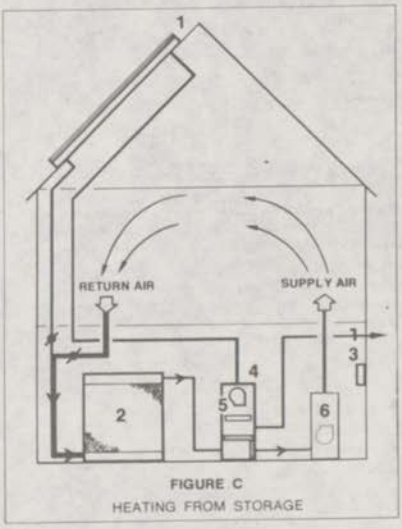


FIGURE C
HEATING FROM STORAGE

SOLARON CORPORATION, MARKETING SERVICES
4850 OLIVE STREET, COMMERCE CITY, COLORADO 80022

TECHNICAL DATA
Series 2000
Air Type Solar Collector

SOLARON CORPORATION

PATENTS PENDING

The Solaron series 2000 flat plate air type collector represents the most advanced technology and manufacturing know-how available today in the solar heating field. The collector is based on over thirty years of research and testing and has proven highly efficient, reliable and maintenance free.

The collectors are completely factory pre-assembled to minimize field installation time and assure uniform quality and performance. The exclusive port and manifold system allows the collectors to be simply butted together and bolted in place. No field fittings are required between collectors.

The Solaron series 2000 collector is universal in application. Substantial energy savings can be realized in commercial, industrial and residential applications such as:

- MAKEUP AND FORCED AIR HEATING
- HYDRONIC SPACE HEATING
- DOMESTIC HOT WATER HEATING
- PROCESS HOT WATER APPLICATIONS
- PROCESS HOT AIR DRYING APPLICATIONS

The Solaron System can be used where application temperatures can be satisfied directly by the collectors as well as where the collectors are used to preheat air or water for high temperature applications.

The Solaron series 2000 collector conforms to the interim performance standards established by the Energy Research and Development Administration for solar collectors. These standards include:

- RESISTANCE TO HAIL, WIND FLUTTERING AND WIND LOAD.
- FREEDOM FROM FREEZING, CORROSION, AND OUTGASSING.
- RESISTANCE TO THERMAL AND SOLAR DEGRADATION.
- CONFORMITY TO NATIONAL SAFETY AND FIRE CODES.

FEATURES

- The Solaron series 2000 air type collector can be used in hydronic applications through the use of a high efficiency air to water heat exchanger. Since the collector uses air as the transfer medium, costly field piping, maintenance and wear are reduced or eliminated.
- Attractive appearance allows for architecturally pleasing applications, including construction of entire roofs and wall sections with solar panels.
- Factory preassembly includes insulation, manifolding and glazing to eliminate field assembly.
- Simple installation system includes all hold down hardware and cap strip necessary for a complete installation. Perimeter flashing, typically field measured is not provided.

CONSTRUCTION

The series 2000 collector module, designed for high efficiency and ease of installation, is constructed of the following materials:

PAN - 24 gauge steel, fully insulated with 3-3/4" fiberglass batt. Painted external surfaces.

COVER PLATES - Two 1/8" hermetically sealed special low iron tempered glass panels with long life neoprene perimeter gaskets. Plates can be easily removed for service or replacement.

ABSORBER - 24 gauge steel with baked on high absorbency flat black coating.

BRIDGE STRIP - Extruded painted aluminum. Designed to assure weather seal between modules.

CONNECTION PORTS - Unique flange configuration permits tight air seal automatically as modules are installed.

PERFORMANCE

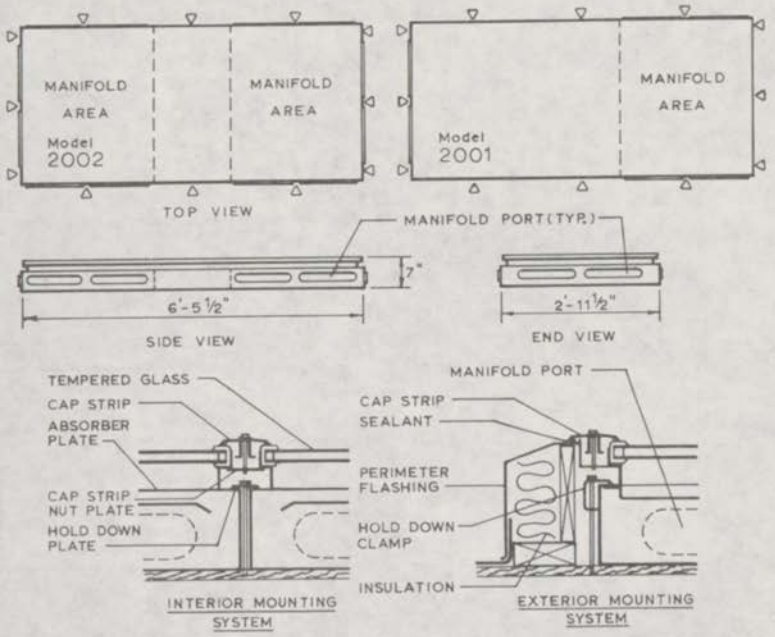
EFFICIENCY - collector efficiency is as high as 64.5% as a function of outlet minus ambient temperature over solar insolation. Where $T_{out} - T_{amb}$ equals 120° and insolation equals 300 BTU's per hour per square foot, a typical operating environment, the Solaron series 2000 collector efficiency exceeds that of flat plate liquid type collector.

REFLECTANCE - the specular reflectance of the absorber surface averages only about 5%.

COVER TRANSMITTANCE - the transmittance of the two plate, low iron tempered glass cover is 80 percent from a 0 to 48 degree angle of solar incidence.

HEAT DELIVERY - the excellent heat delivery characteristics of the Solaron series 2000 collector are shown on Figure 3.

COLLECTOR DIMENSIONAL DATA



The Solaron series 2000 collector is flexible in application. The modules can be installed on a roof section, wall section or free standing roof frame.

The collectors are installed as shown in the mounting system details above. Return and supply air is provided by simply installing a standard starting collar on the bottom of the collector anywhere within the 29" × 36" manifold area, thus collars can easily be located to clear roof trusses or wall studs. Perimeter flashing is field measured and installed to complete the system.

Other product information:

COLLECTOR WEIGHT - 153 pounds

INSTALLED DIMENSIONS - 36" × 78", center to center

PORT NET FREE AREA - 26.7 square inches each

PORT END CAPS - provided by Solaron as required

COLLECTOR PERFORMANCE DATA

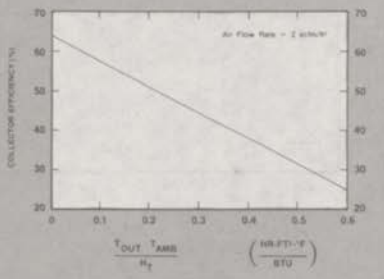


Figure 1.— Collector efficiency as a function of outlet minus ambient temperature over insolation.

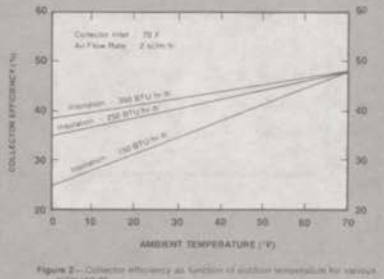


Figure 2.— Collector efficiency as function of outdoor temperature for various solar inputs.

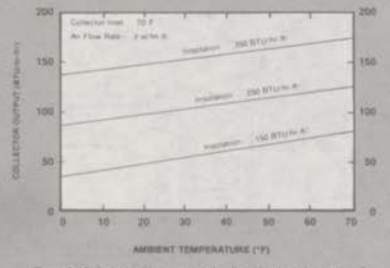


Figure 3.— Collector heat delivery as a function of outdoor temperature for various solar inputs.

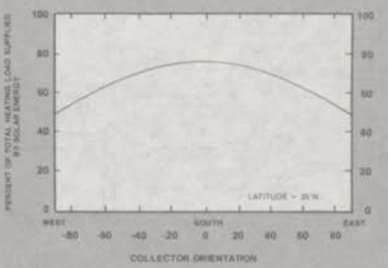


Figure 4.— Effect of collector orientation on total system performance of a typical installation at 35°N latitude. (J. D. Balcomb, J. C. Hedstrom, R. F. Rogers "Design Considerations of Air Cooled Collector/Rock-Bin Storage Solar Heating Systems," presented at 1975 ISES Los Angeles Meeting, Aug. 1975.)

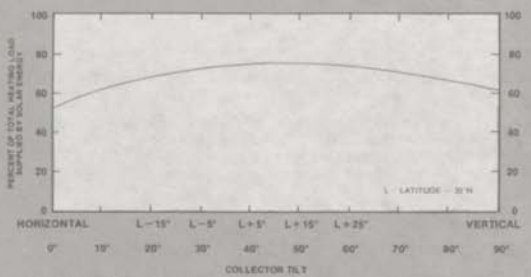
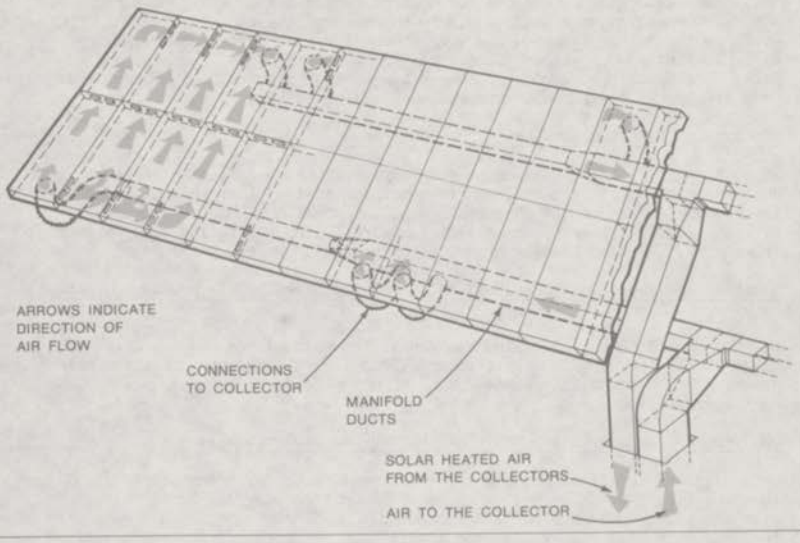


Figure 5.— Effect of collector tilt on total system performance for a typical installation at 35°N latitude (J. D. Balcomb, J. C. Hedstrom, R. F. Rogers "Design Considerations of Air Cooled Collector/Rock-Bin Storage Solar Heating Systems," presented at 1975 ISES Los Angeles Meeting, Aug. 1975.)

TYPICAL COLLECTOR INSTALLATION



The Solaron series 2000 solar collector can be installed in either a horizontal or vertical position. Installation can be efficiently accomplished by a two-man crew. No special tools or installation techniques are required.

The optimal air flow rate through the collector is 2 SCFM/ft.^{2}. The design static pressure is 0.23" when the collectors are ducted as shown above.

On a special order basis, Solaron can provide collectors with precut manifold openings and manifold ports omitted where specified to further reduce field installation time.

Solaron Corporation provides mechanical engineering and field services to assist the local engineer and HVAC contractor in design and installation.

For additional information on the Solaron collector and related Air Handling and Automatic Control systems, contact Solaron Corporation Marketing Services.

Phone 303 / 289-2268
SOLARON CORPORATION / 4850 OLIVE STREET / COMMERCE CITY, COLORADO 80022

INTERACTIONS WITH BUILDING COMMUNITY

1) Federal Agency Research at NBS

Since 1901, NBS has provided a focal point for transferring building technology and measurement systems to Federal agencies with building-related programs. NBS also has conducted research for numerous Federal agencies. Currently, NBS has memorandums of understanding with the Department of Housing and Urban Development, Energy Research and Development Administration, Federal Energy Administration, Occupational Safety and Administration, and the National Parks Service and interagency agreements with many others. NBS is the only Federal laboratory with a comprehensive building research program.

2) Federal and Industry Workshops and Conferences

In 1969, the Office of Management and Budget requested that NBS transfer building standards, criteria, and test methods to the other Federal agencies. In response, NBS conducts monthly and special workshops which are attended by architects, engineers, and building experts. In cooperation with various industries, NBS also hosts a number of other workshops and conferences.

3) National Academy of Sciences/National Bureau of Standards Technical Evaluation Panels

NBS has formed technical evaluation panels for each of its major programs. These panels review and make recommendations for existing and new technical programs. Top technical people from each major field of technology serve on these panels.

4) Department of Commerce's Building Technology Advisory Committee

This advisory committee advises the Department of Commerce on matters relating to the nation's needs in building research and technology. The committee provides policy guidance and a forum for discussion by experts on the complex building community and its diverse interests. Representatives from all segments of the building community also serve on the advisory committee.

5) National Conference of States on Building Codes and Standards and Model Building Codes Groups

Due to the multiplicity of jurisdictional authorities, the States in 1967 formed the National Conference of States on Building Codes and Standards to improve intra- and inter-State compatibility among the Nation's building regulatory jurisdictions. The Conference provides a national forum for the State and local governments, industry, and other interested parties to discuss issues bearing on building regulations, to identify current problems, and to use national resources for the development of solutions. NBS provides technical assistance and the administrative secretariat for the Conference.

At the request of the Conference, NBS performs research on building regulatory procedures including building laboratory accreditation, uniform procedures for building evaluation, methods for the efficient formulation and expression of building standards and codes, and implementation aids for performance-oriented

building standards. Such functions are also provided to model code organizations of local building officials and the newly-formed organization for building officials of the 30 largest cities.

6) Committees of American National Standards Institute (ANSI), American Society for Testing and Materials (ASTM), American Society for Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Etc.

NBS supports the national voluntary consensus standards process through more than 200 memberships on committees which promulgate building standards. NBS provides technical inputs from research to the committees and responds to the priority needs for building standards of ANSI.

7) Post Doctoral Program, Intergovernmental Personnel Act

In cooperation with the National Research Council of the National Academy of Sciences, NBS established an ongoing post doctoral program to provide awards to scientists for basic and applied research.

Under the Intergovernmental Personnel Act of 1970 (P.L. 91-648), NBS has sponsored a number of university faculty and graduate students to do research at NBS. Some local and state government personnel have also participated in this program.

8) Research Associate Program

Under this program, industry personnel work at NBS laboratory facilities on joint research which is of mutual interest. This research is both long and short range and enables NBS and industry to identify further research needs. All research findings are available to the public.

9) Occupational Safety and Health Administration (OSHA), National Institute for Occupational Safety and Health (NIOSH), Environmental Protection Agency (EPA) Federal Power Commission (FPC), and Justice Department

In recent years, Congress has established new Federal regulatory programs which mandate certain building requirements. These Federal programs have set new demands on the design, construction and operation of buildings and have placed further responsibilities on the local building code officials. Through liaison and research programs for these agencies, NBS provides a technical focal point for those who must implement new Federal regulations.

10) NBS' Center for Fire Research and Consumer Product Technology Center

These two new technical centers provide research programs on fire safety and life safety for the consumer. Research results in these areas have strong impact on codes and standards.

11) International Standards, United States Committee, Rilem and Cooperative Research

With increased international business interactions and corporations, strong participation in international standards is essential. Joint cooperative and complementary research with other foreign government research organizations provides more comprehensive research, avoids duplication and permits sharing of facilities and technical staff.

12) American Institute of Architects (AIA)-NBS Architect-in-Residence Program Publications and Membership in all Professional Societies

A strong relationship is maintained with all professional groups within the design community. The AIA/NBS architect-in-residence program places an architect from an architectural/engineering firm for one year at NBS. This program encourages NBS research with the architectural profession and informs NBS of the research needs of this profession.

NBS ENERGY CONSERVATION PROGRAM*

FY 1976 PROJECTS

PROJECTS FUNDED BY OTHER AGENCIES

1 Support CSA Winterization Program
Provide technical support to the Community Services Administration in developing performance criteria, retrofitting guidelines, and evaluating methodologies for winterizing homes of low-income persons.
50.0 - CSA

2 Technical and Management Support of FEA
Coordinate, manage, monitor, and support the overall FEA supported NBS energy conservation buildings program, and respond to FEA requests for technical and quick turnaround assistance and consultation.
50.0 - FEA

3 Retrofitting a Domestic Dwelling
Quantify the energy savings that may be achieved by implementing energy savings modifications on a typical 20 year old dwelling.
50.0 - FEA

4 Computer Control Evaluation of Heating, Ventilating, and Air-Conditioning Equipment
Determine the operational control techniques which will provide the greatest and most practical savings in general purpose laboratories and other commercial buildings.
100.0 - FEA

5 Energy Conservation in Garden Apartments
Determine the energy conservation effects of various retrofit modifications in typical garden apartment buildings.
150.0 - FEA

6 Thermographic Measurement Technology
Develop an innovative thermographic method to measure the heat flux on exterior and interior surfaces of building walls.
50.0 - FEA

7 Performance of Heat Pumps
Evaluate the effect of non-steady state operation on the coefficient of performance of an electric motor driven heat pump and determine the potential for energy conservation of engine driven heat pumps.
90.0 - FEA

8 Conference on Improving Heating, Ventilating, and Air-Conditioning Equipment
In cooperation with Purdue University, conduct a public conference to discuss engineering concepts and systems that improve the performance of HVAC equipment.
30.0 = 15.0 - FEA, 15.0 - ERDA

* Figures are listed in rounded thousands.

9 Oil Burners Field Study
Evaluate the energy conservation potential of various retrofit options for residential oil burners and develop procedures for their implementation.
100.0 - FEA

10 Fuel Oil Utilization
Using an industry advisory group, evaluate research proposals and sponsor research on promising ideas.
200.0 - FEA

11 Economic Equipment Maintenance for Energy Conservation
Analyze maintenance policies for HVAC building equipment to optimize equipment performance, dollar savings, and reduced energy consumption.
35.0 - FEA

12 Impact Scenarios
Investigate impact on building performance standards of factors which quantify the value of one energy source in relation to another.
25.0 - FEA

13 Twin Rivers Energy Conservation
Develop manuals which provide the data collected and the strategies developed in a planned experiment on retrofitting townhouses, and disseminate this information.
330.0 - FEA

Communities

14 Modular Integrated Utility Systems - HUD
Total Program - 1,500.0 - HUD

- Design, Analysis and Technical Support
Provide technical direction and advice to the multi-discipline, multi-agency HUD-MIUS program for development of energy conserving integrated utility systems for communities.
450.0 - HUD

- MIUS Demonstration
Provide technical evaluation and design coordination for the private sector design, construction, and operation of a full-MIUS installation in a residential community of 1000 equivalent dwelling units.
575.0 - HUD

- Total Energy Demonstration
Provide detailed technical measurement and analysis of the functional, technical, and economic performance of the HUD-built total energy plant for a 500-dwelling unit, high-density, urban renewal project in Jersey City, New Jersey.
600.0 - HUD

Industry

15 Industry Energy Conservation Services
Provide management and engineering information to assist industry in implementing energy conservation programs. Energy Conservation Program Guide for Industry and Commerce (EPIC-NBS Handbook 115) and the Waste Heat Engineering Guidebook are examples.
90.0 - FEA

16 Technical Support for DoC
Provide technical assistance and support for Department of Commerce assistance to industry energy conservation programs.
140.0 - DoC

17 Technical Development
Develop and demonstrate improved measurement technology in monitoring industrial processes to enable energy saving materials utilization.
600.0 - ERDA

Standards

18 Building Energy Conservation Standards
Develop performance-oriented energy conservation standards for new residential and commercial buildings.
750.0 = 500.0 - HUD, 250.0 - ERDA

Equipment

19 Energy Conservation in Food Service Equipment
Develop method for measuring part load performance of refrigerator units and determine effects of control systems on the efficiency of such refrigeration units.
251.0 - ERDA

PROJECTS FUNDED BY NATIONAL BUREAU OF STANDARDS

1 Energy Conservation in Buildings
Develop an integrate research plan for energy conservation in buildings.
25.0 - NBS

2 Exterior Envelope Design - Fenestration
Develop methodology and test applications for evaluating the overall performance of windows with regard to architectural, economic, psychological, thermal, and daylight factors.
100.0 - NBS

3 Part-Load Heating, Ventilating, and Air Conditioning (HVAC) Equipment
Establish HVAC equipment efficiency data and criteria based on part-load performance.
150.0 - NBS

4 Ventilation Systems for Energy Conservation
Prepare data to establish energy conservation potential of reduced ventilation rates as a basis for use in design guidelines.
50.0 - NBS

5 Heat Transfer for Thermal Storage
Investigate the mechanisms used for transferring energy in and out of thermal energy storage systems.
45.0 - NBS

6 Thermal Performance of Thick Fibrous Insulating Materials
Investigate the mechanisms active in heat transfer through thick fibrous materials to better predict their performance.
45.0 - NBS

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7 Energy Conservation Information System
Disseminate research findings and other practical information to appropriate users in a timely fashion.
45.0 - NBS

Total Funding by Other Agencies	4,591.0
Total NBS Funding	460.0

Clarification of Terminology: Codes, Standards, Guidelines and Performance and Prescriptive Theory

Building regulatory terminology, particularly codes, standards, guidelines and performance and prescriptive theory, is often misinterpreted since no authoritative definitions have been developed. These terms are frequently used in different contexts. Diverse interpretations of these terms creates a misunderstanding of how they are ultimately used in building regulations. The terms: code, standard, guideline, performance and prescription, as well as other terms, are used to describe legal documents, inputs in legal documents, and approaches (or philosophies) used in developing the inputs for legal documents. The following outline may be useful in clarifying the use of these terms.

I. Description of Legal Documents includes the terms:

- A. Building Code
- B. Federal Regulation

II. Description of documents used as inputs in legal documents:

- A. Model Building Codes
- B. Standards

III. Terms used to describe approaches (or philosophies):

- A. Performance
- B. Prescription

IV. Other Terms

- A. Guidelines
- B. Condition of Participation

I. Terms used to describe legal documents:

Building specifications are regulated by States or local jurisdictions to provide for the health and safety of the community. Every designer and builder must meet the minimum requirements contained in the State or local government's building code. The term building code, as used in this discussion, pertains to the total set of legal requirements for the entire building. Many jurisdictions do have codes which pertain to only portions of the building, i.e., fire code. Building code requirements are legally binding by their incorporation in city ordinances or by other legal actions. An average building code contains approximately 450 standards, through reference, through incorporation in the test or through modification and incorporation.

Although building regulation is primarily a State responsibility, Congress can, and has in the past, establish Federal building-related regulations. For example, the Occupational Safety and Health Act of 1970 establishes Federal regulations for safety in the workplace, including certain building regulations. The minimum legal requirements, in this case established by the Secretary of Labor, would be

Federal regulations. These Federal regulations, like building codes, would also utilize standards (usually the same standards as those used in codes and serve as legally enforceable documents which establish minimum requirements for the buildings under their jurisdiction. As will be discussed in subsequent sections, either prescriptive or performance statements can be used in writing these documents.

II. Terms used to describe inputs in legal documents:

Building codes and Federal regulations are large documents which are extremely technical. Usually, they are developed over a long period of time, utilizing the work of many organizations and individuals. The work of these organizations and individuals goes into the development of model building codes and standards that become the basis or inputs for building codes and Federal regulations.

A model building code is a comprehensive document of minimum requirements which has no legal basis. However, many jurisdictions adopt these model building codes in entirety and thus, for their jurisdiction, make these minimum requirements legally binding. Other jurisdictions adopt these model building codes with minor changes based on their local needs. Some jurisdictions, most notably the large cities, do not use these model building codes at all. Like legally enforceable Building Codes, Model Building Codes reference approximately 450 standards. Model building codes are developed by private organizations, such as the International Conference of Building Officials (Uniform Building Code), Southern Building Code Congress International (Southern Standard Building Code), and the Building Officials and Code Administrators International (Basic Building Code).

A standard describes a technical document issued by an approved standards-generating organization that establishes a uniform procedure, method or convention. Virtually all standards-generating organizations are private organizations. These organizations include the National Fire Protection Association (NFPA), American Society of Civil Engineers (ASCE), American Society for Testing and Materials (ASTM), and others. Approval of these organizations comes from the American National Standards Institute (ANSI), also a private organization, based on the standards adherence to published rules on standards development. Federal agencies are rarely authorized to promulgate standards by Congress. An exception would be NBS' authority to promulgate the standards of basic measurement. Unlike building codes, standards are not comprehensive and only relate to a narrow portion of the total building.

The term, standard, is not without its ambiguities. A standard can relate to a test method, a design procedure, a building product, or some other facet of the total building industry. Also, standards are used for different purposes. For example, there is a need to standardize test methods so building researchers can compare their results; there is a need to standardize the number and type of building products available so that one part of an industry can procure these products from another; there is a need to standardize definitions so that technical communications will be facilitated. This discussion focuses on those standards which are either promulgated by an approved standards-generating organization, or are used in building regulation, either through building codes or Federal regulations. These standards may be either prescriptive or performance based and are developed from building research and expert opinion.

III. Terms used to describe approaches (or philosophies) used in developing the inputs for legal documents:

The two terms used to describe approaches (or philosophies) in developing the inputs for these standards and model code documents, are prescription (or prescriptive) and performance.

Prescriptive is a term used as a prefix to standards, building codes, and Federal regulations to describe the contents of those documents. The prescriptive approach dictates the manufacturer's models, engineering types, dimensions, materials or other terms which are allowable. For example, the statement, a wall shall have six inches of type R-21 insulation is a prescriptive requirement that may be contained in a prescriptive standard or in a prescriptive building code. Generally, it is recognized that prescriptive statements, like the illustrated one, are not adequate since (1) the user (the building occupant and/or owner) is not particularly interested in what type of insulation or in how much is used (i.e., the means) but rather is interested in saving energy or money (the end objective); (2) such statements, when adopted in legal documents, effectively prohibit the use of alternative solutions that may be more effective but are not specifically mentioned; and (3) such statements are not effective over large geographical areas (i.e., Minneapolis vs. Miami).

Performance is also a term used as a prefix to standards, building codes and Federal regulations to describe the contents of those documents. The performance approach describes allowable end goals. A performance standard might read: a building of a particular size and a particular use should utilize x BTU's per year. This statement is essentially an end objective and does not specify the means which the designer, builder or homeowner must use to achieve the end objective.

There are degrees to which a document contains prescriptive statements or performance statements. For example, the American Society for Heating, Refrigerating, and Air-Conditioning Engineers, has developed an energy standard, ASHRAE Standard 90-75, which is generally considered a performance document rather than a prescriptive document, but it is not as totally performance-oriented as a BTU energy approach would be. With respect to building codes, it also should be recognized that these codes contain thousands of requirements; some of which are performance and some of which are prescriptive.

IV. Other related terms:

Guidelines suggest a variety of opportunities without specifying any required minimum level of performance. That is, guidelines provide some helpful recommendations of specific (or prescriptive) solutions, but they are not legally enforceable minimum requirements. Guidelines is not a term used to describe a legal document (such as building codes or Federal regulations). However, one might want guidelines to inform the building designer about which design solution may (or may not) meet the applicable building code or Federal regulation. Such guidelines could be developed by any individual or organization and commercially marketed as a text book. To assist in meeting OSHA safety requirements, private organizations have developed guidelines for business. In this sense, guidelines are helpful suggestions on design solutions that the author feels may meet the building code or Federal regulation. The user of these guidelines could choose to disregard the guidelines advice but could not choose to disregard building codes or Federal regulations.

We could also say that the term, guidelines, is not used to describe inputs in legal documents, as Model Codes and standards are used. However, guidelines could be developed, again by any individual or organization, to provide helpful information for any interested designer. Again, they could be disregarded. By definition, guidelines could not be standards since the substance is different; that is, guidelines relates to the suggestion of building alternatives that could be deemed acceptable. If they were developed and promulgated as a standard, they would cease being guidelines and become standards. If adopted by a legal jurisdiction, they then would become prescriptive building requirements.

Conditions of Participation: In some cases, when Congress authorizes financial assistance to private individuals, organizations, corporations, or States or local agencies, it places stipulations on receiving these finances. Congress has required minimum conditions of participation by the recipient. In the building area, examples of this minimum condition of participation would include HUD's FHA Minimum Property Standards or HEW's Hill-Burton Minimum Requirements.

ENERGY CONSERVATION IN FEDERAL AND FEDERALLY ASSISTED BUILDINGS

WEDNESDAY, NOVEMBER 5, 1975

U.S. SENATE,
COMMITTEE ON PUBLIC WORKS,
SUBCOMMITTEE ON BUILDINGS AND GROUNDS,
Washington, D.C.

The subcommittee met at 10 a.m., pursuant to recess, in room 4200, Dirksen Senate Office Building, Hon. Robert Morgan (chairman of the subcommittee) presiding.

Present: Senator Morgan.

OPENING STATEMENT OF HON. ROBERT MORGAN, U.S. SENATOR FROM THE STATE OF NORTH CAROLINA

Senator MORGAN. We will call the committee to order.

As you know, yesterday we had to recess our hearings on the three building energy conservation bills because of the lateness of the hour, and also because of commitments that we had.

We did, however, get some testimony on two of the bills. S. 2045, introduced by Chairman Randolph, and S. 2095, introduced by Senator Hart of Colorado, were discussed. We did not get onto Senator Tunney's bill, S. 1392.

I began to realize yesterday how complex these bills are. It is going to take a great deal more time to gather information than we had at first anticipated. I want to do a good job no matter how long it takes.

We may have to adjourn from time to time. I don't think we can really make any valid decisions unless we know what is already being done, and how far along the experiments have progressed.

Senator Tunney is not here but we will proceed anyway. I would like, for the record and for those of you who are here, to outline briefly an analysis of his bill, S. 1392.

First of all, S. 1392 would provide that the Administrator of Federal Energy Administration, after consultation with the Director, National Bureau of Standards, establish procedures for identifying existing buildings as candidates for retrofitting with energy conservation installations.

Second, it provides that FEA and Bureau of Standards shall consult with other Federal agencies and architectural and engineering societies.

Third, it provides that FEA shall establish an awards panel, for the purpose of awarding grants to States and municipalities. That

panel shall consist of two FEA designees and one from the Bureau of Standards. It directs the GSA Administrator, using FEA guidelines, to select 40 Federal buildings for retrofitting and solicit bids. That would, in effect, make it a 40-building demonstration project.

It requires agencies to prepare energy utilization analyses and energy economic analyses for each building to be repaired and maintained under this supervision. It also directs that energy utilization and cost data be indicated in prospectuses submitted for approval. It is not clear to me whether he intended this for all prospectuses, but I guess we will learn about that when we hear from Senator Tunney later on.

It also directs that, in selecting building sites, agencies consider the proximity of existing and planned mass transit facilities. Further, it provides that demonstration of experimental energy systems not be precluded.

Also it directs GSA, after consulting with FEA and the Office of Procurement Policy, to survey all Federal procurement in excess of $10,000 from the viewpoint of energy conservation, and report to the President and the Congress, recommending improvements.

There may be some question regarding the last three or four items, and we will clear that up as we go along.

Senator Tunney's bill would authorize $300 million to carry out provisions of the act, which is right substantial.

Yesterday we heard from Senator Hart and the Bureau of Standards regarding some of the things that are being done. Today we have several more witnesses and will try to accommodate you as best we can.

Let us start off with Mr. Walter Meisen, the Assistant Commissioner, Construction Management, General Services Administration. We will proceed as rapidly as possible and try to accommodate those of you who have planes to catch.

Wally, do you have any opening remarks?

STATEMENT OF WALTER MEISEN, ASSISTANT COMMISSIONER FOR CONSTRUCTION MANAGEMENT, PUBLIC BUILDINGS SERVICE, GENERAL SERVICES ADMINISTRATION

Mr. MEISEN. Yes.

Thank you, Mr. Chairman.

I have submitted a brief opening statement for the record. In the interest of time, I will just summarize some of the more pertinent details of the statement.

Senator MORGAN. I think that will be preferable. The full statement will be included in the record. (See p. 161.)

Mr. MEISEN. I am happy to be here representing Mr. Dwight Ink, Acting Administrator, and Mr. Nicholas Panuzio, Commissioner of Public Buildings Service.

As you know, we are deeply committed to the goals of energy conservation in buildings and we are certainly in agreement with the objectives of all three of these bills. We have developed performance oriented guidelines for use in both existing buildings and newly designed buildings which we feel go a long way in meeting the objectives, for example, of S. 2045.

These particular guidelines were developed in coordination with many agencies of the Federal Government, as well as with private practitioners and private building owners. We think they are probably the most widely accepted building guidelines available in this country today.

They are basically performance oriented in that they establish an energy goal for the use and type of buildings involved, and allow the architect flexibility in how he meets those goals. So, in essence, it enables the design professionals to develop innovative solutions to reducing energy usage in buildings. Many of the new concepts that have already been incorporated into a few of our buildings were developed through this performance oriented means.

Many of the helpful comments we received from the design profession have been used to update the original guidelines which had over 5,000 copies in circulation, and use throughout the country. The second edition of the design guidelines includes a greater emphasis on solar use, solar energy, and the use of computer analysis of buildings to determine the most energy efficient means of designing buildings.

We are also coming out in December of this year with energy conservation guidelines for the operation of buildings. We have actually achieved a 30-percent reduction in actual energy usage in the GSA buildings throughout the country. It was based on this particular success that we felt that the operating techniques used in buildings would be a valuable tool for both private as well as Government buildings to save energy.

Again, I would like to reiterate that these standards were developed in conjunction with both public comments, private engineering society comments, as well as comments from most Federal agencies.

When talking about existing buildings, concentration should be directed to those buildings which are high energy users rather than all existing buildings. Some existing buildings have relatively low potential for improvement.

We feel that anything that is going to achieve major energy savings should be those buildings which have at the outset high energy use and if some of the analyses and such are concentrated on those buildings, we think greater savings would be achieved at less cost.

We also feel that in the retrofit area, emphasis has to be placed on the fact that any modification needs to be cost effective as well as energy efficient. We don't feel it is practical to make expensive changes to save minimum amounts of energy. We feel obviously, cost effectiveness has to be a part of the analysis of any energy efficiency changes.

In the context of an energy efficiency analysis for new construction, we feel it is important when we make these economic analyses that we consider life cycle efficiencies as well as initial costs. I think this has been brought out by a number of speakers in the past.

Finally, I would like to say that we think that the technology involved in achieving energy efficiency is a rapidly changing and sophisticated one; and that new procedures that are developed for achieving energy efficiency in buildings should take into account the fact that technology is, in fact, rapidly changing and should not be prescribed in rigid procedures based on the state of the art as it exists today.

If in fact we do get very prescriptive oriented on how to achieve energy efficiency, I think we will preclude major new developments as they occur from playing a meaningful role. In fact, we might discourage new developments that are now under review and under development from finding a rapid place in the marketplace.

We are basically, in GSA, working on all of the areas and programs included in all three of these bills—S. 2045, S. 2095, and S. 1392. We anticipate that with the continuing cooperation of FEA, ERDA, the Department of Health, Education, and Welfare, and the Department of Defense, that we will continue to maintain and develop the Federal Government as a leader in demonstrating energy conservation to the private sector.

I think it is important that we do take this kind of role, but I think we also have to take the role of demonstrating the commercial viability of some of these systems that are now developed.

That concludes my prepared remarks, Mr. Chairman. I would be happy to answer any questions.

Senator MORGAN. Mr. Meisen, I have a number of questions that have been prepared by staff, and probably will have some of my own.

As I recall, all three of these bills deal with performance standards. S. 2045 mandates a system of performance standards that would be applicable to Federal buildings. Is that your understanding?

Mr. MEISEN. That is my understanding, sir.

Senator MORGAN. You say that GSA has already promulgated some performance guidelines?

Mr. MEISEN. Yes, sir.

Senator MORGAN. When did they come out? How long have they been in existence?

Mr. MEISEN. The original guidelines were published in March of 1974. These were for office buildings. They were guidelines for the energy efficient design of new office buildings.

Senator MORGAN. Let's look for a moment and see how these were developed. Did you obtain assistance from the Bureau of Standards, or were these developed solely within GSA?

Mr. MEISEN. No. They were primarily developed as a result of research work done for the design of the Manchester, N.H., building, which was designated as an energy conservation building.

We did in fact utilize resources of the National Bureau of Standards in helping us to develop analytical techniques of any suggestions that came up. We wrote to over 200 universities throughout the country and asked for their suggestions on what types of procedures or concepts might be used to conserve energy in the new buildings. We hired an outside consultant along with a design architect for this project. We actually analyzed thousands of recommendations to save energy.

From these we picked a number of the most viable ones for use in the actual Manchester project. There were just so many things we could put into the Manchester project. We also found many others that were not appropriate to the Manchester project, but which had great potential.

As a result of all of this analysis, working with the Bureau of Standards, outside design consultants, and our in-house staff, we

developed a compilation of those procedures which appeared to have considerable merit to save energy.

We also analyzed about a thousand buildings throughout the country to determine how much energy was actually being used in terms of Btu's per square foot per year. We found that they ran from around 100,000 Btu's to some of them over 500,000 Btu's per square foot per year.

All of our analyses incorporating some of the new techniques that we were developing indicated that we could design a building for somewhere around 55,000 Btu's per square foot per year. This indicated a tremendous savings.

We felt it was important not to prescribe exactly how to design an energy-efficient building, but rather, to establish a goal. It was at this time that we established a goal of 55,000 Btu's per square foot per year. It is the basis of these performance specifications.

Senator MORGAN. Let me see if I have got that clear. You started to develop performance standards at the Manchester project, but didn't limit those standards to that project. You also surveyed other buildings across the country?

Mr. MEISEN. Yes, sir.

Senator MORGAN. You did call on the Bureau of Standards and others for consultation.

Mr. MEISEN. Yes, sir.

Senator MORGAN. But, in the long run, it was GSA's project?

Mr. MEISEN. Yes, sir.

Senator MORGAN. Would you digress a moment, Wally, and tell me again about the Manchester project?

Mr. MEISEN. The Administrator of GSA felt it was important that we try to demonstrate energy-saving techniques in a real office building and get away from just small-scale studies.

Senator MORGAN. What is the building?

Mr. MEISEN. It is a seven-story office building and contains about 190,000 square feet. It is located in Manchester, N.H. It is a general purpose office building. It is located in a relatively cold climate so that heating was a much greater consideration than air-conditioning.

We decided to analyze all different techniques. It has three different heating and air-conditioning systems on three different floors so that we could actually test how each one performs as compared to how we estimated it would perform.

One of the ongoing coordinations we have with the National Bureau of Standards is a contract to instrument—put recording instruments on all of the systems, and for the next 3 or 4 years jointly monitor actual energy use by each of the varied systems in this building.

So it is not a building that is designed in one fashion throughout. It has different systems on different floors so we can test them in different ways of operating as well as different systems themselves.

Senator MORGAN. Is it in operation now?

Mr. MEISEN. No; it is not. It is almost finished.

Senator MORGAN. When do you expect completion?

Mr. MEISEN. I think the completion date is in about 8 months.

Senator MORGAN. You say you prepared performance guidelines but didn't want to limit the architects too rigidly to any given method of achieving this performance?

Mr. MEISEN. Yes, sir.

Senator MORGAN. Are you making the results of this research and experimentation available to them, in order that they may use it to best advantage?

Mr. MEISEN. Yes, sir. In essence that is what the guidelines do. They establish a goal, 55,000 Btu's per square foot per year as the target. They, in essence, say if you can't reach that goal, you should at least know why and be able to explain why.

The guidelines itemize all of those procedures which we found during the course of our investigations which appeared to have energy conserving potential. It tells the architect basically the order of looking at these items in the design of the building and to consider the orientation and the type of systems proposed.

It outlines some of the things which we found to be very helpful in saving energy. In fact, if he uses just some of those, we feel he can achieve a 55,000-Btu goal.

Senator MORGAN. You say we have already achieved a 30-percent savings in energy. Is this in all of our buildings?

Mr. MEISEN. That is in all GSA buildings across the country. That is an average of all of the buildings.

Senator MORGAN. Is part of that cutting down on air-conditioning and lighting like we do in our office?

Mr. MEISEN. Exactly, Senator.

Senator MORGAN. It seems to work all right, and kind of makes them anxious to get out about 5 o'clock.

Mr. MEISEN. We find it is worse in the morning than it is in the afternoon. Actually, when people are looking forward to going home, they don't mind too much if it gets a little warm.

Senator MORGAN. I am sure the staff doesn't mind if it is cut off early.

I assume these performance guidelines are being used by GSA in regard to any buildings under their jurisdiction.

Mr. MEISEN. That is correct, sir.

Senator MORGAN. Of course, as you say, they are not really mandatory.

Mr. MEISEN. He gets this guideline. He has to design the building with that. If, for some reason, there is a special requirement, he has to point that out; but his mandate is he has to meet designability that meets the 55,000 goal.

Senator MORGAN. Or explain satisfactorily to you why he cannot?

Mr. MEISEN. Yes, sir.

Senator MORGAN. But how many other agencies in the Federal Government construct buildings without assistance, or supervision, or guidance from GSA?

Mr. MEISEN. Many agencies.

Senator MORGAN. Name some of the major ones.

Mr. MEISEN. I think the major one would be the Defense Department. HEW, while it does not build directly, it does in fact have many grants that it gives out for buildings. The Veterans' Administration builds hospitals; the Department of Interior builds many Park Service facilities and so on; NASA, of course, builds many special purpose facilities for space oriented things.

Senator MORGAN. What has been your experience, Mr. Meisen, with regard to passing these performance guidelines on to DOD, for ex-

ample, or to the Veterans' Administration? I think this is one of the things we are all concerned about, that they may not be universally used.

Mr. MEISEN. I think that is true. We have had much coordination. I think, in fairness, all agencies have shown a considerable interest in energy conservation. There has not been one single standard adopted by all agencies.

While much is being done in every agency to conserve energy, I think there are various stages of development of energy standards. I think the fact that these are relatively simple in the establishing of the goal, I think makes them, or should make them much more attractive to other agencies because it doesn't really even matter if the goal is somewhat wrong.

If it should have been 50 to 350, the big question is should we wait 3 to 4 years to find out if 55 is right and test Manchester out. Yet, the fact is if it is wrong, we will quickly learn it because they are going to come in and say it is impossible.

It turns out that the more people that are aware now of this goal, the more we are finding it is in fact quite a reasonable goal. We spent very little time in establishing a goal for existing buildings, which is now set at 75,000 Btu's per square foot per year and almost every independent analysis that has been done since then has indicated that this is quite realistic.

But again, if it had not proven to be so, it would be a simple matter to adjust it to 90 or 85, without any traumatic effect on the industry as a whole. So I think it is important that we establish this kind of a deal universally throughout the Federal Government just so we all start talking in the same terms.

Senator MORGAN. I want to come back to that in a minute, but let me first comment on something else. I think it is the feeling of some sponsors of these bills that while a great deal of experimentation is going on, we are not able to go forward and put them into effect to see if they will work.

Mr. MEISEN. I would agree with that, sir.

Senator MORGAN. Would you agree that we need to find some way to move on, even maybe if we may make some mistakes along the way?

Mr. MEISEN. I certainly would agree that that is what we should do. My feeling is I think private industry will respond to any reasonable challenge offered by these guidelines if they are reasonably achievable and if, in fact, there is enough business development in it for them to make the economies.

What I think we are talking about is very comparable, Senator, to knowing how many miles per gallon your car is going to get. One of the biggest problems we have, when he established this first criteria, there was no similar term for energy efficiency in buildings. The Btu's per square foot per year is what finally came out.

But all we are saying is we are establishing, let us say, 20 miles per gallon is what we want our cars to get. If somebody wants to establish 25 or 15, we are not that concerned. What we are saying is you should know how many miles per gallon your building is getting. I am talking about energy now. You can establish that criteria anywhere you want; but we certainly should get on with doing it and be conscious of it.

Senator MORGAN. Has the mere fact that, for the last few years, we have been simply asking questions, had any salutary effect?

Mr. MEISEN. Exactly.

Senator MORGAN. I saw one of your books on life-cycle costing at Harvard the other day. I think it is getting above my head.

Mr. MEISEN. Mine, too.

Senator MORGAN. Is that part of the life-cycling proposition?

Mr. MEISEN. That is all life-cycle, everything in the building, as well as energy; yes, sir.

Senator MORGAN. Let's come back to the point again. We agreed that we need to find ways to put these things into use without waiting for years. It seems to me that when we are talking about relatively modern and conservative requests, we are not going to go too far wrong.

Mr. MEISEN. Yes, sir.

Senator MORGAN. It is my strong feeling that, whenever you are involved in an emergency situation or crash programs to try to meet such situations, the public should understand there may have to be some waste of money involved that would not ordinarily be.

I think LEAA is a good example. I testified before Senator McClellan the other day to the effect that I know we have wasted an awful lot of money in North Carolina and across the Nation, trying to improve the quality of law enforcement, but we didn't have time to wait for years and years to see whether or not a given project would work. We had to put it into being, try it in places, and if it didn't work, start again.

Coming back to the performance standards, what kind of liaison have you got with DOD and the other agencies? What kind of dialogue does GSA have with regard to these performance standards?

Mr. MEISEN. We meet regularly with all of these agencies in the development of energy conservation techniques. We exchange information on solar collectors. We meet regularly on design projects which appear to have great validity. There are no mandating requirements among these agencies, but we do meet regularly on a technical basis to exchange what is developed among us.

Senator MORGAN. It wouldn't be natural if there weren't some departmental jealousies, but does GSA have a good working relationship?

Mr. MEISEN. Yes, sir.

Senator MORGAN. We had a similar arrangement in North Carolina. We had the capital building authority and the department of administration constructed certain buildings. Our own State was involved in that and yet, as a trustee of East Carolina University, we built our own buildings, too.

We were a little bit jealous of our right and we didn't want them to tell us too much about how to do it. I am sure you run into that, some of that.

Mr. MEISEN. I think there will always be some of that.

Senator MORGAN. I think that is what Senator Randolph and the others are trying to get at.

Before I get to John's question, tell me what you are doing about solar energy.

Mr. MEISEN. We are putting two of the largest collectors in this country, one in the Manchester Building, which involves about 10,000

feet of collector, and one in the Saginaw, Mich., environmental demonstration project of about 8,000 square feet.

Those two separate projects, one to demonstrate what you can do to save or to be less polluting on the environment and the other one to save energy, had only one single item that was common to both. That was solar energy. Not only did it save fossil energy, but it also gave us a nonpolluting heating source.

So we at that point recognized that it clearly had to be one of the more important developments that had to come about in this country. We have since been trying to retrofit a number of buildings throughout the country to test viability at different geographical locations.

We clearly believe and we have been doing quite some coordination of who is doing what in the solar energy field—we believe the time has come to start buying solar energy collectors. We feel it is certainly not anything beyond the Model T stage at this point, but we believe we have to start buying a few Model T's if we can expect the industry to respond and develop the late models of the same equipment.

Senator MORGAN. Going back to our crash program, we are going to have to risk some capital to get this program really off the ground.

Mr. MEISEN. I think to get industry tooled up to produce, the cost of solar collectors is somewhere between $10 and $15 a square foot at the present time. I think it could be reduced by two-thirds or even three-quarters with any kind of mass production techniques.

Senator MORGAN. Practically all of the solar units in use around the country now are individually made, aren't they?

Mr. MEISEN. Almost all of them. I think GE is making one now that is starting to tool up, but it is still in the very beginning stages. The volume has not been generated because of the cost. The cost is high because there is no volume. Someone has to break the chicken and egg syndrome. I think that is a legitimate purpose of Federal Government.

Senator MORGAN. It seems to me that if I were constructing an office building, especially at this time when we are not too cognizant of life-cycle costs, I would think about a turnkey job and not so much about what the costs down the road might be.

The same thing would be true in building a home. I would want to get a turnkey job at the best price I could, and would be reluctant to invest in a solar unit that might or might not work.

But it seems to me like we ought to consider taking some of this money, and saying to some builders and even Government agencies, "If you will try solar heat in your building, we will buy the unit provided you install it and maintain it and operate it for a number of years and so forth."

I think it even more important to do it with homes, because we in Government are in a better position. We know we can do it with office buildings. But if I am building a new home, and am counting dollars, this would be a way of getting off the ground.

Mr. MEISEN. I think if the Government could originate a reasonably large buy of collectors at this time, it would be a very positive stimulus to the solar industry to develop the manufacturing techniques that need to be worked on.

Senator MORGAN. In other words, you mean if we could buy a substantial number and get them in mass production?

Mr. MEISEN. Yes.

Senator MORGAN. I think I mentioned yesterday one of my good friends, originally from North Carolina, is in this area and apparently has a good product. It just seems to me it is impossible for him to get it off the ground as long as he has to go on the dollar basis.

Mr. MEISEN. I think probably, even if produced, there will be better models developed. It is just like the military. Every time they produce an airplane, by the time the airplane is in operation, there is a better one in production somewhere else. But you have to buy planes sooner or later or you just don't have an air force. So you generally recognize the development is going to continue.

Senator MORGAN. I have asked many questions that the staff prepared. Let me make sure I get all of the answers.

We have talked about performance guidelines and efforts to work with other agencies. Would you comment on the proposal that these guidelines be mandated by legislation?

Mr. MEISEN. I think if all agencies could agree on some reasonable guidelines which all agencies would follow at a minimum, it would be very worthwhile. I think that such guidelines could be developed. I think the technical cooperation among agencies is such today that there is no doubt that as long as there are reasonably flexible guidelines, but yet very useful guidelines, that all agencies could pretty much go with them.

Senator MORGAN. I think the word flexible is important. On the Banking and Housing Committee, I opposed a bill that would have mandated guidelines, energy guidelines with regard to all federally assisted homes and so forth on the ground that they were making it almost impossible for the small home builder to build a home now. I think maybe I would still do the same thing, but it does look like in the Government, if we made them flexible enough, we might be able to accomplish something.

Mr. MEISEN. I think they have to be performance oriented. One of the things in the prescriptive guidelines, especially in Government, is that they change so rarely, they become long obsolete before they are modified or updated.

Even if the agencies are lax, the performance orientation allows any innovations to automatically come in. It doesn't require that you spell out how many inches of insulation is needed in a house. Someone comes out with a new insulation where you can use much less, by the time the Government changes, it is 6 years later.

If you just say what the use factor should be, not even say that, but what the total energy use is going to be, you can see the technology is encouraged rather than inhibited.

Senator MORGAN. What you are saying is that mandatory guidelines that are too stringent could defeat it?

Mr. MEISEN. Exactly, in the long run.

Senator MORGAN. The chairman's bill, S. 2045, takes site configuration into consideration, and also proximity to mass transportation among other things. How would these affect GSA's policies?

Mr. MEISEN. We already take those factors into consideration. The site configuration, we have found is one of the major factors in achieving energy efficiency. You can do all you want to design the building, but if you just orient it incorrectly, you won't be able to achieve good energy efficiency.

The orientation to mass transit, of course, has a much less direct impact on energy use as far as the building is concerned which certainly in the long run has an impact on total energy use in the United States, primarily, of course, in the transportation area.

Senator MORGAN. We talked about the Manchester building. Are there others across the country that GSA has set up as demonstration projects which we can point to and say, "Here is a GSA project that took into consideration energy conservation methods and practices?"

Mr. MEISEN. Yes; but as you know, the Manchester one is the furthest along with the total concept. When we designed Manchester, we quickly saw that many of the things that we were coming up with were applicable to all Federal buildings. We more or less retrofitted them into other buildings that were in design or construction.

Task-oriented lighting, for example. Rather than putting as many lights in the building as we did, we put lights over the desks rather than over everything. As such, we have been able to get lighting down to as low as 1 watt per square foot where formerly we were talking between 4 and even sometimes 5 watts per square foot on buildings.

The Social Security Administration buildings that we built in Chicago, Philadelphia, and Richmond, Calif., are each lower than the average buildings. They are somewhat between 80,000 and 100,000 Btu's per square foot per year; but clearly, in the lighting area, they are well below. We used the life-cycle analysis in the award of those buildings, which weighed heavily on energy efficiency.

So there are a number of buildings underway and there are many private buildings throughout the country that are starting to also take the same initiative. I have to be perfectly frank. More than half of what we learn, we learn from what others have done.

We are not that imaginative that we know all the answers. We have borrowed wherever we could and the majority has come from that kind of borrowing. We are just trying to assemble it because we have a large number of buildings to utilize that information in.

Senator MORGAN. My thought is that, where these projects have been outfitted or retrofitted, as much attention as possible should be called to them.

Mr. MEISEN. Certainly.

Senator MORGAN. Again I am digressing, but does the Manchester building have a lot of windows?

Mr. MEISEN. Actually, the average part of the building has only about 10 percent windows, which compares to 60 to 90 percent in other buildings. However, we are not necessarily down on windows if you use them prudently.

The top floor is almost all windows because there we are trying to measure whether by using daylight and using electric lights it comes out more cost effective, energy effective, even though we need a little more energy to heat the buildings. There are many checks and balances.

So the top floor of that building, for example, and the second floor which is deeply recessed to put it in shadow, again is being tested to see if you use a lot of glass, but now substitute daylight in lieu of artificial light, it becomes energy effective.

We don't think it will quite prove out, but we thought we would try it, because we think there is no pat answer.

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Senator MORGAN. Has there been a trend, in the last 2 or 3 years, away from these all-glass buildings?

Mr. MEISEN. Very definitely.

Senator MORGAN. I saw an all-glass building in Boston, or rather they tried to make it all glass, but the glass wouldn't stay in it.

Mr. MEISEN. It is completed now. It is all glass. I think there are balances that can be achieved. We can go totally energy efficiency, but I don't think anyone wants to go in the cave either. I think we do want to see the outside. I think we do want glass in the buildings; but how we handle glass and shape, it is becoming more and more important.

Senator MORGAN. There are just a couple more questions. I have been using this term life-cycle costing, but exactly what is it?

Mr. MEISEN. Life-cycle cost compares, if you use the analogy of an automobile, it says how much it is going to cost you to own that car over the life of the car. In other words, it says that if the car is going—let us assume the car is going to last 10 years.

It takes the first cost plus all of the costs that you are going to have to put into that—maintenance, operation, gas, oil, tires—adds them all up and divides it by 10 years, and tells you how much it is going to cost you per year to own that car. If you do that for different cars that you are thinking of buying, you can figure out which one it will cost you the least to own.

It might indicate that a Cadillac will cost you more as the initial cost, but if in fact it costs less for gas and parts, less maintenance, it could show that that car, although it costs more initially, would cost you less in the long run. Perhaps the choice of Cadillac might have been the wrong car, but it doesn't matter what kind it is.

You analyze a building the same way, how much you spend for it initially, how much it is going to cost you in energy, cleaning, and maintenance throughout its life cycle.

I think it is interesting that all of these buildings give special emphasis to life-cycle costs. Our findings are such that you design for energy efficiency, almost invariably comes out cheaper than the first cost, except when you come to the area of solar energy.

Senator MORGAN. What do you mean by "Almost invariably comes out cheaper?"

Mr. MEISEN. Cheaper in first cost; in other words, retrofitting is a different picture. But any new building that you design from the start to save energy, will almost invariably come out with a lower first cost than it would have if you didn't design it for energy efficiency. So life-cycle costing does not become critical in most energy saving concepts.

When we talk about solar energy, it is completely the opposite. As a matter of fact, at the cost of solar energy today, it isn't even cost effective when you consider life-cycle costing because of the cost of collectors today. We think it will quickly become cost effective over the life-cycle as the cost of collectors goes down through mass production and other techniques. We don't feel it is that critical.

We also feel—and that is what one of the people was trying to say yesterday—that life-cycle cost which is in something that is going to last 40 years, obviously places a major emphasis on the cost of, let us say, electricity.

If I have the right to try to predict over the next 40 years what the electricity is going to cost, I can make that answer come out to anything I want. So we feel that the lifecycle efficiency without putting a dollar

value on it can be more helpful in analyzing the system used. It doesn't justify using higher costs, but as I say, in most cases, that is not necessary at any rate.

Senator MORGAN. In predicting a life-cycle cost, aren't there many variables that can be made to come out any way you want them to?

Mr. MEISEN. Yes.

Senator MORGAN. I understand this theory is not really new, but isn't it relatively new in importance?

Mr. MEISEN. Yes. I think with the inflationary trends and rapidly rising energy costs, it becomes much more critical. I think most prudent businessmen in the private sector did automatically—they may not call it life-cycle costing, but they did it.

Senator MORGAN. We probably did it in our head, in building homes. We probably wondered, is electricity going to be cheaper, or oil, but nobody really got down to working it out scientifically.

We may have some technical questions to submit in writing. I know I have on Senator Hart's bill.

Mr. MEISEN. If I might make one comment, I think one of the gentlemen yesterday was trying to explain what he meant by the economic estimate or the energy use estimate as opposed to the energy utilization study.

What we are saying is at the time of the prospectus, a full energy analysis is not possible. What is possible is an estimate of the relative efficiency of that building which would be met. That could clearly be furnished at the time the prospectus is submitted.

It was our goal for the energy utilization in that building, the actual analysis looking at all different systems that would go into meeting that goal after the prospectus is approved.

Senator MORGAN. I think I follow you on that. If not, we will take it up later.

Going now to Senator Hart's bill, to what extent has GSA's effort in this respect been coordinated with ERDA's research and development program, and, also FEA?

Mr. MEISEN. We have a very close working relationship with both ERDA and FEA. FEA, of course, is more involved in the current status of how we use energy naturally and its involvement in Project Independence while ERDA is more responsible for the research and development for new techniques as for energy conservation as well as furnishing energy.

We think that both have clearly mandated roles in the total energy policies of the United States. We feel that in GSA, we have the inventory of buildings and so does DOD, as a matter of fact, have an inventory with which to actually apply some of the research and development. In fact, we would be anxious to apply some of the techniques even before they are proven over a period of years on the understanding that some will not prove to be as effective as we might have hoped.

Senator MORGAN. What do you think of the proposal that we would have to take into consideration the energy that went into products produced? Do you follow what I am talking about?

Mr. MEISEN. There were two aspects. One had to do with the energy use of materials in construction. I don't think that there is enough information available at the present time to do that. I don't think

that is practical to do at this point. I think we will come out to be very close on raw materials in their actual usage at any rate.

The fact that we look at procurement—I am assuming this means fans, motors of all types, anything we buy over 10,000—I think it is good in the sense that it will make manufacturers more conscious of the types of energy use and how relatively energy efficient their equipment is. I don't think you can determine the most energy efficient piece of equipment unless you know what system it is going to be used in.

Senator MORGAN. Wouldn't that be reflected in the price?

Mr. MEISEN. In some sense, when you boil it down to a motor, to make a motor that uses less energy, clearly you have to spend a little more money for that motor. Yes. When you start incorporating that motor into the total system, it becomes a different analysis.

However, you don't know where to break it down. A certain piece of equipment may be energy efficient by itself, but if it is capable of using waste heat by the way it is designed, it could, in fact, in its application be very energy efficient. So it is awfully difficult to break it down without looking at the total system in which it is used.

Senator MORGAN. S. 2095 provides that there would be an automatic authorization, over and above any otherwise established ceiling, for solar energy or other similar systems that might be installed. Can you comment on this? Do you have any idea as to how it might work? Would it be an open door?

Mr. MEISEN. I would say that if some reasonable standards were established on the kinds of systems that would be applicable to that—in other words, if you had some overview that you just couldn't put in a rubber hose on the roof and say I have a solar collector up there—if there were some reasonable standards and it could be done, I think it probably would be one of the most beneficial things in inducing solar energy use as opposed to solar energy study.

I have some concerns—unless it includes both the authorization and the appropriation and the actual dollars—I have some concern it might not be as effective as it should be unless it includes both the authorization and the appropriation.

Senator MORGAN. After we have reviewed the testimony given so far, we will probably have more questions for GSA to answer.

Is there anything else you would like to add now on either of the three bills we have discussed?

Mr. MEISEN. A number of them have requirement for energy analysis of all existing buildings. I would feel that doing an energy analysis on those buildings which are least energy efficient would be more appropriate than doing it on all existing buildings.

In other words, I would set a bottom line of saying you should only do energy analysis of existing buildings that are using more than 100,000 Btu's per square foot per year. If you have a building that is using less, it probably doesn't pay. It costs about $30,000 to do such an analysis.

I would reserve it for those buildings which are less energy efficient. I would certainly want to make such that when we look at the equipment, it is looked at in the total system concept. Other than that, I think I would have no comments on the others at this time.

Senator MORGAN. Thank you, very much.

Mr. MEISEN. Thank you, sir.

[Mr. Meisen's prepared statement follows:]

TESTIMONY OF

WALTER A. MEISEN

Assistant Commissioner for Construction Management

Public Buildings Service

General Services Administration

Before the

Subcommittee on Buildings and Grounds

of the

Senate Committee on Public Works

on November 4, 1975

Chairman Morgan, Committee members and guests. I am Walter Meisen, Assistant Commissioner for the Office of Construction Management, General Services Administration, appearing on behalf of Mr. Dwight Ink, Acting Administrator and Mr. Nicholas Panuzio, Commissioner of Public Buildings Service. I appreciate the opportunity to appear before your subcommittee to discuss S.2045, S.2095, and S.1392; and would like to express appreciation for the subcommittee's continuing interest in energy conservation in Federal facilities.

I will state at the outset that GSA is deeply involved and committed to the concept of energy conservation in buildings. We are in agreement with the objectives of these three bills. Each of these bills deals with specific opportunities for energy conservation which GSA has either implemented or is in the process of studying. GSA fully supports the principles that all Federal and federally assisted construction should utilize energy conserving design standards when such use has proven to be cost effective.

As you know, GSA has developed performance oriented energy conservation design guidelines which have been extensively used in recent design of GSA buildings and have also gained wide acceptance in the private sector.

The first edition was published in March 1974, and over 5,000 copies were distributed to architects; engineers; Federal, state and local construction agencies; schools of architecture and other interested persons in the construction industry. The unique feature incorporated in the guidelines is the concept of a performance oriented energy goal. The energy goals allow the architect complete freedom in designing a building with the exception that the building must meet a specified energy performance standard. Many new and innovative procedures for conserving energy have been developed by allowing the architects this freedom.

Based on the comments and suggestions GSA received from other agencies, design professionals and private individuals, the first edition was updated and expanded in its sections on solar energy and the use of computers in the operation of buildings.

In addition to the new building design guidelines GSA has also published "Energy Conservation Guidelines for Existing Office Buildings." The guidelines for existing office buildings were developed for energy conservation retrofitting since it is estimated that 85 percent of the buildings in the year 2000 are in existance today.

The third in GSA's series of energy conservation guidelines, "Energy Conservation Guidelines for Building Operations," will be available in December of this year. These guidelines are based on the knowledge and expertise we gain in reducing the energy consumption in our buildings by a 30 percent reduction through changes in the operations of the buildings. We are proud of these energy reduction achievements.

GSA is well on its way in meeting the proposed objectives set out in Section 4 of S.2045. GSA has, over the years, rigorously applied these guidelines to its own operation. It is important to know that these guidelines were developed in coordination with many other agencies including FEA, ERDA, professional societies such as the American Institute of Architects and National Society of Professional Engineers, numerous universities throughout the country as well as private owners and developers. These are probably the most widely accepted guidelines in use in this country today.

Currently, we are responsible for 10,000 federally owned or leased buildings, with an inventory of 250 million square feet of building space nationwide. A great potential for conserving energy is through the modification of existing facilities, especially since 85 percent of all existing buildings will be in operation at the turn-of-the next century. In this connection the maximum benefit can be achieved by concentrating on those buildings which are high

but inefficient users of energy. Some facilities will benefit more than others by an energy use analysis. For example, we are already concentrating on those buildings using over 150,000 BTU's/gross square foot/year.

It should be understood that modifications will be made only so long as they are cost effectives as well as energy efficient. These considerations are an integral part of our repair and alteration program. For example, a roof replacement may include additional insulation to improve its energy efficiency. In this case most of the programmed cost is not energy related but an upgrading or replacement cost. Through efforts such as this we have completed over $10 million in energy oriented projects in FY 1974 and FY 1975.

In the context of an energy economic analysis, for new construction, GSA considers both the initial investment cost as well as the long range energy and operating costs for a new facility.

In this effort, we have been working together with the Postal Service, FEA, HUD, ERDA, and Department of Commerce-NBS.

Mr. Chairman the achievement of energy efficiency in new and existing buildings is a complex endeavor. The technology involved is becoming more refined and sophisticated daily and many new procedures and items of equipment are currently under development. It is therefore imperative that any retrofit program remain flexible and responsive to these new developments as they occur. It is important that retrofit discussions reflect the need to concentrate our efforts on those projects which are most cost effective.

Mr. Chairman, GSA is the leader in energy conservation in buildings of the Federal Government. We are currently working on all of the areas and programs included in S.2045, S.2095 and S.1392. We anticipate that with the continued cooperation of FEA, ERDA, DOD, HUD, The Postal Service and private design professionals, the Federal Government will continue to be in the forefront of energy conservation in the built environment.

Thank you. That concludes my prepared remarks. I appreciate the opportunity to present our views and would be pleased to answer any questions relating to these bills or to GSA's initiatives in this area.

Senator MORGAN. Gentlemen, we have a number of other witnesses. I am sorry if we have upset anyone's schedule, but I do thank you all for coming.

Mr. Sigmund I. Gerber from DOD is next, for the record. He is the Director, Construction Standards and Design, Office, Assistant Secretary of Defense, Installations and Logistics, Department of Defense.

Mr. Gerber, we are glad to have you here, and thank you for coming.

STATEMENT OF SIGMUND I. GERBER, DIRECTOR, CONSTRUCTION STANDARDS AND DESIGN, OFFICE, ASSISTANT SECRETARY OF DEFENSE, INSTALLATIONS AND LOGISTICS, DEPARTMENT OF DEFENSE

Mr. GERBER. Mr. Chairman, I have just a short statement. As you know, we were asked to address S. 2095. Since yesterday's discussions, I did have the opportunity to review both S. 2045 and S. 1392 and if the chairman will bear with me, I will try to cross-reference some of my comments on S. 2095 to the provisions of the other two bills.

The Department of Defense appreciates the opportunity to comment on S. 2095 and to present our views on this important energy bill.

The Department of Defense, as the result of close attention to the situation over the past several years, is keenly aware of the current energy problem and the great need not only to conserve existing energy sources, but also to develop, as soon as possible, new sources available within the United States.

It has been Defense policy for over 15 years that our facilities would be designed and constructed to assure the minimum use of all utilities in order to achieve the most economical operation. Defense criteria have stressed the need for optimum insulation levels and we have been the leader in the Federal Government in our specific insulation requirements.

Since 1956, the DOD has required all large heating plants, located in normal coal marketing areas, to be constructed so as to be convertible to the burning of coal.

In 1967, Defense incorporated all existing instructions, directives, and other issuances relating to construction and alteration of all types of Defense facilities into a single publication entitled "DOD Construction Criteria Manual." This criteria manual establishes DOD policy on all aspects of construction including utilites and energy conservation.

This manual was updated in 1972 and is currently being revised again to reflect changing technologies. We believe this manual meets the intent of section 4 of the bill S. 2095 as well as the comparable requirements of S. 2045 with respect to design, construction, and renovation of Defense buildings.

For many years, Defense design criteria for new construction and major alterations have included significant numbers of energy conservation measures. While many of these measures have been included in new construction over the past 15 years, many other conservation

measures were found not to be cost effective until the dramatic increases in the cost of all energy forms.

In order to reduce the use of scarce fuels and to decrease the cost of utilities operations of Defense buildings, we have initiated an energy conservation investment program designed specifically to make existing buildings less energy intensive through a proposed $1.35 billion, 6-year retrofit program. This program includes only those readily identifiable projects which have a rapid amortization period.

The Congress was requested to provide $138 million for fiscal year 1976 in the military construction and appropriation bills as a start of this program, and the average amortization period for these fiscal year 1976 projects is about 4 years. We believe this program meets the intent of section 5(a)(2) of S. 2095 as well as the comparable provisions of S. 1392.

With specific regard to the use of solar energy, Defense testified in favor of Public Law 93-409, Solar Heating and Cooling Demonstration Act of 1974, and we are an integral part of the demonstration program.

Subsequently, we were a major contributor to the implementing plan for that act which is embodied in the Energy Research and Development Administration's Report Number 23A, "The National Program for Solar Heating and Cooling." Currently, we are implementing our portion of this plan through the installation of 50 solar heating units in residences at some 14 Army, Navy, and Air Force installations.

In addition, we are installing solar heating and cooling on a new administration and classroom building at Fort Hood, Tex. Plans are also being made to use solar heating and cooling on three Army Reserve facilities.

Additionally, we are investigating the possibility of utilizing solar energy for the heating of domestic hot water for two dispensaries and nine dormitories. The Navy has just made a decision to put solar collectors on 600 family housing units that they just recently acquired from the Air Force when the Air Force disestablished the Air Force base near Orlando.

While our experience from these efforts will make a contribution to the national program, it will also provide us with much needed information for evaluating the cost benefits to the Department of Defense from using solar heating and cooling systems on our new buildings, and where practical, for retrofitting existing buildings.

The analysis which we would propose to conduct in order to determine whether solar heating and cooling systems should be used on Department buildings would, we feel, be compatible with the energy use analysis called for in S. 2095 and S. 2045.

The major difficulty that we foresee in implementing the provisions of S. 2095 relating to the use of solar energy, and similar provisions of S. 2045, is that we do not feel that there is sufficient cost and performance data on solar heating and cooling systems available at this time.

Such data is basic to the conduct of a meaningful life-cycle cost analysis. The national program for solar heating and cooling should provide us with the needed data on cost and performance of solar heating and cooling systems, and it is our considered opinion that full

implementation of S. 2095 should be deferred until such data are available to permit us to conduct a sound life-cycle cost analysis.

We expect that by the time sufficient cost and performance data are available, better knowledge on the future cost and availability of alternative sources of energy will also be available. As to our position on specific provisions of S. 2095, there are four major areas of concern.

Section 3(a)(5)(B)(iii) appears to place an unfair burden on the building designer to determine the amount of energy required to produce and transport construction materials. Other witnesses have discussed this point also. This is beyond the designer's knowledge and responsibility, and would require decisions in areas in which he does not have expertise; namely, manufacturing and transportation.

It is recommended that this section be delegated. On the other hand, if it is desirable to identify energy-intensive construction products, these should be identified by either the FEA or the Department of Commerce.

Second, section 5(a)(1) would require submission to the Congress of an energy use analysis as part of normal procedures relating to construction. We interpret this to mean a submission at the time of the request for the military construction program, MCP. This would normally be prior to design completion, and the energy use analysis may have been started, but probably not completed.

Further, such timing would be a burdensome and very costly task as there are from 600 to 900 line items in our annual construction program, and some energy studies exceed 100 pages in length. It is, therefore, suggested that the first part of this section be deleted and that on page 10, section 5(a)(1) begin with the word "incorporate" in line 21.

Third, section 5(a)(2) requires, within 1 year, an inventory and energy use analysis of all existing buildings. The DOD has over 600,000 buildings worldwide, with about 20 percent of them overseas, and it would be impossible to comply with this section of the bill.

Realitsically, even 10,000 buildings per year would be an overpowering task, even though many are of a repetitive nature. Furthermore, the absence of hard data on solar costs and operations would preclude a meaningful analysis. Accordingly, we recommend the deletion of this section.

Lastly, section 5(c)(2) would require manufacturers to submit a detailed life-cycle energy cost analysis for major components of heating, ventilating, air-conditioning, lighting, and other energy-consuming systems for any building. Life-cycle costing is reflective of the particular design, exact use of the building, and of the particular equipment, local utilities costs, and the relationship to many other building components.

We would suggest that such suppliers only be required to submit efficiency data for their components and systems or such other data which could be used to determine efficiencies for the particular product as it is actually utilized in a particular project.

We strongly support the spirit and intent of S. 2095, S. 2045, and S. 1392, but would urge the committee to ease the requirements I have just spoken to. We would be pleased to respond to any questions the committee might have.

Senator MORGAN. Thank you.

We have a number of questions. Has DOD developed any guidelines similar to those established by GSA, that could be disseminated to other agencies?

Mr. GERBER. Yes, sir. We do have very specific guidelines as well as guidelines based on performance criteria. We have not gone to the specificity of the Btu requirement per square foot per year such as the 55,000 figure that Mr. Meisen addressed because that is primarily addressed to general purpose administration-type buildings; and although Defense has some of those buildings, it is not the commonplace type of facility we have.

Senator MORGAN. I was going to ask that. Are these primarily for military use?

Mr. GERBER. Yes, sir.

Senator MORGAN. What is your opinion regarding ASHRAE—do you know what I am talking about, the Association of Heating, Refrigeration & Air-Conditioning?

Mr. GERBER. Yes, sir.

Senator MORGAN. What is your opinion with regard to their standards becoming a national standard? For example, could the content of DOD's criteria and the GSA guidelines be combined with these ASHRAE standards?

Mr. GERBER. We do embrace and cross-reference ASHRAE requirements. It is the basic design criteria for most of our energy studies. It is a nationally and internationally recognized institution with high repute for their publications.

Senator MORGAN. How much coordination have you done with the Bureau of Standards, ERDA, and other agencies?

Mr. GERBER. We work very closely with them, and DOD technical representatives participate in all of the interagency considerations.

Senator MORGAN. You talked a little about solar energy, noting the Navy had installed some in Air Force housing.

Mr. GERBER. They had inherited those houses from the Air Force.

Senator MORGAN. They would have to make some changes. I assume they couldn't just live in them, like the Air Force. What has their experience been with solar energy?

Mr. GERBER. Actually, our experiences are too embryonic, and we don't have any feedback yet. They are still in the status of installation.

Senator MORGAN. The National Observer, Washington Post, and other papers have recently published articles urging caution with respect to solar energy. Do you have any comment on this?

Mr. GERBER. We are very optimistic? We do feel that it should be treated and handled with due consideration, be technically analyzed by experts in the field. We do feel that solar energy should, and will, play an important role in our energy consumption. Therefore, we do feel that we should be aggressive and take advantage of what solar energy can provide for us.

Senator MORGAN. I agree. I think anytime you try to develop this kind of program, there will be some wasted money. Of course, there are some who will claim the Defense Department is good at wasting money, but I am not one of those. It would seem to me, however, that the Defense Department can afford to take a calculated risk much better than some others. I would like to see you pursue that.

Mr. GERBER. We are pursuing it, sir. We are pursuing it very aggressively. We do have a common problem that all Federal agen-

cies have and that is a scarcity of financial resources to apply to such purposes. Nevertheless, we do have an existing inventory that is of such magnitude that it should be used for demonstration purposes.

Senator MORGAN. You mentioned a number of projects in your presentation. Is that an exhaustive list, or just an illustrative list?

Mr. GERBER. Those are the major projects. There are other projects. That list is not fully comprehensive.

Senator MORGAN. Could you elaborate a little on those projects, and their location? Maybe the committee or staff might want to take a look at them.

I myself would like to, if time is available, but for now I would like to pull as complete a list together as I can on demonstration projects on this area. I would appreciate that.

Mr. GERBER. We would be happy to comply with that.

Senator MORGAN. What do you think of the requirements in some of these bills, that guidelines be mandated by legislation?

Mr. GERBER. You would have to get specific, but we do agree with the objective and the intent. As Mr. Meisen said, I would concur, that there has to be some flexibility in the application.

Senator MORGAN. Thank you, very much.

The witness now scheduled to testify is Mr. Carl Bruechert, representing the National Society of Professional Engineers. Are you from Pennsylvania?

STATEMENT OF CARL BRUECHERT, NATIONAL SOCIETY OF PROFESSIONAL ENGINEERS, AMERICAN SOCIETY OF MECHANICAL ENGINEERS, AND INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS

Mr. BRUECHERT. From Atlanta, Ga.

Senator MORGAN. I am sorry. We are pleased that you could come, and apologize for any inconvenience.

Mr. BRUECHERT. Thank you, very much.

Mr. Chairman, my name is Carl Bruechert and I speak today on behalf of the National Society of Professional Engineers, (NSPE) as well as the American Society of Mechanical Engineers, (ASME) and the Institute of Electrical and Electronics Engineers, (IEEE). These three societies consist of nearly 300,000 members engaged in virtually every aspect of engineering practice.

I am a registered mechanical engineer in the State of Georgia and for the last 15 years have been associated with the Frank A. Player Co., a mechanical and industrial construction contractor located in Atlanta. I now serve as the company's president.

We are pleased to be here this morning at your invitation to present our views on S. 1392, S. 2045, and S. 2095, and the broader questions of energy conservation in buildings. While we have a number of specific comments and suggestions to make about each, I would like to state at the outset that the societies support the objectives of all three bills.

Engineers have long recognized that it is good business to minimize energy costs, even if energy sources are plentiful. The conservation efforts of members of the engineering profession, and of our national associations, have intensified as the energy crisis emerged in recent years.

I personally have been involved for several years in the development of energy conservation guidelines and in organizing and directing a series of seminars on the subject. I should add that NSPE has recently taken several important steps in response to the energy crisis.

It is assisting the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in organizing a series of seminars designed to educate building designers, administrators of building codes, lending agencies, and others, on ASHRAE standard 90–75, which are energy conservation guidelines for new building construction. I will discuss this successful development of conservation guidelines by the private sector later in my remarks.

NSPE is also sponsoring a legislative forum on the topic of energy to be held in March in Washington. We expect this forum to create a dialogue among the Nation's leaders on energy uses, management and alternatives and to help focus public attention on the need for a long-term solution to the present crisis.

Finally, NSPE has just completed a "Statement on Energy", which contains an analysis of alternative energy sources, and their limitations, and a discussion of what I think we all recognize must be achieved—a comprehensive, coordinated, and priority-charged energy program on a national level. We would like to present each member of the committee with a copy of this statement.

In brief, the statement provides that such a national energy program should include at a minimum: (1) Effective conservation efforts; (2) an increase in production of all existing domestic forms of energy; (3) rapid expansion of sources with demonstrated reserves and productive potential; and (4) provision for adequate research, development, funding and other needed stimuli of new energy sources.

The bills before you today would meet some of these objectives. We are particularly pleased to see a commitment to innovation in design and construction in S. 1392 and the emphasis on the development of solar energy in S. 2095. And we are, of course, gratified that S. 1392 and S. 2045 require the Administrator of GSA to consult with engineering societies to insure a broad perspective and the utilization of professional expertise. The societies have worked closely and productively with GSA on many occasions in the past.

I would like first to address the specific provisions of S. 1392. This bill seeks to establish a demonstration program for retrofitting selected existing Federal, State, and municipal buildings, using innovative technology to the extent possible.

It requires the Administrator of the Federal Energy Administration, in consultation with the Director of the National Bureau of Standards and appropriate architectural and engineering societies, to establish procedures for identifying buildings as candidates for retrofitting. It specifically provides for the selection of at least 40 federally owned buildings to be retrofitted, and it empowers the Administrator of GSA to solicit proposals and award contracts for the design and installation of energy conservation equipment. And finally, S. 1392 provides for Federal matching grants on a 3-to-1 basis for retrofitting State and municipal buildings.

We wholeheartedly support the passage of S. 1392. It would encourage new and creative systems of energy conservation through Federal sponsorship of retrofitting experiments, with private sector participation. The bill correctly acknowledges, in our view, that the

greatest potential for conserving energy is through the modification of existing facilities.

A significant percent of all buildings in use today will remain in use past the year 2000. One of our highest priorities should be to conserve energy in these buildings. I should add, parenthetically, that an emphasis on conserving energy in existing Federal buildings is even more important since, according to the Commissioner of the Public Building Service, 80 percent of all existing Federal buildings will be in operation at the turn of the century.

I like now to suggest three changes which we believe would improve S. 1392.

First, we feel that the committee should consider modifying section 6 relating to State and municipal grants. The societies support a grant program designed to broaden the interest in retrofitting; and to encourage greater participation by smaller communities, we suggest that the fundings ratio for municipalities with a population of less than 50,000 be 4 to 1. Participation in the proposed program by communities with smaller, older, and often less efficient public buildings may help to answer some key questions involved in retrofitting.

Second, the bill should, in our view, place greater emphasis on novel and innovative approaches to achieving energy conservation. It is essential if this bill is to have its intended impact that there be a strong and clearly stated congressional commitment to innovative economical design and construction.

Finally, with respect to section 5(b), we recommend the establishment of a review panel to evaluate and screen proposals received in response to the Administrator's solicitation. This panel would provide the Administrator with its recommendations, and should the Administrator choose not to follow them, he would be required to substantiate his decision in writing.

While this procedure would, unfortunately, impose an additional burden on the Administrator, it would help to remove the threat or appearance of a contract award as a result of political pressures. The review panel would, of course, be composed of qualified engineers and other design professionals. A system similar to this is already well established and functioning in GSA with respect to traditional design contracts.

S. 2045, introduced by Senator Randolph, raises somewhat more difficult questions in our mind. It directs the Administrator of GSA, after consultation with other agencies, to publish energy conservation and management guidelines and provides that they shall include information on all variable factors that may affect energy conservation and utilization, such as architectural features, site orientation, building composition, energy consumption practices, new techniques, and energy expended in manufacturing and handling the basic materials use in construction, repair, or maintenance of such buildings.

The societies seriously question the desirability of legislating variable factors of the type specified in section 4(b) of S. 2045 and section 3(a)(5) of S. 2095. We have long felt that Congress should confine this type of legislation to energy conservation objectives and performance standards. The Congress would be ill advised, in our view, to freeze into legislation any form of design or building specifications or factors to evaluate energy uses or costs. A regulatory system

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in this area simply cannot remain flexible enough to reflect the rapid developments in technology.

Beyond this, we quesetion the necessity of guidelines of the sort specified in S. 2045. GSA has already developed and published two volumes on this subject, "Energy Conservation Design Guidelines for Federal Office Buildings" and "Energy Conservation Guidelines for Existing Buildings." We understand also that GSA anticipates the publication next month of a third handbook in this series. In short, GSA has administered an effective conservation program in Federal buildings without the mandate proposed in S. 2045. Their achievements have been indeed remarkable—even while the total office space under GSA control was increasing, the agency reduced energy consumption in Federal buildings in 1974 by approximately 20 percent over the amount used in 1973.

Finally, let me add that the private sector is developing energy conservation guidelines which we feel may preclude the necessity of any federally legislated standards or guidelines. As I mentioned earlier, the American Society of Heating, Refrigerating & Air-Conditioning Engineers has recently published standard 90–75, entitled "Energy Conservation in New Buildings." These standards were developed at the request of the National Conference of States on Building Codes and Standards, and include a comprehensive list of conservation techniques and suggested limits on the uses of energy for heating, lighting, and cooling in new buildings. The purpose of 90–75 is to provide industry with flexible performance-oriented design and evaluation criteria for energy-efficient buildings. ASHRAE is presently also undertaking the development of another standard which will provide design assistance for existing buildings. Both of these standards will, in all probability, become widely used and accepted guides for future design.

Let me now turn my attention to S. 2095, introduced by Senator Hart, which includes the development of guidelines by GSA similar to those proposed in S. 2045. S. 2095 goes a step further, however, and encourages the use of solar energy and directs that the guidelines incorporate the use of solar energy systems into the design, construction, and renovation of Federal buildings. We fully endorse experimentation with solar energy in Federal buildings. Solar energy sources are inexhaustible within conversion technology limitations, involve no pollution, and we hope will in time become less expensive to utilize. I am sure you are aware of GSA's solar energy components in their Manchester, N.H., and Saginaw, Mich., demonstration project buildings, as well as several solar heating projects sponsored or planned by the Department of Defense and many experimental projects sponsored by the National Science Foundation and the Energy Research and Development Administration. These and other Federal projects will be beneficial as another source of much-needed experience in the solar energy field.

I'd like to caution the committee, however, about several provisions of S. 2095. Section 5 would require the Administrator of GSA and the Secretary of Defense to submit an energy-use analysis to the Congress for the acquisition or leasing of any new building and also to develop a detailed life-cycle cost analysis for each building to be constructed, acquired, or leased. While we support the concept of energy-use analysis and life-cycle costing, we have misgivings about these

requirements. For example, in 3(a)(5)(iii), we are uncertain about how to measure the energy expended in the manufacture and transportation of building materials. Similarly, the requirement of a detailed life-cycle costing does not specify a method of calculation. This is a complex concept which perhaps ought not to be legislated. It involves a variety of factors beyond energy conservation. Over the past few years, representatives of the societies have met with several Federal agencies to discuss the issue of life-cycle costing, and while there is general agreement that the concept is a valuable tool, it is fair to say that there are no industrywide uniform methods of calculation.

I want to add two final observations about S. 2095. First, we suspect that section 5 fails to anticipate problems in regard to facilities leased by the Federal Government. It may not be good long-term economy to remodel leased private property. Second, the authors of the bill apparently intended to include solar systems in the life-cycle costing requirements. It would seem to me that presently there is insufficient cost and performance data on solar use to apply any form of life-cycle costing to it. A federally sponsored program for solar development, together with a Federal effort to compile technological advances by the private sector could, of course, in time supply us with the needed data.

In conclusion, Mr. Chairman, I would like to place the various comments and suggestions that I have made today in the following perspective. The societies support the energy conservation objectives of these bills, and particularly the demonstration program that would be authorized by S. 1392 and the experimentation with solar energy encouraged by S. 2095.

But, the Congress must remember that energy conservation is only part of the solution to our national energy crisis. By some estimates, the United States will consume more energy within the next 25 years than in its entire history, despite rigorous conservation measures. To resolve permanently our present crisis, we must develop a comprehensive and coordinated energy program and substantially reduce our dependence on foreign sources of energy.

That concludes my prepared remarks. Thank you again, Mr. Chairman, for the opportunity to present our views. I would be pleased to answer any questions.

Senator MORGAN. You have given the most careful and analytical analysis of all three bills that I have yet heard presented. Thank you, very, very much.

John Purinton of our staff, is a member of your organization, NSPE. I really appreciate the testimony you have given. It was a very fine analysis and well presented.

Mr. BRUECHERT. Our staff has done a good job.

Thank you for the opportunity. We appreciate it.

Senator MORGAN. The next witness is Mr. John McGinty, from the American Institute of Architects. Mr. McGinty comes from Texas. He has been here waiting to testify, and we do appreciate it.

I must leave shortly for a final vote on the foreign aid bill, but we understand that Mr. McGinty will go ahead and make his presentation, and Mr. Purinton will continue to carry on any dialog that is necessary to get AIA's position and testimony into the record.

STATEMENT OF JOHN M. McGINTY, VICE PRESIDENT AND CHAIRMAN, ENERGY COMMITTEE, THE AMERICAN INSTITUTE OF ARCHITECTS, ACCOMPANIED BY JOHN EBERHARD, PRESIDENT, AMERICAN INSTITUTE OF ARCHITECTS RESEARCH CORP.

Mr. McGINTY. I would like to introduce John Eberhard, president of AIA Research Corp. After commenting on the three bills under consideration, we would also like to address the issue of energy conservation standards in a general way.

The American Institute of Architects endorses the adoption of long-term, comprehensive energy conservation policies for all sectors of the economy. Buildings, as the second largest energy-consuming sector, offer a significant opportunity to save energy. Government at all levels can set examples for the Nation in conserving energy in existing buildings by means of retrofitting and by having new buildings designed to be energy efficient.

Senator MORGAN. Let me interrupt. Five bells have sounded and I have got to go. If you do comment in connection with your prepared remarks, I wish you would do so to Mr. Purinton, with regard to what effect you think these mandatory guidelines might have on your profession. Also, would their effect spill over into commercial areas?

Again, I apologize for having to go, but I have no choice. If my people read in the paper on Sunday morning that I didn't vote on this bill, I would catch more from them than from you, believe me.

Mr. Purinton, what you do now is for the record.

Mr. McGINTY. We believe that solar energy, both its direct and indirect use in buildings, is a high priority concern deserving of major support by Congress. We also endorse the concept of life-cycle costing in the evaluation of energy design alternatives.

The AIA supports the general purpose and intent of S. 2045, the Federal Facilities Energy Conservation and Utilization Act, and S. 2095, the Conservation and Solar Energy-Federal Buildings Act. We would, however, raise some cautions about several of the provisions in the legislation.

Life-cycle energy costs as defined in S. 2095 makes an assumption that if the cost of energy-consuming equipment, the operating costs and the maintenance costs are all positive, energy use will be reduced. That is not always true.

Therefore, professional judgment will be required in the use of life-cycle energy cost analysis. The AIA would be happy to cooperate in a joint venture with other professional organizations to develop energy-effective methods for this purpose.

We are also concerned that the energy use analyses call for consideration of the amount of energy required to produce and transport materials used in construction. This is certainly a logical requirement; unfortunately, sufficient data to do it are not yet available.

We question the sections in which new techniques for energy supply, generation, and transmission are listed as considerations in an energy use analysis. With so many new ideas emerging daily, when does one reach the point where consideration of alternatives should be suspended?

These and other examples suggest that legislation such as S. 2045 and S. 2095 should be less specific with respect to the methodology of energy analysis and life-cycle cost calculations.

The provisions of section 4 of S. 2095 which call for energy guidelines for Federal buildings to be built or renovated seem plausible. The AIA Research Corp. has worked with the General Services Administration in the early development of such guidelines.

GSA's early recognition of the need for energy guidelines and their support of work to produce them has resulted in published documents. Those that are now available are: "Energy Conservation Guidelines for Existing Office Buildings," "Energy Conservation Design Guidelines for Office Buildings," and "Energy Conservation Design Guidelines for New Office Buildings," second edition.

Regarding section 5(a)(2) of S. 2095 which authorizes a 1-year effort to produce an inventory and energy use analysis of all existing buildings under Federal jurisdiction, we recommend that a statistically significant sample be done first. This would indicate the cost/benefit ratio of doing an analysis for every building.

If we are to advocate the use of tools such as life-cycle energy cost analysis and energy use analysis, then it would seem wise to test them first on a few demonstration projects. The demonstration program proposed in S. 1392, the Energy Conservation in Buildings Demonstration Act, could lend itself to that purpose.

Therefore, the American Institute of Architects supports the intention, concept, and program plan described in this legislation. As in the case of S. 2045 and S. 2095, we have some modifications to recommend.

Of major concern to achitects is a currently prevalent misconception that the reason buildings use energy is because they have mechanical and electrical systems. The prior question is: Why do buildings have mechanical and electrical systems?

The answer is: To provide for human comfort. The comparatively recent availability of such systems to provide for human comfort has overshadowed some basic design principles. Such principles at one time permitted widespread use of architectural solutions to the problems of human comfort without heavy, if any, reliance on mechanical systems sustained by nonrenewable energy sources.

Therefore, we suggest that the emphasis in S. 1392 to energy conservation equipment and systems ignores a whole range of architectural decisions which could reduce energy consumption. For example, architectural decisions which could reduce energy consumption. For example, architectural redesign could include modifying existing office arrangements, changing or adding windows or light-wells, providing protection from sun glare by exterior sunshades, and modifying fixed windows in order to make it possible to open them for natural ventilation, and many other such specific examples.

We recommend that a definition of energy conservation should be included in the bill. For your consideration, we suggest the following language: "Energy conservation technology means any concept, technique, equipment, or system that can be utilized in reprograming, replanning, or retrofitting existing buildings."

Work done for the General Services Administration by the AIA Research Corp., as I mentioned previously, has produced documents which could provide a base for the evaluation surveys proposed in section 7, and the Institute would welcome an opportunity to participate in the evaluation phase of the demonstration program. We also

offer our cooperation in disseminating information resulting from the demonstration program if it is enacted into law.

The American Institute of Architects would be pleased to respond to the provisions in S. 2045 and S. 1392 which call for consultation with the administering agencies. We strongly recommend that section 4 of S. 2095 be amended to include participation by the design profession in the development of energy guidelines for Federal buildings.

Turning now to the issue of energy conservation standards, AIA opposes the development of prescriptive standards for energy conservation in buildings for the following reasons:

Prescriptive standards apply only to new construction, thus overlooking the entire inventory of existing buildings.

Prescriptive standards do not treat one of the basic causes of energy waste; that is, existing financial and tax processes actually provide economic incentive to waste energy rather than to conserve it.

Prescriptive standards, or component performance standards, as they sometimes are called, are applicable only to individual components of buildings rather than to the entire structure. They ignore the way a building is designed, assembled, and operated. In other words, the optimization of individual building parts does not necessarily result in the optimization of the entire building.

Prescriptive standards which establish minimum energy conservation levels tend to establish maximum conservation levels as well, and do not encourage innovation or the development of new technology.

Prescriptive standards do not utilize the ingenuity and talents of the design professions, building trades, or manufacturers.

The AIA supports the development by the Federal Government of performance-based national standards for energy conservation or energy conscious design of buildings. We see such performance standards as tied to energy budgets—number of Btu's per square foot per year—for entire buildings, taking into account building types and climatic zones as moderating factors.

These should be used rather than either prescriptiove standards or component performance standards, such as ASHRAE 90–75, which the AIA does not consider to be performance-based. We believe that the specific provisions of performance standards should be developed in consultation with design professionals.

Nationally promulgated performance standards are preferable to the alternative—each State and/or local municipal government developing energy standards—which is likely to result in a proliferation of different requirements similar to the present situation with building codes.

The American Institute of Architects is prepared to respond to any opportunity to work with the Congress and the administration on this important problem.

We thank you for the opportunity to express our views.

We would be happy to respond to questions now, or in writing.

Mr. PURINTON. Thank you, Mr. McGinty.

I am sorry that Senator Morgan had to bring the hearing to an end and rush off to vote. He did ask that you be allowed to go ahead and continue with your testimony so it would be in the record.

The hearing is officially closed.

[Whereupon, at 12 noon, the subcommittee recessed, to reconvene subject to the call of the Chair.]

[Additional statements follow:]

THE GENERAL COUNSEL OF HOUSING AND URBAN DEVELOPMENT
WASHINGTON, D. C. 20410

November 4, 1975

Honorable Robert Morgan
Chairman
Subcommittee on Buildings & Grounds
Committee on Public Works
United States Senate
Washington, D. C. 20510

Dear Mr. Chairman:

Subject: S. 2045, 94th Congress (Randolph)

This is in response to your request for the views of this Department on S. 2045, the proposed "Federal Facilities Energy Conservation Act of 1975."

Section 4 of S. 2045 would direct the Administrator of General Services, in consultation with other specified Federal agencies, including HUD, to publish energy conservation guidelines for use in the design, construction, renovation, and operation of Federal or Federally assisted buildings.

Section 5 of the bill would require preparation of an energy utilization analysis and an energy-economic analysis in connection with the construction of any Federal or Federally assisted building or the renovation of any Federal or Federally assisted building having twenty-five thousand or more square feet of usable floor space. A "Federally assisted building" would, under the terms of the bill, include a building constructed or renovated in whole or in part with Federal funds, including funds guaranteed or insured by a Federal agency.

With respect to the issuance of energy conservation guidelines for Federal buildings, we defer to the General Service Administration as to whether legislation in this regard is necessary

or desirable in view of ongoing activities directed toward development of standards and increasing the energy efficiency of all Federal facilities and operations. However, we would have serious reservations regarding the application of the proposed guidelines to Federally assisted housing.

Section 526 of the National Housing Act already requires this Department to establish minimum property standards to promote the use of energy saving techniques in the construction of residential housing covered by HUD-insured mortgages. In order to qualify for loans and loan guarantee and insurance under programs administered by HUD, the Farmers Home Administration and the Veterans Administration, residential structures must meet the Minimum Property Standards (MPS) published by HUD's Office of Housing Production and Mortgage Credit. In recent years, the sections of the HUD MPS dealing with the thermal performance of residential structures have been upgraded -- in 1972 for multifamily dwellings and on November 22, 1974 for single family dwellings. Most significantly, HUD has also monitored and participated in standards development activities undertaken by independent professional societies such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and is currently reviewing the recently published ASHRAE standard 90-75 for potential use in part of the MPS.

In addition, this Department is also charged, under the Solar Heating and Cooling Demonstration Act of 1974, with the development of performance criteria for solar heating and cooling of dwellings and other buildings. Interim performance criteria have already been published under this Act, and while our current schedule does not contemplate the issuance of definitive performance criteria for at least two years, we are working with the National Bureau of Standards and other agencies and organizations to develop intermediate "minimum property standards" for solar systems within a year.

In view of the above, we believe that the proposed guidelines, if applied to HUD-insured mortgages, would result in proliferation of conflicting authorities and standards and would not provide for any action that cannot already be accomplished under existing law.

In connection with the energy utilization and economic analysis required under section 5 of the bill, we would again defer to the General Services Administration regarding the desirability of the requirement with respect to Federal buildings. However, we would be strongly opposed to such a requirement in connection with HUD-insured or assisted construction. We note in this regard that, although S. 2045 provides that Federal agencies may determine, for a category or type of building, that energy conservation benefits to be derived from the analysis do not justify the expense, such a determination may prove difficult to make and, in any event, our concerns with this requirement are applicable to all categories of HUD-assisted or insured housing.

One concern in this regard is that this requirement would not apply to all residential construction, but only to that percentage of construction which is financed with Federally insured or guaranteed loans. With specific respect to HUD mortgage insurance programs, the proposed requirement in this regard will place builders and developers in the position of meeting additional requirements and incurring delays and costs with which they would not otherwise be burdened, with the likely result that they will be discouraged from utilizing HUD-insured financing and from building needed housing for the low and moderate income groups that HUD programs are designed to assist. Secondly, there is also a danger that the additional processing and study costs required for the analysis, when added to the cost of the housing for which the analysis is performed, will increase the cost of that housing beyond the mortgage ceilings imposed by statute for our various mortgage insurance programs. We would also question whether most residential builders would have the capability of performing the detailed and highly complicated analysis required under the terms of the bill.

Another area of concern relates to construction undertaken -- even without Federally insured or guaranteed financing -- with the assistance of community development block grants under Title I of the Housing and Community Development Act of 1974. We believe that the requirement for an energy utilization and economic analysis in this instance would be inconsistent with the general approach of Title I of minimizing Federal constraints such as have been associated in the past with Federal assistance programs.

With respect to the concept of energy utilization and cost analysis in general we believe that while it has much to commend it, its implementation on a broad scale would involve many problems that would take time to resolve, with the result of considerable disruption and confusion in the building industry and in the provision of needed facilities -- particularly since the bill as presently written does not provide for uniform requirements or procedures to assure timely review and approval, or methods of utilizing or evaluating these studies.

We believe that the most desirable approach at this time for encouraging energy conservation in buildings -- and one that would avoid the problems discussed above -- would be the approach proposed by the President last January under the "Building Energy Conservation Standards Act of 1975" (Title X of S. 594). Such an approach should seek to insure that there is uniformity in the performance standards issued by the Federal Government, and that, by encouraging adoption of such standards under State and local building codes, they have applicability to more than a limited sector of the construction market.

For the reasons discussed above, this Department is opposed to enactment of S. 2045.

The Office of Management and Budget has advised that there is no objection to the presentation of this report from the standpoint of the Administration's program.

Sincerely,

Robert R. Elliott

THE GENERAL COUNSEL OF HOUSING AND URBAN DEVELOPMENT
WASHINGTON, D. C. 20410

November 4, 1975

Honorable Robert Morgan
Chairman
Subcommittee on Buildings & Grounds
Committee on Public Works
United States Senate
Washington, D. C. 20510

Dear Mr. Chairman:

Subject: S. 1392, 94th Congress (Tunney)

This is in further reply to your request for the views of this Department on S. 1392, a bill "To establish a demonstration program in energy conservation, using promising innovative technology to the maximum extent possible, through retrofitting existing buildings with energy conservation equipment and systems, and for other purposes."

S. 1392 would require the General Services Administrator to undertake, on a demonstration basis, a program of retrofitting no fewer than forty Federally owned buildings with energy conservation equipment and systems. Procedures for identifying the buildings as candidates for retrofitting would be developed by the Federal Energy Administrator in consultation with the Director of the National Bureau of Standards.

In addition, the bill would authorize an Awards Panel, composed of the Federal Energy Administrator, the Director of the National Bureau of Standards and one other person chosen by the Administrator, to make grants to States and municipalities for retrofitting of State and municipal buildings.

The General Services Administration and State or local officials responsible for administering a grant would be required to submit reports and other requested information to the Federal Energy Administration for evaluation purposes.

The Department of Housing and Urban Development supports the objectives of S. 1392. However, we would defer to the Federal Energy Administration, the General Services Administration, and the National Bureau of Standards with respect to the adequacy or desirability of the specific provisions of the bill.

The Office of Management and Budget has advised that there is no objection to the presentation of this report from the standpoint of the Administration's program.

Sincerely,

Robert R. Elliott

STATEMENT OF ROGER SANT BEFORE THE SUBCOMMITTEE ON GROUNDS AND OPERATIONS OF THE SENATE COMMITTEE ON PUBLIC WORKS

Mr. Chairman, and Members of the Committee:

I appreciate this opportunity to appear before you today to present the Federal Energy Administration's views on three Bills relating to energy conservation in public buildings and the use of solar energy: S. 1392, S. 2045, and @. 2095.

I would also like to express appreciation for the Committee's continuing interest in energy conservation. There is still much to be done and every proposal should be explored thoroughly.

Each of these three bills deals with distinct opportunities for energy conservation. I will state at the outset that FEA supports in general the objectives of all three bills. We foresee some specific problems with the programs and policies proposed by S. 1392 and S. 2095 which prevent us from supporting their enactment at this time.

In my Statement, I will discuss each of these proposals separately and will specify the objections we have to their enactment.

Space heating and cooling of buildings accounts for about 18 percent of total U.S. energy consumption. It is in this area where the greatest potential for building energy conservation exists.

The greatest long-term potential for energy conservation

in buildings clearly lies in improving the design and construction of new buildings.

However, a large fraction of the existing stock of buildings was built before the existence of any thermal standards for buildings. For the short term, we must, therefore, focus on opportunities for conserving energy in existing residential, commercial and public buildings.

We believe the Federal sector can and should play a leadership role in demonstrating the value of conservation in buildings.

For these reasons, Federal agencies have instituted many programs both to achieve major energy savings and to encourage the adoption of energy conserving practices in the public buildings controlled by State and local governments. For the most part, these initial efforts have concentrated on changing the traditional operating practices of building managers by encouraging adjustments in thermostat, ventilation and lighting levels. We are convinced, however, that far greater savings can be achieved in many buildings through the institution of a well-defined and executed retrofit program.

S. 1392, the "Energy Conservation in Buildings Demonstration Act of 1975," would promote energy conservation in existing buildings by instituting a demonstration program for retrofitting selected Federal, State and Municipal buildings with energy conserving materials and systems, [illegible] ive technology to [illegible]ent [illegible] the basic objec[illegible]

legislation. We are convinced that through the adoption of energy conserving practices and, we are convinced that in many cases the retrofitting of existing structures, public institutions can realize both substantial energy and dollar savings. Such savings would not only contribute to national energy independence but would also lessen the burden of higher energy costs on those public institutions that are already pressed by other financial difficulties. We see, as a part of our mission, the provision of information to such institutions to ensure that the costs and benefits of energy conservation are well understood and, in doing so, to motivate energy conservation actions. Federal agencies have taken the lead by adopting numerous energy conserving practices.

Last fall the President, as a part of this effort, called for all Federal agencies to examine their facilities and operations for energy conservation potential. Additionally, he asked the Administrators of GSA and FEA to recommend to the Energy Resources Council a multi-year program to increase energy efficiency in all Federal facilities and operations.

In response to this second request, FEA and GSA on September 5 reported to the Energy Resources Council. This report identified specific long-range opportunities to conserve energy in Federal facilities and operations.

A great deal of effort was expended by eleven working committees to investigate major energy intensive Federal [illegible] operations. Their assignments ranged from [illegible] operations. They

identified various strategies to achieve energy efficiency and determine the funding, legislative and other actions needed for implementation.

This committee effort, drawing on the collective expertise of numerous Federal agencies under the leadership of FEA and GSA, was guided by a steering group composed of 22 agency members at the Assistant Secretarial level.

Several of the working committees looked at various aspects of buildings and facilities and developed analyses and methods to improve operations and maintenance, implement modifications or retrofitting, develop new design, siting and utilization criteria and identify research and development opportunities.

By way of an example of the information being developed, implementation of the conservation possibilities dealing with Federal office and warehouse facilities alone could save a significant amount of oil equivalent per year by 1985 and if the same actions being investigated were adopted by the private sector commensurate savings could be realized. We feel that this program, coupled with the existing contract authority of FEA and ERDA and the State/Federal energy conservation program announced sometime ago, will be sufficient to accomplish the objectives of S. 1392. Therefore, we oppose the enactment of S. 1392 at this time.

I would now like to comment on S. 2095. S. 2095 would require that buildings financed with Federal funds utilize the best practicable measures for the conservation of energy and consider the use of solar energy systems. We note that this bill is identical to H.R. 8546, H.R. 8630 and H.R. 8711.

At the present time, due to Executive Branch initiatives now underway, we would not favor its enactment. More basically, however, we believe it is premature to enact into law such a highly specific set of provisions as is contained in H.R. 8711.

We are moving rapidly to develop and implement a number of conservation and solar energy measures in the Government buildings area, as I will describe shortly. We believe we can accomplish most if not all of these purposes with existing statutory authority, but this will become more clear as our implementation plans are developed. I would like to add that a number of innovative ideas are contained in H.R. 8711. These will be fully considered in our planning.

I would now like to discuss some of the specific actions we have underway in FEA on conservation and solar energy.

Conservation

The President has proposed the Buildings Energy Conservation Standards Act as Title X of the Energy Independence Act of 1975. This measure would provide that energy conservation standards be evaluated for new buildings in both the public and private sectors. For both new and existing buildings [illegible]

conserve energy and reduce operating costs. For example, we can improve the thermal efficiency of a building's shell, reduce lighting levels, and modify ventilation rates. Such actions permit the use of smaller, more efficient heating and cooling equipment. By such measures, energy consumption can be significantly reduced.

To ensure that energy efficient investments are made in Federally-owned or leased buildings, the Federal Energy Management Program (FEMP), now being revised, will require that new construction not exceed a thermal performance standard (or energy consumption level) similar to GSA's Design Guidelines. Existing buildings will be required to reduce annual fossil energy consumption. Estimates of the energy savings from such administrative actions currently range from 1 to 3.6 million barrels of oil equivalent per year by 1985. The major variables here are the different levels of energy consumption allowed in new buildings and the rate of reduction in fossil fuel consumption in existing buildings.

Contribution of Solar Energy

As we look to the future, it seems probably that energy from the sun may play an important role in our energy picture.

The greatest impact from solar energy will likely occur after 1985, but we estimate that solar energy could produce a significant oil equivalency before that date.

occur in the near future. Solar technologies--including heating and cooling, wind, ocean thermal, bioconversion, thermal electricity and photovoltaics (solar cells)--require either engineering refinement, research effort, or demonstration as to commercial feasibility.

FEA Solar Energy Program

FEA has made substantial progress this year in several project areas to accelerate the commercialization of solar energy. These project areas include a revision of the Project Independence Report, Department of Defense (DOD) energy self-sufficiency, State/local programs, accelerated standards for solar heating and cooling.

I will be pleased to provide the Committee with further and more detailed information in regard to each of these project areas.

Finally, I will comment on S. 2045, the Federal Facilities Energy Conservation and Utilization Act of 1975. This bill mandates optimum energy utilization and conservation practices in all federally owned, federally assisted and certain federally leased buildings. Such practices would be particularly applicable to the design and construction of new buildings, renovation of older buildings and the energy-use operation of all buildings.

Energy conservation and management guidelines, published by the General Services Administration (GSA) after consultation with other [illegible] new or renovated [illegible]

When justified by cost benefit or energy conservation potential, any Federal agency constructing or renovating a qualified building would be required to prepare an energy utilization analysis and an energy economic analysis for such building. Considerations required in both types of analyses are described in the bill.

In Section 6, "Federal Procurement," GSA and FEA would be required to study all Federal agency procurement above $10,000 from the aspect of energy conservation, and to report to the President and to appropriate Congressional committees within one year after enactment. This report would recommend measures to assure that energy conservation is a major consideration in Federal agency procurement policies and practices.

A detailed annual report would be required of GSA on its activities under this act. Each Federal agency would be required to inventory its buildings. Within one year, a report would be coordinated with GSA, on what could be done to make agency buildings the most energy-economically practicable.

At the request of the President, the FEA and GSA have developed a long-term action plan to improve energy efficiency in all Federal facilities and operations. The plan was developed in cooperation with several other Federal agencies and is currently under review. This plan provides a means of identifying, developing, implementing, and managing [illegible] conservation activities [illegible]

Section 4 of S. 2045 calls for "Energy Conservation Guidelines" to be prepared within one year. We support this objective, but find that Section 4's requirement duplicates current efforts. GSA has at the present time two such sets of guidelines, "Energy Conservation Design Guidelines for Office Buildings" published in January 1974, and "Energy Conservation Guidelines for Existing Office Buildings," published in February 1975. The Federal Energy Administration's own "Lighting and Thermal Operations Guidelines" was issued in 1974. FEA's publication is now being used in connection with an FEA energy management action program for commercial, public and industrial organizations.

The study required by Section 6 is commendable, but a requirement to survey either all Federal agency procurement contracts or all Federal agency procurement items appears very costly. The time limit of one year set forth in Section 6 would require that a very substantial number of personnel be assigned to such a study.

The Federal Energy Administration views S. 2045 as duplicating energy conservation planning currently being developed within the Executive Branch for actions to increase energy efficiency in the operation of all Federal facilities. We, therefore, recommend against passage at this time.

Summary

We believe the Federal Government can, with its own buildings, provide leadership to the Nation in energy conservation and in the use of solar energy as an alternate source for heating and cooling. Major energy impacts from this and similar efforts cannot be achieved immediately. But it is important to start now, since actions by the Federal Government may have a major stimulative effect in accelerating the application of technology. We do not believe that specific legislation is needed at this time to implement an effective program for both conservation and the use of solar energy in Federal buildings.

ADDITION TO THE

STATEMENT OF ROGER SANT BEFORE THE SUBCOMMITTEE ON GROUNDS AND OPERATIONS OF THE SENATE COMMITTEE ON PUBLIC WORKS

In January the President proposed the Buildings Energy Conservation Standards Act of 1975. This proposal provides for the development and implementation of national energy efficiency standards for the construction of all new buildings - residential, commercial, and institutional. (The conservation potential of this proposal includes and exceeds that of the bills under consideration today.) The standards, which would be developed and promulgated by the Secretary of Housing and Urban Development, would reduce energy consumption in new buildings by at least 30 percent below typical 1973 practice. While Federal buildings can and will be used to demonstrate this savings potential, our broader goal is to improve the energy efficiency of all new buildings, public and private.

STATEMENT BY

ARTHUR J. SCHULTZ, JR.

ASSOCIATE DEPUTY ADMINISTRATOR

VETERANS ADMINISTRATION

BEFORE

THE SUBCOMMITTEE ON

BUILDINGS AND GROUNDS

SENATE PUBLIC WORKS COMMITTEE

November 4, 1975

Gentlemen, I am pleased to appear before you today to discuss the provisions of Senate Bills 2045 and 1392. First, I want to address my remarks to Senate Bill 2045. The Veterans Administration is fully in accord with the purposes of this Bill, and we will offer no opposition to the Bill in general. Frankly, we are just delighted with the ideas expressed in the Bill.

However, we would like to point out that it is not clear as to whether the guidelines to be published by the Administrator of the General Services pursuant to Section 4 of the Bill would apply to our loan guaranty program for residences. We believe that this matter should be clarified as to the Bill's application to single family housing guaranteed or insured by the Veterans Administration.

Also, it is our understanding that the purpose of this legislation is to establish on a coordinated basis, guidelines which will not impinge upon the statutory authority of the VA to direct and manage its health care facilities and properties. We would assume that the guidelines will represent broad concepts, policies and philosophy rather than being specific, controlling, or regulatory in nature.

In reviewing Section 6 of the Bill pertaining to a study and survey by the General Services Administration of all federal agencies procurement in excess of $10,000, the VA has several comments. Even if the report requested in the Bill is limited to procurement for construction, building services, and custom-made equipment, it will be necessary to limit the study to selected examples in each area. An attempt to review all procurement within the three referenced categories would take an inordinate amount of time and funds, since the report is required in one year.

There are currently a number of General Services Administration and Office of Federal Procurement Policy studies on energy conservation in procurement. One in particular relates to purchase of equipment utilizing Life Cycle Costing Techniques. The VA is in full support of this technique and as studies are completed will utilize life cycle costing. Under these circumstances, we feel that this section needs further clarification.

In connection with these Bills which you are considering, permit me to tell you briefly about our involvement in the effort already underway by Government departments and agencies. I speak with some knowledge and a great deal of concern on this subject. My concern is two-fold.

First, as Associate Deputy Administrator of Veterans Affairs, I have a major responsibility within the VA for our agency's energy conservation program.

Second, realistically, I appreciate the relationship now, but particularly long-range, between quality VA hospital care for America's veterans and a successful VA energy conservation and discovery program.

The magnitude of the energy crisis and the difficulty of quickly developing satisfactory alternative sources of fuel caused us to approach the problem on four fronts.

First, we determined our total energy consumption requirements. For example, we used 34 trillion BTU's of energy throughout the VA hospital system's 5,284 buildings in Fiscal Year 1975. This is the equivalent to the total residential requirements for 167,000 homes.

By summarizing our total requirements, we established a base line to monitor our second approach, which was immediate conservation. We did all of the obvious things with which you are familiar, such as reducing light levels in non-critical areas and adjusting thermostats for heating and cooling. We have critically reviewed our equipment maintenance and replacement schedules, and adjusted controls for the most efficient operation.

In addition, we began the third attack, which involves Retrofit; a term applied to modifying an existing condition to meet the current situation.

For example, we are installing storm windows, solar screening, more convenient and selective light controls, and computer assisted load balancing and load shedding controls to coordinate equipment operation throughout the utility system. This computer program will distribute loads to avoid electrical demand peaks and shut down certain systems during specified periods. Not only will we be reducing energy consumption, but we will be saving America's taxpayers a considerable amount on our utility bills, which are often based on peak demand.

The fourth advance is the development of new design criteria, and alternative and supplementary fuels or sources of energy. While our design efforts have shown that initial capital investment is increased, some of the systems being studied amortize themselves in reasonably short periods, 4 to 10 years, based on today's fuel costs.

Some of the areas we are investigating or using include:

1. Heat Recovery Wheels, which will return some of the energy that would normally be lost through the exhaust air of the building. First introduced to VA in our Phoenix hospital in 1969, it is now a standard VA design practice.

2. Heat Pumps, which use natural heat contained in the ground or in the air, are now in operation at our Durham, North Carolina; Long Beach, California; and Tuscaloosa, Alabama VA hospitals.

3. Solar Energy is one of the most promising and practical heating systems being considered today. We are planning to install collectors for a solar energy system on an existing Research Building at our Wilmington, Delaware facility. We are also incorporating this concept in a new nursing home under design for Palo Alto, California. And we are planning to install solar energy systems in a number of other VA facilities in the future.

4. An Annual Cycle Energy System is also being considered. This is a unique concept, developed by the Oak Ridge National Laboratory, in which heat energy taken out of the ground during the winter produces the ice used to cool the building during the summer. Our VA engineers are incorporating this system in a design for a new nursing home to be constructed in Wilmington, Delaware, early next year.

5. VA is also developing and investigating other areas for new and supplementary energy. For example, we are developing a so-called "Selective Energy System". Briefly, in this system, a hospital would generate a portion of its own electric power, and capture waste heat to run certain air conditioning equipment. An additional advantage of this

system is that during a power failure at the electric company, this generator would automatically take over the emergency energy workload of the hospital.

From the outset, our studies have been made available to other government agencies and interested professionals. Through this coordination of Government efforts, we expect to help industry and the scientific community solve America's energy problem.

I greatly appreciate the opportunity to share with you information about a very important Veterans Administration program, energy conservation and discovery.

With respect to Senate Bill 1392, as I have indicated, the Veterans Administration already has been attempting various energy conservation measures as are contemplated in the Bill. We agree that the national interest will be best served by encouraging innovative technology and approaches so that a wide diversity of geographic and technological circumstances may be treated with a maximum of cost effectiveness.

In connection with Section 5 of the Bill dealing with the Federal Program, the Veterans Administratioun would certainly plan to cooperate with the General Services Administration in an effort to select appropriate health care facilities for participation in the program. We believe that our facilities could play a significant part in the accomplishment of the intent of this portion of the Bill.

I thank you for the opportunity to present our views on these Bills.

STATEMENT OF

LAWRENCE G. SPIELVOGEL

BEFORE THE

BUILDINGS AND GROUNDS SUBCOMMITTEE
OF THE
SENATE PUBLIC WORKS COMMITTEE

ON S. 1392
S. 2045
S. 2095

4 NOVEMBER 1975

INTRODUCTION

My name is Larry Spielvogel of Wyncote, Pennsylvania and I am pleased to offer my testimony today on the bills before this Committee.

I am a Consulting Engineer dealing exclusively in energy management in buildings, having spent my entire career in this field. I have a B.S. Degree in Mechanical Engineering from Drexel University and have studied at the graduate level at the University of Pennsylvania. I am a registered Professional Engineer admitted to practice in 34 States.

My major field of endeavor is consulting on energy systems in buildings to architects, engineers, and building owners and have been involved in numerous major building projects throughout the country. One project that you may be familiar with is the GSA Manchester, New Hampshire Federal Office Building, which is the GSA Energy Conservation Demonstration Project.

I am on the faculty of the Graduate Schools of Architecture at Yale and the University of Pennsylvania teaching energy in buildings on a part time basis.

I am also a very active member of the American Society of Heating, Refrigerating and Air Conditioning Engineers, the principle technical society in the energy field, and am currently serving as a member of the Executive Committee of Standard 90-75, "Energy Conservation In New Building Design",

and as chairman of the Panel on Heating, Ventilating and Air Conditioning systems. ASHRAE Standard 90-75 is a national voluntary consensus Standard, in accordance with the procedures of the American National Standards Institute. This Standard was initiated at the request of the National Conference of States on Building Codes and Standards and has just recently been issued. It is intended to serve as the technical basis for legislation in those states and cities which wish to adopt it. Compliance with the Standard will yield a building whose occupants should be able to operate it at minimum levels of energy consumption. Copies of the Standard have been made available to the Committee.

GENERAL

These three bills, S. 1392, S. 2045 and S. 2095 require the use of life cycle cost analyses as the fundamental basis for selecting energy systems, both for energy conservation and solar energy in Federal facilities. I urge you to consider the life cycle cost concept with caution. Fundamentally, I am very much in favor of life cycle cost analysis, provided it is accompanied by professional judgment.

It is mistakenly thought by most people that the energy system with the lowest life cycle cost will consume the lowest amount of energy. There is no fundamental or applied theory that relates life cycle cost to energy consumption. True, in the majority of cases those energy systems that have the lowest life cycle cost will frequently have the lowest energy consumption. However, there are too many exceptions to this general

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rule so that in each case professional judgment must be applied to yield a reasonable building. I would hate to see this type of judgment legislated.

The private and Government organizations which favor the use of life cycle cost principles are those which either have premium cost products to sell or more expensive concepts to promote. Premium cost products which hopefully may save energy can be more easily justified on a life cycle cost basis. All too often those energy savings do not materialize, but it is too late since the product has already been installed and paid for. More expensive concepts such as solar energy and heat recovery systems for buildings are being promoted with the life cycle cost concept. Here too, the supposed cost benefits attributed to these concepts may never be realized during the life cycle.

The experience that we have to date in doing life cycle cost analyses for buildings and especially for their energy systems indicates that the inflation rate and energy cost escalation have the most significant bearing on life cycle cost. Since inflation and energy cost escalation are not known factually at the time the life cycle cost is made, their selection becomes pure speculation. The selection of the life to be used in the analysis is also subject to speculation. Manipulation of the inflation and escalation rates and the life cycle can result in a life cycle cost being most anything that anyone wants it to be.

Appendix I contains a summary and backup for a life cycle cost analysis I recently completed for a conservative private corp-

oration. System number 6 was selected because the first cost premium was modest, the life cycle cost was reasonable and there were a number of intangible benefits. It should be noted that about 2/3 to 3/4 of the life cycle costs were energy costs and that the system with the lowest life cycle cost did not have the lowest energy budget.

In the private building sector, life cycle cost considerations are frequently looked at in a somewhat different way. The life cycle is frequently less than the expected life of the building. First costs and energy costs based on current known rates are determined. Then, the sensitivity of the particular building to various inflation and escalation rates is studied. Most frequently the sensitivity of these variables is significant and not knowing what they are really going to be tends to place more emphasis on the construction cost and operating cost that we at least know are factual today.

I would prefer to see the selection of energy systems remaining with the professional judgment of the Federal agencies involved until such time as it is demonstrated that the judgment that they are using is not in conformance with Congressional policy.

S. 1392

Section 5(a) requires that the Administrator of GSA select no fewer than 40 federally owned buildings for retrofit. I understand that not only GSA, but all of the Federal agencies with construction responsibility have already begun programs to retrofit existing buildings for energy conservation where there appears to be some valid economic basis.

In this same section the bill requires that energy conservation measures be "justified on a life cycle cost basis". A more workable terminology would be rewording to say "justified on an economic basis". Tying the hands of the Administrator on the basis of life cycle cost eliminates the professional judgment that I believe is necessary in the proper execution of the Administrators duties.

The procurement procedures specified in Section 5(b) do not appear to be consistant with current Federal procurement policies. This paragraph requires the solicitation of proposals for retrofitting buildings prior to the aware of design contracts. Meaningful proposals cannot be made prior to the design evaluation of energy conservation measures.

I believe that the essential purpose of this bill with respect to Federal buildings is already being accomplished.

S. 2045

The Administrator of General Services has already completed excellent sets of guidelines for both new and existing Federal office buildings as required by Section 4. These guidelines have been beneficial to the entire building industry.

These guidelines have not addressed the requirements under Section 4(b)(4) and (5), which could be added with very little trouble. Expansion or rewrite of the guidelines to incorporate other building types could be readily accomplished.

These guidelines for new buildings might well follow ASHRAE Standard 90-75. It should be recognized that the ASHRAE Standard is intended to cover all types of new buildings and

that it is certainly possible to make more specific guidelines for certain building types. The great value in the ASHRAE Standard lies in its highly diverse and wide spread input from all segments of the building industry.

Section 5(d) requires the preparation of energy analyses and detailed cost estimates for buildings prior to design. It is hardly practical or beneficial to require such analyses and estimates prior to design and prior to inclusion in a prospectus. Such studies are far more effectively carried out during the design phase of the project. This paragraph would virtually require that buildings be designed prior to Congressional authorization and would introduce a number of problems and costs, as well as spreading out the time between design decisions and construction, thereby not permitting implementation of the most up to date energy conservation techniques.

S. 2095

Section 2(b) appears to mandate both energy conservation and solar energy in every facility covered by Sections 4 and 5. Energy conservation is such a general term that most anything one does to a building could be considered energy conservation and thereby comply with this requirement. However, there are still many, many buildings that will not justify solar energy systems, yet this paragraph would seem to mandate that "solar energy technology utilization be employed in the design and construction of every facility to which Sections 4 and 5 are specifically applicable". I think that the language should be softened to indicate consideration of solar energy.

Just as the requirements and design of most Federal facilities vary considerably, so do the potential applications for solar energy. As a taxpayer, I would hesitate to commit the Federal Government to a massive program of solar heating and cooling of all of its new buildings until such time as the technology and application has matured. If solar technology was sufficiently mature, why is the Government spending hundres of millions of dollars in research on it?

At this point in time the number of actual installations of solar energy systems is very limited. Certainly in the future it will grow. I am not sure that even with a program that would require solar systems in all Federal buildings that this would be sufficient stimulus for a solar energy industry to become viable.

Few, if any, solar energy buildings either in existance or being planned met the criteria for low life cycle cost. The U. S. Postal Service received bids about 10 days ago for a small solar heated and cooled suburban Post Office. The low bid was $120 per square foot of building. Even if the local utility companies sent checks every month equal to what the bills would have been for a conventional heating and cooling system, the solar heating and cooling system would never pay for itself.

In todays construction market the utilization of energy conservation techniques generally is about ten times more effective on a life cycle cost basis than solar energy systems. This is not to say that there aren't exceptions and

certainly those exceptions should be fully explored and any legislation not eliminate the possibility of utilizing solar energy. In addition, there appear to be substantial funds already allocated to ERDA to pay for the premium costs of solar energy systems on Federal buildings.

Section 3(a)(3)(A)(i) requires that buildings "acquired" after the date of this Act be classified the same as a "new building" and therefore have to meet all the same requirements. Meeting the requirements of this Act for buildings which have already been completed may be a substantial problem since the buildings would probably have to be retrofitted much sooner than the end of the economic life of the original building construction and systems.

Section 3(b)(5) and (6) become the fundamental problems when doing life cycle cost analyses. While historical economic trends are certainly available, their use in any current economic climate becomes questionable, especially in light of those situations where certain materials and systems have no historic trend or where it can be reasonably expected that those historic trends will not continue at the same rate. An even more difficult job is that of estimating the future cost of depletable resources.

Since energy costs are becoming one of the more significant components of the total owning and operating cost of a building, the use of future costs of energy will have substantial, if not overwhelming bearing on the results of any life cycle cost analysis. It is therefore possible to make a life cycle cost analysis turn out any way one wishes, simply by "guessing" the future costs of various depletable resources.

In Section 4(a) the bill requires that energy guidelines be developed with ERDA and FEA. At the current time ERDA and FEA have little if any practical information that would sever as the basis for such guidelines. The Administrator of GSA and the Secretary of Defense probably could do just as well on their own and by utilizing information already available in those agencies and the private sector.

Section 5(a)(1) again requires the submission of an energy analysis for each new building prior to Congressional authorization. As I have indicated previously in commenting on S. 2045 this procedure is unworkable and burdensome.

Section 5(a)(2) requires an energy use analysis for all existing buildings in GSA and DOD. According to the definition of "energy use analysis" in Section 3 this would be a very substnatial effort. Furthermore, the definition of energy use analysis was obviously written to be used for new building design rather than for existing buildings and must be changed if it is to apply to this paragraph.

Section 5(c)(2) requires life cycle cost analyses for energy consuming components of buildings as a prerequisite for procurement. In most situations, especially in buildings larger than houses, life cycle cost analyses of components cannot be performed in isolation from all those other components and factors that influence energy use. This requirement can become meaningless in those situations. I think that more study

Section 6(a)(1) discusses "special energy equipment" which is not defined anywhere. Either it should be defined or deleted. I am not aware of any equipment that could be called "special energy equipment".

APPENDIX I

SUMMARY OF LIFE CYCLE COSTS

SYSTEM NUMBER	FIRST COST $	ANNUAL ENERGY COST $	LIFE CYCLE COST $	ENERGY BUDGET MBTU/GSF/YR
1	-0-	349,300	13,178,295	82.5
2	+75,000	345,209	13,139,615	79.0
3	+125,000	340,271	12,534,528	48.9
4	+325,000	335,165	12,720,649	45.6
5	-50,000	357,587	12,643,621	59.5
6	+75,000	338,111	12,916,086	70.9

ECONOMIC COMPARISON OF SYSTEMS FOR - LIFE CYCLE COST ANALYSIS ECS 1

DATA FOR SYSTEM 1

GROSS INVESTMENT, $ 3500000.

MONTHLY PAYMT, $ 27595.

DEBT/EQUITY RATIO 100.0/ -.0

END OF YEAR	DEBT BALANCE	DEBT INTEREST (8.5 PCT)	EQUITY BALANCE	EQUITY INTEREST (.0 PCT)	BOOK DEPRC (SL METH)	INSURANCE (1.0 PCT)	AD VALOREM TAX (2.0 PCT)	TOTAL OWN COST*	TOTAL OPR COST	TOTAL OWN + OPR COST	EQUIV CURR DOLLARS (10.0 PCT)
1	3465021.	296158.	0.	0.	116667.	35000.	70000.	552804.	349300.	902104.	820094.
2	3426951.	293066.	0.	0.	116667.	35000.	70000.	552804.	378978.	931782.	770068.
3	3385515.	289701.	0.	0.	116667.	35000.	70000.	552804.	411239.	964042.	724299.
4	3340417.	286039.	0.	0.	116667.	35000.	70000.	552804.	446313.	999117.	682410.
5	3291312.	282052.	0.	0.	116667.	35000.	70000.	552804.	484455.	1037258.	644056.
6	3237909.	277714.	0.	0.	116667.	35000.	70000.	552804.	525940.	1078743.	608923.
7	3179744.	272992.	0.	0.	116667.	35000.	70000.	552804.	571071.	1123875.	576726.
8	3116480.	267852.	0.	0.	116667.	35000.	70000.	552804.	620180.	1172984.	547206.
9	3047691.	262259.	0.	0.	116667.	35000.	70000.	552804.	673628.	1226432.	520127.
10	2972635.	256170.	0.	0.	116667.	35000.	70000.	552804.	731812.	1284616.	495275.
11	2891042.	249544.	0.	0.	116667.	35000.	70000.	552804.	795166.	1347970.	472455.
12	2802237.	242332.	0.	0.	116667.	35000.	70000.	552804.	864166.	1416969.	451490.
13	2705582.	234482.	0.	0.	116667.	35000.	70000.	552804.	939332.	1492135.	432218.
14	2600345.	225939.	0.	0.	116667.	35000.	70000.	552804.	1021234.	1574038.	414493.
15	2485848.	216641.	0.	0.	116667.	35000.	70000.	552804.	1110500.	1663304.	398182.
16	2361271.	206528.	0.	0.	116667.	35000.	70000.	552804.	1207816.	1760619.	383162.
17	2225640.	195505.	0.	0.	116667.	35000.	70000.	552804.	1313933.	1866737.	369324.
18	2078019.	183517.	0.	0.	116667.	35000.	70000.	552804.	1429679.	1982483.	356567.
19	1917351.	170468.	0.	0.	116667.	35000.	70000.	552804.	1555961.	2108764.	344800.
20	1742480.	156267.	0.	0.	116667.	35000.	70000.	552804.	1693773.	2246577.	333939.
21	1552153.	140810.	0.	0.	116667.	35000.	70000.	552804.	1844211.	2397015.	323910.
22	1345003.	123985.	0.	0.	116667.	35000.	70000.	552804.	2008477.	2561281.	314643.
23	1119542.	105676.	0.	0.	116667.	35000.	70000.	552804.	2187891.	2740695.	306076.
24	874153.	85748.	0.	0.	116667.	35000.	70000.	552804.	2383907.	2936710.	298151.
25	607073.	64057.	0.	0.	116667.	35000.	70000.	552804.	2598122.	3150925.	290818.
26	316386.	40456.	0.	0.	116667.	35000.	70000.	552804.	2832294.	3385098.	284028.
27	5.	14756.	0.	0.	116667.	35000.	70000.	552804.	3088359.	3641163.	277740.
28	5.	0.	0.	0.	116667.	35000.	70000.	221667.	3368447.	3590114.	248951.
29	5.	0.	0.	0.	116667.	35000.	70000.	221667.	3674905.	3896571.	245638.
30	5.	0.	0.	0.	116667.	35000.	70000.	221667.	4010316.	4231983.	242529.
TOTAL		5440781.		0.	3500000.	1050000.	2100000.	15590695.	45121405.	60712099.	13178295.

* PRINCIPAL REPAYMENT (IF APPLICABLE) INCLUDED. BOOK DEPRECIATION INCLUDED

UCC
UNIVERSITY COMPUTING COMPANY

ECONOMIC COMPARISON OF SYSTEMS FOR LIFE CYCLE COST ANALYSIS ECS 1

DATA FOR SYSTEM 2

GROSS INVESTMENT, $ 3575000.

MONTHLY PAYMT, $ 28186.

DEBT/EQUITY RATIO 100.0/ -.0

END OF YEAR	DEBT BALANCE	DEBT INTEREST (8.5 PCT)	EQUITY BALANCE	EQUITY INTEREST (.0 PCT)	BOOK DEPRC (SL METH)	INSURANCE (1.0 PCT)	AD VALOREM TAX (2.0 PCT)	TOTAL OWN COST*	TOTAL OPR COST	TOTAL OWN + OPR COST	EQUIV CURR DOLLARS (10.0 PCT)
1	3539272.	302504.	0.	0.	119167.	35750.	71500.	564649.	345209.	909858.	827144.
2	3500345.	299346.	0.	0.	119167.	35750.	71500.	564649.	374390.	939039.	776065.
3	3458062.	295909.	0.	0.	119167.	35750.	71500.	564649.	406093.	970742.	729333.
4	3411997.	292168.	0.	0.	119167.	35750.	71500.	564649.	440542.	1005192.	686560.
5	3361861.	288096.	0.	0.	119167.	35750.	71500.	564649.	477983.	1042633.	647393.
6	3307293.	283665.	0.	0.	119167.	35750.	71500.	564649.	518683.	1083333.	611513.
7	3247962.	278842.	0.	0.	119167.	35750.	71500.	564649.	562935.	1127584.	578629.
8	3183261.	273592.	0.	0.	119167.	35750.	71500.	564649.	611057.	1175706.	548476.
9	3112987.	267878.	0.	0.	119167.	35750.	71500.	564649.	663399.	1228048.	520812.
10	3036334.	261660.	0.	0.	119167.	35750.	71500.	564649.	720344.	1284993.	495421.
11	2952993.	254891.	0.	0.	119167.	35750.	71500.	564649.	782309.	1346958.	472101.
12	2862285.	247525.	0.	0.	119167.	35750.	71500.	564649.	849752.	1414401.	450672.
13	2763559.	239507.	0.	0.	119167.	35750.	71500.	564649.	923173.	1487822.	430969.
14	2656187.	230781.	0.	0.	119167.	35750.	71500.	564649.	1003120.	1567770.	412843.
15	2539157.	221283.	0.	0.	119167.	35750.	71500.	564649.	1090195.	1654845.	396157.
16	2411870.	210946.	0.	0.	119167.	35750.	71500.	564649.	1185055.	1749704.	380787.
17	2273392.	199695.	0.	0.	119167.	35750.	71500.	564649.	1288421.	1853070.	366620.
18	2122548.	187449.	0.	0.	119167.	35750.	71500.	564649.	1401084.	1965733.	353554.
19	1958437.	174121.	0.	0.	119167.	35750.	71500.	564649.	1523910.	2088559.	341496.
20	1779819.	159615.	0.	0.	119167.	35750.	71500.	564649.	1657851.	2222500.	330361.
21	1585414.	143827.	0.	0.	119167.	35750.	71500.	564649.	1803951.	2368600.	320070.
22	1373824.	126643.	0.	0.	119167.	35750.	71500.	564649.	1963355.	2528005.	310555.
23	1143532.	107941.	0.	0.	119167.	35750.	71500.	564649.	2137323.	2701972.	301751.
24	892885.	87585.	0.	0.	119167.	35750.	71500.	564649.	2327235.	2891885.	293600.
25	620082.	65430.	0.	0.	119167.	35750.	71500.	564649.	2534612.	3099261.	286049.
26	323166.	41317.	0.	0.	119167.	35750.	71500.	564649.	2761123.	3325772.	279050.
27	6.	15072.	0.	0.	119167.	35750.	71500.	564649.	3008603.	3573253.	272559.
28	6.	0.	0.	0.	119167.	35750.	71500.	226417.	3279073.	3505490.	243082.
29	6.	0.	0.	0.	119167.	35750.	71500.	226417.	3574755.	3801171.	239624.
30	6.	0.	0.	0.	119167.	35750.	71500.	226417.	3898093.	4124510.	236370.
TOTAL		5557288.		0.	3575000.	1072500.	2145000.	15924781.	44113626.	60038406.	13139615.

* PRINCIPAL REPAYMENT (IF APPLICABLE) INCLUDED. BOOK DEPRECIATION INCLUDED

UCC

ECONOMIC COMPARISON OF SYSTEMS FOR LIFE CYCLE COST ANALYSIS ECS 1

DATA FOR SYSTEM 3

GROSS INVESTMENT, $ 3625000.

MONTHLY PAYMT, $ 28580.

DEBT/EQUITY RATIO 100.0/ -.0

END OF YEAR	DEBT BALANCE	DEBT INTEREST (8.5 PCT)	EQUITY BALANCE	EQUITY INTEREST (.0 PCT)	BOOK DEPRC (SL METH)	INSURANCE (1.0 PCT)	AD VALOREM TAX (2.0 PCT)	TOTAL OWN COST*	TOTAL OPR COST	TOTAL OWN + OPR COST	EQUIV CURR DOLLARS (10.0 PCT)
1	3588772.	306735.	0.	0.	120833.	36250.	72500.	572547.	340271.	912818.	829834.
2	3549342.	303353.	0.	0.	120833.	36250.	72500.	572547.	367493.	940039.	776892.
3	3506496.	300044.	0.	0.	120833.	36250.	72500.	572547.	396802.	969430.	728354.
4	3459717.	296254.	0.	0.	120833.	36250.	72500.	572547.	428643.	1001190.	683826.
5	3408880.	292126.	0.	0.	120833.	36250.	72500.	572547.	462935.	1035481.	642953.
6	3353549.	287632.	0.	0.	120833.	36250.	72500.	572547.	499970.	1072516.	605407.
7	3293327.	282742.	0.	0.	120833.	36250.	72500.	572547.	539967.	1112514.	570896.
8	3227783.	277418.	0.	0.	120833.	36250.	72500.	572547.	583165.	1155711.	539148.
9	3156444.	271625.	0.	0.	120833.	36250.	72500.	572547.	629818.	1202364.	509920.
10	3078800.	265319.	0.	0.	120833.	36250.	72500.	572547.	680203.	1252750.	482989.
11	2994293.	258456.	0.	0.	120833.	36250.	72500.	572547.	734620.	1307166.	458154.
12	2902317.	250987.	0.	0.	120833.	36250.	72500.	572547.	793389.	1365936.	435229.
13	2802216.	242857.	0.	0.	120833.	36250.	72500.	572547.	856860.	1429407.	414048.
14	2693265.	234008.	0.	0.	120833.	36250.	72500.	572547.	925409.	1497956.	394459.
15	2574670.	224378.	0.	0.	120833.	36250.	72500.	572547.	999442.	1571988.	376322.
16	2445603.	213896.	0.	0.	120833.	36250.	72500.	572547.	1079397.	1651944.	359511.
17	2305127.	202487.	0.	0.	120833.	36250.	72500.	572547.	1165749.	1738295.	343913.
18	2152214.	190071.	0.	0.	120833.	36250.	72500.	572547.	1259009.	1831555.	329421.
19	1985897.	176556.	0.	0.	120833.	36250.	72500.	572547.	1359729.	1932276.	315943.
20	1804712.	161848.	0.	0.	120833.	36250.	72500.	572547.	1468508.	2041054.	303390.
21	1607587.	145839.	0.	0.	120833.	36250.	72500.	572547.	1585988.	2158535.	291684.
22	1393039.	128415.	0.	0.	120833.	36250.	72500.	572547.	1712868.	2285414.	280754.
23	1159526.	109450.	0.	0.	120833.	36250.	72500.	572547.	1849897.	2422443.	270534.
24	905373.	88810.	0.	0.	120833.	36250.	72500.	572547.	1997889.	2570435.	260965.
25	628755.	66345.	0.	0.	120833.	36250.	72500.	572547.	2157720.	2730266.	251993.
26	327686.	41895.	0.	0.	120833.	36250.	72500.	572547.	2330337.	2902884.	243568.
27	6.	15283.	0.	0.	120833.	36250.	72500.	572547.	2516764.	3089311.	235646.
28	6.	0.	0.	0.	120833.	36250.	72500.	229583.	2718106.	2947689.	204403.
29	6.	0.	0.	0.	120833.	36250.	72500.	229583.	2935554.	3165137.	199528.
30	6.	0.	0.	0.	120833.	36250.	72500.	229583.	3170398.	3399982.	194848.
TOTAL		5635012.		0.	3625000.	1087500.	2175000.	16147505.	38546988.	54694493.	12534528.

* PRINCIPAL REPAYMENT (IF APPLICABLE) INCLUDED. BOOK DEPRECIATION INCLUDED

END OF YEAR	DEBT BALANCE	DEBT INTEREST (8.5 PCT)	EQUITY BALANCE	EQUITY INTEREST (.0 PCT)	BOOK DEPRC (SL METH)	INSURANCE (1.0 PCT)	AD VALOREM TAX (2.0 PCT)	TOTAL OWN COST*	TOTAL OPR COST	TOTAL OWN + OPR COST	EQUIV CURR DOLLARS (10.0 PCT)
1	3784773.	393659.	0.	0.	1275000.	382500.	765000.	6041359.	3351659.	9393000.	8539099.
2	3745168.	378288.	0.	0.	1275000.	382500.	765000.	6041359.	3619778.	9661134.	7984641.
3	3698884.	318652.	0.	0.	1275000.	382500.	765000.	6041359.	3909936.	9951272.	7476122.
4	3645598.	314599.	0.	0.	1275000.	382500.	765000.	6041359.	4223211.	10264347.	7010009.
5	3586966.	309243.	0.	0.	1275000.	382500.	765000.	6041359.	4559988.	10601284.	6584253.
6	3538572.	303507.	0.	0.	1275000.	382500.	765000.	6041359.	4921467.	10962603.	6190804.
7	3475098.	298341.	0.	0.	1275000.	382500.	765000.	6041359.	5311865.	11353000.	5829948.
8	3405847.	292724.	0.	0.	1275000.	382500.	765000.	6041359.	5734414.	11775549.	5498802.
9	3330543.	286611.	0.	0.	1275000.	382500.	765000.	6041359.	6193367.	12234502.	5193369.
10	3248865.	279958.	0.	0.	1275000.	382500.	765000.	6041359.	6691946.	12733132.	4911233.
11	3159496.	272716.	0.	0.	1275000.	382500.	765000.	6041359.	7233596.	13274731.	4650362.
12	3062445.	264834.	0.	0.	1275000.	382500.	765000.	6041359.	7818484.	13859619.	4411501.
13	2956815.	256256.	0.	0.	1275000.	382500.	765000.	6041359.	8446062.	14487138.	4194474.
14	2841849.	246919.	0.	0.	1275000.	382500.	765000.	6041359.	9115523.	15156658.	3999128.
15	2716721.	236757.	0.	0.	1275000.	382500.	765000.	6041359.	9844444.	15885580.	3802093.
16	2580552.	225697.	0.	0.	1275000.	382500.	765000.	6041359.	10632288.	16673336.	3628861.
17	2432706.	213659.	0.	0.	1275000.	382500.	765000.	6041359.	11480256.	17521391.	3467701.
18	2270978.	200557.	0.	0.	1275000.	382500.	765000.	6041359.	12390117.	18444252.	3317705.
19	2095398.	186297.	0.	0.	1275000.	382500.	765000.	6041359.	13339326.	19443461.	3177771.
20	1904242.	170777.	0.	0.	1275000.	382500.	765000.	6041359.	14446472.	20550607.	3046810.
21	1696281.	153885.	0.	0.	1275000.	382500.	765000.	6041359.	15621190.	21662324.	2923737.
22	1469895.	135499.	0.	0.	1275000.	382500.	765000.	6041359.	16871165.	22912300.	2807477.
23	1223499.	115489.	0.	0.	1275000.	382500.	765000.	6041359.	18222138.	24263273.	2697962.
24	955324.	93718.	0.	0.	1275000.	382500.	765000.	6041359.	19679909.	25721044.	2595128.
25	663444.	70006.	0.	0.	1275000.	382500.	765000.	6041359.	21253342.	27294477.	2498920.
26	345765.	44206.	0.	0.	1275000.	382500.	765000.	6041359.	22955369.	28995504.	2408284.
27	0.	16126.	0.	0.	1275000.	382500.	765000.	6041359.	24788999.	30831134.	2323174.
28	0.	0.	0.	0.	1275000.	382500.	765000.	6041359.	26772219.	32813578.	2242453.
29	0.	0.	0.	0.	1275000.	382500.	765000.	6041359.	28915504.	34956863.	2166990.
30	0.	0.	0.	0.	1275000.	382500.	765000.	6041359.	31222824.	37265074.	2096648.
TOTAL		5945909.		0.	38250000.	11475000.	22950000.	17038403.	37960565.	55006966.	12720649.

* PRINCIPAL REPAYMENT (IF APPLICABLE) INCLUDED. BOOK DEPRECIATION INCLUDED

ECONOMIC COMPARISON OF SYSTEMS FOR LIFE CYCLE COST ANALYSIS ECS 1

DATA FOR SYSTEM 5

GROSS INVESTMENT, $ 3450000.

MONTHLY PAYMT, $ 27201.

DEBT/EQUITY RATIO 100.0/ -.0

END OF YEAR	DEBT BALANCE	DEBT INTEREST (8.5 PCT)	EQUITY BALANCE	EQUITY INTEREST (.0 PCT)	BOOK DEPRC (SL METH)	INSURANCE (1.0 PCT)	AD VALOREM TAX (2.0 PCT)	TOTAL OWN COST*	TOTAL OPR COST	TOTAL OWN + OPR COST	EQUIV CURR DOLLARS (10.0 PCT)
1	3415521.	291927.	0.	0.	115000.	34500.	69000.	544906.	357587.	902491.	820449.
2	3377994.	288886.	0.	0.	115000.	34500.	69000.	544906.	386194.	931100.	769504.
3	3337151.	285363.	0.	0.	115000.	34500.	69000.	544906.	417089.	961996.	722762.
4	3292697.	281952.	0.	0.	115000.	34500.	69000.	544906.	450457.	995363.	679846.
5	3244313.	278023.	0.	0.	115000.	34500.	69000.	544906.	486493.	1031400.	640418.
6	3191654.	273747.	0.	0.	115000.	34500.	69000.	544906.	525413.	1070319.	604167.
7	3134319.	269092.	0.	0.	115000.	34500.	69000.	544906.	567446.	1112352.	570812.
8	3071959.	264026.	0.	0.	115000.	34500.	69000.	544906.	612841.	1157748.	540098.
9	3004064.	258512.	0.	0.	115000.	34500.	69000.	544906.	661869.	1206775.	511790.
10	2930169.	252511.	0.	0.	115000.	34500.	69000.	544906.	714818.	1259724.	485678.
11	2849741.	245979.	0.	0.	115000.	34500.	69000.	544906.	772004.	1316910.	461569.
12	2762265.	238870.	0.	0.	115000.	34500.	69000.	544906.	833764.	1378670.	439287.
13	2666931.	231133.	0.	0.	115000.	34500.	69000.	544906.	900465.	1445371.	418673.
14	2563236.	222711.	0.	0.	115000.	34500.	69000.	544906.	972502.	1517408.	399581.
15	2450375.	213546.	0.	0.	115000.	34500.	69000.	544906.	1050302.	1595209.	381880.
16	2327519.	203578.	0.	0.	115000.	34500.	69000.	544906.	1134326.	1679233.	365450.
17	2193845.	192712.	0.	0.	115000.	34500.	69000.	544906.	1225073.	1769979.	350181.
18	2048333.	180895.	0.	0.	115000.	34500.	69000.	544906.	1323078.	1867985.	335974.
19	1889960.	168033.	0.	0.	115000.	34500.	69000.	544906.	1428925.	1973831.	322737.
20	1717588.	154034.	0.	0.	115000.	34500.	69000.	544906.	1543239.	2088145.	310389.
21	1529979.	138798.	0.	0.	115000.	34500.	69000.	544906.	1666698.	2211604.	298855.
22	1325788.	122215.	0.	0.	115000.	34500.	69000.	544906.	1800033.	2344940.	288066.
23	1103548.	104167.	0.	0.	115000.	34500.	69000.	544906.	1944036.	2488942.	277961.
24	861645.	84523.	0.	0.	115000.	34500.	69000.	544906.	2099559.	2644465.	268481.
25	598401.	63142.	0.	0.	115000.	34500.	69000.	544906.	2267524.	2812430.	259576.
26	311866.	39872.	0.	0.	115000.	34500.	69000.	544906.	2448926.	2993832.	251199.
27	5.	14545.	0.	0.	115000.	34500.	69000.	544906.	2644840.	3189746.	243306.
28	5.	0.	0.	0.	115000.	34500.	69000.	218500.	2856427.	3074927.	213226.
29	5.	0.	0.	0.	115000.	34500.	69000.	218500.	3084941.	3303441.	208247.
30	5.	0.	0.	0.	115000.	34500.	69000.	218500.	3331736.	3550236.	203459.
TOTAL		5362977.		0.	3450000.	1035000.	2070000.	15367971.	40508600.	55876570.	12643621.

* PRINCIPAL REPAYMENT (IF APPLICABLE) INCLUDED. BOOK DEPRECIATION INCLUDED

ECONOMIC COMPARISON OF SYSTEMS FOR LIFE CYCLE COST ANALYSIS ECS 1

DATA FOR SYSTEM 6

GROSS INVESTMENT, $ 3575000.

MONTHLY PAYMT, $ 28186.

DEBT/EQUITY RATIO 100.0/ -.0

END OF YEAR	DEBT BALANCE	DEBT INTEREST (8.5 PCT)	EQUITY BALANCE	EQUITY INTEREST (.0 PCT)	BOOK DEPRC (SL METH)	INSURANCE (1.0 PCT)	AD VALOREM TAX (2.0 PCT)	TOTAL OWN COST*	TOTAL OPR COST	TOTAL OWN + OPR COST	EQUIV CURR DOLLARS (10.0 PCT)
1	3539272.	302504.	0.	0.	119167.	35750.	71500.	564649.	338111.	902760.	820691.
2	3500385.	299346.	0.	0.	119167.	35750.	71500.	564649.	366524.	931174.	769565.
3	3458062.	295909.	0.	0.	119167.	35750.	71500.	564649.	397375.	962024.	722783.
4	3411997.	292168.	0.	0.	119167.	35750.	71500.	564649.	430876.	995525.	679957.
5	3361861.	288096.	0.	0.	119167.	35750.	71500.	564649.	467263.	1031913.	640736.
6	3307293.	283665.	0.	0.	119167.	35750.	71500.	564649.	506791.	1071441.	604800.
7	3247902.	278842.	0.	0.	119167.	35750.	71500.	564649.	549739.	1114389.	571858.
8	3183261.	273592.	0.	0.	119167.	35750.	71500.	564649.	596412.	1161061.	541644.
9	3112987.	267878.	0.	0.	119167.	35750.	71500.	564649.	647141.	1211790.	513917.
10	3036334.	261660.	0.	0.	119167.	35750.	71500.	564649.	702291.	1266940.	488460.
11	2952993.	254891.	0.	0.	119167.	35750.	71500.	564649.	762258.	1326907.	465073.
12	2862285.	247525.	0.	0.	119167.	35750.	71500.	564649.	827476.	1392126.	443574.
13	2763549.	239507.	0.	0.	119167.	35750.	71500.	564649.	898421.	1463070.	423799.
14	2656107.	230781.	0.	0.	119167.	35750.	71500.	564649.	975610.	1540260.	405599.
15	2539157.	221283.	0.	0.	119167.	35750.	71500.	564649.	1059613.	1624262.	388836.
16	2411870.	210946.	0.	0.	119167.	35750.	71500.	564649.	1151050.	1715700.	373386.
17	2273332.	199695.	0.	0.	119167.	35750.	71500.	564649.	1250603.	1815252.	359138.
18	2122548.	187449.	0.	0.	119167.	35750.	71500.	564649.	1359016.	1923665.	345988.
19	1958437.	174121.	0.	0.	119167.	35750.	71500.	564649.	1477106.	2041755.	333843.
20	1779819.	159615.	0.	0.	119167.	35750.	71500.	564649.	1605767.	2170417.	322619.
21	1585414.	143827.	0.	0.	119167.	35750.	71500.	564649.	1745981.	2310630.	312237.
22	1373824.	126643.	0.	0.	119167.	35750.	71500.	564649.	1898821.	2463470.	302627.
23	1143532.	107941.	0.	0.	119167.	35750.	71500.	564649.	2065468.	2630118.	293727.
24	892885.	87585.	0.	0.	119167.	35750.	71500.	564649.	2247217.	2811866.	285476.
25	620082.	65430.	0.	0.	119167.	35750.	71500.	564649.	2445486.	3010135.	277823.
26	323166.	41317.	0.	0.	119167.	35750.	71500.	564649.	2661836.	3226485.	270720.
27	6.	15072.	0.	0.	119167.	35750.	71500.	564649.	2897979.	3462628.	264121.
28	6.	0.	0.	0.	119167.	35750.	71500.	226417.	3155797.	3382213.	234534.
29	6.	0.	0.	0.	119167.	35750.	71500.	226417.	3437358.	3663774.	230962.
30	6.	0.	0.	0.	119167.	35750.	71500.	226417.	3744935.	3971352.	227592.
TOTAL		5557288.		0.	3575000.	1072500.	2145000.	15924781.	42670318.	58595099.	12916086.

* PRINCIPAL REPAYMENT (IF APPLICABLE) INCLUDED. BOOK DEPRECIATION INCLUDED

UCC
UNIVERSITY COMPUTING COMPANY

ECONOMIC COMPARISON OF SYSTEMS FOR LIFE CYCLE COST ANALYSIS ECS 1

ESCALATED VALUES OF ANNUAL OPERATING COST
(ESCALATION PERCENT SHOWN IN BRACKETS BELOW EACH ITEM)

SYSTEM 1

YEAR NUMBER	ELECTRICITY (8.0 PCT)	GAS (.0 PCT)	AUX FUEL (12.0 PCT)	MAINTENANCE (.0 PCT)	OPER LABOR (.0 PCT)	MISC 1 (.0 PCT)	MISC 2 (.0 PCT)
1	305945.	0.	43355.	0.	0.	0.	0.
2	330421.	0.	48558.	0.	0.	0.	0.
3	356854.	0.	54385.	0.	0.	0.	0.
4	385403.	0.	60911.	0.	0.	0.	0.
5	416235.	0.	68220.	0.	0.	0.	0.
6	449534.	0.	76406.	0.	0.	0.	0.
7	485496.	0.	85575.	0.	0.	0.	0.
8	524336.	0.	95844.	0.	0.	0.	0.
9	566283.	0.	107345.	0.	0.	0.	0.
10	611585.	0.	120227.	0.	0.	0.	0.
11	660512.	0.	134654.	0.	0.	0.	0.
12	713353.	0.	150813.	0.	0.	0.	0.
13	770422.	0.	168910.	0.	0.	0.	0.
14	832056.	0.	189179.	0.	0.	0.	0.
15	898620.	0.	211881.	0.	0.	0.	0.
16	970509.	0.	237306.	0.	0.	0.	0.
17	1048150.	0.	265783.	0.	0.	0.	0.
18	1132002.	0.	297677.	0.	0.	0.	0.
19	1222562.	0.	333398.	0.	0.	0.	0.
20	1320367.	0.	373406.	0.	0.	0.	0.
21	1425996.	0.	418215.	0.	0.	0.	0.
22	1540076.	0.	468401.	0.	0.	0.	0.
23	1663282.	0.	524609.	0.	0.	0.	0.
24	1796345.	0.	587562.	0.	0.	0.	0.
25	1940053.	0.	658069.	0.	0.	0.	0.
26	2095257.	0.	737038.	0.	0.	0.	0.
27	2262877.	0.	825482.	0.	0.	0.	0.
28	2443907.	0.	924540.	0.	0.	0.	0.
29	2639420.	0.	1035485.	0.	0.	0.	0.
30	2850574.	0.	1159743.	0.	0.	0.	0.
TOTAL	34658429.	0.	10462976.	0.	0.	0.	0.

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ECONOMIC COMPARISON OF SYSTEMS FOR LIFE CYCLE COST ANALYSIS ECS 1

ESCALATED VALUES OF ANNUAL OPERATING COST
(ESCALATION PERCENTAGE SHOWN IN BRACKETS BELOW EACH ITEM)

SYSTEM 2

YEAR NUMBER	ELECTRICITY (8.0 PCT)	GAS (.0 PCT)	AUX FUEL (12.0 PCT)	MAINTENANCE (.0 PCT)	OPER LABOR (.0 PCT)	MISC 1 (.0 PCT)	MISC 2 (.0 PCT)
1	306105.	0.	39104.	0.	0.	0.	0.
2	330593.	0.	43796.	0.	0.	0.	0.
3	357041.	0.	49052.	0.	0.	0.	0.
4	385604.	0.	54938.	0.	0.	0.	0.
5	416452.	0.	61531.	0.	0.	0.	0.
6	449769.	0.	68915.	0.	0.	0.	0.
7	485750.	0.	77184.	0.	0.	0.	0.
8	524610.	0.	86446.	0.	0.	0.	0.
9	566579.	0.	96820.	0.	0.	0.	0.
10	611905.	0.	108438.	0.	0.	0.	0.
11	660858.	0.	121451.	0.	0.	0.	0.
12	713726.	0.	136025.	0.	0.	0.	0.
13	770824.	0.	152348.	0.	0.	0.	0.
14	832490.	0.	170630.	0.	0.	0.	0.
15	899090.	0.	191106.	0.	0.	0.	0.
16	971017.	0.	214038.	0.	0.	0.	0.
17	1048698.	0.	239723.	0.	0.	0.	0.
18	1132594.	0.	268498.	0.	0.	0.	0.
19	1223202.	0.	300708.	0.	0.	0.	0.
20	1321058.	0.	336793.	0.	0.	0.	0.
21	1426742.	0.	377209.	0.	0.	0.	0.
22	1540882.	0.	422474.	0.	0.	0.	0.
23	1664152.	0.	473176.	0.	0.	0.	0.
24	1797284.	0.	529951.	0.	0.	0.	0.
25	1941067.	0.	593545.	0.	0.	0.	0.
26	2096352.	0.	664770.	0.	0.	0.	0.
27	2264061.	0.	744543.	0.	0.	0.	0.
28	2445185.	0.	833888.	0.	0.	0.	0.
29	2640800.	0.	933954.	0.	0.	0.	0.
30	2852064.	0.	1046029.	0.	0.	0.	0.
TOTAL	34676555.	0.	9437071.	0.	0.	0.	0.

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ECONOMIC COMPARISON OF SYSTEMS FOR LIFE CYCLE COST ANALYSIS ECS 1

ESCALATED VALUES OF ANNUAL OPERATING COST
(ESCALATION PERCENT SHOWN IN BRACKETS BELOW EACH ITEM)

SYSTEM 3

YEAR NUMBER	ELECTRICITY (8.0 PCT)	GAS (.0 PCT)	AUX FUEL (.0 PCT)	MAINTENANCE (.0 PCT)	OPER LABOR (.0 PCT)	MISC 1 (.0 PCT)	MISC 2 (.0 PCT)
1	340271.	0.	0.	0.	0.	0.	0.
2	367493.	0.	0.	0.	0.	0.	0.
3	396892.	0.	0.	0.	0.	0.	0.
4	428643.	0.	0.	0.	0.	0.	0.
5	462935.	0.	0.	0.	0.	0.	0.
6	499970.	0.	0.	0.	0.	0.	0.
7	539967.	0.	0.	0.	0.	0.	0.
8	583165.	0.	0.	0.	0.	0.	0.
9	629818.	0.	0.	0.	0.	0.	0.
10	680203.	0.	0.	0.	0.	0.	0.
11	734620.	0.	0.	0.	0.	0.	0.
12	793389.	0.	0.	0.	0.	0.	0.
13	856860.	0.	0.	0.	0.	0.	0.
14	925409.	0.	0.	0.	0.	0.	0.
15	999442.	0.	0.	0.	0.	0.	0.
16	1079397.	0.	0.	0.	0.	0.	0.
17	1165749.	0.	0.	0.	0.	0.	0.
18	1259009.	0.	0.	0.	0.	0.	0.
19	1359729.	0.	0.	0.	0.	0.	0.
20	1468508.	0.	0.	0.	0.	0.	0.
21	1585988.	0.	0.	0.	0.	0.	0.
22	1712868.	0.	0.	0.	0.	0.	0.
23	1849897.	0.	0.	0.	0.	0.	0.
24	1997889.	0.	0.	0.	0.	0.	0.
25	2157720.	0.	0.	0.	0.	0.	0.
26	2330337.	0.	0.	0.	0.	0.	0.
27	2516764.	0.	0.	0.	0.	0.	0.
28	2718106.	0.	0.	0.	0.	0.	0.
29	2935554.	0.	0.	0.	0.	0.	0.
30	3170398.	0.	0.	0.	0.	0.	0.
TOTAL	38546988.	0.	0.	0.	0.	0.	0.

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ECONOMIC COMPARISON OF SYSTEMS FOR LIFE CYCLE COST ANALYSIS ECS 1

ESCALATED VALUES OF ANNUAL OPERATING COST
(ESCALATION PERCENT SHOWN IN BRACKETS BELOW EACH ITEM)

SYSTEM 4

YEAR NUMBER	ELECTRICITY (8.0 PCT)	GAS (.0 PCT)	AUX FUEL (.0 PCT)	MAINTENANCE (.0 PCT)	OPER LABOR (.0 PCT)	MISC 1 (.0 PCT)	MISC 2 (.0 PCT)
1	335165.	0.	0.	0.	0.	0.	0.
2	361978.	0.	0.	0.	0.	0.	0.
3	390936.	0.	0.	0.	0.	0.	0.
4	422211.	0.	0.	0.	0.	0.	0.
5	455988.	0.	0.	0.	0.	0.	0.
6	492467.	0.	0.	0.	0.	0.	0.
7	531865.	0.	0.	0.	0.	0.	0.
8	574414.	0.	0.	0.	0.	0.	0.
9	620367.	0.	0.	0.	0.	0.	0.
10	669996.	0.	0.	0.	0.	0.	0.
11	723596.	0.	0.	0.	0.	0.	0.
12	781484.	0.	0.	0.	0.	0.	0.
13	844007.	0.	0.	0.	0.	0.	0.
14	911523.	0.	0.	0.	0.	0.	0.
15	984444.	0.	0.	0.	0.	0.	0.
16	1063200.	0.	0.	0.	0.	0.	0.
17	1148256.	0.	0.	0.	0.	0.	0.
18	1240117.	0.	0.	0.	0.	0.	0.
19	1339326.	0.	0.	0.	0.	0.	0.
20	1446472.	0.	0.	0.	0.	0.	0.
21	1562190.	0.	0.	0.	0.	0.	0.
22	1687165.	0.	0.	0.	0.	0.	0.
23	1822134.	0.	0.	0.	0.	0.	0.
24	1967904.	0.	0.	0.	0.	0.	0.
25	2125342.	0.	0.	0.	0.	0.	0.
26	2295369.	0.	0.	0.	0.	0.	0.
27	2478999.	0.	0.	0.	0.	0.	0.
28	2677319.	0.	0.	0.	0.	0.	0.
29	2891504.	0.	0.	0.	0.	0.	0.
30	3122824.	0.	0.	0.	0.	0.	0.
TOTAL	37968565.	0.	0.	0.	0.	0.	0.

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ECONOMIC COMPARISON OF SYSTEMS FOR LIFE CYCLE COST ANALYSIS ECS 1

ESCALATED VALUES OF ANNUAL OPERATING COST
(ESCALATION PERCENT SHOWN IN BRACKETS BELOW EACH ITEM)

SYSTEM 5

YEAR NUMBER	ELECTRICITY (8.0 PCT)	GAS (.0 PCT)	AUX FUEL (.0 PCT)	MAINTENANCE (.0 PCT)	OPER LABOR (.0 PCT)	MISC 1 (.0 PCT)	MISC 2 (.0 PCT)
1	357587.	0.	0.	0.	0.	0.	0.
2	386194.	0.	0.	0.	0.	0.	0.
3	417089.	0.	0.	0.	0.	0.	0.
4	450457.	0.	0.	0.	0.	0.	0.
5	486491.	0.	0.	0.	0.	0.	0.
6	525413.	0.	0.	0.	0.	0.	0.
7	567446.	0.	0.	0.	0.	0.	0.
8	612841.	0.	0.	0.	0.	0.	0.
9	661869.	0.	0.	0.	0.	0.	0.
10	714818.	0.	0.	0.	0.	0.	0.
11	772004.	0.	0.	0.	0.	0.	0.
12	833764.	0.	0.	0.	0.	0.	0.
13	900465.	0.	0.	0.	0.	0.	0.
14	972502.	0.	0.	0.	0.	0.	0.
15	1050302.	0.	0.	0.	0.	0.	0.
16	1134326.	0.	0.	0.	0.	0.	0.
17	1225071.	0.	0.	0.	0.	0.	0.
18	1323078.	0.	0.	0.	0.	0.	0.
19	1428925.	0.	0.	0.	0.	0.	0.
20	1543239.	0.	0.	0.	0.	0.	0.
21	1666698.	0.	0.	0.	0.	0.	0.
22	1800033.	0.	0.	0.	0.	0.	0.
23	1944036.	0.	0.	0.	0.	0.	0.
24	2099559.	0.	0.	0.	0.	0.	0.
25	2267524.	0.	0.	0.	0.	0.	0.
26	2448926.	0.	0.	0.	0.	0.	0.
27	2644840.	0.	0.	0.	0.	0.	0.
28	2856427.	0.	0.	0.	0.	0.	0.
29	3084941.	0.	0.	0.	0.	0.	0.
30	3331736.	0.	0.	0.	0.	0.	0.
TOTAL	48508606.	0.	0.	0.	0.	0.	0.

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ECONOMIC COMPARISON OF SYSTEMS FOR LIFE CYCLE COST ANALYSIS ECS 1

ESCALATED VALUES OF ANNUAL OPERATING COST
(ESCALATION PERCENT SHOWN IN BRACKETS BELOW EACH ITEM)

SYSTEM 6

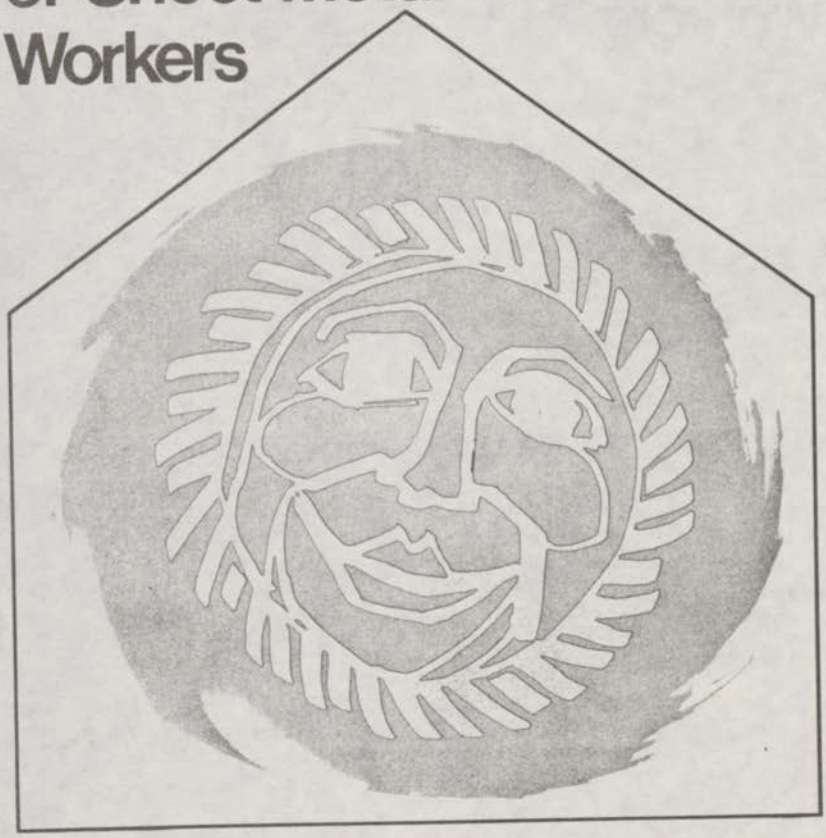
YEAR NUMBER	ELECTRICITY (8.0 PCT)	GAS (.0 PCT)	AUX FUEL (12.0 PCT)	MAINTENANCE (.0 PCT)	OPER LABOR (.0 PCT)	MISC 1 (.0 PCT)	MISC 2 (.0 PCT)
1	363999.	0.	34112.	0.	0.	0.	0.
2	328319.	0.	38205.	0.	0.	0.	0.
3	354584.	0.	42790.	0.	0.	0.	0.
4	382951.	0.	47925.	0.	0.	0.	0.
5	413587.	0.	53676.	0.	0.	0.	0.
6	446674.	0.	60117.	0.	0.	0.	0.
7	482408.	0.	67331.	0.	0.	0.	0.
8	521001.	0.	75411.	0.	0.	0.	0.
9	562681.	0.	84460.	0.	0.	0.	0.
10	607695.	0.	94595.	0.	0.	0.	0.
11	656311.	0.	105947.	0.	0.	0.	0.
12	708816.	0.	118660.	0.	0.	0.	0.
13	765521.	0.	132900.	0.	0.	0.	0.
14	826763.	0.	148847.	0.	0.	0.	0.
15	892904.	0.	166709.	0.	0.	0.	0.
16	964336.	0.	186714.	0.	0.	0.	0.
17	1041483.	0.	209120.	0.	0.	0.	0.
18	1124802.	0.	234214.	0.	0.	0.	0.
19	1214786.	0.	262320.	0.	0.	0.	0.
20	1311969.	0.	293798.	0.	0.	0.	0.
21	1416926.	0.	329054.	0.	0.	0.	0.
22	1530280.	0.	368541.	0.	0.	0.	0.
23	1652703.	0.	412766.	0.	0.	0.	0.
24	1784919.	0.	462298.	0.	0.	0.	0.
25	1927713.	0.	517773.	0.	0.	0.	0.
26	2081930.	0.	579906.	0.	0.	0.	0.
27	2248484.	0.	649495.	0.	0.	0.	0.
28	2428363.	0.	727434.	0.	0.	0.	0.
29	2622632.	0.	814726.	0.	0.	0.	0.
30	2832442.	0.	912493.	0.	0.	0.	0.
TOTAL	34437981.	0.	8232339.	0.	0.	0.	0.

APPENDIX A

MATERIAL SUBMITTED BY THE SHEET METAL WORKERS INTERNATIONAL ASSOCIATION

Strategic Implications of Solar Energy for Employment of Sheet Metal Workers

A study performed by Stanford Research Institute for the Sheet Metal Workers International Association



Strategic Implications of Solar Energy for Employment of Sheet Metal Workers

A study performed by Stanford Research Institute for the Sheet Metal Workers International Association

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G. R. MURRAY
J. D. McCONNELL
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JUNE 1975

STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

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I INTRODUCTION

The Sheet Metal Workers International Association, hereafter referred to as "the Union," is a strong association with journeymen and production worker members. Membership in the Union has grown over the years, due in large measure to the farsightedness of its leadership. This is seen in the Union's willingness to anticipate change and to prepare its members so that they are qualified to adapt to changing technologies and thus maintain and improve their living standards. One historical illustration of this occurred in Hawaii, where the apprenticeship training program included making sheet metal components from plastics. The results were that when plastics ductwork and plastics fabrication became factors in the market, sheet metal workers and sheet metal contractors obtained the business.

Most sheet metal journeymen depend on heating, ventilating, and air conditioning (HVAC) work for their livelihoods. Thus, any social, economic, or technological factors likely to affect the HVAC market are of great concern to the Union. The shortages of electric power, the reported dwindling of natural gas reserves and supplies, and the growing dependence on high priced imported crude oil have caused the federal government to increase its funding of research and development (R&D) projects in the energy area.

An area where research expenditures have been increased substantially is solar energy. Should solar energy become a major factor in the marketplace, considerable uncertainty surrounds its likely impacts on the HVAC industry and sheet metal employment.

The leadership of the Union, perceiving this, requested assistance from Stanford Research Institute (SRI) in evaluating the nature of threats and opportunities presented by the advent of solar energy and in developing a strategy for dealing with them.

The objectives of the study were to provide the Union with:

(1) An evaluation of the major threats and opportunities relating to Union membership and employment over the decade to 1985 that will stem from the U.S. energy situation.

(2) A strategy to enhance employment opportunities for Union members in the years ahead.

These two objectives were broken down into four objectives, namely, to:

- Review the present situation and the future outlook for energy in the United States.
- Identify and evaluate solar and other energy related technological developments.
- Evaluate probable impacts of solar energy on sheet metal work.
- Identify and recommend strategic alternatives for the Union.

The project team comprised J. Douglas McConnell (project supervisor), George Murray (project leader), James C. Snipes, and Horace W. Brock. The study was undertaken during the period January through May 1975. The project team received unqualified cooperation from members of the Union, from sheet metal contractors, from practitioners in the solar energy field, and from government agency personnel. This assistance is fully and gratefully acknowledged.

The study restricted its major investigations to the solar energy area commonly referred to as solar heating and cooling. Thus, geothermal developments, ocean thermal, wind, photovoltaic cells, and other such R&D areas were omitted from detailed consideration despite their being classified as forms of solar energy, because their energy end product is electric power and thus the impact on HVAC will be minimal.

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II CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations drawn from the analyses made in later sections of the report are presented as follows:

Conclusions

(1) Solar heating and cooling will represent a small percentage of energy from all sources this century. It is unlikely that solar heating and cooling will be employed in as many as 5.8 million buildings out of 59.9 million buildings by the year 2000, as projected by Operation Independence assuming an accelerated program with oil priced at $11 per barrel (in 1974 dollars). After many decades of successful operation, hydroelectric power supplies only about 1 percent of the nation's energy needs and nuclear power an even smaller proportion after 25 years of unfulfilled promises. Change occurs more slowly than most people are prepared to concede.

(2) At best, using the most optimistic assumptions, solar heating and cooling could represent a $2 billion annual market by 1990. This is made up of $1 billion for collectors (at retail); storage tanks, ducting, and allied equipment could amount to a maximum of $500 million; and total labor for installation will cost an additional $500 million, of which perhaps $250 to $300 million may be expected to go to sheet metal workers.

On a most likely basis, however, the annual market for solar heating and cooling will not exceed $1 billion by 1990.

(3) Solar heating and cooling is only one of a dozen energy alternatives funded for research and development. Of the total R&D funding for fiscal 1975, solar energy (all forms) and geothermal received only a little more than 5 percent. This compares with 40 percent of energy R&D funds for nuclear fission plus 9 percent for nuclear fusion, 23 percent for coal, 10 percent for environmental control, and 7 percent for conservation. It is also unlikely that all funds allocated to solar can be spent

wisely within the year. There is a practical limit to how many projects can be thoughtfully developed and implemented in a given period of time.

(4) Solar heating and cooling systems, except in a few geographic regions of the country, cannot be expected to provide more than 50 to 80 percent of the heating and cooling requirements for buildings. Thus, solar heating and cooling systems will be installed in parallel with conventional systems, rather than in place of conventional systems. Therefore, it is considered that sheet metal employment opportunities will be enhanced rather than threatened by the development and acceptance of solar heating and cooling systems.

(5) Where solar heating and cooling are concerned and water is the storage and heat transfer medium, jurisdictional problems can be anticipated with the plumbers. In solar heating and cooling installation where solar collectors form a part of the roof or a wall, jurisdictional problems are likely to arise with the carpenters.

(6) The solar heating and cooling field is so new that crafts with the training and skills to handle installations will be given the work irrespective of historical jurisdictional rights. Thus, if sheet metal workers have training and experience in installation of solar collectors, the fact that these become parts of roofing or wall systems will have little import.

(7) Any penetration of the heating and cooling market by solar collector systems will be in residential buildings (one family and low-rise multifamily), and in low-rise commercial and institutional buildings, such as shopping centers, schools, post offices, and colleges.

(8) Market penetration will probably require a substantial cost reduction in systems, substantial and sustained increases in costs of alternative forms of energy, government incentivies and government decree, and recurring energy crises. As the latter factors relate primarily to changing consumer attitudes, market penetration will be slow.

(9) A significant proportion of solar heating and cooling systems using water-based heat storage will require ducting. Ducting is necessary because of factors such as the need to minimize use of ethylene-glycol in systems

subject to freezing temperatures, the relative cost of copper piping and ducting, and technological developments relating to air flows.

(10) Sheet metal work for the construction industry in the next decade will increase by approximately one-third (33 to 34 percent). Of this growth, about 27 percent will occur from the increasing volume of construction likely to be undertaken--5 percent from nonsolar changes such as trends to larger core units requiring more ducting and fewer smaller units with limited ducting and 1 to 2 percent from solar heating and cooling.

(11) The sheet metal industry and the Union will be little affected in the next ten years by solar heating and cooling systems.

(12) The Union has problems, threats, and opportunities relating to its position in various markets that should be accorded higher priorities than solar heating and cooling. The residential construction market for example, stands out as a large area of opportunity for the Union.

Recommendations

The Union has good penetration in major industrial and commercial construction markets, has a position of real strength in the railroads, and has been highly successful in organizing manufacturing plants. With one or two exceptions, such as Detroit, the Union has lost ground in residential construction to the point where almost all sheet metal work is undertaken by nonunion labor. Regaining a portion of this lost ground will have a major effect on the level of unemployment currently experienced by Union members.

Therefore, SRI recommends that the Union accord a high priority to developing a strategy to regain a significant share of the residential construction business for Union members and contractors. With respect to solar energy, the Union should maintain a low level but highly visible posture. The following strategic alternative actions could be undertaken.

(1) Define Union Objectives and Priorities--It is recommended that the Union:

- Begin a study of Union priorities, to look at where solar heating and cooling falls in terms of all Union objectives. This may actually be a study to establish priorities, if the Union does not already have such a list.

- Set up a time phased plan for the use of Union resources in the heating and cooling area to include personnel and dollars.

(2) Maintain a close watch on the situation--This would include:

- Expansion of a solar energy library to include copies of regulations, codes, manuals and incentive actions collected from federal, state, and local levels through various contacts. This library should also include available energy studies, and as they can be obtained, cost estimate data from developers, contractors, and architects. The use of these data in discussions with state and local contacts would lead to a voluntary exchange of information.

- Studying in more detail which products fabricated by or installed by union contractors (as listed in the red book) will be affected by solar heating and cooling and in what way (for instance, changes in insulation, double glazing of windows). This would then permit an evaluation as to whether new processes, techniques, or training sessions are needed to bring membership up to date on such matters.

- Volunteering to government agencies to provide knowledgeable experts in labor and craft aspects of construction and design matters, who can serve as advisory members of policy, planning, and operational tasks under the National Plan for Solar Heating and Cooling. ERDA, HUD, GSA, DoD, and The National Bureau of Standards are the principal agencies.

- Surveying cooperating contractor firms and manufacturers to determine which are concerned with solar demonstration products. Arrange visits by a national Union representative to the principal firms to discuss solar heating and design. Westinghouse, General Electric, PPG, and Revere should probably be included.

- Talking informally with research organizations regarding their conclusions on sheet metal content of construction. This might include MITRE, Arthur D. Little, Battelle, and SRI.

- Reviewing the directory of state energy offices published by FEA and having Union representatives called on state energy office heads in their jurisdictional areas. In some cases, it might be worthwhile to include a national

representative. This would be evident when reviewing the directory, which outlines the current state program.

- Following a similar procedure in selected local communities.
- Looking into solar energy industry associations and joining if membership is appropriate.
- Touching base with each university doing major work in solar heating and cooling, to discuss sheet metal implications (local or regional representative of the Union can do this).

(3) Become involved in potentially advantageous demonstration programs--The Union should:

- Ask to be put on ERDA's list of addressees for the requests for proposals that are being issued in connection with the program.
- Work out a joint test program with ASHRAE, and perhaps one with AIA.
- Initiate solar heating and cooling discussions with AIA offering to provide technical advice as appropriate in heating and cooling matters.
- Initiate similar talks with the American Society of Heating, Refrigerating, and Air Conditioning Engineers.
- Intensify the cooperative work being done with SMACNA on solar matters.
- Engage sharp, articulate members in a solar construction project.
- Join with SMACNA in providing assistance to Colorado State University's Solar Energy Applications Laboratory (SEAL) and perhaps to other experiments of different systems, where they will include sheet metal. In such demonstration cases, the Union should endeavor to find sufficient numbers of similarly interested organizations so that investments of Union funds are minimal.

(4) Lobby as appropriate to ensure that potentially advantageous programs and projects receive adequate attention and funding --The Union should:

- Make courtesy calls on the Chairman of the House and Senate Committee dealing with solar energy matters and on selected Committee and Committee staff members.

- Make similar calls on solar energy officials of ERDA, HUD, GSA, National Bureau of Standards, and FEA. Establish contact with the elements of the Department of Labor concerned with manpower training aspects of the energy program. (The most important figure is considered to be Dr. Robert C. Seamans, Jr. of ERDA.)

(5) Become the preeminent authority on labor and manpower requirements and training in solar energy manufacture of components and installation--Suggestions for accomplishing this are to:

- Volunteer with the Department of Labor training people, ERDA, and HUD to serve as consultant in developing a training portion of the solar heating and cooling program.

- Work up a solar heating and cooling training packet for use in membership meetings. This might include audiovisual tape presentations, general orientation on solar heating and cooling, and specifics on methods Initially, a simple brochure explaining terms, equipment components, and principles of operation would be advantageous. It may well prove to be practical if the Union negotiated to buy and utilize the primer just published by the American Institute of Architects. Joining forces with the AIA may also have some other long-term benefits in this area.

III THE OUTLOOK FOR ENERGY IN THE UNITED STATES

The principal U.S. government report on energy, Project Independence, was published by the Federal Energy Administration in November 1974. Because it is the basic foundation for administration energy policy, it is an appropriate basis for summarizing the energy outlook.

The highlights of the current energy situation are as follows:

- U.S. demand for energy has been growing at about 3.5 percent annually.
- This country is no longer self-sufficient in the industry, because, in contrast with a demand increase, coal production is still at the levels of the 1940s, crude oil production has been declining since its peak in 1970, and the increase in natural gas consumption has exceeded new discoveries of that commodity since the late 1960s.
- As a result, the United States is now heavily dependent on foreign petroleum--in 1973, foreign oil and products used in the United States approximated 35 percent of the domestic petroleum, as shown in Figure 1.
- Middle East countries dominate the world market--they have 60 percent of world reserves and currently produce 70 percent of world oil exports.
- U.S. dependence on imported oil as a source of energy creates a substantial economic problem. The 1973-74 embargo had an economic impact on the Gross National Product (GNP) estimated at between $10 billion and $20 billion, and the unemployment increase attributed to the embargo at its peak was more than 500,000.

The demand for energy in the United States depends not only on domestic needs but also on the availability of energy resources and on the prices charged for these energy producing commodities. Project Independence studies of demand indicate that a range of $11 to $7 per barrel in world oil prices would provide corresponding demand growths at the annual rate of 2.7 percent per year, or 3.2 percent per year between 1972 and 1985, respectively, if there were no change in current major policies. This assumes availability of the petroleum. Production is also

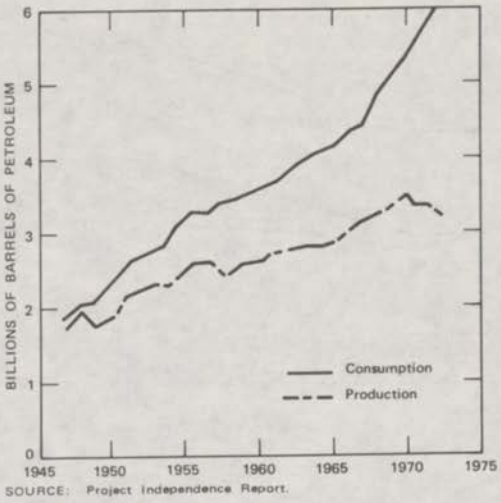


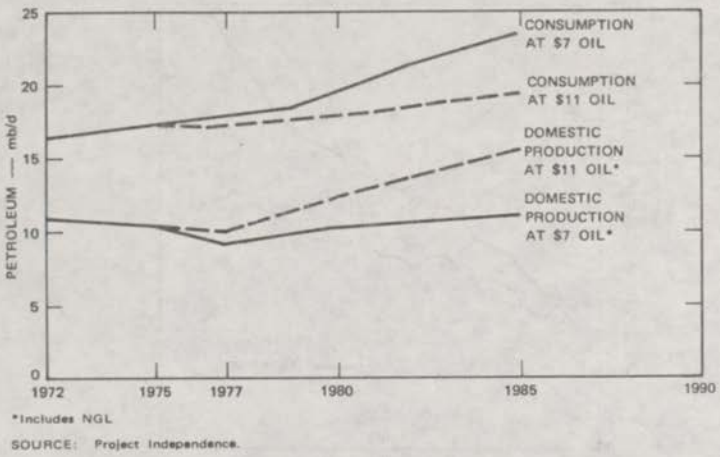
FIGURE 1 U.S. ENERGY PRODUCTION AND CONSUMPTION, 1947 - 1973

directly affected by price under the Project Independence assumptions. At the $11 price, domestic production would increase enough to decrease the demand for foreign oil, whereas at the $7 price the gap between total requirements and domestic oil availability would continue to increase, concurrently increasing U.S. dependence on foreign oil, as shown in Figure 2.

Under the assumptions of this base case, it is expected that by 1985 coal use will increase; but production of coal could be expanded to more than meet this increase. Other factors (lower electric growth, increasing nuclear capability, and environmental restrictions) will limit the need for this production increase under the base case.

Domestic natural gas production is limited regardless of price. Continued regulation could result in a reduction of production of that commodity by 1985 to a level 38 percent below what it would be if natural gas prices were deregulated.

By 1985, nuclear power is forecast to provide approximately 30 percent of total electric power generation. Synthetic fuels are not expected to contribute materially between now and 1985, nor are geothermal,



*Includes NGL

SOURCE: Project Independence.

FIGURE 2 EFFECTS OF FOREIGN OIL PRICE ON U.S. CONSUMPTION AND PRODUCTION

solar, and other advanced technologies, although in total, these are considered to have a high potential as sources after 1985. However, substantial research and development will be required so that these renewable sources (so designated because they do not deplete existing reserves) will be able to contribute substantially to the solution of the energy problem.

FEA suggests three alternatives under which the United States can reduce its dependence on imported fuels--accelerating domestic supply, reducing demand through conservation of energy (perhaps by price adjustments), and emergency actions such as special fuel storage actions and intercountry arrangements under the International Energy Program (IEP). In addition, certain conservation or curtailment plans may be carried to a point short of implementation and placed on "standby" for use under emergency conditions. Whatever actions are taken (or not taken), there will be an effect on the economy, on industry in general and on the portions of the economy that utilize the professional talents of sheet metal workers. The degree of influence and the timing of these impacts will differ among the several alternative actions. The United States already has been exposed to some of the short term impacts, but the longer term effects are not yet visible. Both impacts are discussed below in further detail. In addition, this report includes more specific information on the determinants of these effects--particularly the forecasts of the demand and supply of energy under varying circumstances and the variance in a number of separate forecasts.

Energy Demand and Supply

Table 1 indicates the projected demand for 1985 as developed under various assumptions and by varying studies. It is noted that the FEA forecast of energy demand is lower than the other studies cited if $11 prices are assumed.

Table 1

COMPARISON OF FEA ENERGY DEMAND
PROJECTION FOR 1985 WITH OTHER PROJECTIONS,
(Quadrillions of Btu per Year)

	Projected Demand	Compound Annual Growth Rate 1972-1985 (percent)
FEA at $4 per barrel	118.3	3.8%
FEA at $11 per barrel	102.9	2.7
Ford Foundation, Energy Policy Project	115.0	3.6
Dupree-West	116.6	3.7
National Petroleum Council	124.9	4.2

Source: Project Independence

Table 2 compares the FEA base case forecast and demand by sector.

At higher oil prices, the decline in energy growth rates is greatest in the sectors that depend the most on petroleum and that are least able to switch to other fuels.

Table 3 presents the composition of the total energy production by energy source for 1972 and for 1985 at the $7 and $11 per barrel price basis. As indicated, little contribution is expected by 1985 from new technologies under current government R&D policies.

Table 2

COMPARISON OF SECTORAL GROWTH RATES

Sector	1972 Consumption (quads)	1985 Forecast $7	1985 Forecast $11	Compound Growth Rates (percent) 1960-1972	1972-1985 $7	1972-1985 $11
Household and commercial	18.0	25.9	25.1	3.9%	2.8%	2.6%
Industrial	22.9	30.4	29.0	3.1	2.2	1.8
Transportation	18.1	24.5	22.0	3.9	2.3	1.5
Total	59.0	80.8	76.1	3.6	2.4	2.0

Source: Project Independence

Table 3

SOURCE OF U.S. DOMESTIC ENERGY PRODUCTION,
1972 and 1985
(Quadrillions of Btu)

	1972	1985, $7 per Barrel	1985, $11 per Barrel
Oil	22.4	23.1	31.3
Gas	22.1	23.9	24.6
Coal	12.5	19.9	22.9
Nuclear	0.6	12.5	12.5
Other	2.9	4.9	5.1
Total production	60.4	84.3	96.4

Source: Project Independence

Table 4 provides an estimate of the effects on energy supply and demand of the application of the several alternatives posed in the Project Independence study. The impact in terms of solar heating and cooling is discussed in later sections of the report.

Table 4

U.S. ENERGY SUPPLY, DEMAND, AND IMPORTS IN 1985

	U.S. Energy Demand (quads)	Domestic Energy Supply (quads)	Oil Imports* (millions of barrels per day)
At $7 per barrel world oil price			
Base case with and without emergency programs	109.1	84.2	12.4
Accelerated supply	109.6	92.6	8.5
Conservation	99.2	79.6	9.8
Accelerated supply plus conservation	99.7	88.5	5.6
At $11 per barrel world oil price			
Base case with and without emergency programs	102.9	96.3	3.3
Accelerated supply	104.2	104.2	0
Conservation	94.2	91.8	1.2
Accelerated supply plus conservation	96.3	96.3	0

*A million barrels of oil per day equals one quad.

Source: Project Independence

Forecasts Beyond 1985

According to the Project Independence report, R&D will be the key factor in the energy balance beyond 1985. Gasification of coal, solar heating and cooling, and geothermal energy sources appear competitive at the higher prices of oil that are expected in that time period; and the degree to which these new technologies are applied will heavily

influence the supply/demand ratio. This is particularly true because at that point the United States will have begun to deplete more quickly its existing conventional reserves, even though the conservation strategies are followed. Thus oil production will be declining domestically, and the new technologies will be needed to offset the consequent production reductions.

The shifts in domestic fuel consumption by source will differ with the supply strategy exercise. Table 5 reflects this difference.

Table 5

DOMESTIC FUEL CONSUMPTION BY SOURCE IN 1985
(Quads)

		$7 Oil			$11 Oil		
Fuel Source	1972 Actual	Base Case	Accel-erated Supply	Percent Change	Base Case	Accel-erated Supply	Percent Change
Coal	12.5	19.9	17.7	-11.0%	22.9	20.7	-9.6%
Oil	22.4	23.1	30.5	+32.0	31.3	38.0	+21.4
Gas	22.1	23.9	24.7	+3.3	24.8	25.5	+2.8
Hydroelectric and geothermal	2.9	4.8	4.8	0	4.8	4.8	0
Nuclear	0.6	12.5	14.7	+17.6	12.5	14.7	+17.6
Synthetics	--	--	0	--	--	0.4	--
Imports	11.7	24.8	17.1	-31.0	6.5	0	-100.0
Total	72.2	109.0	109.5	+0.4	102.8	104.1	+1.2

Source: Project Independence

In summary, the accelerated strategy results in substantial reduction of oil imports through an increase in nuclear capacity, opening national production reserves, exploiting new fields and utilizing additional oil and gas pipelines, increased federal leasing, actions to reduce environmental and water constraints so as to allow oil shale production, and possible mandatory allocation to assure the availability of critical materials and equipment in oil and gas production.

There are potential constraints in the areas of water resources, manpower, materials, and equipment in the application of the "accelerated supply case." The Project Independence report indicates that, by 1980, certain highly skilled categories of manpower that require many years of training may be in short supply, among these engineers and construction craftsmen. Most of these shortages are expected to be reduced or resolved by 1985. In the accelerated case as in the base case, new technology such as solar and geothermal power will not have a major impact until after 1985.

A major prerequisite for an accelerated energy R&D effort will be adequate funding. A major source will be government appropriations, largely now centralized in the Energy Research and Development Administration (ERDA).

For fiscal year 1976, ERDA has requested almost $900 million for plant and capital equipment and $3,700 million for activity (program) funding.

The largest proportions of these funds are for nuclear energy development and national security. The proportion of research for solar development is small--in the FY 1976 estimate, no funds are assigned to solar for plant and capital equipment, and the $57 million for solar in the activity estimate represents less than 2 percent of the overall total.

Congressional action, however, appears to lean toward increasing rather than decreasing the funds provided for solar energy research, as indicated in Table 6.

Decreasing Domestic Demands

The strategy of decreasing domestic demands provides a number of potential possibilities for energy conservation. The examples cited in the Project Independence report, which are regarded as principally illustrative, are presented in Table 7. The primary items that might affect steam fit sheet metal workers--tax credit for commercial building and modifications of new thermal standards for homes and offices--represent somewhat over 10 percent of the total estimated savings among these actions.

Table 6

CONGRESSIONAL SUBCOMMITTEE INCREASES
FOR ENERGY RESEARCH AND DEVELOPMENT,
FISCAL YEAR 1976
(Millions of Dollars)

	ERDA Request	Subcommittee Increase	Total
Solar energy			
Heating and cooling	$26.0	$14.4	$ 40.4
Solar thermal	13.2	15.3	28.5
Photovoltaic	12.8	16.7	29.5
Wind	11.5	6.6	18.1
Bioconversion	3.6	2.9	6.5
Ocean thermal	3.2	8.0	11.2
Other	0.0	9.5	9.5
Subtotal	$70.3	$73.4	$143.7
Geothermal energy			
Pilot and demonstration plants	0.0	23.0	23.0
Resource utilization	14.8	3.0	17.8
Supporting R&D	8.0	7.0	15.0
Subtotal	$22.8	$33.0	$55.8
Conservation			
Electric power transmission	13.8	0.0	13.8
Energy storage	10.9	20.0	30.9
Advanced transportation power systems	9.4	15.6	25.0
End use	5.0	53.0	58.0
Improved conversion efficiency	1.8	5.2	7.0
Subtotal	$40.9	$93.8	$134.7

Source: Federal Budget, FY 1976 (January 1975).

Table 7

IMPACT OF ENERGY CONSERVATION
ACTIONS IN 1985

Action	Savings in Quads at $11 per Barrel
20 mpg mandatory auto standards	1.9
Automobile use disincentives, such as 15¢ per gallon gasoline tax	1.2
Incentive for retrofit of homes, such as 25 percent tax credit	0.8
15 percent investment tax credit for commercial buildings	0.2
National thermal standards for new homes and offices	1.0
National commercial lighting standards	0.3
Appliance efficiency standards	0.5
R&D for efficiency in industrial processes	1.5
Total net savings	7.4
Demonstrations for efficiency at utilities	0.9

Source: Project Independence

Energy Sources

The evaluation of the FEA task forces regarding the potential energy supply sources is summarized by source below.

Oil

The gross consumption of all energy sources and the total demand for petroleum are presented in Figures 3 and 4 on an historical basis. The task force found that domestic production of crude oil and natural gas liquids (NGL) will continue to decline for the next two years regardless of higher prices or incentives for expanded exploration. This downward production trend would be reversed after a few years under both business as usual (BAU) and accelerated development (AD)

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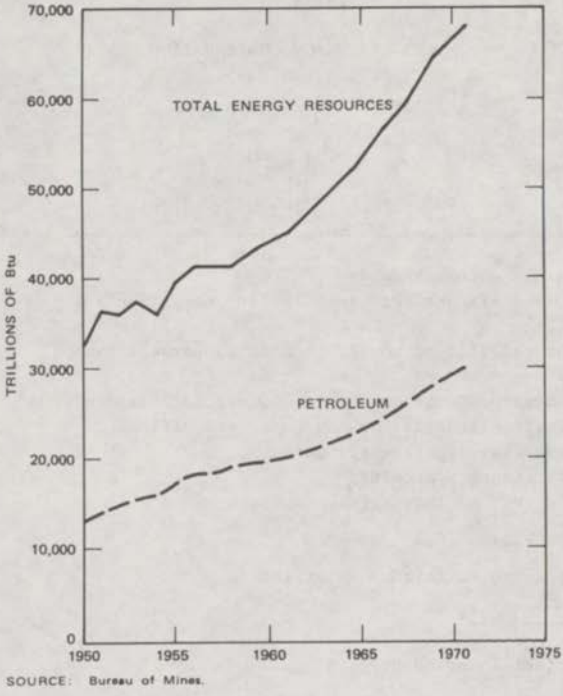

FIGURE 3 U.S. GROSS CONSUMPTION OF ENERGY RESOURCES

assumptions. The quantities of production would be affected not only by various prices, but also by discount rates, financial costs, and finding rates, as well as drilling costs, depletion rates, and product prices. Other factors that directly affect cost and production levels include competition for available labor, material, and capital; technology levels and utilization of secondary and tertiary recovery; access to resources; government price and fiscal policies; and environmental considerations.

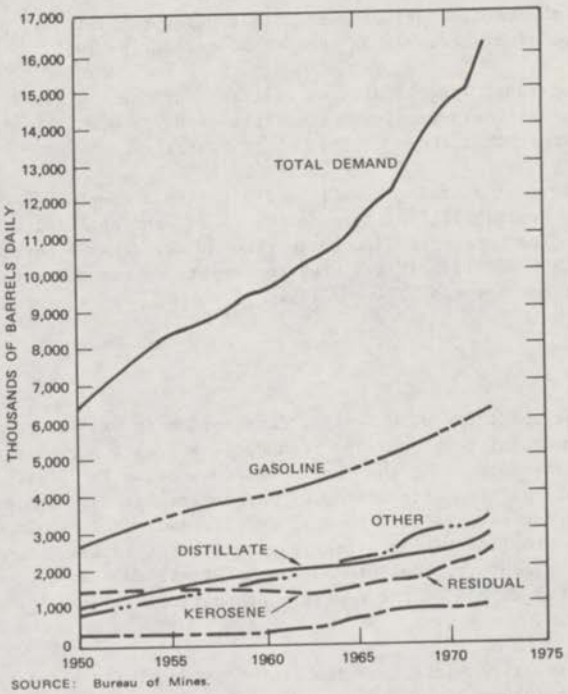

FIGURE 4 DOMESTIC DEMAND FOR PETROLEUM

Natural Gas

Task force conclusions are summarized as follows:

- Gas production from the lower 48 states should continue to decline until nearly 1980 regardless of price. By 1985, however, with a minimum price of $1 per thousand cubic feet, production could increase by 10 percent over 1974 under BAU conditions. Under AD conditions with the same minimum price, production could expand more than 25 percent over 1974.
- Production in Alaska could provide major increases in new gas production by 1985, depending on oil prices.
- Improved technology could provide an additional 12 percent production by 1985.

- Under the continuance of current gas price regulations, production might decrease as much as 30 percent by 1985.

SRI's long-range study indicates that the outlook for gas supplied from Canada is extremely promising since its reserves are estimated at 2-1/2 times larger than those of the United States.

The demand for natural gas will be limited by a combination of higher prices, availability of alternative fuels, and anticipated end-use controls. The consumption increase rate of more than 5 percent per year between 1960 and 1971 is expected to drop to an annual increase rate of about 1 percent between 1971 and 1990.

Coal

The historical trend of U.S. coal consumption in Btu has been flat in specific numerical terms and has been declining as a percentage of total energy consumption for the last 50 to 60 years. The declining proportion of coal has been accelerated by government actions such as the stimulation of nuclear electric power, the elimination of oil import quotas, and the implementation of environmental legislation. Since the beginning of the century, coal production has remained almost constant. In 1973 about two-thirds of the domestic production was used for electric power generation.

For the past five years, surface mining productivity rates have remained constant (about 31 pounds per man-day). Because of the Mine, Health, and Safety Act provisions, difficulties in labor management relations and an influx of untrained workers, productivity in underground mines has decreased from 50.9 tons to 11 tons per man-day.

With environmental emphasis, use of low-sulfur content coals is increasing rapidly. This type of coal is found mostly west of the Mississippi; accordingly, production in that area has increased substantially. In total, U.S. coal reserves are enough to last more than 800 years at 1973 use levels. Although these reserves are split about evenly between west and east, on a Btu basis somewhat more is located east of the Mississippi because the Btu content of western coal is lower.

About 50 percent of the underground and 10 percent of surface minable coal cannot be recovered by conventional mining methods. The principal constraints to coal production are those of sulfur content, difficulty in recovery under current methods, requirements for heavy capital outlays, and environmental standards in the use of coal. In fact, the Project Independence group found that the coal industry can

satisfy almost any foreseeable demand by 1985 at prices near 1972-73 levels. (See Table 8.) Other factors that will influence coal demand are the price and availability of oil and natural gas and the rate of increase in the consumption of electricity.

SRI research indicates that future coal mining emphasis will be on large, low-cost operations that deliver their output to one or a few major consumers. Although mining and transportation are the most significant costs of coal, land reclamation and health and safety compliance costs are expected to be increasingly important. Virtually an unlimited potential supply of coal exists in North America, and it can be mined in sufficient quantities to be a major factor in interfuel price competition. Other constraints could include equipment shortages, railroad transportation shortages, government edicts and environmental restrictions, and labor problems.

Nuclear Fuels

Uranium ore, which is the source of nuclear electric power, is a depletable commodity of finite size. Current estimates indicate that the production rate of the industry will not be able to meet uranium fuel requirements for the accelerated case beyond 1985, unless the rate of exploration and mine/mill facility construction are increased in the near future. Nuclear generating plant construction programs have recently been deferred or cancelled, which could postpone or reduce capacity currently projected for 1985.

Constraints to the expansion of nuclear power include:

- Uranium resources and exploration.
- Uranium mining and milling capacity.
- Uranium enrichment capacity.
- Spent fuel reprocessing capacity.
- Uncertainties regarding the schedule for bringing additional nuclear generating capacity on line.

The Project Independence report indicates that, to meet demand, an investment of almost $2 billion dollars, with 15 to 20 new milling plants may be required. Additional capacity for the isotopic enrichment of uranium will require expansions estimated to cost $1.5 billion, including about 30 percent for meeting foreign requirements. Other factors that may deter the necessary expansion include difficulties in raising investment

Table 8

COAL PRODUCTION POTENTIAL, 1977-1990
(Millions of Tons)

Region and Mine Type	Business As Usual				Accelerated			
	1977	1980	1985	1990	1977	1980	1985	1990
Northern Appalachia								
Surface	82.1	93.2	107.5	138.1	92.7	135.6	192.2	269.8
Deep	118.7	123.4	135.9	145.8	120.4	177.4	267.0	352.2
Subtotal	200.8	216.6	243.4	283.9	221.1	313.0	459.2	622.0
Southern Appalachia								
Surface	92.6	110.0	137.2	164.6	132.5	166.6	245.1	359.3
Deep	171.6	195.3	237.0	273.0	199.8	300.1	445.6	588.0
Subtotal	264.2	306.3	374.2	437.6	332.3	466.7	690.7	947.3
Midwestern								
Surface	118.8	133.7	159.1	187.9	139.1	196.5	287.7	416.3
Deep	58.5	63.4	68.1	80.2	65.3	91.6	136.0	178.3
Subtotal	177.3	197.1	227.2	268.1	204.4	288.1	423.7	594.6
Gulf								
Surface	11.2	28.9	42.5	54.0	25.0	50.0	75.0	105.0
Deep	--	--	--	--	--	--	--	--
Subtotal	11.2	28.9	42.5	54.0	25.0	50.0	75.0	105.0
Northern Great Plains								
Surface	64.4	99.6	152.0	184.5	98.5	185.9	302.6	380.6
Deep	1.3	2.0	3.1	3.6	0.7	0.9	1.2	1.5
Subtotal	65.7	101.6	155.1	188.1	99.2	186.8	303.8	382.1
Rocky Mountain								
Surface	16.9	19.8	24.4	28.8	19.8	29.9	49.4	65.1
Deep	10.8	12.3	14.7	17.3	12.3	18.1	27.2	38.8
Subtotal	27.7	32.1	39.1	46.1	32.1	48.0	76.6	103.9
Pacific Coast								
Surface	7.9	12.3	18.5	21.9	12.3	23.1	33.8	47.8
Deep	0.1	0.1	0.2	0.2	0.1	0.2	0.3	0.4
Subtotal	8.0	12.4	18.7	22.1	12.4	23.3	34.1	48.2
National								
Surface	393.9	498.5	641.2	779.8	519.9	787.6	1,185.8	1,643.9
Deep	361.0	396.5	459.0	520.1	406.6	588.3	877.3	1,159.2
Total	754.9	895.0	1,100.2	1,299.9	926.5	1,375.9	2,063.1	2,803.1

Source: Operation Independence Report

capital for utilities, equipment and manpower limitations, and some delay of public acceptance of nuclear power.

Electricity

Existing and projected electrical power generating capacity by type of generation is shown in Table 9.

The projection of electricity requirements is subject to many uncertainties--whether reductions in electrical demand will continue, alternative fuel price and availability, difficulty in raising capital, and power plant siting problems because of environmental restrictions or public discontent. Also, there may be construction delays due to engineering, manpower, and equipment difficulties as well as questions of reliability of operation, particularly in nuclear plants.

While considerable development is expected for existing technologies (such as low-Btu gas from coal in combined cycle systems), it is not anticipated that a substantial production of electricity will be achieved during the period to 1990 from such revolutionary technologies as the breeder reactor, fusion power, or solar energy.

Shale Oil

The use of shale oil in production of petroleum is currently only experimental, and substantial investments of time and capital will be required to make this technique commercially useful. Production in commercial quantities is projected to begin only in 1980. The rate of development of the oil shale technique depends on a number of factors--availability of capital, environmental restrictions, availability of water for processing, and incentives such as depreciation allowances and accelerated depreciation. A highly coordinated federal-state-local program must evolve if the use of shale oil is to be successful.

Synthetic Fuels

This energy source entails the conversion of coal through chemical processing to eliminate impurities and produce a clean gas or liquid fuel. The constraints are meeting the higher costs, availability of new technology and water, and transportation costs. The study concludes that synthetic fuels can supply only a very small amount of the U.S. gas and oil requirements by 1985, with the real potential in the latter 1980s or 1990s. Figures 5 and 6 present the estimated capacity potentials between start-up at or near 1980 and the year 2000.

Table 9

EXISTING AND PROJECTED ELECTRICAL CAPACITY

	Existing Capacity, End of 1973	1985 Projections*† (gigawatts) BAU $11 per Barrel	1985 Projections*† (gigawatts) Demand Management
Total electricity Capacity	424	922	1,002
Growth rate, 1973-1975, percent per year	--	6.3%	7.4%
Hydro capacity GWe	65	100	100
Nuclear capacity GWe	20	204	240‡
Coal capacity GWe	167	327	379
Oil capacity GWe	78	81	64§
Gas capacity GWe	61	48	48
Combustion turbine GWe**	33	162	171

*Beginning of year projections (nuclear at end of year would be 234 and 275 for BAU and AD, respectively.

†Without conservation.

‡Accelerated nuclear construction schedules.

§The demand management projection includes conversion of about 16,500 megawatts of existing oil-fired generation capacity to coal.

**These figures reflect projected increased market penetration of intermediate load combined cycle plants and continued use of gas turbine peaking plants.

Source: Project Independence

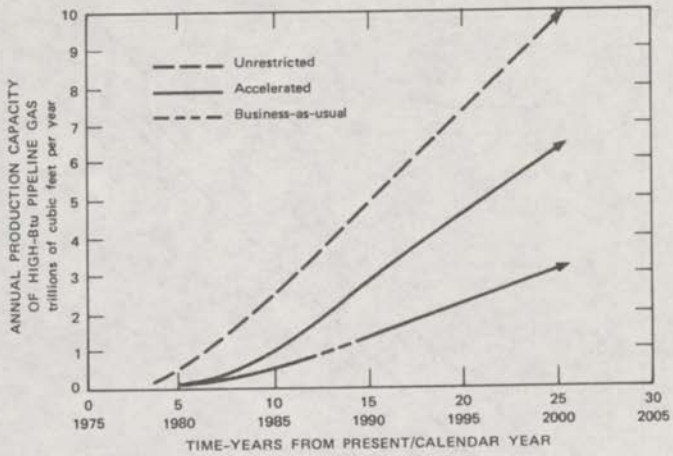

FIGURE 5 GROWTH OF ANNUAL PRODUCTION CAPACITY OF SYNTHETIC HIGH-Btu (PIPELINE) GAS

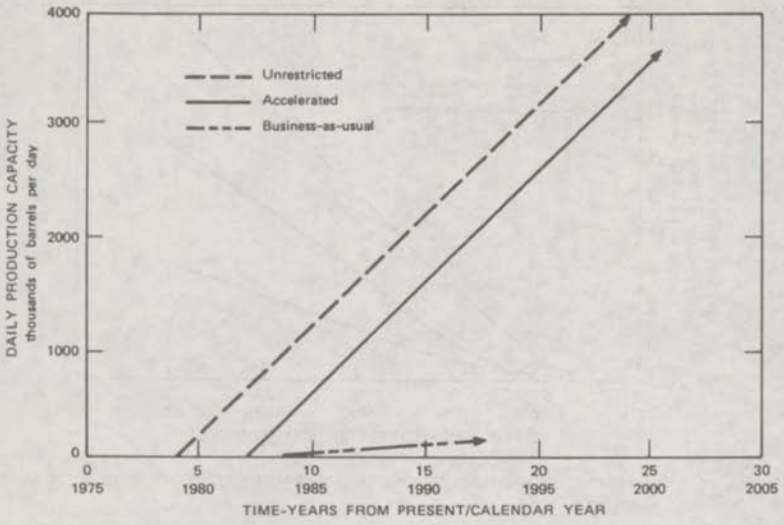

FIGURE 6 GROWTH OF PRODUCTION CAPACITY OF SYNTHETIC LIQUID FUEL

Geothermal Energy

Geothermal energy is only in minimum use in the United States. However, vast potential resources exist in the earth that could be utilized--dry steam, high and low enthalphy geothermal waters, hot dry rock, and geopressured reservoirs. Geothermal exploration and research has been actively pursued by commercial and by government agencies, principally in the western United States.

Full-scale utilization of geothermal energy will not take place, according to the Project Independence report, until after the 1990s. Factors in applying this technique include coordinated federal and state government plans, resolutions of tax disparities, restructuring of the utility rate base to make geothermal plant investment attractive, and appropriate legal decisions with respect to the ownership and legal category (whether gas, water, or mineral) of geothermal resources.

Solar Energy

Technological advances in the solar energy field and increasing costs in the prices of other energy sources have combined to make the potential of solar energy substantially more competitive. Commercial development has previously been impeded by storage and high capital cost requirements, but there is increased support for solar research and development both by government and by industry. Wind energy systems are expected to be economically viable in a few years. Photovoltaic systems (solar cells) are expected to have applications in rooftop uses and in central power station facilities. Bioconversion of fuels entailing recycling of urban and agricultural wastes or the use of biomass farms both terrestrial and marine are also applications of high potential.

The Project Independence study assumed the successful completion of a $1 billion accelerated R&D program in this area during the next five years. Factors in the application of solar systems include their acceptance by consumers, the requirement for storage capability in most systems, the need for conventional backup systems during periods of inadequate storage capability, and the availability of financial and regulatory incentives such as tax credits and exemptions, guaranteed loans, and land availability.

Long-Term Energy Projections

Beyond 1985, it appears that the most serious constraint on energy consumption is the amount of recoverable oil and gas in the ground. Because of a shortfall beginning in the 1980s and lasting through about 2000, synthetic liquid gas and gas from coal or shale are the most readily available domestic sources for replacement, but both coal and shale and the water needed for processing are also limited on a long-term basis. Electrical power does not appear to be so severely constrained either by resources or by technology within the next 20 to 30 years, since a number of existing sources and hopefully new ones will be developed--geothermal steam and hot water, organic wastes, and the breeder reactor, fusion, and solar energy. In general, the long-term analysis shows the following basic trends under any combinations of demand and supply options:

- Oil and gas will become increasingly scarce.
- Shale oil and synthetics from coal will be needed to make up for the long-term shortage.
- Conservation will be essential in the long run.
- Increased reliance on electric power will be necessary, and this probably means nuclear power or other sources and improved technologies.

Additional Perspective

SRI has engaged extensively in research in the field of energy over the past quarter of a century. Results of SRI work have not always agreed with the findings of Operation Independence. In part, this is attributable to the use of different basic assumptions and, in many studies, to the objective of looking over a longer time period than was used in the Project Independence work.

The most commonly accepted SRI position assumes that:

- Balance of payments considerations will force the United States to restrict imports of petroleum fuels to a level below the present 37 to 40 percent.
- Despite the strength of OPEC and the possible use of oil as a political weapon, adequate supplies of foreign oil will be available to the United States at prices competitive with domestic resources.

- Rising prices will reduce demand in user categories where conservation is possible.

SRI research has led to the following conclusions:

- Rising prices and adjusting environmental goals and guidelines will provide the supplies of energy necessary to maintain the economic health of the United States.
- GNP in real terms will be able to grow at an average rate of about 4 percent per year to 1990 without constraint from insufficient energy supplies.
- After a relatively short delay of a few years, environmental cleanup will continue to be implemented. Even before 1990, it is likely that air and water quality will reach acceptable levels.
- With end-use control on the use of natural gas for power generation, gas will gradually be phased out of power plants and some major industrial boiler fuel uses. Thus, supplies of natural gas will be adequate for petrochemical, residential, commercial, industrial, and transportation uses. The need for SNG from oil and coal is considered questionable.
- The potential supply of coal by 1990 will be substantially greater than demand; however, if U.S. coal resources can be transported and utilized to the extent that they can be mined in 1990, petroleum imports in that year can be substantially reduced to about 6 million barrels per calendar day. However, this high coal utilization will represent a massive undertaking, and it will require planning activities at unprecedented levels. The probability of this occurring is considered low.

SRI envisions that the goals of Operation Independence are more likely to be attained in the early to mid-1990s, rather than the mid-1980s. If the United States adopts a national energy policy to fully utilize its available resources at a moderate rate, energy selfsufficiency can be achieved in the early 1990s while meeting needed social goals--expanded economy and environmental protection. Energy selfsufficiency is defined as limiting imports to a level such that their sudden curtailment will not seriously disrupt the economy; a reasonable level of energy imports probably is desirable. There is only limited evidence of the development of a strong national policy at this time.

IV SHEET METAL WORK IN THE CONSTRUCTION INDUSTRY

Introduction

Several nonsolar energy related developments in the construction industry will probably have significant impacts on the level of sheet metal worker employment over the next decade. The discussion focuses on significant changes in the technologies of heating, air conditioning, and ventilation of buildings and plants that are expected to occur as a result of energy economics and changes in the HVAC state of the art. This analysis demonstrates that these technological developments on balance will have a positive bearing on the level of sheet metal worker employment, but that the various sectors of the construction industry will be affected differently.

Because construction statistics are available on the basis of types of building, the analysis is structured on similar lines rather than on the changing technologies per se, since this enables impacts on employment to be determined more readily.

According to data provided by the Union, employment in September 1974 was distributed as follows:

Building Trades	97,875
Railroad	7,691
Production	51,330
Other	5,377
Total	162,273

Workers in the building trades thus account for 62 percent of total Union membership (excluding "Other"), compared with 33 percent employed in production work, and 5 percent employed in railroad work. Accordingly, the analysis, which related to heating, air conditioning, and ventilation of buildings and plants, has a direct bearing on 62 percent of the current Union membership. Energy related phenomena (exclusive of solar) do not appear to bear directly on the volume of sheet metal work that can be expected in factory production and railroad construction/repair activities.

Status of Sheet Metal Work

To analyze the effect of changing technology on sheet metal worker employment, it is necessary first to determine the level of construction, both historical and forecast. Also, on the basis of the proportion of construction accounted for by HVAC, and the proportion of HVAC accounted for by sheet metal work, it is then possible to derive a base level from which change in sheet metal work can be estimated.

Table 10 shows the volume of construction by U.S. Census building categories at five-year intervals between 1960 and 1985. Because the figures are in constant 1975 dollars, the results of the analysis are free from the effects of inflation. Thus, likely impacts on sheet metal worker earnings resulting from a given technological development, are expressed in real changes in earnings.

The most significant aspect of Table 10 is the absolute importance of residential construction throughout the past 15 years, and this is projected to continue in the decade ahead; residential construction represents 48 percent of all construction in 1975 and is estimated to be 45 percent of total construction in 1985. This is considered to be too large a segment of the market for the Union to neglect.

Table 11 is a profile of the distribution of sheet metal worker earnings (before income taxes) by type of building for 1975, which is also the base year for subsequent analyses. The table indicates how the level of sheet metal worker earnings by type of construction were calculated. Total sheet metal labor earnings (Union and nonunion) in 1975 are estimated at $1.822 billion. This compares with total wage earnings of $587 million in the production sector.

The source for total earnings for 1975 from the production of sheet metal is the 1972 Census of Manufactures, MC72(P)-34C-4. This report gives the total earnings for sheet metal workers in 1967 and 1972 engaged in the production of sheet metal work for buildings and of sheet metal stovepipe, light tanks, and other products included in the Standard Industrial Classification (SIC) Code 3144. To arrive at the 1975 estimate of $587 million, the 1972 estimates were extrapolated on the basis of historical growth rates and the result was converted to 1975 dollars. The table also indicates that in excess of 43 percent of sheet metal labor dollars in the construction industry are accounted for by the residential sector, an area where the Union is not strongly represented. Certain exceptions, as in Detroit, indicate that lack of organizational success in the residential area is not due to the inherent nature of residential construction but more likely reflects Union priorities either implicit or explicit.

Table 10

LEVEL OF CONSTRUCTION BY BUILDING CATEGORY, 1960-1985*
(Billions of 1975 Dollars)

Building Category	1960	1965	1970	1975	1980	1985	Average Annual Growth Rate, 1960-1985 (percent)
Residential	$ 42.8	$ 47.4	$ 43.6	$ 43.2	$ 47.0†	$ 52.0†	0.78%
Single unit‡	34.3	37.0	29.1	28.3	23.0	21.0	-1.9
Multiunit	8.5	10.4	13.9	20.5	23.0	31.0	5.3
Industrial	5.4	8.5	8.2	7.1	8.0	9.8	2.4
Commercial	8.2	11.3	12.2	13.6	15.0	17.4	3.1
Office Building§	3.6	5.1	5.5	6.1	7.0	8.3	3.4
Stores	4.5	6.2	6.6	7.4	8.0	9.1	2.9
Power plants**	4.1	4.9	6.2	7.6	9.0	11.4	4.2
Educational (public)††	5.5	7.4	7.1	6.5	7.0	7.6	1.3
Hospital and institutional‡‡	3.3	4.4	5.4	5.4	7.0	7.7	3.4
Other	8.1	9.8	7.7	7.3	8.2	8.8	0.3
Total	$128.3	$152.4	$145.5	$154.0	$162.2	$184.1	1.52

*Unless otherwise indicated, the source for these numbers is Predicast, Issue #58, January, 1975. The historical data in the Predicast tables are from the U.S. Bureau of the Census, Construction Reports, Series C30. Series C30 data are not entirely consistent with the data found in the U.S. Census of Construction Industries, for reasons noted on page 2 of the "U.S. Summary" of the 1972 Census of Construction Industries, CC72(P)-28. In particular, we feel that the Predicast numbers may be low and that therefore there may be a conservative bias to our subsequent analysis.

†Source: SRI.

‡The breakdown into single and multiunit structures over time is consistent with the U.S. Industrial Outlook, 1974, With Projections to 1980, U.S. Department of Commerce.

§This assumed 45%:55% ratio of expenditures on office buildings to expenditures on commercial complexes is consistent with data for 1967-1972.

**From the Statistical Abstracts of the United States, 1974, U.S. Department of Commerce. Estimates beyond 1970 assume a 4.2% average annual growth rate for power plant construction.

††While the Predicast forecasts detail expenditures on public educational construction, expenditures on private schools are not detailed. Presumably, these latter expenditures are part of the category entitled "Other."

‡‡SRI assumed the level of construction activity in this category to total 40% of the level of activity in the commercial sector. This is consistent with data appearing in the "U.S. Summary" of the 1972 Census of Construction Industries, CC72(P)-28 (page 4).

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Table 11

SHEET METAL WORKER EARNINGS BY TYPE OF BUILDING, 1975

Type of Building	Construction Receipts* (billions of 1975 dollars)*	Percent of Receipts Allocation to Heating, Ventilating and Air Conditioning†	Percent of Total HVAC Cost Allocated to Sheet Metal Work‡	Labor Factor (percent)	Union and Nonunion Sheet Metal Worker Earnings (millions of 1975 dollars)
Industrial	$ 7.11	13.2%	21%	50%	$ 98.54
Office buildings	6.20	13.5	37	50	153.89
Hospitals and institutions	5.40	16.8	46	50	207.58
Stores	7.40	13.1	42	50	204.29
Schools	6.50	14.3	30	50	138.96
Power plants	7.60	3.1	70	50	82.28
Low-rise residential**	39.70	7.0	55	50	763.42
High-rise residential	3.50	7.0	25	50	30.42
Other	7.30	13.1	30	50	142.82
Total					$1,822.21

*Figures in this column are from Table 10 except for those for low- and high-rise residential.

†From 1975 Building Construction Cost Data, R. S. Means.

‡Based on consultation with large mechanical and electrical contracting firms. The labor and material factor varies from 45 to 55 percent depending on the type of building; therefore, 50 percent is a reasonable estimate in all cases. The "material" factor includes associated airside equipment (ducts, fans, vents) but not heavy equipment.

§Assumed that high rise expenditures amount to 9 percent of total residential expenditures. This is consistent with the "U.S. Summary" of the 1972 Census of Construction Industries.

Source: SRI

Effect of Technological Developments on Sheet Metal Worker Employment and Earnings

Several technological developments in the heating, air conditioning and ventilating industry are expected to have an impact on sheet metal work in the coming decade. Since the discussion is organized around four different types of buildings, it is possible to relate the technological changes to construction and to sheet metal employment. The building types are:

- Core-type buildings--these are edifices with extensive zoned interior space. This category includes most office buildings, banks, hospitals, and institutional buildings.
- Commercial complexes--this category includes shopping centers, stores, and schools. (Large department stores are included in the first category above.) The distinguishing characteristics of buildings in this category are either a small portion of interior space (i.e. most rooms will have windows to the outside, as in schools), or else--if the interior space is large--it will be unzoned (i.e. free from partitions, as in discount stores).
- Industrial plants.
- Power plants.

Core-type Buildings

Construction of buildings in the core-type category is expected to grow more rapidly than in any other sector of the construction industry, except for power plants and multiunit residential as indicated in Table 11. The growth rate at 3.5 to 3.8 percent annually is approximately double that of total construction industry.

Until 1970, at least 90 percent of all HVAC installations in core-type buildings has been one of five traditional types of systems. These are defined briefly below, although there are numerous variations and modifications to these systems.

- Induction systems--in an induction system, two different kinds of air are used for ventilation, heating, and cooling. First, ducted air is delivered to the room from the central plant. The other kind of air is "induced air", that is, room air that is cooled (heated) locally by means of a water cooling (heating) coil, or a similar device.

- Traditional fan-coil systems--these hydronic systems are frequently installed in the perimeters of core-type buildings. The cooling (heating) medium is usually running chilled (heated) water.
- Dual duct systems--these are typically medium pressure, high velocity systems that feature two ducts. One duct transmits cool air and the other transmits warm air. The air from these ducts is blended in a mixing box just above the point of emission of air into the room.
- Multizone systems--multizone systems are quite similar to dual duct systems. However, instead of mixing the air streams at a place adjacent to the point of emission, the air streams are mixed at or near the main air-moving device in the system, i.e., near the fan and coils in the equipment room. From that point on, a single duct is ordinarily used to transmit the air.
- Terminal air reheat systems--these systems might well be called "maximal cooling" systems; since the air that is delivered to each room in the building is chilled down to the maximum degree necessary to ensure that any room in the building will be as cool as desired. Because the constant volume air stream of chilled air will make many rooms too cold, air in such rooms is reheated locally.

From about 1970, the trend has been away from these traditional systems toward the use of more sophisticated "variable volume" air-based systems. In these systems, a thermostat serves to throttle down the flow of air into a room to keep the temperature at the desired level.*

The primary reason for the trend toward variable volume lies in energy economics. The traditional systems detailed above are not especially energy efficient. Terminal reheat systems and dual duct systems are highly inefficient from an energy standpoint. Terminal reheat systems are run for a maximal cooling load. With a modern variable volume system, cooling is matched to the requirements of each room in the building. The horsepower load on the central fans is substantially relieved at any given time.

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*The variable volume system is not particularly new. Versions of it existed in the 1930s. However, in its early days it was often unpopular because of uncomfortable "downdraft" problems. Today, the downdraft problem--and other problems--have been solved. Air is sent horizontally across the ceiling of the room in such a way to ensure that uniform thermal mixing is achieved.

It is normal to find many of the air outlets throttled down and emitting very little air. Also, there is less air to be cooled by the equipment in the central station. This also saves energy and reduces the size of the central equipment that is needed for the building.

An emphasis on energy saving HVAC equipment has already surfaced. For example, the 1975 Construction Guidelines of the General Services Administration (GSA) forbids the installation of terminal air reheat systems and of systems that mix hot and cold air for control purposes in any new GSA buildings. It should be noted that the GSA is the largest owner and operator of core-type buildings in the country.

The foregoing discussion does not imply that the only attraction of variable volume systems is their energy efficiency. Another reason for their attractiveness is that they require somewhat less ductwork than dual duct systems.

SRI estimates that as of the current year (1975), variable volume systems account for 28 percent of the market share in core-type buildings. Moreover, since this system is more energy efficient that traditional systems, this share is expected to grow significantly in the next decade to an estimated 54 percent of all systems installed in the year 1985.

The impact of the trend toward variable volume systems over the next decade is traced in Tables 12 and 13. Table 12 shows SRI's estimates of market shares for the various types of HVAC systems in both 1975 and 1985. Table 13 displays the percentage of total HVAC work in a typical hospital and office building accounted for by sheet metal work as a function of the type of HVAC system installed. As one would expect, the percentage is highest for dual duct systems--these use the most ductwork--and lowest for fan coil types.

The tabulation below shows the result of computing the average percentage of total HVAC work in a typical office building/hospital accounted for by sheet metal work in two cases: the case corresponding to the 1975 market share mix, and the case corresponding to the 1985 market share mix (as shown in Table 12). These percentages are calculated by a weighted average of the percentages appearing in Table 14; the "weights" are the entries in Table 12 for 1975 and 1985.

System Mix	Office Building	Hospital
1975	37%	46%
1985	40	49

Table 12

ESTIMATED MARKET SHARE
OF AIR CONDITIONING SYSTEMS
FOR CORE-TYPE BUILDINGS, 1975 and 1985
(Percent)

Type of System	1975	1985
Variable volume	28%	54%
Dual duct	24	15
Induction	18	11
Multizone	12	9
Fan-coil	10	7
Air reheat	8	4

Table 13

SHEET METAL COST AS A PERCENTAGE OF HVAC COST
FOR CORE-TYPE BUILDINGS

Type of System	Office Building	Hospital*
Variable volume	42%	51%
Dual duct	45	54
Induction	30	39
Multizone	40	49
Fan-coil	20	29
Air reheat	38	47

*It is assumed that the percentage of sheet metal work in hospitals is 9 percent greater (as a percentage of total HVAC work) than in office buildings.

This information and that from Tables 10-13 were used to calculate the growth in sheet metal earnings in the construction of core-type buildings. This growth is tabulated below at both levels of earnings (in millions of 1975 dollars).

System Mix	1975 Construction Level			1985 Construction Level		
	Office	Institutional and Hospital	Total	Office	Institutional and Hospital	Total
1975	$154	$208	$362	$197	$300	$497
1985				214	320	534

Total sheet metal worker earnings from the construction of core-type buildings rise from a 1975 total of $362 million to an estimated 1985 total of $534 million,* an increase of 48 percent in real (1975) dollars. The two distinct sources of this growth are growth of 37 percent due to an expansion of the volume of construction of core-type buildings and growth of 11 percent due to the increase in sheet metal work associated with the trend toward variable volume systems. A comparison of the two totals shows that if it were not for the trend toward variable volume systems, the projected 1985 total would be $497 million rather than the projected $534 million.

Commercial Complex-Type Buildings

The trend over the past two and a half decades has been toward "packaged," prefabricated rooftop climate control units in the 50-ton range. Developers have been attracted by the flexibility of these systems, which permit individual operation and individual metering of utility charges to tenants.

Despite the growth in market share accounted for by these systems over the past years, it is expected that during the next decade there will be a moderate shift away from small rooftop units toward larger rooftop units of 100-tons and up, and central station equipment. Several reasons account for this shift.

- In general, the larger the system, the more energy efficient it is. Specifically, the cost of electricity per Btu of heating/cooling falls off significantly with the size of the installation--at least over a reasonable range of tonnages.

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*SRI believes this is a conservative estimate, because the estimates of current and future construction by building type that underlie these numbers (and that are tabulated in Table 11) may be low.

- The installation costs associated with larger systems are less for a shopping complex or school of any reasonable size.
- The larger the system, the more reliable and long-lived it tends to be. (This is especially true when central station equipment is contrasted with conventional rooftop equipment.)
- Developers are becoming more sophisticated in the cost/benefit analyses they perform when deciding which type of system to install. In particular, they are leaning toward "lifecycle costing" which, in light of the factors above, makes larger systems that much more attractive.
- In the case of some central station systems currently being installed, there are gains, not only in energy efficiency, but also in flexibility. Sophisticated automatic control systems make it possible to direct cooling/heating to portions of the complex that need it--and only to those portions. Cool air can be dispatched to the southwest exposure, with warm air (often reclaimed at the point of central station cooling) being sent to the northeast exposure.

Based on the field work undertaken it is considered that the market shares of various types of air conditioning systems for commercial complex-type buildings will change, as shown in Table 14.

Table 14

ESTIMATED MARKET SHARE OF
AIR CONDITIONING SYSTEMS FOR
COMMERCIAL COMPLEX-TYPE BUILDINGS,
1975 and 1985
(Percent)

Type of System	1975	1985
Rooftop, 50-ton	65%	45%
Rooftop, 100-ton	15	25
Central	20	30

Source: SRI.

The impact on sheet metal work associated with this trend toward larger systems should be favorable on balance. Table 15 displays the percentage of total HVAC work in the two types of buildings analyzed--commercial buildings and schools.

Table 15

SHEET METAL COST AS A PERCENTAGE OF HVAC COST FOR COMMERCIAL COMPLEX-TYPE BUILDINGS

Type of System	Commercial	School
Rooftop, 50-ton	40	28
Rooftop, 100-ton	45	33
Central	50	38

Source: SRI

Several reasons account for the increased sheet metal work associated with central station equipment. First, the decision to install a central system usually goes hand in hand with a desire for better air quality and air control. This in itself implies more ductwork and associated airside equipment. More pertinent, however, is the fact that central station units have larger air handling equipment, which implies more extensive--and heavier--ductwork.

The tabulation below shows the result of computing the sheet metal cost as a percentage of total HVAC work averaged for the system market share for a typical commercial complex and school. The numbers are weighted averages computed as for the entries for the core-type buildings.

System Mix	Commercial	School
1975	42%	30%
1985	45	33

The impact of the trend toward larger systems on sheet metal worker earnings is assessed in the following tabulation. It displays the level

of total sheet metal worker earnings from the construction of the commercial complex-type buildings--as a function of the trend previously discussed (millions of 1975 dollars).

	1975 Construction Level			1985 Construction Level		
System Mix	Commercial	School	Total	Commercial	School	Total
1975	$204	$139	$343	$261	$163	$424
1985				280	178	458

Earnings grow in real terms from $343 million in 1975 to $458 million in 1985, an increase of about 34 percent. The tabulation permits isolation of the portion of this increase that is directly attributable to the trend toward larger systems as opposed to the increase in construction activity charted in Table 11. If it were not for the trend toward larger systems, total earnings in 1985 would be some $424 million rather than $458 million.

Industrial Plants

Although it is difficult to generalize about trends in the heating, ventilating, and air conditioning of manufacturing plants, the trend toward increased air conditioning of plants is one development that has a significant bearing on projected sheet metal work in this sector of the construction industry.

There are several explanations for this development. Increasing numbers of workers are coming to expect air conditioning, for a variety of sociological reasons. Moreover, unions are backing up these workers in their demands for greater comfort. Office blocks in plants are increasingly air conditioned, as are special areas such as computer rooms and research laboratories where controlled atmospheres are required. From the standpoint of the other side of the bargaining table, management is becoming aware of the fact that significant productivity gains can be associated with the improvement of working conditions made possible by air conditioning. This is especially true as the proportion of the work force that is engaged in sophisticated light industrial activity (computer manufacturing and electronics) grows. In this kind of work, the productivity gains from air conditioning more than pay for the cost of air conditioning.

SRI's estimate of the current (1975) and projected share of new plant construction that is or will be air conditioned* is shown below.

	1975	1985
Not air conditioned	50%	25-35%
Air conditioned	50	65-75

It is straightforward to ascertain the impact of the trend portrayed above on projected sheet metal work. The percentage of total HVAC work accounted for by sheet metal work as a function of whether a (typical) plant is air conditioned or not then is calculated as:

Type of System	Percentage Sheet Metal Work
Not air conditioned	13%
Air conditioned	30

The tabulation below shows the average percentage of total HVAC work accounted for by sheet metal work as a function of the market share mix (as between air conditioned and not air conditioned) that prevails.

System Mix	Percentage
1975	21%
1985	23-26

From these calculations, the implications of the trend toward more air conditioning on the projected level of sheet metal worker earnings have been computed in millions of 1975 dollars as shown below:

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*Approximately 12 percent of all existing plants are currently air conditioned. In this discussion, heavy plant construction is combined with light plant construction.

System Mix	Construction 1975 Level	Construction 1985 Level
1975	$99	$136
1985		146-162

Between 1975 and 1985 real earnings increase in the optimistic case by 64 percent from $99 million to $162 million. Of this increase, $26 million is due solely to the trend toward greater use of air conditioning in industrial plants.

Power Plant Construction

Total installed generating capacity in the United States currently amounts to 452 gigawatts. This is expected to grow at an annual rate of 4 percent over the next decade to an expected capacity of 669 gigawatts in 1985.

At present approximately 35 percent of new capacity added is nuclear. SRI energy experts expect this percentage to grow to 55 percent by 1985. A typical nuclear plant will require twice as much dollar expenditure on sheet metal work as a conventional fossil fuel fired plant. However, since the capacity of the nuclear plant is twice that of the conventional plant, there will be no net effect on the total amount of sheet metal work resulting from a shift toward nuclear energy. Sheet metal work expressed as a percentage of megawatts of capacity added is constant, irrespective of the type of plant constructed. This can be seen from the fact that the sheet metal worker earnings from construction of a typical nuclear plant (1,000 megawatts) amount to $3 million in 1975 dollars as contrasted to $1.5 million in the case of a conventional plant (500 megawatts).

There are several reasons why nuclear plants use more sheet metal work:

- Ventilation--In the "containment area" (which houses the reactor), the purge system that filters out radioactive particles will have to be airtight. Joints will have to be completely welded instead of being riveted. Sheet metal workers perform this work.
- The sheet metal used will be of heavier gauge.

- Atomic Energy Commission regulations require three separate ventilation and air conditioning systems in the three principal areas of the power plant, namely the containment area, the auxiliary area (which contains the radioactive waste and fuel handling equipment), and the turbine area.
- Nuclear plants may have some prefabricated panel work. If the sheet metal workers claim the installation of such paneling as within their jurisdiction, there is that much more sheet metal work for them.

The trend toward nuclear installations should have virtually no impact on the total level of sheet metal worker earnings over the next decade--notwithstanding the fact that a nuclear plant will require twice the sheet metal work of a conventional plant. The reason for this is simply that the capacity of a typical nuclear plant (1,000 megawatts) is twice that of a typical fossil fuel fired plant (500 megawatts). To provide a given increment of generating capacity, only half as many nuclear plants need be built as conventional plants.

Thus, any increase in sheet metal worker earnings from power plant construction over the next decade will come from growth in the construction of power plants, of whatever type.

It has been noted that an annual growth rate of 4 percent in installed generating capacity is expected over the next decade.* This expectation is reflected in the estimates of total annual expenditures for the construction of power plants in 1975 and 1985 appearing in Table 11 ($7.6 billion in 1975, $11.4 billion in 1985). By applying the cost factors characterizing power plant construction that appear in Table 12 to these dollar figures, the following estimates have been calculated for growth of sheet metal worker earning power: $82 million at the 1975 level and $125 million at the 1985 level. This amounts to a growth of 50 percent in constant dollars. It is emphasized that all this growth is accounted for by the increased activity in power plant construction and not by the trend toward nuclear power.

Other Developments

Several technological trends and related developments will have, at most, a slight impact on sheet metal work.

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*Four percent is perhaps more optimistic than some experts have forecast. Should prices of power continue to rise and conservation efforts succeed, the demand for power may increase at an average annual rate of about 3 percent.

The Residential Market

The residential market consists of two different segments in terms of sheet metal related work--the high-rise and the low-rise segments, which include single family and multiple family residences. In the high-rise market, approximately a 15 percent share has traditionally gone to centrally circulated water-based HVAC systems. The remainder has gone to "split systems," a combination of systems. SRI does not expect this to change over the next decade.

It is anticipated that one development in the construction of low-rise housing may have a slight impact on the level of sheet metal work. There is a trend toward flatter roofs and reduced attic space. The flatter the roof, the less space there is for overhead ductwork. Associated with this trend is a shift away from the use of systems with single air handlers (i.e., blowers and coils) located in a central position in the house toward the use of systems with two air handlers. There is usually one handler at each end of the house. They can be operated independently, which saves energy. For example, one air handler might service the kitchen and dining area, with another handler servicing the living and bedroom areas. Each handler will have local ductwork running off it. However, less ductwork may be going across the entire house.

All in all, no major threats or opportunities are anticipated for sheet metal work in the residential sector; the status quo is likely to prevail over the next decade.

The Industrial Market

In the industrial market, a considerable increase in the amount of sheet metal work can be anticipated as a direct outcome of companies having to comply with Environmental Protection Agency guidelines relating to emissions into the atmosphere and FEA energy conservation programs. The latter especially can frequently be shown to have significant cost savings for companies. Wherever air is trapped for cleansing or recycling of heat, additional ductwork blowers and other equipment are required.

Large plants of large companies may not represent the greatest potential since they probably have in-plant capability. Small and medium-sized plants of small and medium-sized manufacturers are probably the best target market. This is an area of immediate potential where a cooperative program by the Union and the Sheet Metal and Air Conditioning Contractors National Association (SMACNA) could have significant benefits to the industry.

The Heat Pump

The heat pump should begin to gain more widespread acceptance in residential, commercial, and institutional applications. The heat pump has become much more efficient that it used to be. It now has a coefficient of performance of 2.5 in climates that are not excessively cold in winter. The solar-assisted heat pump (which is currently on the drawing board) has an estimated coefficient of performance of 4.5. The heat pump is also attractive because it has a longer estimated life than several conventional systems and lower maintenance costs. The one drawback to the heat pump is that its initial cost is high relative to conventional systems. It is expected that the heat pump will be used as a piece of central equipment.

The essential point about the heat pump from the standpoint of this study is that its arrival should have little impact on the level of sheet metal work in the residential market. The central heat pump will simply replace traditional systems, e.g., gas or oil furnaces. The extent of ductwork required to transmit air throughout the house from the central station will not be affected by the nature of the unit.

"Sealant" Technology

Labor-saving technological progress is taking place in the technology of the "sealing" of ductwork joints. Typically, chemical-sensitive tape is wrapped around joints. Heat lamps are being used to shrink the tape into airtight "boots" that seal the joint. This operation replaces more time-consuming and traditional ways of sealing joints (such as the use of nonshrinkable paste-like sealants).

SRI sources estimate that in a typical core-type building, 50 percent of the sheet metal work goes into branchwork, i.e., into the ductwork that is found immediately above the rooms and corridors. Of the total amount of branchwork hours, 25 percent will be devoted to sealing joints and ducts, provided that traditional methods of sealing are used. Typically, it has required 10 to 15 minutes to seal a joint. With the new techniques described above, this time can be reduced to an estimated 3 minutes. The net effect of this could be a reduction of to 18 percent in the total branchwork hours of sheet metal work.

Air Purification Systems

The combination of the increasing price of energy and possible legislation mandating a reduction in the amount of energy used by HVAC

systems in large buildings and plants may signal an increase in the installation of sophisticated air purification systems. These purification systems would serve to reduce the required ventilation load. Moreover, since increased quantities of room temperature air could be recirculated, there would be a reduced need for heating and cooling capability. All in all, the impact of this development would not be favorable for sheet metal work. However, the negative impact such as it would be very slight. One estimate obtained suggested that the total amount of sheet metal work in a typical core-type building would be reduced by 3 percent.

Insulation Standards

The increasing price of energy in conjunction with possible federal and state legislation may result in the superior insulation of office buildings, plants, and homes. The impact of this development would imply smaller scale and possibly even less ductwork, other things being equal. However, the extent of this impact is expected to be slight.

Use of Plastics

In recent years, plastic components have replaced certain HVAC components that were traditionally made of sheet metal. For example, it is possible to install flexible plastic ductwork. To the best of our knowledge, the sheet metal workers have claimed and will be able to claim the installation of such substitutes as work falling within their jurisdiction. It goes without saying that the Union should be vigilant in seeing that it establishes jurisdictional priorities wherever possible. The situation in Hawaii, where sheet metal training in the fabrication of plastics has automatically resulted in sheet metal workers getting such work, is illustrative. In point of fact, the substitution of plastic for sheet metal components may level off. The reason for this is that fire codes may proscribe the use of plastics that emit toxic gases during fires. This is a minor point, and it has not been investigated in any detail.

The foregoing discussion is summarized by exhibiting the total projected sheet metal worker earnings in 1985 by type of building. Table 16 also makes clear the average annual growth rate of earnings between 1975 and 1985 by type of building.

Table 16

SUMMARY OF SHEET METAL EARNINGS GROWTH
(Millions of 1975 Dollars)

Type of Building	1975 Earnings	1985 Earnings	1985 Earnings Resulting from Technology Change	Average Annual Growth Rates, 1975-1985 (percent)
Industrial	$ 99	$ 162	$28	5.0%
Office	154	214	17	3.3
Hospital and institutional	208	320	20	4.4
Stores	204	280	19	3.2
Schools	139	178	15	2.5
Power plants	82	123	--	4.1
Low-rise residential	763	924	--	1.9
High-rise residential	30	36	--	1.8
Other	142	173	--	2.0
Total Earnings	$1,821	$2,410	$97	2.8

Source: SRI.

The analysis indicates that, of the total increase of $589 million over the coming decade, about 16 percent, or $97 million is directly traceable to anticipated technological change. The biggest growth will occur from the overall growth of the construction industry itself.

V SOLAR ENERGY HEATING AND COOLING

Introduction

Earlier sections of this report described the historical and future trends in the demand for and supply of energy and the impact of these trends on sheet metal work associated with the heating and cooling of buildings. This section deals with a particular aspect of this matter--the expected impact of solar energy technology.

The ways in which the sun's power may be used to provide domestic energy are generally grouped into the following technologies:

(1) Solar heating and cooling of buildings--the comfort heating and cooling of residential, commercial, and industrial building space, the provision of domestic hot water, and certain agricultural applications such as crop drying.

(2) Solar thermal conversion--In this technology, systems collect radiation from the sun and utilize it for industrial processes or in the generation of electrical power.

(3) Wind energy conversion--This application entails the use of wind power to drive a rotor device, which in turn drives an electrical generator.

(4) Bioconversion to fuels--This technology concerns the production by solar photosynthesis of plant material (biomass) and its conversion to clean fuels and other useful forms of energy. Ground and marine crops, agricultural waste, and urban solid waste provide sources of biomass.

(5) Ocean thermal conversion--This technique involves the extraction of heat from the surface waters of the ocean for use in a process similar to a refrigeration cycle, for the production of electrical power or chemical products.

(6) Photovoltaic electrical power systems--These systems use sunlight on light sensitive solar cells to produce electricity directly.

As indicated above, this report deals only with heating and cooling of buildings which are highly significant, in terms of fossil fuel

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conservation, since building heating and cooling utilize more than one-fourth of all the energy consumed in the United States. The other solar technologies described are not believed currently to be important factors in terms of sheet metal work.

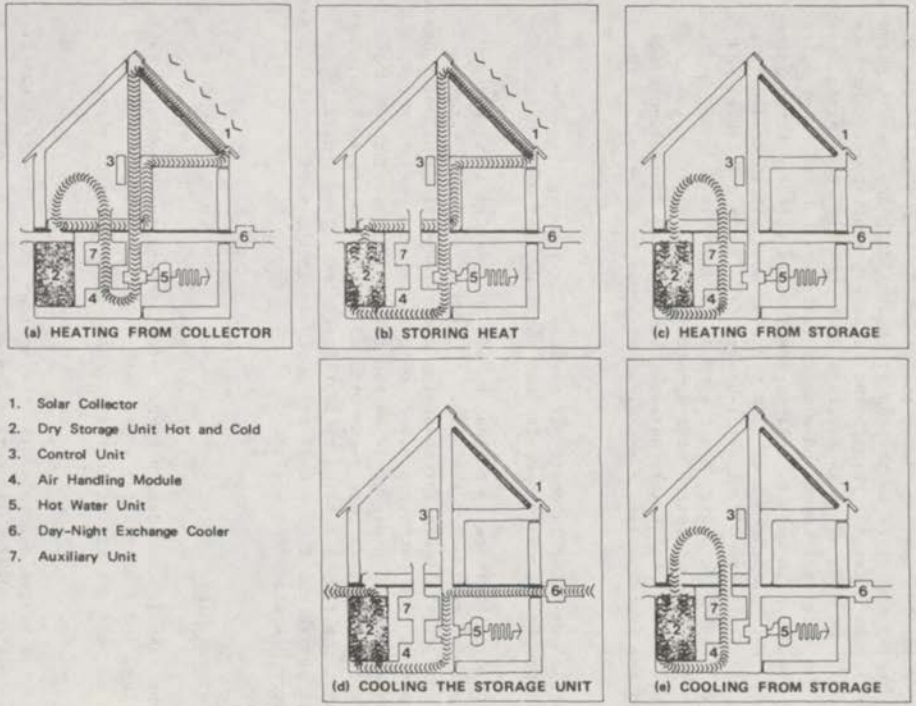
This section describes typical solar heating and cooling systems, discusses the state of the technology, particularly as related to construction techniques, discusses the economics of the systems, summarizes current activities in the field, and draws conclusions as to the estimated size of the market that is developing in this field. The political, economic, and social power and pressure points related to solar heating and cooling activities and their development also are considered, together with a consideration of the implications of solar heating and cooling development to sheet metal work and more especially to the Union.

Because solar heating and cooling are still very much in the development stage, the body of knowledge commonly accepted as authoritative is still relatively small. Hence, this report has drawn heavily not only on the limited number of scientific studies available in the field but also on material in industrial and popular literature and on personal discussions with leading designers, contractors, and researchers, backed up in some cases by on-site inspection of operational and demonstration systems in being or under construction. The research grants and work planned and in progress are given in Appendix A.

Typical Systems

For this study, a very significant aspect of the solar heating/cooling system is that it provides only a part (from 25 to 80 percent) of the heating and cooling energy needs of a house or building. This is because no reliable method has been developed for storing the solar energy needed to meet heating or cooling needs during a protracted period of sunless days. Therefore, a conventional auxiliary system is always needed. Except for its tie-in with the solar portion of the system, the backup system is no different from conventional heating and cooling systems. It may use gas, oil, coal, or electricity to generate the heat, and distribution systems may be forced hot water or forced air. In fact, some residences with solar systems also use wood stoves, fireplaces, or other individual space heaters as backup heating systems.

The principal functions of the solar portion of the heating/cooling system are the collection, storage, and distribution of heat from the sun. Figure 7 graphically traces the flow of heat through an air-type solar system. In mode A (heating direct from the collector) heat is picked up



SOURCE: Solaron Corporation, Denver.

FIGURE 7 FLOW OF HEAT THROUGH AN AIR-TYPE SOLAR SYSTEM

by a solar collector mounted on the roof (marked 1); the air in the collector is heated and rises to the top of the building and then is drawn down generally by a fan (4) through the auxiliary heating unit and into the room to be heated. Through a return duct, the air moves again to the bottom of the solar collector and when it rises again to the roof is reheated by the sun. In mode B, solar-heated air is directed through the storage unit which captures and holds the heat until it is needed (for instance, at night when direct solar-heated air is not available) and then distributes it as forced air into the room, as shown in mode C. Modes D and E illustrate the operation of a simplified cooling unit which draws cool night air in at inlet (6), passes it through the storage unit (2), and during the next day uses the cool storage medium to circulate the air.

Domestic hot water is heated by circulating the water to a coil mounted in the hot air duct opposite the auxiliary hot water unit (5).

The unit illustrated is called an "air" unit in that it uses air as the transporting medium for the heat. A "liquid" or "wet" system uses water or some other liquid for absorbing and transporting the solar heat; it would have a flow pattern similar to that pictured, except that the fluid flowing through pipes would be substituted for air through ducts. Air conditioning systems integrated with solar systems are somewhat more complex than the simple cooling cycle illustrated. They generally use coils that absorb the stored heat and apply it in the same way that a gas refrigerator operates from a flame.

Techniques Used

In the past few decades, a number of different techniques for capturing, storing, and distributing solar heat have been devised. Table 17 lists the methods identified in the HUD/NASA cooling demonstration program.

Among the system's components, the most extensive research has probably been done on solar collectors. The American Society of Heating, Refrigerating, and Air Conditioning Enginneers (ASHRAE) has described the principal types of collectors in a comprehensive study of currently available design data. The illustration of the 14 types described in the study is presented in Figure 8.

A brief explanation of the techniques may be useful in visualizing possible sheet metal craft potential.

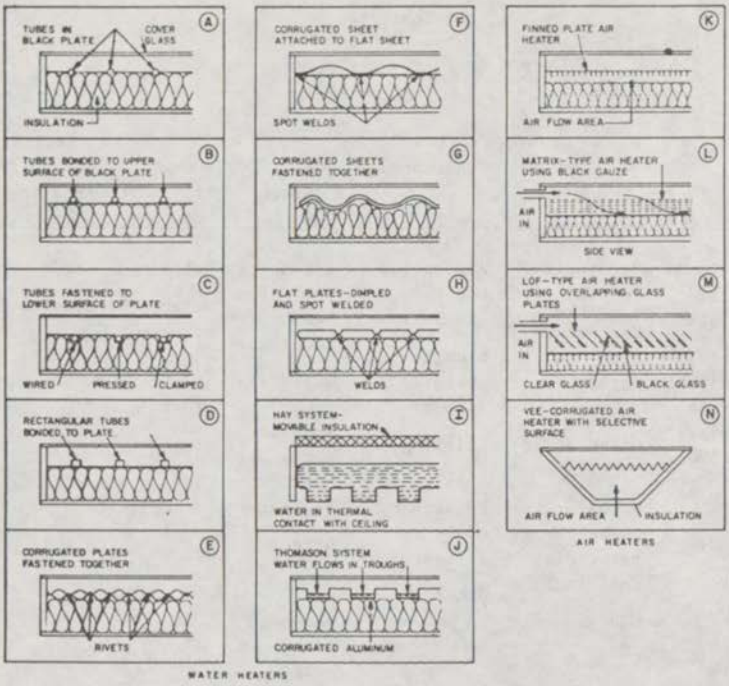
Table 17

TYPES OF SOLAR HEAT SUBSYSTEMS

Solar Collector	Thermal Storage	Heat Actuated Air Conditioner	Space Heater	Energy Transport Medium	Auxiliary Energy for Heating/ Cooling
Conventional flat plate with black paint	Pressurized hot water	Absorption cycles (Servel)	Air duct hot water heat exchanger	Water	Gas
Conventional flat plate with special absorptive coating	Unpressurized hot water	Rankine cycle (steam)	Wall/ floor mounted hot water heat exchanger	Water mixture	Electricity
Vacuum flat plate	Rock or other solid materials	Stirling cycle	Direct air heat exchange with solid storage material	Air	Oil
Tubular	Waxes or phase change materials (melting)	Dessicant cycle (air-drying)	Other	Other	Other
Direct water exposure	Other	Other			
Day heat					
Night cool					
Other					

Source: SHC-1001, Program Plan, Solar Heating and Cooling Demonstration Program (Residential Dwellings), HUD/NASA (Dec. 30, 1974)

Drawing A shows a bonded sheet design in which the tubes carrying the fluid are integral with the black plate heat absorber in the solar collector, thus guaranteeing a good thermal connection between the plate and the fluid transporting in the tubes. Drawings B and C show fluid collectors, with the tubes soldered or otherwise fastened to upper or lower surfaces of the metal plate. Drawing D shows tubing in a rectangular



SOURCE: 1974 APPLICATIONS HANDBOOK, American Association Society of Heating, Refrigerating, and Air Conditioning Engineers, 1974 (Reprinted in NSF 74-41).

FIGURE 8 VARIATIONS OF SOLAR WATER AND AIR COLLECTORS

format, which provides for more surface contact between the tube and the plate. Mechanical pressure, thermal cement, or braising may be used to make the actual assembly.

Drawings E, F, and G show different methods of fastening corrugated sheets of metal to provide fluid passages without special tubes. Drawing H features a method for use of parallel sheets of copper, aluminum, or galvanized steel to provide fluid passage by welding. (Such nontubular types of containers are not generally suited for U.S. systems because of the high line pressures frequently used.)

Drawing I pictures the Hay system, which uses plastic bags on a flat roof to contain water over a metal ceiling, with insulation above the water

surface that can be moved into place to prevent loss of heat. Additional heat dissipation may be obtained by evaporation through flooding the water bags to provide an uncovered, pond-like surface.

Drawing J shows an early system developed by Thomason, utilizing corrugated aluminum as the channels for water sun-heated while running from the top to the bottom of the roof and then piped to a basement storage tank.

Drawings K, L, M, and N illustrate collectors that use air as the transport medium and are specially designed to maximize the heat absorption of the air as it passes through the collector.

An additional type of fluid collector (not illustrated) is a trough shaped reflector that concentrates the sun's heat on a glass tube suspended above it; the inventor says this technique reduces the surface area requirements by 50 percent compared with flat plate collectors.

Copper piping is generally used in fluid systems between solar collectors, storage tanks, and auxiliary systems. Sheet metal ducts, usually insulated to minimize heat loss, are generally used for air/type systems. However, the study team talked with an air system developer who fabricated ducting from sheet rock. Another stated that with his system, which utilized spaces behind the walls through which to channel the air, metal ducting would be eliminated.

Storage tanks are made of various materials--wood, concrete, steel, and sheet metal--all heavily insulated and generally placed in a basement or buried underground. In fluid systems, heat is stored in water, ethylene glycol, light oil, or eutectic salts. Air systems use fist sized rocks, gravel, or salts.

The connections between the solar portion of the system and the conventional auxiliary portion are generally made at or near the storage tank. Their complexity is largely determined by the compatibility between the two parts of the system--i.e., if the solar portion uses air as the transport medium, it can feed directly into a forced air conventional system. If the auxiliary system uses hot water, the exchange of heat between air and water would require use of a heat exchanger (coil) in the air duct. A similar arrangement would be required for connection of a fluid-transport solar portion of a system to a forced air auxiliary system.

The different components have advantages and disadvantages, which are often significant in choosing a system for a particular application.

Since these factors also directly influence the choice of materials and techniques used in construction, it is considered useful to list the principal points identified during the study and relate them to the choices entailed in system selection.

With respect to sheet metal construction, the principal consideration is whether the system uses fluid or air as the medium for distribution of the solar heat. The most common arguments are as follows:

- A fluid system utilizes one collection and distribution medium. The storage system is easily installed and serviced. Supporters say it costs less than a fluid/heat exchange/air system, but opponents point out that copper piping costs more than sheet metal duct. A pipe system takes less space than ducting. However, there are leakage problems with fluid systems and freezing problems in colder climates. The use of antifreeze solutions increases costs and supply difficulties and generates corrosion problems.
- A dry system using rock storage eliminates the freezing problem. Its components are nontoxic, nonflammable, noncombustible, and readily available. However, the required ducting takes up more space than pipe; so does the rock storage, which is less heat-absorbent than fluid. Use of borax pellets increases heat absorbency but also increases expense. Use of gravel keeps expense down but increases resistance to air flow and requires larger fan units. Once rocks are in place, access to plumbing (e.g., the heat exchanger) is difficult.
- An air system requires larger collectors and higher fan speeds because of lower heat capacity of air compared with liquids. No entirely satisfactory air-based air conditioning system has been developed, because a heat-generated refrigerating cycle requires a higher temperature than an air system can readily develop.
- Use of eutectic salts for storage increases capacity per unit volume, thereby reducing storage space needs; but salts are corrosive and toxic, and repeated cycling breaks them down.
- Supporters of fluid systems say that they are cheaper than air systems to install, use less energy, and are cheaper to operate.
- Where solar systems are being added to existing systems, an additional factor is the characteristic of the conventional

system--whether is is fluid or air. Adding a solar air system to a fluid conventional system (or vice versa) will require the additional expense of a heat exchanger coil, with a likely probability of increased operating cost and some loss of efficiency.

Application of Selection Criteria

Because of the developing state of the industry, it is difficult to obtain a consensus with respect to the appropriate system for a given set of circumstances. Although there are supporters of older, time-proven systems, there are strong counterclaims that some of the older systems are not efficient. No system at this time has been acceptably proved nor is even generally acknowledged as the most promising system. Opinions are still changing, even in the industry. It is too early to determine dominant technological trends. Based on the work done by the study team, however, the following points of view are representative of the trends.

- Climate--Air systems are likely to be more efficient in colder climates where freezing would pose a problem to fluid systems and where air conditioning is not a necessity. Water systems have advantages in hot climates because they are more effective in the air conditioning mode.
- Environment--Because less maintenance is indicated for air type systems, they appear more desirable for rural areas where maintenance is difficult to obtain. Conversely, liquid systems are suited to larger cities where maintenance is available.
- Size of Building--In most small residences, a wet system appears preferable, because it requires a smaller storage area and less space is used in the distribution piping than would be used in air ducting. Larger residences could use a panel system. In commercial buildings and public buildings, space is also at a premium and designers interviewed leaned toward liquid systems for this reason. Supporters of air systems counter that in office buildings air ducting is a code requirement and could be used with a dry system.
- Retrofit--Where a solar system is added to existing construction, it appears generally desirable to utilize the system most compatible with the existing heating and cooling system, all other factors being equal.

- Economics--If the application of the criteria above provide no strong preference as to type of system, the economic consideration of costs both initial and life cycle will be especially significant. This aspect is discussed in detail later in the section.

It must be recognized that application of the criteria above is tentative, based on trends observed by the study team. Substantial research funded by NSF and ERDA is currently going on to provide more definitive bases for system selection--for example, in the area of thermal storage in solar systems, SRI is conducting a one-year study and ERDA recently convened a conference of several days of government, industry, and research organizations in Charlotesville, Virginia, to discuss thermal storage alternatives. More substantive indications should be available as a result of research current and planned over the next several years.

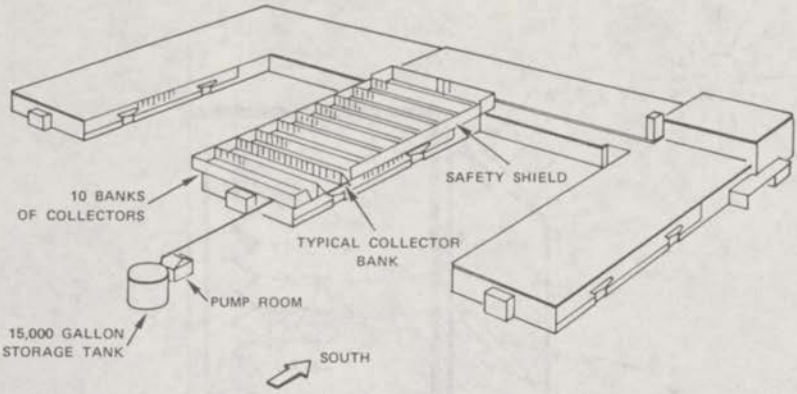
For purposes of construction estimates, a reasonable assumption is to consider that the proportion of fluid and air heating/cooling systems will not change substantially as a result of conversion to solar technology in this field. However, it is essential that the Union keep in touch with these trends as they develop over the next several years.

Operating Examples

The Timonium Elementary School in Baltimore is the first school in the United States to be heated by solar energy. Funded by the National Science Foundation, the project entailed the retrofit of an existing school building heated by a steam system to install solar heating equipment on one of three wings as shown in Figure 9.

Operation of the solar system began in March 1974. It is illustrated in Figure 10. Water warmed at the solar collection plants is transmitted through insulated pipes to a 15,000 gallon storage tank constructed from 6061-T6 aluminum, with sides rolled and welded. From there, the hot water is piped to 20 hot water forced air convectors in the school rooms and returns through the cold portion of the storage tank to the solar heat collection point again. The total cost of this retrofit program was approximately half a million dollars. Because it is primarily a water system, very little sheet metal work was required.

Among the early solar heating experimenters was H. E. Thomason of Washington, D.C. His system uses an "open" nonpressurized method of transporting solar heat, with corrugated aluminum as collectors as shown in Figure 11.



AREA CENTER WING (67 x 143)	9581 sq. ft.
SOLAR PANEL AREA	28 sq. ft.
AREA OF SOLAR COLLECTOR (180 PANELS)	5049 sq. ft.
RATIO OF COLLECTOR AREA TO FLOOR AREA	0.527
STORAGE - HOT WATER VOLUME	15,000 gal.
RATIO OF STORAGE VOLUME TO COLLECTOR AREA	2.98 gal./sq. ft.

AVAILABILITY OF SOLAR HEATING (@ 40% EFFECTIVENESS) TO HEATING REQUIREMENT - %

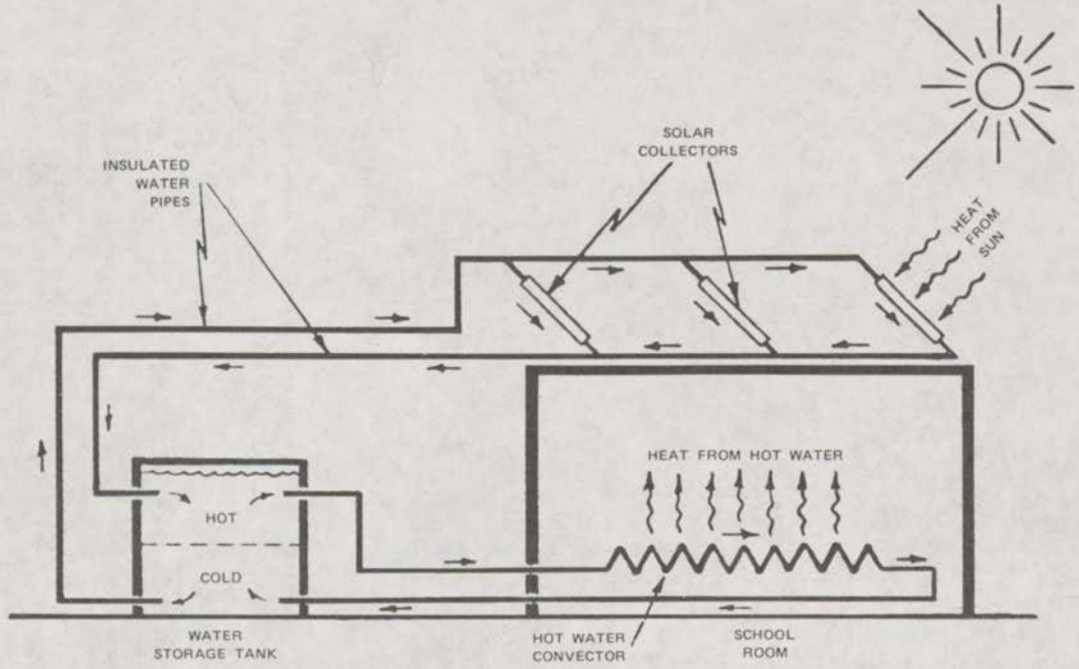
OCTOBER	300%	JANUARY	52%
NOVEMBER	105%	FEBRUARY	94%
DECEMBER	50%	MARCH	160%

SOURCE: NSF Report ER-7934, June 1974

FIGURE 9 SOLAR ENERGY EXPERIMENT, TIMONIUM ELEMENTARY SCHOOL, BALTIMORE

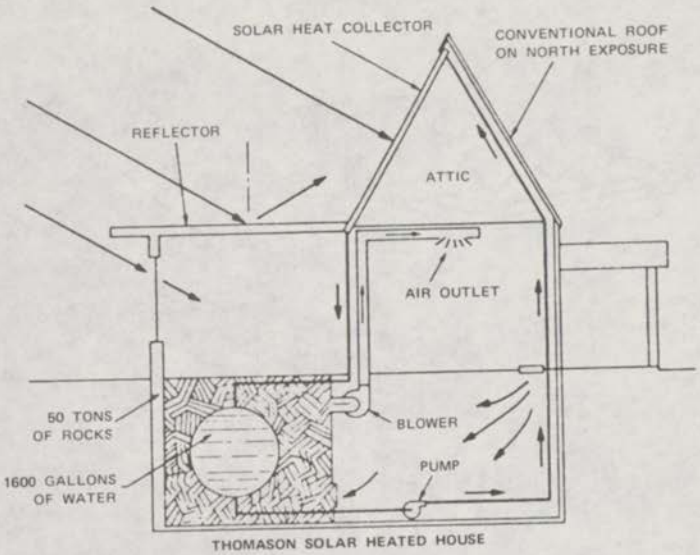
Figure 12 shows the Thomason solar house. The system specifications, drawn from Shurcliff's Solar Heated Buildings: A Brief Survey, are summarized below.

Thomason Solar House, built in 1963 by H. E. Thomason, inventor, owner--It is one story (plus basement) 4-bedroom house (74 feet x 44 feet) with 1500 square feet heated in winter, plus swimming room, game room. Collector (about 60 x 15 foot area, 900 square feet) is tilted 60° from horizontal. Water from horizontal distribution pipe trickles down 1-inch wide valleys (2-1/2 inches apart on centers) in a blackened aluminnum sheet under single glass sheet. Water is collected by gutter flows to a concrete-block, rectangular (45 inches x 45 inches x 25 feet), 2500 gallon tank in the basement and is 2/3 filled with water (1600 gallons).

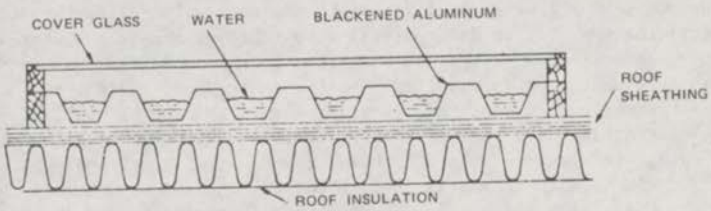


SOURCE: NSF Report ER-7934, June 1974.

FIGURE 10 SOLAR SYSTEM, TIMONIUM ELEMENTARY SCHOOL, BALTIMORE



THOMASON SOLAR HEATED HOUSE



CROSS SECTION OF ROOF MOUNTED SOLAR WATER HEATER

SOURCE: ASHRAE 1974 Applications Handbook

FIGURE 11 THOMASON SOLAR HEATING SYSTEM, USING ROOF-MOUNTED, SINGLE-GLAZED COLLECTORS WITH OPEN WATER FLOW

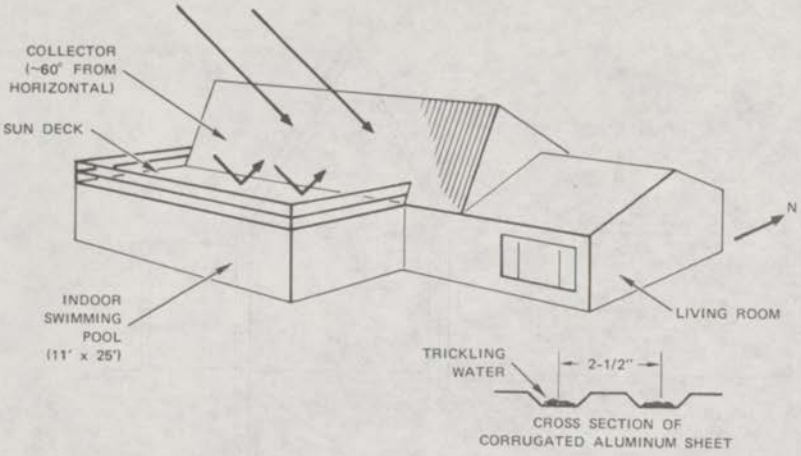


FIGURE 12 THOMASON SOLAR HEATING SYSTEM SPECIFICATIONS

The tank is surrounded on all sides by 25 tons of fist-sized stones contained in a 10 x 7 x 30-foot bin. When rooms need heat, a blower blows air upward through an array of stones to the rooms. A reflective (but nonmetallic) near-horizontal roof (15 x 40 feet) or sunporch over the swimming pool directs additional radiation to the collector. A fraction of winter's heat need is supplied by solar energy: 85 percent in (mild) 1973-74 winter, 75 percent in a typical winter. Source of auxiliary heat is an oil furnace. In summer, an air-conditioner capable of 34,000 Btu/hour output is operated at night (when outdoor air is cool and city demand for electricity is small) to cool and dry the stones. During the hot humid day, the stones cool and dry the air circulated to the rooms. (It is said that an air-conditioner of half this output would suffice.)

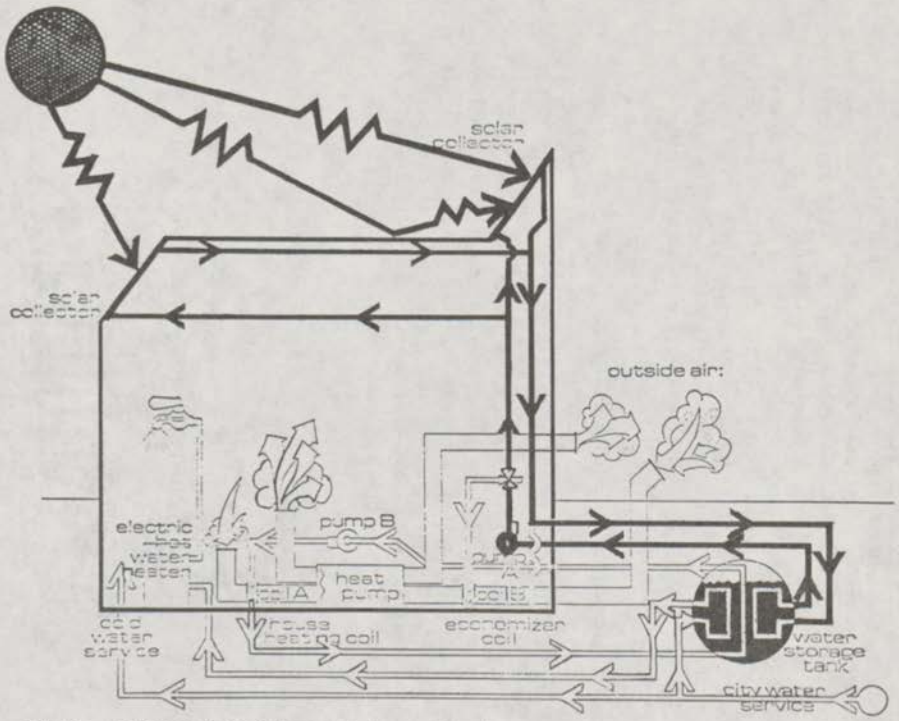
Although some leading solar researchers regard Thomason's system as inefficient, the inventor is actually pursuing its commercial production, and it may currently be used in more operating solar homes than any other single system. While the Thomason system uses forced air heating, it is designed to minimize the need for sheet metal ducting, using instead the existing spaces behind the building walls and between the joists to channel the hot air. In one Thomason-type application inspected by the study team, the builder had used wall board to construct a central duct, which could not be accommodated within the wall spaces.

The Phoenix Project of City of Colorado Springs--This solar heated home is a direct result of the energy crisis. In June 1973, the City of Colorado Springs imposed a moratorium on the connection of new loads to its gas distribution system because of gas shortages. The projected procurement rate created a sudden and substantial interest in other energy sources, and after a consulting study, a committee of local professional and business people backed by the mayor worked with the National Science Foundation to design and build a model solar heated home. This home was completed in September 1974 and has been occupied by a family since January 1975. Figure 13 shows the house, and Figure 14 is a graphic representation of the operational concept.

Designed to accommodate a middle income family of five, the house is a two-level 2,190 square foot dwelling, excluding the finished family room in the basement. A heat transfer fluid (Dowtherm J) is heated in the solar collectors and flows to a coil in an underground storage tank where the heat energy is transferred to water. The hot water is passed through a house heating coil where the energy is transferred to a forced air heating system used to heat the rooms. Backup heating capacity is provided by a two-step electrical resistance air heater in the house duct, which cycles automatically on thermostat demand when the stored water is not hot enough to handle the heating requirement.

SOURCE: NSF Report GI-44210, Assessment of a Single Family Residence Solar Heating System in a Suburban Development Setting. April 1975.

FIGURE 13 THE PHOENIX HOUSE OF COLORADO SPRINGS



SOURCE: NSF Report GI-44210, Assessment of a Single Family Residence Solar Heating System in a Suburban Development Setting: April 1975

FIGURE 14 SCHEMATIC OF HEATING SYSTEMS FOR THE PHOENIX HOUSE OF COLORADO SPRINGS

There is virtually no sheet metal work in the solar "front end" of the system, but the house has standard perimeter sheet metal air ducting in the conventional portion of the system, with returns arranged for satisfactory air distribution in both heating and cooling applications. The system is fully implemented, with data logged continuously since January 1975 to accumulate performance data for analysis. The total cost for construction of the house was $95,400, of which approximately 10 percent is for the solar portion of the system.

Because of the variety in the stages of development and conceptual design, these systems described above cannot really be said to typify the heating and cooling systems under construction and in use today, but they represent some of the many approaches. Examples of solar heated and cooled dwellings may be found in Appendix B.

Current State of Technology

The technology in solar heating and cooling is still in the development state, with substantial basic research still going on. Under the impetus of the energy crisis, federal funds for energy research and development tripled between FY 1973 and 1975. In the solar program area, they increased more than ten times, as shown in Table 18 which details the programs for these years.

NSF funds for research have largely been concerned with technical processes such as fluids for heat pumps, development of a salt-water absorption cooling unit, and technical aspects of solar energy collectors (NSF-funded heating and cooling projects for FY 1973 and 1975 are listed in Appendix C). ERDA budget hearings on the FY 1976 fund requirements brought out clearly the desire of the Congress to move from the study to the demonstration phase. The ERDA program is designed to have as many as 2,000 residential units and 400 commercial buildings heated and cooled by the sun by 1979. The Chairman of the House Energy Subcommittee thinks at least 4,000 buildings should be built, and his committee proposes to more than double ERDA's 1976 solar energy budget. The final figure will represent a joint agreement between Senate and House, but there appears to be an agreement in principle for a substantial expansion of research in this field.

A major basis for the program is Public Law 93-409, "Solar Heating and Cooling Demonstration Act of 1974" which became effective in September 1974. Its overall purpose is to provide for the demonstration within a three-year period of the practical use of solar heating technology, and within a five-year period for the practical use of combined heating and cooling technology. In furtherance of this program, a series of major projects have been undertaken:

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Table 18

FEDERAL PROGRAM FOR SOLAR ENERGY RESEARCH AND DEVELOPMENT
1973-1975
(Millions of Dollars)

Program Area	FY 1973	FY 1974	FY 1975	Percent Change From FY 1974 to FY 1975	Agencies
Conservation	$ 32.2	$ 65.0	$ 128.6	+78	Interior, EPA, FEA
Oil, gas and shale	18.7	19.1	41.8	+119	Interior, EPA
Coal	85.1	164.4	415.5	+160	Interior
Environmental control	38.4	65.5	178.5	+173	EPA, AEC
Nuclear fission	406.5	530.5	724.7	+37	AEC
Nuclear fusion	74.8	101.1	168.6	+67	AEC
Solar	4.0	13.8	50.0	+262	NSF, NASA, AEC
Geothermal	4.4	10.9	44.7	+310	NSF, USGS, AEC
System studies	7.2	17.3	33.1	+73	Most
Misc.	0.9	11.5	32.1	+159	Various
Total Direct	$672.2	$999.1	$1,815.5	+81	

Source: Aerospace Daily (Feb. 5, 1974)

- National Bureau of Standards has begun the development of performance criteria for solar heating and cooling.
- Westinghouse, General Electric, TRW, and others have done comprehensive analyses of the technical, economic, social, environmental, and institutional factors affecting the feasibility of using solar energy for heating and cooling buildings. They also have designed proof-of-concept experiments in support of the demonstration act purposes, which will use both single family residences and large buildings for demonstration projects over a three-year period.
- The American Institute of Architects has supervised the development of a group of eight studies by architects, designers, and engineers, which have analyzed residence heating and cooling requirements for different requirements and designs and quantitatively analyzed appropriate dwelling structures and associated solar heating and cooling systems optimized for energy conservation. The study team reviewed the detailed reports of these projects. A summary report and evaluation by the American Institute of Architects research operations staff will be available shortly.
- Colorado State University has established a solar energy applications laboratory (SEAL) headed by Dr. George O. G. Loef, a leading U.S. authority on solar energy. In carefully designed demonstration experiments initially funded by NSF and currently supported by the university and contributions, different solar heating and cooling systems will be tested as to performance and characteristics in three identical residential-type buildings.

  The SEAL experiment is particularly noteworthy to the Union, since its outcome will probably be significant to the degree of acceptance of air-based systems with their larger ducting requirements. The first house, already completed and in use, contains the first operational heating and airconditioning solar system in the United States. The system consists of the 768 square foot solar collector mounted on the roof, a 1,100-gallon hot water tank for thermal storage, hot water as the solar heat transport fluid, a central forced air system, a separate domestic hot water tank, and an absorption refrigeration unit for cooling. The refrigeration unit is modified to use hot water instead of natural gas as the heat supplied to the generator.

Construction is in progress on the other two identical houses. The second house will contain a solar system utilizing air as the primary heat transfer agent, with dry pebble-bed thermal storage backed up by a conventional forced air system. Also included is an evaporative cooler integrated into the solar system and capable of utilizing the thermal storage for storing cooled night air for daytime use. The dry solar system is being donated by the Solaron Corporation of Denver, Colorado. SMACNA is providing the funds for installation of the system.

The third system will utilize 20 Corning Glass evacuated tubes as collectors, with a liquid transfer medium and thermal storage providing heat through an exchanger to a forced air conventional heating system.

Except for the SEAL experiment at the Colorado State University, the study team found no program that directly compared different systems under similar conditions. However, NSF sponsored experiments and demonstrations, experiences of developers, and competition have identified specific strengths and weaknesses and arguments for and against certain types of systems. Some of these were set forth in an earlier section.

In spite of the ever increasing interest in the potential usefulness of solar heating and cooling systems, they are still mostly in the developmental and experimental stages. Fewer than 100 projects are actually in use or well along in construction in the United States.

Although there is substantial entrepreneurial interest--Congressional testimony indicates the number of solar energy manufacturers and vendors at about 400--actual production of solar components is negligible in terms of their effect on the energy conservation at this time. An FEA survey found that the total area of all high temperature solar collectors manufactured in 1974 was 136,000 square feet. At maximum Btu rating, this quantity of collectors will generate only enough energy to heat four public schools and 220 houses. The corresponding savings in crude oil will be 56 barrels per day.

In construction, the state of the art is mixed. A study by Westinghouse Corporation concluded that nonresidential building contractors have the necessary technological resources for adaptation to the installation and servicing of solar systems. Residential building contractors lack some of the experience; they will require more substantial technical support (such as "factory packaged" system designs) to be able to utilize solar systems in their work. Congressional testimony indicates that the significant deterrent to industry getting into the solar market was the

lack of design specification performance documents and knowledge of individual manufacturers. The House hearings repeatedly emphasized that the level of solar technology could be raised only through more direct, broader involvement by industry in solar energy development activities.

The same point is applicable to construction companies and to representatives of labor--more involvement is essential if they are to be prepared to contribute and profit in this developing field.

As the level of technology rises, the commercial potential will follow suit, providing the demand for solar products exists. In part, this depends on the economics of the situation, which is discussed in the following paragraphs.

Systems Economics

One cannot generalize with confidence about solar system costs. Some of the systems developed have been supported by careful cost recording, but the methods and formats for cost collection and analysis in this area have not yet been standardized. Cost elements have not been precisely defined. Hence, even carefully documented experiments cannot be meaningfully compared from a cost standpoint.

A second problem in cost analysis is the use of cost data that are inflated because of the experimental nature of the projects. In some cases, the project staff has attempted to compensate for this weakness by projecting normal costs from the actual cost data from an experimental project.

Examples of project cost data are provided below. Table 19 presents costs for the Timonium Elementary School, which was described earlier. The first column costs are scaled down from the actual figures to a "non-expedited" basis. These costs are compared with estimates of what the costs would have been under two other conditions--first, for a similar school with a compatible existing hot water heating system, and second, for a new school. Note substantial variations in cost and in the percentage distribution among cost elements.

Table 20 provides capital cost data from the project report on the Colorado Springs solar house, also described earlier. While useful internal comparisons have been included in this cost analysis, differences in format and cost elements from the previous exhibit are evident.

Table 21 presents the estimates of the annual cost of energy for the Colorado Springs solar house, compared with the estimated costs of other heating systems.

Table 19

CAPITAL COST COMPARISONS AND PROJECTIONS FOR ELEMENTARY SCHOOL SOLAR HEATING SYSTEMS

Cost Element	Timonium Elementary School		Typical School with Existing Hot Water Heat		New School with Solar Heating Designed in Original Plan	
	Nonexpedited Dollars	Percent of Total System Cost	Nonexpedited Dollars	Percent of Total System Cost	Nonexpedited Dollars	Percent of Total System Cost
Collectors	$106,450	23%	$ 86,850 (Engineering not required)	39%	$ 86,850 (Engineering not required)	72%
Mounting trusses	72,941	17	72,941	33	7,294	6
Collector plumbing	48,983	11	7,800*	3	7,800*	6
Insulated storage tank (1500 gal)	33,139	8	9,000†	8	9,000†	7
School plumbing and convectors	64,744	15	3,230	1	Part of basic heating system	
Instrumentation	66,052	15	1,320	1	1,320	1
Installation	47,407	11	42,700	19	9,480	8
Total system cost	$439,716	100%	$223,841	100%	$121,744	100%
System cost per square foot of collector (5,200 square feet)	$84.56		$43.05		$23.41	
If the collector cost were reduced from $16.70 to $5.40 per square foot (one-third), the system cost/square foot of collector would be:						
5,200 square feet	--		$31.74		$12.11	

Conditions: No escalation in price

Nonexpedited programs

All schools the same size in the same climate with the same size solar system

*Based on plumbing costs of $1.50 per square foot of collector area.

†Based on the use of a prefabricated, insulated tank procured from an established tank fabricator.

Source: NSF Report ER-7934, June 1974 (percentages added)

Table 20

COST OF SOLAR HEATING AND MECHANICAL SYSTEMS
FOR PHOENIX SOLAR HOUSE - COLORADO SPRINGS

Collector panels (30 ea. - 36" x 104")	$ 774.30
1/8" Tempered plate glass	750.00
Cover frames	738.42
Framing and insulation	425.00
Painting	50.00
Heat pump with supplementary electric heater	990.00
Controls (operating)	398.00
House and condensor ductwork	2,180.00
Fluid coils A and B	595.96
Storage tank with heat exchangers	1,290.00
Electric wiring	1,232.72
Piping with insulation--pumps and exp. tank	1,500.00
Dowtherm J - 52 gallons at $3.75	195.00
Nitrogen	3.00
Total	$11,122.40
Balance of house, including, structure, carpet, drapes, landscaping, and applicances	70,377.60
Land	6,900.00
Architects fee	7,000.00
Total cost	$95,400.00

Total collector area: 780.30 square feet

Collector cost per square foot of collector (piping not included)	$ 3.50
Total solar and mechanical systems cost per square foot of floor	5.08
Total project cost per square foot of floor	43.56
Estimated cost nonresearch solar and mechanical system	$6,000.00
Estimated cost gas fired hot air system with A.C. for this house	3,980.00
Estimated cost gas fired hot water system with A.C. for this house	6,600.00
Estimated cost electric resistance hot air system with A.C. for this house	5,500.00
Estimated cost electric resistance hot water system with A.C. for this house	6,200.00

Source: NSF Report GI-44210, Assessment of a Single Family Residence Solar Heating System in a Suburban Development Setting (April 1975)

Table 21

COMPARATIVE OPERATING COSTS
FOR THE COLORADO SPRINGS SOLAR HOUSE
(Btu Load: 130.17 Million)

System		Energy Cost per Million Btu	Annual Energy Cost*
Natural gas fired		$1.49	$193.96
Electric resistance		6.45	839.62
Solar with optimized heat pump Ratios of solar energy to conventionally produced energy:			
Percent Solar	Percent Conventional		
12%†	88%	1.75	227.80
20	80	1.58	205.67
30	70	1.50	195.26
40	60	1.25	162.72
50	50	1.08	140.59
60	40	0.88	114.55
70	30	0.75	97.63
80	20	0.58	75.50
90	10	0.37	48.16
100	0	0.17	22.13
Propane fired‡		7.56	984.11

*Annual energy cost is obtained by multiplying Btu load times the energy cost per million Btu.

†Domestic hot water heated by solar energy and the house heated by optimized heat pump.

‡Propane and fuel oil costs are judged as equal in this geographic area, and no fuel oil is used for residential heating.

Source: NSF Report GI-44210 (April 1975)

Comprehensive financial analyses were included in the studies funded by the National Science Foundation in 1974 on solar heating and cooling in buildings. These studies included cost comparisons of different systems under different climatic conditions and at different points in time

and, based on these data, projected the potential and probable market for the systems. The study team reviewed several of these systems and selected one produced by the Westinghouse Electric Corporation as the appropriate basis for the consideration of the solar impact on sheet metal activities. Since sheet metal costs were not separately presented, it was necessary to work partly from assumptions.

Table 22 is extracted from the Westinghouse study report. It presents the results of an analytical cost study, which considered the

Table 22

INVESTMENT AND LIFE-CYCLE COST
FOR A SINGLE-FAMILY RESIDENCE
WITH 50 PERCENT SOLAR DEPENDENCY

Heating/Cooling Region and System	1975 Dollar Investment	1975 15-Year Life-Cycle	1985 Dollar Investment	1985 15-Year Life-Cycle
West Coast, Santa Maria, Calif.				
Solar heating and cooling	3,650	5,820	2,840	6,640
Solar heat pump	--	--	--	--
Solar heating only	2,540	3,500	1,970	3,730
Conventional heating and cooling	2,220	5,020	2,850	8,100
Conventional heating only	1,110	2,530	1,420	4,110
Northeast, Wilmington, Del.				
Solar heating and cooling	8,810	12,700	6,850	13,800
Solar heat pump	4,800	9,930	3,740	13,400
Solar heating only	4,220	5,860	3,290	6,300
Conventional heating and cooling	2,220	7,600	2,850	13,200
Conventional heating only	1,140	3,420	1,460	5,870

Source: Solar Heating and Cooling of Buildings, Phase O, Westinghouse Electric Corporation, Baltimore (May 1974)

initial cost (investment column) and the total cost (15-year life-cycle column) for alternative solar and conventional systems in two different plants, calculated at two different points in time. The calculations used constant 1973 dollars, discounting future costs 8 percent but including an annual inflation factor of 5 percent on equipment and maintenance costs and a fuel escalation cost of 7 percent per year. Thus, the life-cycle cost for each system and each date is equal to the investment cost plus the sum of the discounted annual charges.

The study points out that, as seen in Table 22, in 1975 the life-cycle cost of a solar associated heat pump providing 50 percent solar dependency is $2,330 more than a more conventional heating and air conditioning system for a single family residence in the northeast region. By 1985, the solar assisted heat pump is projected to be within $200 of the conventional system.

The study concludes that only solar domestic hot water systems are currently cost-competitive with conventional systems. In a very few cases, solar systems compare favorably with conventional systems in 1975, but by 1985, many solar systems are more cost-effective.

On a more basic level, one design engineer interviewed estimates the output of a one-square-foot collector under certain conditions at 400 Btu per day. This is equivalent to the Btu output of one gallon of oil used for heating over a year's period. At an estimated installed cost of $10 for the collector and 40 cents for the gallon of oil, the length of time to break even on the solar system (25 years) is clearly too long for such an investment on a cost basis alone at this time. However, as Table 22 shows, by 1985 the solar system is expected to become a much more favorable alternative.

So much variation existed among the detailed system cost estimates studied that no accurate factors on the proportion of sheet metal work cost included in total cost could be developed. However, discussions with industry representatives indicated that for a conventional heating and cooling system, it is reasonable to consider that labor would constitute 50 percent of the total charges for the system, and that the addition of a solar "front end" to a conventional system would not change this proportion.

Current Activities

Before 1974, the work in cooling research was on a fragmented basis, with little help from government funding. With the energy crisis, government interest picked up, and NSF-funded projects increased from four in

1973 to almost 50 in 1974. Congressional support and directions were provided in 1974 with the passage of four acts--the Demonstration Act already mentioned, the Energy Reorganization Act (PL 93-438), the Solar Energy Research Development Demonstration Act (PL 93-473), and the Federal Non-Nuclear Research Development Act (PL 93-577).

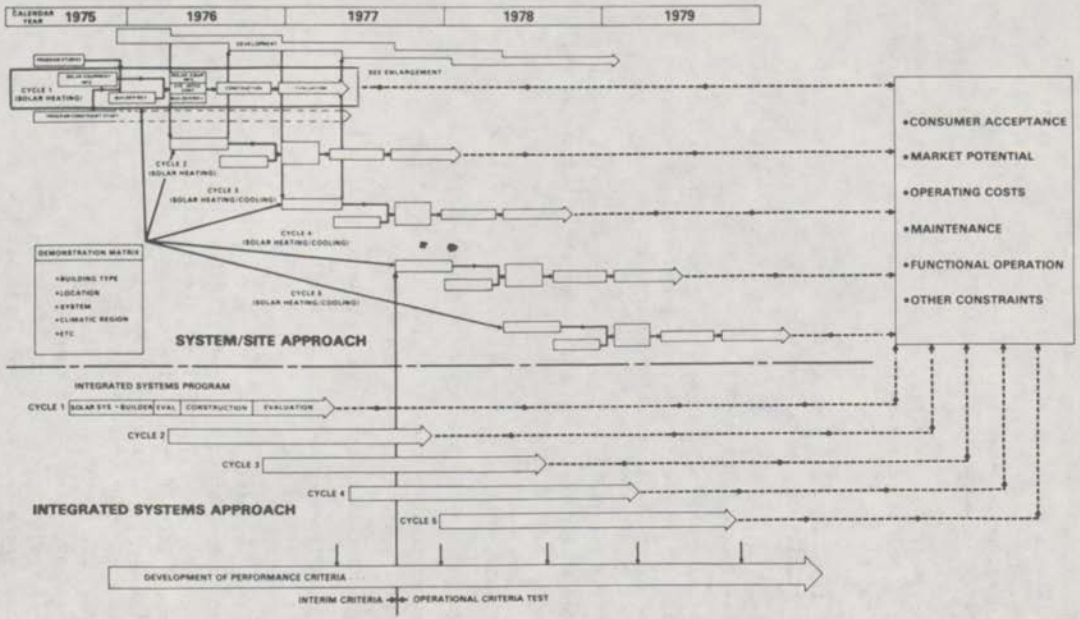
With firm Congressional backing, the scattered projects became a coordinated program, the National Plan for Solar Heating. The plan includes three major elements:

- Demonstrations for both commercial and residential applications, initially utilizing available systems.
- Development in support of the demonstrations, initially utilizing available subsystems and components.
- Research and development to advance solar heating and cooling technology to permit timely progress of the demonstrations and eventual large-scale application.

The time phased program for commercial and residential demonstrations is presented in Figures 15 and 16. Under the schedules shown, the residential program is organized to:

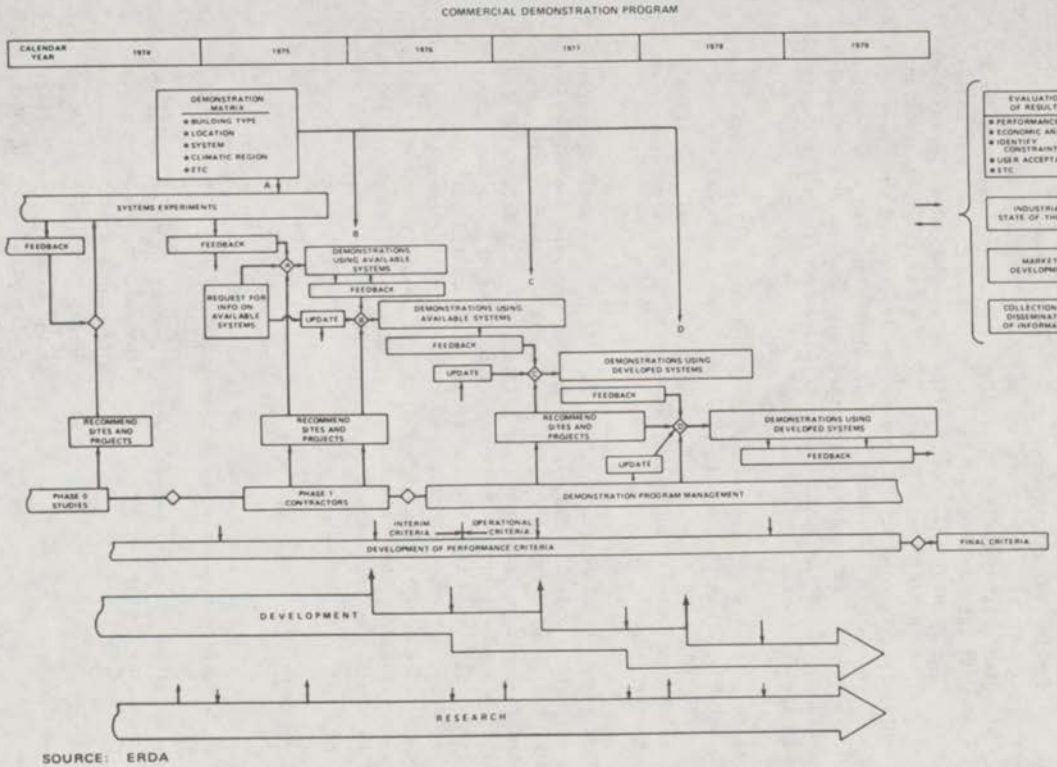
- Identify and demonstrate the best available hardware.
- Encourage industry to develop new equipment.
- Provide a data base of technical information of hardware characteristics, performance, and acceptability.
- Identify potential institutional barriers, such as codes.
- Provide experience to industry and regulatory bodies in solar energy use.

Phase 0 studies by Westinghouse, TRW, and General Electric have provided recommended demonstration programs. These reports are currently under review. The results will form the basis for issuance of requests for proposals in a series of five cycles to permit utilization of technological development as the program develops. When locations have been chosen for the demonstrations, proposals will be solicited from developers for participation. The developer will be expected to provide the land, construct the building, purchase the solar equipment (on a directed subcontract), install the solar equipment, market the property, and provide a warranty for the purchaser. This federal contract will provide for payment of a portion of the additional cost for the solar energy system.



SOURCE: ERDA

FIGURE 15 RESIDENTIAL DEMONSTRATION PROGRAM



SOURCE: ERDA

FIGURE 16 COMMERCIAL DEMONSTRATION PROGRAM

The program will include retrofitting of housing as well as new construction, and military as well as private housing projects. One task will be the development of a manual of acceptable practices for integrating solar equipment into dwellings. These manuals will be developed through standard-setting bodies and professional societies. The demonstration design will include consideration of such factors as local building codes and zoning regulations, construction practices, market conditions, and architectural preferences. It is expected that the demonstrations will identify constraints to the program and develop and test ways to remove these constraints. Although the published plan does not specifically discuss the question of trade jurisdiction, the study team's discussion with federal agencies indicated that this was recognized as an important factor in the demonstration program.

The commercial demonstrations will follow a generally similar approach, but most commercial applications will require larger and, therefore, more specialized solar systems. Some projects will be carried on at federal installations, including the Department of Defense, GSA, and the Postal Service.

Underlying the demonstration program will be a supporting research and development program, including analyses of consumer demand, economies of scale, design of components, applied materials research, building design implications, and resource constraints, including materials, capital equipment, and labor skills. With regard to financial and labor requirements, ERDA has stated that the requirements associated with the installation of solar systems represent a small additional percentage of those required for the construction of buildings equipped with conventional heating and cooling. Their availability, in ERDA's opinion, will be dominated by the larger requirement of the building industry itself.

Representative Private Projects

Although space does not permit an exhaustive listing of current activities, a number of examples of private projects are given below.

Bridgers & Paxton, Consulting Engineers Albuquerque, New Mexico	Pioneers in solar energy designs for buildings. Solar heated headquarters office building completed in 1956.
Science Building Madeira School Greenway, Virginia Flack & Kurtz, Project Consultants	A 4,500-square-foot collector system will cost $68,500 including $14,000 for collectors, $14,000 for a 10,000-gallon

	storage tank, $8,000 for installation of piping in the tank, $18,000 for piping and control, $13,500 for additional training and glass covers for the collectors. This will be amortized over 30 years. For the system to break even--based on a 10 percent interest rate--oil will have to climb from 40 cents to $1.25 to $1.50 per gallon.
Covington Properties, Inc. Jim Mitchell, Vice President Marketing	Developing a 5,300-acre tract near Land O'Lakes, Florida. Fifty percent of the customers have expressed interest in the Solar energy system the company hopes to offer in one of its houses. System is to cost about $5,000 and to be incorporated into the roof design.
Rockefeller Center, Inc. and RCA Corp. Solar energy design - Ford & Earl Design Associates, New York City, Structural Engineers	A $6 million addition on a setback on RCA Headquarters Building will use solar energy to provide part of its heat requirements. Solar collectors will be attached to the structure's south wall and also on the roof.
Dubin-Mindell-Bloome, Consulting Engineering firm Fred Dubin, President, New York City	This company has 11 major solar projects under design or study. It says that the first major market breakthrough in the solar field will be solar heaters for domestic hot water, followed by space heating, then dehumidification to supplement conventional air conditioning systems and then solar cooling. It sees a major market opportunity in industrial plants and laboratories where solar collectors could be economically used for preheating makeup air and process water. In the residential market, it sees collectors being used first

in multifamily dwellings, followed by mass applications in single family dwellings. The firm is designing a multifamily building planned for construction starting in 1975 in Brookline, Vermont, using solar collectors for heat and hot water; 4,500 square feet of collectors will be located next to the building.

Manufacturers of Solar Energy Systems and Components

According to NSF, a dozen companies at most make solar energy collectors for heating purposes and another 20 or 30 sell solar air conditioning systems. Literature sources indicate some small companies will fill orders on custom designed projects. Large corporations are getting into the market such as PPG Industries, Inc. of Pittsburgh; Honeywell, Inc., Minneapolis; Westinghouse Electric Corp., Pittsburgh; and General Electric Co., New York City. PPG can fill orders of collectors at $6 a square foot. Corporations are cautious about gearing up for mass production until they are sure of the market. Appendix C lists manufacturers of solar components.

A more complete directory of manufacturers of solar units will soon be available from Environmental Action of Colorado, University of Colorado, 2239 East Colfax Street, Denver, Colorado 80286.

Associations of Solar Energy Firms

The Solar Energy Industries Association was a year old in May 1975. The Solar Energy Research and Information center is located at 1001 Connecticut Avenue, N.W., Washington, D.C. 20036. The center is completing a membership roster that will cover every aspect of solar energy contractors, architects, manufacturers, and so forth.

Power and Pressure Points

Several organizations have authority, responsibility, or strong interest in solar heating and cooling activities. Their active interest will influence in varying degrees the direction of programs, projects,

and possibly the emphasis of the technological development of solar heating and cooling. A knowledge of their existence, their activities, and their points of view is important to the determination of the Union's strategy.

Congressional Committees--have general responsibility for overseeing governmental solar programs.

- Senate Interior Committee--plans major hearings in May 1975 on action being undertaken by the Executive Branch to comply with the Solar Heating and Cooling Demonstration Act of 1974.
- House Committee on Science and Technology (Subcommittee on Energy Research Development and Demonstration)--February 1975 budget hearings on ERDA discussed the federal solar heating and cooling program. The committee is making a strong effort to get this program out of the study stage and into actual demonstrations to test concepts and to identify problems.

Executive Branch Agencies--excercise the control and dispersion of funds for research activities and are responsible for administration of government energy policies. In addition, they provide inputs that help fashion policy.

- ERDA (Energy Research and Development Administration) chairs an interagency task force formed to review and refine the present National Plan for Solar Heating and Cooling. ERDA inherited many responsibilities in the field from other agencies on its formation. It will control most federal solar energy development funds.
- HUD (Department of Housing and Urban Development) was originally named in the Demonstration Act as the one with responsibility for initiating and carrying out the development and demonstration of solar heating systems for use in residential dwellings. It will have the lead responsibility for solar demonstrations in residential structures. HUD and NASA led the development of the initial detailed plans for the housing demonstration program.
- GSA (General Services Administration) provides services and consultation for the pilot projects for installing solar systems in government buildings. Of current concern are two office building projects, one in Manchester, New Hampshire, and the other in Saginaw, Michigan.
- NBS (National Bureau of Standards) will provide services and consultation in the establishment of design and performance criteria for the solar systems; its draft of criteria is currently being coordinated within government and industry.

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- DoD (Department of Defense)--A large number of the demonstration houses to be constructed under the act will be Defense housing.
- NASA (National Aeronautics and Space Agency) worked with HUD in the development of the housing demonstration program.
- NSF (National Science Foundation)--Before the establishment of ERDA, NSF had most of the solar energy money. It continues as a strong influence in the development of the program as a member of the task force.
- FEA (Federal Energy Administration) provides services and consultation, especially in matters concerning fossil fuel conservation. This agency has recently issued a catalog of state energy organizations and activities.

Appendix D presents in more detail the responsibilities and relationships of federal agencies with regard to each program element and task.

Associations--Industry and trade associations are concerned in varying degrees, but are bound to be the channel of much of the coordination with industry that is required under the solar energy legislation.

- AIA (American Institute of Architects)--Through its Research Corporation, AIA is responsible for supervising eight basic design studies concerning solar heating and cooling for residential buildings. It is currently preparing an analytical summary and report on these study results. AIA works closely with HUD in the development and maintenance of the solar heating and cooling information data bank required by the legislation.
- ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc.)--Under a government grant, ASHRAE produced a chapter in its handbook on the use of solar energy and its field. ASHRAE will become more active as the federal program develops.
- SMACNA (Sheet Metal and Air Conditioning Contractors National Association)--SMACNA is providing funding and sponsorship for the installation of a dry-type solar heating/cooling system in one of the three Colorado State University experimental buildings.
- Solar Energy Industries Association--A year-old organization with membership from contractors, architects, manufacturers, and the like. It publishes a bi-weekly news letter and has published an industry directory.

Institutions of learning--The University of Arizona, Colorado State University, Massachusetts Institute of Technology, University of Delaware, and the University of Ohio are among schools with strong or growing involvement in solar energy heating and cooling. Colorado State has a Solar Energy Applications Laboratory (SEAL) which is moving actively toward direct comparison testing of three major types of systems.

Industry leaders--Westinghouse, General Electric, and TRW did substantial studies on solar heating and cooling of buildings under Phase 0 of the National Science Foundation's grant for Research Applied to National Needs (RANN). They are likely to participate in later phases and studies. Pittsburg Plate Glass and Revere Copper are among other large companies actively working in the field.

Research organizations--The MITRE Corporation, Arthur D. Little, and SRI have done important research in the solar energy field.

State and local governments--These jurisdictions will be issuing regulations and codes that have an impact on solar energy work. To date, the impacts are mostly incentive in nature for introduction of solar devices. Florida legislation, for example, requires that all newly constructed homes have plumbing for solar domestic water heating. Arizona is offering an income tax deduction for capital investment in solar devices. Indiana has exempted from real property taxes the first $2,000 investment in solar systems costs. California energy legislation includes funds for solar research and development.

Market Size

The following quotations are illustrative of the considerable speculation surrounding the size of the market for solar heating and cooling.

"The manufacturers being licensed to produce the backyard solar furnace...should be delivering units by the Fall of 1975. Market estimates place the number of units delivered and installed before the end of the summer of 1976 between 200,000 and 1 million in the United States alone. This would represent a 2 percent market penetration during the next 18 months..." (from a solar furnace market letter).

"The estimate of gross volume sales in solar heating industry in the next few years ranges from seventy-seven billion dollars to two hundred twenty-five billion dollars...there is more business than one thousand manufacturers can handle, selling properly represented, properly engineered systems." (A solar developer)

"A total of 170 firms were identified as possible manufacturers of solar collectors, and...

"Of the 170 firms contacted, only 39 were actively engaged in production. These produced a total of 136,540 square feet of high-temperature collectors in 1974. About 18,000 square feet of this was used to equip four public schools with solar heating systems. If applied to space heating, the remaining square footage could provide power to heat an estimated 220 houses...

"The chief barrier to wider use of solar heating and cooling is neither a shortage of Federal research dollars, nor a lack of technology; it's a limitation of demand in the marketplace." (FEA Office of Energy Statistics and FEA Administrator Frank G. Zarb)

Just what the market outlook is for solar heating and cooling in the future, what types of units will be expected to sell, and to what degree will their manufacture, installation, and maintenance require sheet metal workers are factors whose determination will constitute the degree of impact of this developing industry on the Union and its members.

Aside from the sales optimism of a manufacturer's marketing representative and the historical statistics of government agencies, a number of serious studies have been made in the last few years regarding the alternatives to fossil fuel and how quickly the use of these might develop.

The National Petroleum Council, the National Academy of Engineering, Bechtel, and SRI are among those doing research in this area. The largest effort, by industry, government, and research organizations, was convened in 1974 for the development of the most ambitious study to date, the Project Independence report.

The degree of solar usage depends on the future supply of energy from conventional sources, and all authorities agree that fossil fuels will be in increasingly short supply. The Project Independence task force concluded that domestic production of crude oil and natural gas liquids will continue to decline in the next few years, but the trend will reverse, with production rising with a rate dependent on many factors--e.g., prices, drilling costs, taxes, availability of labor and material, and capital. Natural gas production in the United States is expected to decline until nearly 1980 regardless of the price, but could increase by 10 percent over 1974 by 1985, with a minimum price of $1.00 per 1,000 cubic feet. Production could increase more than 25 percent under accelerated development conditions. Coal production is expected

to increase, and the Project Independence task force believes that the Industry can satisfy most any foreseeable demand by 1985, with coal at prices near 1972-73 levels. Coal demand will be influenced by price and availability of oil and natural gas and the rate of increase in the consumption of electricity.

Nuclear expansion is constrained by uranium availability, the problem of raising investment capital, and public acceptance. Useful production of shale oil is projected to begin in 1980; substantial investment will be required to make the production of the petroleum by this technique commercially useful. The potential for synthetic fuels by coal conversion is not expected to have real potential until the later 1980s or 1990s. Geothermal energy will not be utilized on a full scale until after the 1990s.

Studies of energy supply and demand relegate solar energy to a very low point in terms of its contribution to solar national energy between now and the year 2000. In a study in 1974, the National Academy of Engineering compared the relative contribution forecast from a number of studies. Table 23 forecasts a significant solar contribution in only one study, that of the Federal Energy Office. The forecast by FEO for solar energy by 1985 is the equivalent to a contribution of 1.9 million barrels of oil per day.

The Project Independence study forecast, summarized in Figure 17, shows a solar contribution even lower than that of the FEO study. However, while the proportion with respect to the other forms of energy is small, it entails large investments in the solar industry, including billions of dollars in solar heating and cooling.

The results of the Project Independence analysis of solar heating and cooling potential, which considered all available studies and their variances, are shown graphically in Figure 18, which projects on a cumulative basis the total number of new buildings between now and the year 2000, the portion of those that are potential customers for solar systems, and the considered judgment as to the actual number that will be installed under an accelerated energy program with oil at $11 a barrel. These conditions probably represent the maximum or most optimistic case. Table 24 shows the annual market demand for solar energy units at two different oil prices. The Project Independence task force indicated the annual demand could not be met until 1990 on the "business as usual" (BAU) basis.

The BAU scenario assumes that the adoption and widespread utilization of solar energy research and technology, while restricted by government sponsorship, will be left to the operation of market forces following

Table 23

SELECTED FORECASTS OF THE ENERGY SUPPLY IN THE UNITED STATES IN 1985
(Millions of Barrels per Day)

Energy Source	1972, NPC Case I	1972, NPC Case II	1972, NPC Case III	1972, NPC Case IV	1973, JCAE	1973, IGT Pre-73 Scenario	1973, IGT Post-73 Scenario	1973, Shell Oil	1972, Dept. of the Interior	1973, Stanford Research Institute	1973, AGA	1972, Bureau of Natural Gas	1972, AEC	1971, Denver Research Institute	1974, Federal Energy Office-- Base Case	1974, Federal Energy Office-- High Case	Range High	Range Low	This Study
Fossil Fuels																			
Petroleum																			
Domestic	14.969	13.452	11.500	10.121	11.0	11.7	14.5	10.2	11.7						10.4	16.2	16.2	10.1	12.5
Imports					14.6	13.7	2.6	17.8									17.8	2.6	--
Shale syncrude	0.698	0.372	0.372	0.093	0.1	0.3	1.027		13.1						0.3	1.6	1.4	0	0.5
Coal syncrude	0.703	0.083	0.083			0.2	1.292	0.6									1.3	0	0.6
Total petroleum	14.370	13.907	11.955	10.214	25.7	25.9	19.419	28.6	25.0	30.89					10.7	17.6	30.9	10.2	13.6
Coal	12.801	10.103	10.103	9.589	11.1	10.5	10.511	8.5	10.58	9.32					11.2	18.0	18.0	8.5	10.0
Gas																			
Domestic	14.929	12.907	9.963	7.309	7.1	9.5	14.205	7.40	11.09			8.9			8.8	11.7	14.9	7.1	14.5
Imports					3.0	2.9	1.058	1.95	2.90			2.4			--	--	3.0	1.1	--
Syngas	1.705	0.960	0.960	0.233	0.7	0.5	1.744	1.75	0.99			1.3					1.8	0	1.1
Total gas	16.634	13.867	10.903	7.542	10.8	12.9	17.007	11.10	14.98	12.52	14.5	12.6		21.1	8.8	11.7	21.1	7.5	15.6
Total fossil fuels	43.805	37.877	32.961	27.346	47.6	49.3	46.937	48.20	50.56	52.73					30.7	47.3	52.7	27.3	39.2
Other																			
Nuclear	14.081	11.927	9.55	7.617	9.4	10.3	10.274	8.5	5.79	7.20			5.408		5.6	8.6	14.1	5.4	8.3
Hydro	1.563	1.568	1.568	1.568	1.5*	2.0	1.957		2.33	1.40					1.4	1.6	2.0	1.4	1.5
Geothermal	0.859	0.312	0.243	0.121	0.2										0.3	1.4	1.4	0.1	0.2
Solar															--	1.9	1.9	0	--
Total other	16.308	13.807	11.361	9.306	11.1	12.3	12.231	8.5	7.92	8.73					7.3	13.5	16.3	7.3	10.0
Subtotal, domestic	62.114	51.684	44.323	36.652	41.3	45.0	55.301	36.95							38.0	60.8	62.1	36.7	49.2
Subtotal, imports	5.80				17.6	16.6	3.658								16.7	-9.9	16.7	-9.9	
Total					58.7	61.6	59.159	36.70	58.48	61.46					54.7	50.9	61.5	50.9	

*Hydropower converted to 10,250 Btu/kwh heat rate.

Source: "U.S. Energy Prospects, An Engineering Viewpoint," National Academy of Engineering, 1974

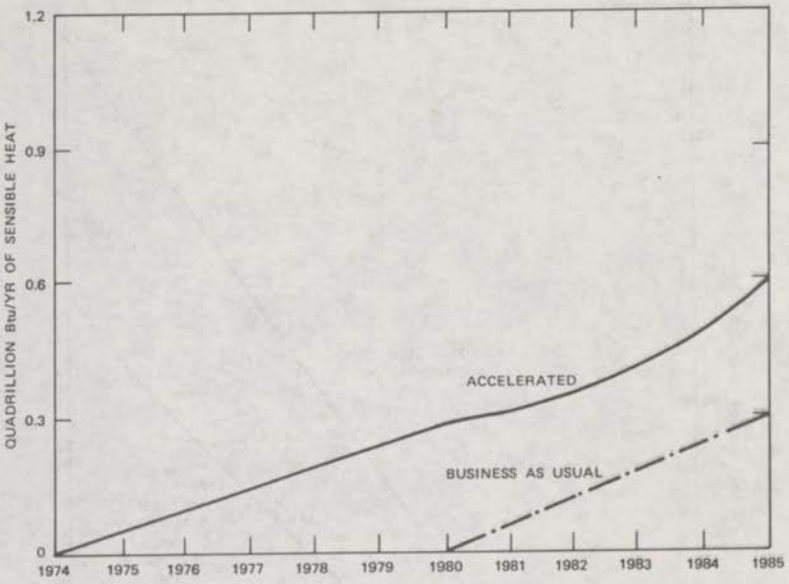

FIGURE 17 POTENTIAL FOR SOLAR HEATING AND COOLING OF BUILDINGS

Table 24

SUMMARY OF TOTAL U.S. ANNUAL MARKET DEMAND
FOR SOLAR ENERGY UNITS AT INDICATED OIL PRICE*

Type of Solar Unit	$4 per barrel	$11 per barrel
Single family, hot water only	$88,940	$136,700
Single family, heating and hot water	44,470	68,300
Small commercial, hot water only	37,240	84,100
Small commercial, heating and hot water	18,260	42,000

*Adjusted to eliminate double counting.

Source: Project Independence Task Force Report, Solar Energy

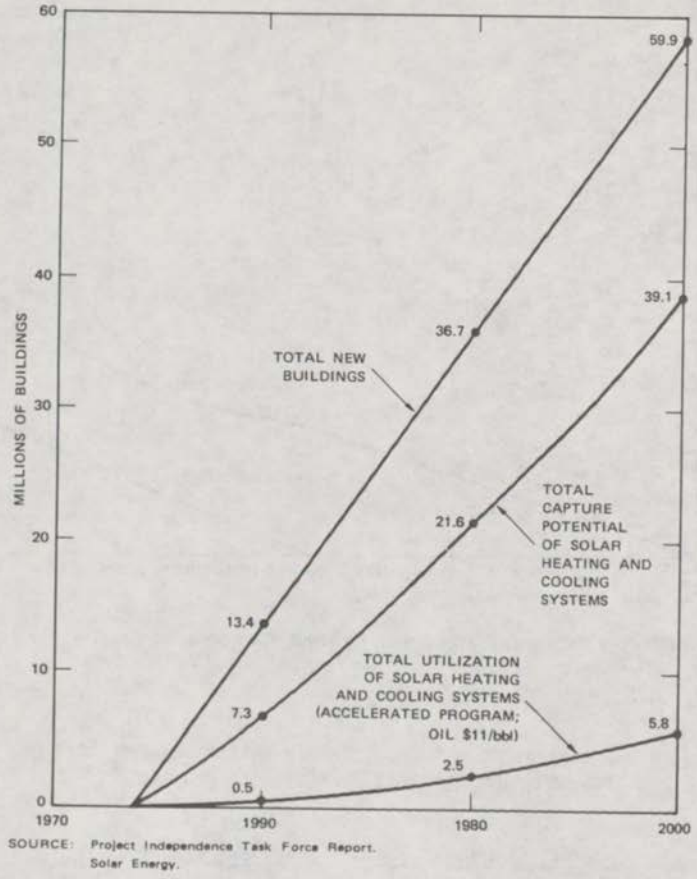

FIGURE 18 CAPTURE POTENTIAL AND UTILIZATION OF SOLAR HEATING AND COOLING SYSTEMS

federally sponsored pilot plans and demonstration programs. The second scenario, the accelerated development (AD) program, assumes that substantial federal and local governmental efforts will be devoted to overcoming the nontechnology constraints to widespread utilization. These constraints are principally economic and institutional. They would include tax relief, loan and interest incentives, and special depreciation policies. Under the accelerated scenario, the maximum market penetration level would be advanced from 1990 to 1985.

An extension of the estimates shown in Table 24 projects the total capital required for the solar heating unit program on the BAU and AD bases. These figures are provided in Table 25.

Table 25

U.S. TOTAL CAPITAL REQUIREMENTS
FOR BUSINESS AS USUAL PROGRAM AT INDICATED OIL PRICE
(Hundreds of Millions of Dollars per Year)

	1980		1990	
Type of Solar Units	$4 per barrel	$11 per barrel	$4 per barrel	$11 per barrel
Single family, hot water only	$0.09	$ 0.14	$ 0.76	$ 1.2
Single family, heat and hot water	1.77	2.7	5.4	8.1
Small commercial, hot water only	1.56	3.7	8.5	20
Small commercial, heat and hot water	4.75	10.5	27.2	60
Total	$8.17	$17.0	$41.8	$89.3
Capital requirements, accelerated U.S. total	25	53	42	89

Note: The capital requirements include both the capital invested by the manufacturer of the solar systems and by the owner of the building that uses the system. Analysis of the heating, ventilating, and air-conditioning industry indicates that the plant equipment investment is typically 35 percent of the consumer capital investment. Therefore, the capital figures shown should be broken down into:

Plant investment = 0.26 of total capital
Consumer investment = 0.74 of total capital.

Source: Project Independence Task Force Report, Solar Energy

Table 25 can be used to estimate the proportion of the dollars spent for manufacture and installation of solar heat and cooling systems that would be spent on sheet metal labor. The figure represents only a rough order of magnitude, because it entails several assumptions; however, a change in the situation could be applied by changes in the assumption.

The computation is as follows:

From Table 25, the total capital requirement in 1990 at $11 per barrel, with a BAU program = $8.93 billion. Of this, 74 percent is consumer investment (see note at the bottom of the table), or $6.6 billion.

If, since the product is new, it is assumed that the distribution of consumer cost on heating and cooling systems is 60 percent for the materials and 40 percent for labor, the labor portion is 40 percent of $6.6 billion, or $2.64 billion. Assume that one-half of the new solar systems are "dry" type, which will require sheet metal ducting between the solar collectors and storage tanks. Then, the labor portion for this is $1.32 billion.

Assuming that the sheet metal labor represents 10 percent of the total installation labor (the rest would be plumbers, electricians, and others), then the addition to sheet metal installation wages would be $132 million each year beginning in 1990.

Using this approach in association with the capital requirements in Table 25 for the accelerated case produces the following estimates for sheet metal work:

For the accelerated case: if oil is priced at $4 per barrel--annual new sheet metal work on solar heating and cooling installation will amount to $38 million by 1980 and $63 million by 1990. If oil is priced at $11 per barrel, sheet metal work will amount to $80 million by 1980 and $134 million by 1985 (allowing for the five-year gain in schedule under the accelerated case).

Although the precision of these estimates is certainly open to question, they do provide an order of magnitude of the potential income to sheet metal workers from the solar heating and cooling industry. Added to these figures, which consider only installation, are potential incomes from sheet metal work in the manufacture of solar equipments such as collector plates, prefabricated ducting, and sheet metal storage tanks. While it is too early to determine the extent of these applications, the market for sheet metal wages appears to be worthy of careful attention by the Union.

Implications for the Union

The discussion on the implications of the solar heating and cooling activities on the Union can be grouped into four areas--market size, technology, participation, and power and pressure points.

Market Size

The key point for market size is the determination of whether the size of a new payroll indicated by this study or by the Union's independent analytical efforts is worth emphasis in the overall Union program--that is, whether it will be worth the expenditure of time and money by the Union to protect or enhance the potential increase in sheet metal worker earnings or the expansion of the sheet metal worker population that this new technology may generate.

On the basis of the rough market share estimate in this study, it appears that the potential increase in sheet metal work dollars from the advent of solar energy could range, in the most optimistic case, from 1.5 to 3 percent in the BAU case, and from 4 to 7 percent in the accelerated case. It is an historical fact that most development programs take longer than proponents project to reach given levels of success. Nuclear power is a classic illustration of this. Likewise, market penetration of new products generally takes longer to achieve than most proponents forecast. In housing, consumers have proven to be conservative, as are architects and contractors. For these reasons, it is considered that the optimistic forecasts of Operation Independence can probably be halved. The matter is probably not as much a question of whether to include solar matters as an element in the Union's program, as it is one of determining the timing and the degree of the emphasis. This question concerns the consideration of solar matters in relation to other Union priorities that have not been made available to the study team.

Technology

As indicated in the report, design, form, materials used, and manners of application of solar heating and cooling components are still in the development stage. Aluminum, steel, and glass are among the materials used in fabricating solar collectors. Storage tanks are being made of steel, cast iron, wood, sheet metal, and other materials. Ducting, traditionally made from sheet metal, is being fabricated from sheet rock and, in some cases, not being used at all. Federally funded research studies are in progress and more are planned to select the best existing solar

equipment for use in tests and to encourage the development of new innovative equipment and methods of use.

A significant issue in the technological area appears to be the relative advantages and disadvantages of a liquid solar system compared with a dry, air-type system. The dry-type system seems to be more advantageous to the Union in that it utilizes more sheet metal; but it is essential that all systems be correctly tested to determine their merits and to obtain the values that may accrue through such experiments. The study team was told (but could not verify) that three-fourths of the funding on systems was going toward testing wet systems rather than dry systems. One of the criteria in the selection of a wet or dry system is its compatability with the backup system. The 1970 census indicates that 42 percent of the dwellings surveyed have forced heat systems, while the remaining 58 percent do not. (These may include some dwellings that have no central heating system at all.) The presence of such a large group of existing systems that appear to be "ready made" for retrofitting on a dry system basis seems to provide an opportunity for promotional action by those interested in supporting the use of dry systems.

Project Independence estimates do not consider the large commercial building as a reliable candidate for solar heating and cooling at this time, although some design projects are directed toward discovering the feasibility of solar work for this sized building. While some designers interviewed indicated that wet systems would probably be preferred under such circumstances, other members of the industry supported dry systems because of the code requirements in most locations for ducting that would be available for integration with solar ducting. Active efforts by the Union in this field might help to clarify the best solutions, in terms of construction.

Throughout the testimony reviewed by the teams, conversations with Congressional staff, and review of the latest executive department planning documents runs the need for more participation by industry at all levels and for identification of institutional constraints. This emphasis seems to provide the ideal opportunity for the Union to enter discussions at the policy and planning levels and to respond on an independent or joint basis to the requests for proposals that are being issued by ERDA and other agencies with responsibilities under the National Plan for Solar Heating and Cooling.

Activity

In addition to work in the technological area, the federal plan now includes organized consideration of virtually all the other factors that are relevant to the success of the solar heating and cooling plan. This includes such matters as the industrial capability in terms of design and construction, personnel and equipment, and material resources. It also includes provisions for training personnel to develop and implement construction plans, the resolution of questions with regard to building codes, the provision for sources of funding (which sometimes present difficulties in unfamiliar methods of construction), the possible requirement for modification of traditional labor-management jurisdictional procedures, and the matter of zoning. While not all these issues are direct concerns of the Union, many of them are; and interest from a community standpoint in the consideration of the others should provide the Union with an opportunity for establishing its right and meeting its responsibilities to participate in solar development early enough in the cycle to have an impact.

The question of training will probably become an agenda item in seminars and workshops on solar energy within the next year. The Union should be ready with a position on the training or retraining of members which could be presented for discussion at such meetings.

Following the development of architectural and design standards will come the consideration of building code and construction regulations at state and local levels. The Union should be prepared to put forward its position on this matter as an input for consideration in the numerous decisions that will be forthcoming over all the country as these systems move toward commercial applications.

Of the 60 or more products listed in the SMWIA union label directory as bearing the Union label, more than 30 are products that either are used in solar heating and cooling systems or are affected by their development. It is essential that the Union keep up to date on solar system developments that affect these products.

The legislation governing federal programs in the solar heating and cooling area specifically requires the dissemination of information to the building industry and related segments of the economy. The Union can assist in this effort by offering itself as a communication channel between interested construction workers and fabricators and policy and decision makers. To maintain its position in the industry, the Union must be recognized as a stakeholder in the solar heating and cooling area.

Power and Pressure Points

If the Union moves aggresively in becoming an active participant in the areas discussed above, it will not only be brought into contact but also cooperation with the power and pressure points that can maximize its usefulness both to the industrial community and to its own members. Although the principal contact points are covered in this report, these change by the nature of development, and it is essential that the Union maintain an active program of contacting, lobbying, and intelligence gathering that will keep it both up to date and concerned at federal, state, and local levels with government, industry, professional associations, and research communities.

Although it would appear from the forecast that solar systems will make a relatively small contribution compared with other forms of energy during the rest of the 20th century, in total dollar terms the outlook for solar heating and cooling is not small. Furthermore, during this period the guidelines will be developed within which solar systems must be constructed, maintained, and operated. Experimental systems will be demonstrated, tested, and evaluated. In addition, it is conceivable that this technology will take hold and that the public will accept it more quickly than expected. In either case, it is essential to the continued health of the Union for it to participate actively in this development and demonstration phase of the solar energy cycle.

APPENDICES

Appendix A

NSF/SOLAR ENERGY RESEARCH GRANTS AND CONTRACTS, 1973 AND 1975

Institution and Program Manager	Title and Grant Number	Amount, Duration (Months) and Effective Date
Heating & Cooling of Buildings		
American Society of Heating, Refrigeration & Air Conditioning C. MacPhee	Preparation & Publication of an ASHRAE Guide Chapter on the Application of Solar Energy for Heating & Cooling of Buildings (GI-39247)	$ 5,000/12 7/1/73
University of Florida E. Farber	Formulation of a Data Base for the Analysis, Evaluation, and Selection of a Low Temperature Solar Powered Air-Conditioning System (GI-39323)	49,400/9 7/1/73
University of Maryland R. Allen	Optimization Studies of Solar Absorption Air-Conditioning Systems (GI-39117)	129,300/18 8/15/73
University of Wisconsin J. Duffie	Computer Modeling & Simulation of Solar Heating and Cooling Systems (GI-34028-1)	65,300/12 10/1/73
AAI Corporation Thomas J. Holden	Solar heating proof-of-concept experiment for a public school building (CPTP74-12918 A03--formerly C-871)	294,074/05 (PTP) 10/31/74
Auburn University Robert N. Brewer Jerry R. Dunn	Potential for conversion and utilization of solar energy in poultry production (CPTP74-23987)	41,200/07 (PTP) 09/30/74
Battelle Columbus Laboratories Donald H. Frieling James A. Eibling	A critical review and analysis of the advanced research implications of the phase 0 program results on solar heating and cooling of buildings (74-24326)	40,200/03 08/26/74
Boeing Aerospace Company Roger B. Gillette	Research on vacuum insulated glass solar energy collectors with dyed fluid absorbers for the heating and cooling of buildings (74-09139)	75,400/12 08/27/74
California, University of (LA) J. D. Mackenzie	Research on transparent glass honeycomb structures for energy loss control in solar energy collectors for the heating and cooling of buildings (74-08848)	84,400/12 07/29/74
Delaware, University of Jerome E. Scott	Consumer demand analysis: solar heating and cooling of buildings (75-02168)	55,500/10 09/74
Dynatherm Corporation Walter B. Bienart	Research on flat plate solar collectors employing the heat pipe principle for heating and cooling of buildings (74-09164)	53,400/12 08/26/74
Hittman Associates, Inc. Henry M. Curran	Assessment of solar powered cooling of buildings (7400733A01)	32,400/08 10/74
Honeywell, Inc. John D. Kopecky	Solar energy school heating augmentation experiment (74-12916A02)	105,604/-- 10/18/74
Honeywell, Inc. Robert LeChevalier	Transportable solar laboratory (74-01555A03--formerly GI-41537)	97,500/-- 10/15/74
Honeywell, Inc. Henry Y. B. Mar	Research on low cost means of achieving solar collector absorber coatings and anti-reflection coatings for the heating and cooling of buildings (74-09104)	144,000/12 9/30/74
Lockheed Missiles and Space Co., Inc. Elmer H. Streed	Research on metal and plastic honeycomb flat plate collectors for the heating and cooling of buildings (74-09060)	86,500/12 9/74
Los Alamos Scientific Laboratory J. Douglas Blacomb	Research on integrated solar collector roof structures for the heating and cooling of buildings (74-09003)	126,000/12 7/74
Maryland, University of Stephen L. Sargent	Workshop on solar collectors for heating and cooling of buildings (GAER74-24639)	57,300/12 9/30/74
Texas A&M University Richard R. Davison	Further development of the compressed-film floating-deck solar water heater (GAER73-03172A01)	73,900/12 10/31/74
Texas Instruments, Inc. Reuvo Santala	Research on cost-effective and durable composite collector plates for solar energy collectors for heating and cooling of buildings (74-09036)	79,100/12 8/26/74
Waterloo, University of K.G.T. Hollands	Research on methods for reducing heat losses from flat plate solar collectors for the heating and cooling of buildings (74-09110)	48,900/12 08/27/74

Appendix B

EXAMPLES OF SOLAR HEATED AND COOLED DWELLINGS

The examples of solar heated and cooled dwellings were provided by the Research Corporation of the American Institute of Architects. It is an extract of a report prepared by the Solar Energy Applications Team of the College of Architecture, Arizona State University, for the American Institute of Architects and the National Bureau of Standards. In addition to one-line summaries of 70 dwellings that utilized solar energy, the report includes one-page data sheets that provide more detailed information on each dwelling, and a section that provides detailed descriptions and full sets of drawings for ten residences which were selected as principal examples of using solar radiation for heating and cooling. Other pertinent information regarding the basic principles of solar space heating and analysis of the use of these methods in the principal examples as well as additional useful reference data are included. The report provides the following explanatory note for the table.

The 70 dwellings have met the criteria of

- Significance in the development of solar heating and cooling.
- Availability of sufficient information to permit an intelligible description to be given.
- Completion and operation or completion of design and progress in construction to the point where operation is assured.

Each project has a serial number, assigned in the order of presentation, and a year number, which gives the year of completion and a sequence number within that year. Each project also has a verbal designation, generally derived from the name of the builder or the owner, the location in which it was built, or some other well recognized terminology. Next come notations of the means of collection, and storage of solar energy, the means of heat distribution, of cooling (if any) and of providing auxiliary heat. Finally, there is a brief characterization of the architectural aspects of each project and an assignment to one of the four principal systems that are described in the AIA report.

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SUMMARY OF DATA SHEETS, TABLE 1.1

AIA R/C Report, Page 5

PROJECT NO. (YEAR PLUS #)	PROJECT DESIGNATION	DATE OF SOLAR INSTALLATION	COLLECTION MEANS			STORAGE MEANS				HEAT DISTRIBUTION MEANS:	COOLING MEANS	AUXILIARY HEATING MEANS:	ARCHITECTURAL CHARACTERIZATION (SEE DATA SHEETS FOR ADDITIONAL DETAILS) (*ARCHITECT DESIGNED)
			DIRECT USE OF SOLAR RADIATION	CONVERSION OF SOLAR RAD. TO HEAT BY		SPECIFIC HEAT			CHEMICAL				
				AIR	WATER	BUILDING FABRIC: WALLS, FLOORS	ROCK BED: HOR. OR VERTICAL	WATER: TANKS OR HOR. PONDS	HEAT OF FUSION: EUTECTIC SALTS				
1100-1 / 1	Montezuma's Castle	1100 AD	X			X				Radiation & Convection	Ventilation	Wood Fire	Totally passive system emphasizing the integration of man, his functions and his environment.
38-1 / 2	Keck-Sloan Houses	1938-1939	X			X				Radiation & Convection	Ventilation	Oil Furnace	See No. 4 *
39-1 / 3	M.I.T. Solar House #1	1939			Copper to Water	X		Horizontal Tank		Warm Air			No significant impact on the design of the house other than south-facing roof with a collector. *
40-1 / 4	Duncan-Keck House	1940	X			X				Radiation	Ventilation	Oil Furnace	Specially designed on an east-west axis to allow major rooms to have maximum southern exposure. *
45-1 / 5	Hutchinson-Purdue House	1945	X			X				Rad. & Convec.		Electric Resist.	Typical frame house with more south-facing glass than normal.
45-2 / 6	Löf Boulder Cottage	1945		Glass to Air			Vertical			Warm Air		Gas Furnace	A retrofit house with no design impact except the visual impact of the collectors.
47-1 / 7	M.I.T. Solar House #II	1947	X		Alum. to Water	Y		Vertical Tanks		Rad & Convec.		Electric Resist.	A structural box for experiments. *
49-1 / 8	Dover House	1949		X					5 Gal. Steel Drums	Warm Air			All rooms are oriented to the south to provide for a large collection area. *
49-2 / 9	M.I.T. Solar House #III	1949			Copper to Water			Horizon. Tank		Radiation	Ventilation	Kerosene & Electric	The collector and storage were a major design feature which was added on, but not integrated. *
53-1 / 10	"State College Solar House"	1953		Metal to Air					X	Warm Air		Gas Furnace	No architectural information.
54-1 / 11	Lefever House (New York)	1954		Metal to Air		X				Radiation & Fan		Gas Furnace	Major characterization is a second story vertical, south-facing collector.
54-2 / 12	Bliss Amado Hse (30 mi. South of Tucson)	1954		Cloth to Air			Horiz.			Warm Air	Nocturnal	Electric Resist.	No architectural characterization since collector was separate from building.
56-1 / 13	Odeillo Solar Houses, Trombe Type	1956	X	Concrete to Air		X				Rad. & Convec.	Ventilation	Electric Resist.	South-facing window wall backed by dark painted concrete wall with east-west axis; one room in depth. *
56-2 / 14	Yanagimachi Solar House No. 1	1956			Alum. to Water			Tank		Rad. & Convec.	Heat Pump & Nocturn.	Sol.Asst Heat Pump	No architectural information.
57-1 / 15	Van Dresser Retrofit	1957		Metal to Air			Horiz. Gravel			Radiation	Ventilation	Electric Resist.	Retrofit to change roof line form by adding 2 collector structures.

SUMMARY OF DATA SHEETS, TABLE 1.2

PROJECT NO. (YEAR PLUS #)	PROJECT DESIGNATION	DATE OF SOLAR INSTALLATION	COLLECTION MEANS			STORAGE MEANS				HEAT DISTRIBUTION MEANS:	COOLING MEANS	AUXILIARY HEATING MEANS:	ARCHITECTURAL CHARACTERIZATION (SEE DATA SHEETS FOR ADDITIONAL DETAILS) (*ARCHITECT DESIGNED)
			DIRECT USE OF SOLAR RADIATION	CONVERSION OF SOLAR RAD. TO HEAT BY		SPECIFIC HEAT			CHEMICAL				
				AIR	WATER	BUILDING FABRIC: WALLS, FLOORS	ROCK BED: HOR. OR VERTICAL	WATER TANKS OR HOR. PONDS	HEAT OF FUSION: EUTECTIC SALTS				
55-1 / 16	AFASE Solar House	1958			Metal to Water			Horiz. Tank		Warm Air	Heat Pump	Heat Pump	An attempt to create its own vernacular within the 1950's style of zoned open plan."
58-2 / 17	White Los Angeles Residence	1958			Copper to Water			Horiz. Tank		Radiant			West Coast vernacular, ranch style, unaffected by the system because it is separated from the house."
58-3 / 18	M.I.T. House No. IV	1959			Copper to Water			Horiz. Tank		Warm Air		Oil Furnace	Dominant roof structure to contain solar collectors. Also utilizes earth berms."
58-4 / 19	Yanagimachi Solar House No. II	1958			Alum. to Water			Tank		Warm Air	Heat Pump	Heat Pump	Roof of different material (bare aluminum) than conventional roof, but building form is relatively unaffected.
59-1 / 20	Thomason Solar House No. I	1959			Alum. to Water		Horiz. Rocks	Horiz. Tank		Warm Air	Nocturn. & Evap.	Oil Furnace	Traditional house with altered south facade totally of collectors.
59-2 / 21	Lof Denver (Englewood) Residence	1959		Glass to Air			Vertical Cyl.			Warm Air			An attempt at design integration. Grid system plan with tilted collectors on flat roof."
60-1 / 22	Thomason Solar House No. II	1960			Alum. to Water		Horiz. Rocks	Horiz. Tank		Warm Air	Refrig.	Electric	See No. 20.
60-2 / 23	Saunder's Weston House	1960	Y	Metal to Air		X				Rad. & Convec.			South-facing glass wall; basically a box with glazed flat roof for additional collection.
60-4 / 24	K.S.C. Solar Assisted Heat Pump Study	1958		Metal to Air				Plastic-Sealed Cans		Warm Air	Heat Pump	Heat Pump	No architectural information.
62-1 / 25	Mowry & Davis Adaptation	1962		Metal to Air			Horiz. Rocks			Warm Air	Heat Pump	Heat Pump	No architectural impact since collectors are free-standing.
63-1 / 26	Thomason Solar House No. III	1963			Alum. to Water		Horiz. Rocks	Horiz. Tank		Warm Air	Refrig.	Oil Furnace	Attempt to use the building shape for maximum solar collection. Architectural expression is in local vernacular.
63-2 / 27	University of Florida House	1963			Copper to Water			Tank		Radiant	Evap. Cool Air		Retrofitted house with no design impact but high visual impact.
66-1 / 28	Brisbane "Solar House"	1966			Copper to Water			Tank			Li Br Absorption		Collector incorporated into free-standing roof providing large overhangs.
67-1 / 29	"Coos Bay House"	1967			Galv. Steel to Water			Tank		Convec.		Electric	Conventional house with unconventional collector placement at ridge line.
68-1 / 30	Hoffman (Surrey) House	1971			Copper to Water			Tank		Convec.		Electric	Retrofitted house with modified design to accommodate collectors.

SUMMARY OF DATA SHEETS, TABLE 1.3

PROJECT NO. (YEAR PLUS #)	PROJECT DESIGNATION	DATE OF SOLAR INSTALLATION	COLLECTION MEANS			STORAGE MEANS				HEAT DISTRIBUTION MEANS:	COOLING MEANS	AUXILIARY HEATING MEANS:	ARCHITECTURAL CHARACTERIZATION (SEE DATA SHEETS FOR ADDITIONAL DETAILS) (*ARCHITECT DESIGNED)
			DIRECT USE OF SOLAR RADIATION	CONVERSION OF SOLAR RAD. TO HEAT BY		SPECIFIC HEAT			CHEMICAL				
				AIR	WATER	BUILDING FABRIC: WALLS, FLOORS	ROCK BED: HOR. OR VERTICAL	WATER: TANKS OR HOR. PONDS	HEAT OF FUSION: EUTECTIC SALTS				
71-1 31	Baer House, Near Albuquerque "Zomeworks"	1971	X					Barrels		Radiation	Nocturnal	Wood Stove	Very significant architectural expression. Passive system, utilizing form and function for maximized comfort.
72-1 32	Davis House Corrales	1972		Wire Mesh to Air			Horiz.			Natural Convec.		Fireplace & Electric	Major response within accepted vernacular. Utilizes form and function for maximum comfort using passive systems.
72-2 33	Reines "ILS" Energy Low Residence	1972			X			Tank					Architectural response not in terms of solar heating systems, but attempt to create own vernacular thru optimum structure.
73-1 34	Atascadero "Skytherm" House	1973	X					Horiz. Pond		Radiation	Nocturnal	Gas Furnace	System is adaptable to any flat-roofed structure with no special orientation or style.*
73-2 35	Meinel House Retrofit	1973		X				1,000 1 Gal. Bottles		Warm Air	Evap.		No design impact since system is separated from the building.
73-3 36	"Solar One" Univ of Del. Solar-Electric House	1973		X					X	Warm Air		Electric	Designed in existing regional vernacular. Major design impact is roof collector system.
73-4 37	Monte Vista School Greenhouse	1973	X					55-Gal. Drums		Rad. & Convec.			South-facing plexiglass bead wall.*
74-1 38	MSFS (NASA) Solar House	1974			Alum. to Water			Horiz. Tank			Li Br Refrig.	Electric	Completely separate roof structure housing three trailers.
74-2 39	Watson-Barber House	1974	X		Copper to Water	X		Tank		Warm Air, Rad.		Oil Furnace	Attempt to break up the large collector area and integrate it with the building forms.*
74-3 40	Cottrell-Visalia Solar House	1974			Alum. to Water			Tank		Warm Air	X	Fireplace & Stove	Solar collection devices dictate slope of roof but not the form of the building.
74-4 41	Pinchot Garage House	1974			Copper to Water			Concrete Tank		Warm Air		Oil Heater	Retrofit with collectors added to roof.*
74-5 42	Ouroboros South House	1974			Steel to Water		Horiz.	Tank		Warm Air			Form of building is responsive to environmental factors in an integrated manner.*
74-6 43	Ouroboros East Retrofit	1974			Steel to Water			Tank		Warm Air			Retrofit that has major impact on south wall and roof.*
74-7 44	New Paltz House	1974	X		Iron to Water	Concrete Floors	Horiz.	Tank		Rad. & Warm Air			No architectural information.*
74-8 45	P P and L Solar House	1974			X			Tank		Warm Air	Heat Pump	Electric	No architectural impact other than visual. Collector is separate and acts as a fence. *

SUMMARY OF DATA SHEETS, TABLE 1.4

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PROJECT NO. (YEAR PLUS #)	PROJECT DESIGNATION	DATE OF SOLAR INSTALLATION	COLLECTION MEANS			STORAGE MEANS				HEAT DISTRIBUTION MEANS:	COOLING MEANS	AUXILIARY HEATING MEANS:	ARCHITECTURAL CHARACTERIZATION (SEE DATA SHEETS FOR ADDITIONAL DETAILS) (*ARCHITECT DESIGNED)
			DIRECT USE OF SOLAR RADIATION	CONVERSION OF SOLAR RAD. TO HEAT BY		SPECIFIC HEAT			CHEMICAL				
				AIR	WATER	BUILDING FABRIC: WALLS, FLOORS	ROCK BED: HOR. OR VERTICAL	WATER: TANKS OR HOR. PONDS	HEAT OF FUSION: EUTECTIC SALTS				
74-9 46	Colorado State University Solar House	1974			Alum. to Water			Tank		Warm Air	Li Br Absorp.	Gas Boiler	Designed within existing vernacular with solar collectors designed into roof.
74-10 47	"Phoenix of Colorado Springs"	1974			Alum. to Water			Tank		Warm Air & Rad.	Heat Pump	Heat Pump	Attempt to create own vernacular by allowing shape of system to dictate the form.*
74-11 48	Peter Wood House	1974			X		Horiz.	Tank		Warm Air	Nocturnal & Evap.	Gas Furnace	See No. 47.*
74-12 49	Davis House at Bar Harbor	1974	X		Alum. to Water	X	Horiz.	Tank		Warm Air Rad.		Wood Stove	Major impact on south facade, only.*
74-13 50	Ohio State Univ. Solar House, Columbus Fair Grnd	1974			Alum. to Water			Tank		Heat Pump	Li Br Absorp.	Electric Heater	Attempt to integrate solar collectors into accepted contemporary vernacular.*
74-14 51	Thomason Solar House No. VI	1974			Alum. to Water		Horiz.	Tank		Warm Air	Refrig.	Oil Heater	See No. 26.
74-15 52	Crowther Retrofit, Denver	1974		Metal to Air			Horiz.			Gravity Convec.		Gas Furnace	Retrofit with little impact on design of residence other than visual.
74-16 53	"David Wright's House"	1974	X			X				Rad.	Ventilation		Response to passive systems which creates its own vernacular.*
74-17 54	Shore Snowmass House	1974	X		Alum. to Water	X		Concrete Tank		Rad. & Gravity Convec.	Ventilation		Uses many energy conserving systems which are integrated into internal functions of the building.*
74-18 55	NBS Solar House	1974			X			Tank		Warm Air	Li br Absorp.		Visual impact of collector on second floor area, wall and roof.
74-19 56	Seaton Village House	1974		X			Horiz.			Warm Air			No architectural information.*
74-20 57	Crowther Denver Residence	1974	X		Alum. to Water	X		2 Tanks		Warm Air	Convec. Cooling & Evap.	Gas Furnace	Integration of greenhouse, glazed south wall and roof collectors into its own vernacular.*
74-21 58	Yazaki Solar CHC System	1974			Alum. to Water		X	Tank		Warm Air	Li Br Absorp. Refrig.	Gas Water Heater	Integration of roof collector system into local idiom.
74-22 59	Sinton Retrofit	1974			X			2 Tanks					No architectural information.*
74-23 60	Miller Residence	1974	X	Metal to Air			Horiz.			Warm Air	Ventilation	Gas Furnace	Retrofit significantly alters south facade of existing adobe structure.

SUMMARY OF DATA SHEETS, TABLE 1.5

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PROJECT NO. (YEAR PLUS #)	PROJECT DESIGNATION	DATE OF SOLAR INSTALLATION	COLLECTION MEANS			STORAGE MEANS				HEAT DISTRIBUTION MEANS:	COOLING MEANS	AUXILIARY HEATING MEANS:	ARCHITECTURAL CHARACTERIZATION (SEE DATA SHEETS FOR ADDITIONAL DETAILS) (*ARCHITECT DESIGNED)
			DIRECT USE OF SOLAR RADIATION	CONVERSION OF SOLAR RAD. TO HEAT BY		SPECIFIC HEAT			CHEMICAL				
				AIR	WATER	BUILDING FABRIC: WALLS, FLOORS	ROCK BED: HOR. OR VERTICAL	WATER: TANKS OR HOR. PONDS	HEAT OF FUSION: EUTECTIC SALTS				
74-24 61	Aller Log Cabin Guest House	1974		X			Horiz.			Warm Air			Adaptation of solar collectors to roof of existing building.*
75-1 62	Perna House (60 miles north of Denver)	1975		Metal to Air			Horiz.			Warm Air		Liquid Gas Furnace	Very significant impact on the design.*
75-2 63	Guadalupe Project No. 1 (Near Phoenix)	1975	X	Alum. to Air		X	Horiz.			Natural Convec.	Ventila. & Evap. (RBR)	Elec. & Fire-place	Attempt at using several systems and integrating them into the cultural idiom.
75-3 64	Engle House (N.E. Oklahoma)	1975			Alum. to Water			Tank		Warm Air	Refrig.	Electric Boiler	Attempt to integrate solar concepts into total design process.*
75-4 65	Decade 80 Solar House	1975			Copper to Water			Tank		Warm Air	Lt Br Absorp-tion		Attempt to incorporate solar roof system into regional vernacular.*
75-5 66	Barber House at Guilford	1975			Copper to Water		Horiz.	Tank		Warm Air & Rad.	Ventila-tion	Oil Furnace	Incorporates new vernacular with a regional character.*
75-6 67	Karen Terry Residence	1975	?			?		22 55-Gal. Drums		Rad. & Convec.	Ventila-tion	2 Wood-Burning Stoves	See No. 53.*
75-7 68	Ponton House at Alpine (S.E. of El Paso)	1975	X			X		Swimming Pool		Rad. & Convec.	Ventila-tion	Fire-places & Furnace	Passive systems incorporated into local idiom.*
75-8 69	Arcosanti-Basilica & Amphitheater Cordes Junct., AZ	1975	X	Metal to Air		X				Rad., Convec. & Warm Air			Very organic. Establishes a unique character.*
75-9 70	Arcosanti Greenhouse	1975	X			X				Rad. & Convec.			Very organic. Establishes a unique character.*

Appendix C

INDUSTRIAL PRODUCERS OF SOLAR COMPONENTS

The following partial list of producers of solar components and systems was derived from various sources by GSA. It should not be assumed that these producers are recommended or preferred by the General Services Administration, to others not included.

Solar Equipment Sales Division (Beasley Solapax hot water system)
Solar Energy Digest
P. O. Box 17776
San Diego, California 92117
Phone: (714) 277-2980

Energex Corporation
Suite C-137
5441 Paradise Road
Las Vegas, Nevada 89119

Fun and Frolic, Inc. ("Solarator" pool water heater)
Department S
P. O. Box 277
Madison Heights, Michigan 48071

Sky Therm Processes and Engineering
945 Wilshire Boulevard
Los Angeles, California 90017
Phone: (213) 624-7261

Solar Systems, Inc.
P. O. Box 744
1515 West Southwest Loop 323
Tyler, Texas 75701
Phone: (214) 592-0945

General Dynamics Corporation
Convair Aerospace Division
P. O. Box 748
Fort Worth, Texas 76101
Phone: (817) 732-4811

General Electric Company
Space Division
P. O. Box 8555
Philadelphia, Pennsylvania 19101
Phone: (215) 962-7591

Honeywell, Inc.
2700 Rideway Parkway
Minneapolis, Minnesota 55413
Phone: (612) 231-4141

Intertechnology Corporation
P. O. Box 340
Warrenton, Virginia 22186

AAI Corporation
P. O. 6767
Baltimore, Maryland 21204
Phone: (301) 666-1400

Corning Glass Works
Mr. Daniel Willkens
Products Sales Manager
Corning, New York 14830

PPG Industries
Mr. Richard Lewchuk
Product Manager
1 Gateway Center
Pittsburgh, Pennsylvania 15222

The following companies also are manufacturing components.

Energy Systems Inc. El Cajon, California	Refined wet type solar system for space and water heating integrated into $135,000 to $300,000 homes in Vista del Colinas, a subdivision near San Diego. Total value of contract to provide systems for 23 homes is equal to $149,000.
Revere Copper and Brass Inc. New York, New York	Marketing solar energy collectors for heating and cooling for use in heating buildings, water, swimming pools, and operating absorption air conditioning units.

PPB Industries Pittsburg, Pennsylvania	Produces solar energy collector cells for heating and hot water.
Solar Energy Company Washington, D. C. George Hamilton, President	
Solar Power Corporation Elliot Vernon, President	Financed by Exxon. For orders for 1,000 units or more, they will sell 5-cell modules with output of 1-1/2 peak watts at $30 each. The company has sold arrays for navigation lights, offshore gas production platforms, radio message repeater stations in Yellowstone National Park and railroad signaling devices.

Appendix D

FEDERAL AGENCY AREAS OF RESPONSIBILITY FOR SOLAR HEATING AND COOLING

Program Element/Task	ERDA	HUD	NASA	FEA	DoD	NSF	GSA	NBS	Other Agencies
Research	L	C	C	C	C	C	C	C	
Components Research	L/U		U			C		U	
Applied Materials Research	L/U		U			C		U	
Building Design Implications	L/U	U	U	C	C	C	C	U	
Systems Analysis	L/U	C	U	C	C	C	C	U	
Insolation and Climatic Data	L/U	C	C		C	U	C	U	U (NOAA)
Development for Demonstration Program	L	C			C		C	C	
System Development	L/U		U						
Additional Development of Proposed Systems	L		U						
System Development of Available Subsystems	L		U						
Data Collection Subsystem	L		U					C	
Data Collection	L/U		U					C	
Additional Development of Proposed Subsystems	L		U						
Purchase of Available Subsystems	L		U						
New Subsystem and Components Development	L/U		U						
Demonstration Engineering Support	L		U						
Test and Evaluation	L		U					C/U	
Development	L/U		U		C	C			
Residential Demonstration	J	J	C	C	C		C	C	
Preliminary Program Development Studies and Program Management									
Detailed Design of Demonstration	J	J			C/U				
Technical Design and Data Requirements	C	L/U	C	C	C		C	C	C (NOAA)
Environmental Impact Statements	U	L		C					C (EPA)
Potential Market Incentives		L/U		U		C			
Utility Company Options	U	L		C					C (FPC)
Solar Energy Systems Consultant	C	L/U							
Program Management	C	L/U							
Performance Criteria									
Develop Interim Performance Criteria		L	C		C	C		U	
Monitor Demonstration for Feedback	C	L	C	C	C			U	
Develop Definitive Performance Criteria	C	L	C		C			U	
Certification Procedure	C	L	C		C			U	
Criteria for Accreditation of Testing Labs		L	C		C			U	
Conduct of Demonstrations									
Integral System Design	J/U	J/U			C				
Solicitation for Information on Available Systems and Subsystems	J/U	J/U	C	C	C			C	
Systems Qualification and Testing	C	L	U					U	
Site and Site Developer Solicitation	C	L/U			C				
Design Integration	C	L/U	C					C	
Construction		L/U			C/U				
Repair and Maintenance of Units		L/U			C/U				
Federal Properties		L			U		C		U (DOI)
Demonstration Support and Data Collection									
Collect and Evaluate Technical Performance Data	C/U	L	C/U		U			C/U	
Collect Demonstration Data		L/U		C/U	U			C/U	
Prepare Recommended Actions	C	L/U		C/U				C	
Develop and Publish Acceptable Practice Manuals	C	L/U	C		U			C	
Data for Warranty Program		L/U						C	
Market Development									
Develop Detailed Financial Procedures and Recommendations Supporting the Use of Solar Energy Systems		L/U		C/U					
Develop Standard Tax Appraisal and Assessment Procedures Supporting the Use of Solar Energy		L/U		C/U					
Develop Consumer Preferences Data	C	L/U		C/U				C/U	
Economic Analysis Techniques to Predict Savings Potential of Solar Energy	C	L/U		C/U	C			C/U	
Commercial Demonstration	L		C	C	C		C	C	
Preliminary Program Development Studies	L/U								C (USDA, USPS, DOI, HEW)
Detailed Design of Demonstration	L/U	C			C		C		
Technical Design and Data Requirements	L/U	C			C		C	C	
Environmental Impact Statements	L/U				C				C (EPA)
Utility Company Options	L/U			C	C		C		C (FPC)
Potential Market Incentives	L/U			U					

Program Element/Task	ERDA	HUD	NASA	FEA	DoD	NSF	GSA	NBS	Other Agencies
Commercial Demonstration (Continued)									
Performance Criteria									
Develop Interim Performance Criteria	L	C	C		C		C	U	C (USDA, USPS, DOI, HEW)
Monitor Demonstrations for Feedback	L	C	C	C	C		C	U	C (USDA, USPS, DOI, HEW)
Develop Definitive Performance Criteria	L	C	C		C		C	U	C (USDA, USPS, DOI, HEW)
Certification Procedure	L	C	C		C		C	U	
Criteria for Accreditation of Testing Labs	L	C	C		C		C	U	
Conduct of Demonstrations									
Integrated Systems	L/U	C			C				
Selection of Available Systems and Subsystems	L/U	C	C		C				
Repair and Maintenance of Units	L/U	C			U		C		
Federal Properties	L	C			U		U		U (USDA, USPS, DOI, HEW)
Demonstration Support and Data Collection									
Collect and Evaluate Technical Performance Data	L/U		U		C		C	U	C (USDA, USPS, DOI, HEW)
Collect Demonstration Data	L/U	C			C		C		C (USDA, USPS, DOI, HEW)
Prepare Recommended Actions for Achieving Utilization	L/U	C		C/U					
Develop and Publish Manuals	L/U				U		U		U (USDA, USPS, DOI, HEW)
Market Development									
Develop Detailed Financial Procedures and Recommendations Supporting the Use of Solar Energy Systems	L/U			C/U	C/U		C/U		C/U (USDA, USPS, DOI, HEW)
Develop Standard Tax Appraisal and Assessment Procedures Supporting the Use of Solar Energy	L/U			C/U	C/U		C/U		C/U (USDA, USPS, DOI, HEW)
Develop Consumer Preference Data	L/U			C/U	C/U		C/U		C/U (USDA, USPS, DOI, HEW)
Economic Analysis Techniques to Predict Savings Potential of Solar Energy	L/U			C/U	C/U		C/U	C/U	C/U (USDA, USPS, DOI, HEW)
Collection and Dissemination of Information	L/U	U/C	U	U	U	U	U	U	U (all others)
Demonstration Information	L/U	U	U	U	U			U	
Residential	J	J	U	U	U				
Central agency	L	U/C	U		U			U	
Program activity	J	J	U	U	U			U	U (NOAA)
Dissemination to building industry	C	L/U						U	
Commercial	L/U								
Central agency	L/U		U					U	
Program activity	L/U		U					U	U (NOAA, USDA, USPS, HEW)
Dissemination to building industry	C	L/U						U	
Supporting Development Information	L/U	U	U	U					
Central agency	L/U	U	U						
Program activity	L/U	U	U						
Research and Development Information	L/U	U	U	U		U		U	U (all others doing R&D)
Central agency	L/U	U	U			U		U	
Program activity	L/U	U	U	U		U		U	U (all others doing R&D)

Legend: L = Lead Responsibility

J = Joint Responsibility

C = Consultation/Coordination

U = "Utilizing the Services of"

Source: Interim Report, National Plan for Heating and Cooling, March 1975 (ERDA-23)

Impact of Energy Developments on the Sheet Metal Industry

A study performed by the Mitre Corporation for the Sheet Metal Workers International Association

Impact of Energy Developments on the Sheet Metal Industry

A study performed by the Mitre Corporation for the Sheet Metal Workers International Association

ARNOLD COHEN
MARY HARLOW
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PETER SPEWAK

JUNE 1975

THE MITRE CORPORATION
WASHINGTON OPERATIONS

FOREWORD

The energy crisis of the last two years has taught us that we must press the development of the mid-range options, coal and nuclear energy; but that we must also accelerate the utilization of renewable energy sources such as solar radiation. In the long run, the renewable sources will be all we have, since the finite reserves of the earth will inevitably be used up some day. In the meanwhile, every bit of useful energy we can gather from the sun, or that we can save through sound conservation practices, will stretch our fossil fuels and ease the demand for imported oil which causes the United States many economic and political problems.

This document surveys the present energy situation, the federal government's energy policies and programs, and the state-of-the-art in solar heating and cooling of buildings and in energy conservation. It recommends a program of specific action for the Sheet Metal Workers International Association which will, at the same time, serve the nation's energy needs and provide employment opportunities for the Union's members.

Some recommended actions are in the area of solar heating and cooling, where, for instance, steps should be taken immediately to see that air-operated solar systems receive equal consideration with water-operated systems. An action program should also be formulated in energy conservation in buildings, and in the conservation and beneficial use of industrial energy, often now wasted.

The Sheet Metal Workers International Association deserves commendation for undertaking this careful look at its opportunities to serve both the nation and its members. The MITRE Corporation is pleased to have participated in the effort.

Charles A. Zraket
Senior Vice President

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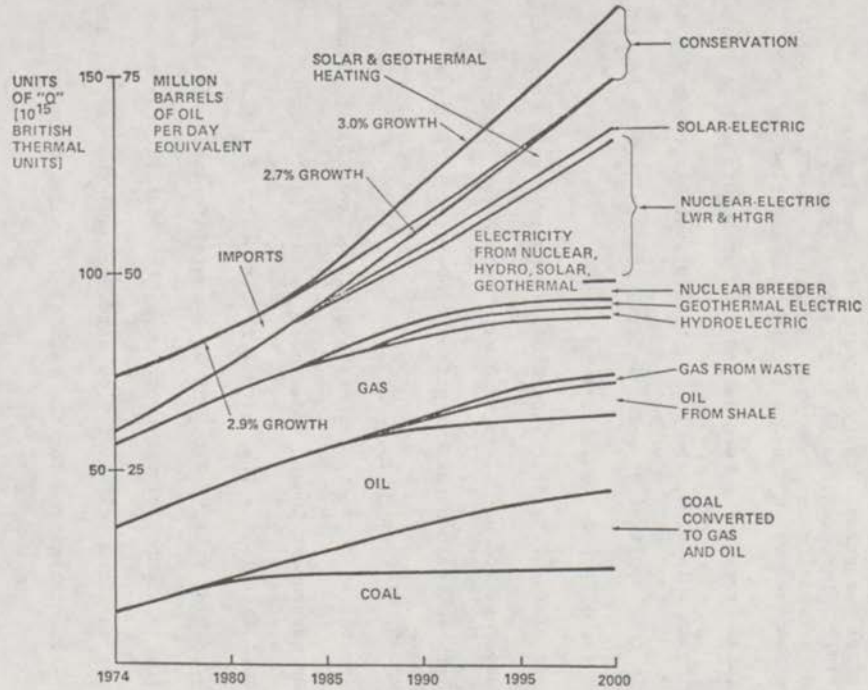
1.0 SUMMARY

Increasing energy consumption and decreasing production have changed the United States in recent years from an energy exporter to an energy importer. This has made the country vulnerable to economic and political pressure from energy-exporting nations. A number of major studies of this problem have shown that all possible means of closing the national energy gap must be pursued vigorously: increasing domestic production, developing new sources of energy, and using energy more efficiently. Figure 1-1 presents MITRE's best estimate of the nation's energy future up to the year 2000.

Two areas which will be receiving considerable emphasis are the conservation of energy used to heat and cool buildings and the employment of solar energy for these purposes. Here the Sheet Metal Workers International Association can make a major national contribution, and simultaneously ensure employment opportunities for its members.

Four major pieces of legislation have been enacted which will promote the use of solar energy for heating and cooling buildings. They are:

- Solar Heating and Cooling Demonstration Act of 1974. A $60 million program of demonstrations on residential and commercial buildings throughout the United States,
- Energy Reorganization Act of 1974. Established the Energy Research and Development Administration (ERDA),
- Solar Energy Research, Development and Demonstration Act of 1974. Stated a national policy of intensive solar development. Provided for a comprehensive plan, a Solar Energy Research Institute and a Solar Energy Information Data Bank.



[SOURCE: MITRE 5/8/75]

FIGURE 1-1
ESTIMATED ANNUAL U.S. ENERGY SOURCES

- Federal Nonnuclear Energy Research and Development Act of 1974. Directed the Administrator of ERDA to formulate and carry out a comprehensive nonnuclear development pro program, and established its guiding principles.

A national program has been designed to stimulate a large nationwide industry in this area, and substantial private interest has also developed in this application. The federal program is expected to produce the results shown in Table 1-I.

A number of federal, state and local incentives have been proposed to encourage the use of solar energy and energy conservation in buildings. These include tax exemptions, low-interest loans and outright government grants.

Solar energy systems are competitive with conventional systems, even without government incentives, under certain circumstances. The most important factors are the thermal requirements of the buildings, the available solar energy, the cost of competitive fuels, (for example, solar heating is cheaper almost everywhere than electric resistance heating), the cost and reliability of hardware, and the cost of the capital investment required for the initial installation of solar equipment.

As the prices for energy continue to increase, solar heating and cooling will become competitive in more parts of the country. Figure 1-2 presents MITRE's projections of energy prices. The mass production of solar equipment by responsible manufacturers can be expected to improve its reliability and reduce its initial cost.

TABLE 1-I

1985 TARGETS OF NATIONAL PROGRAM FOR

SOLAR HEATING AND COOLING OF BUILDINGS

TYPE OF BUILDING	NUMBER INSTALLED BY 1985
Residential Units	596,000
New Commercial Units	54,000
Existing Commercial Buildings	13,000
Annual Fuel Savings	36 Million Barrels of Oil

FIGURE 1-2 ESTIMATED FUEL PRICES
1973-1985

(CONSTANT 1975 DOLLARS)

		OCT. 1973	1975	1977	1980	1985
CRUDE OIL	($/BARREL)	4	12	14	16	18
HOME HEATING OIL	($/BARREL)	6	14	16	18	20
	($/MM BTU)	1.03	2.41	2.76	3.10	3.45
COAL (UTILITY)	($/TON)	10	25	30	35	40
NATURAL GAS	($/1000 CU. FT. OR APPROXIMATELY $/MM BTU)					
AVG. RESIDENTIAL RATE(WITHOUT/WITH DEREGULATION OF PRICES OF "NEW"GAS IN 1976)						
NEW ENGLAND		2.22	2.50	2.60/2.75	2.75/4.50	3.00/4.75
MIDWEST		0.92	1.25	1.50/1.85	2.00/4.00	2.30/4.25
WEST-SOUTH-CENTRAL		1.04	1.35	1.65/2.00	2.20/4.15	2.40/4.35
ELECTRICITY						
NATIONAL AVG. RESIDENTIAL RATE	(¢/Kw hr)	2.00	2.50	2.70	2.80	3.00
EQUIVALENT HEAT COST	($/MM BTU)	5.86	7.30	7.90	8.20	8.80

	CURRENT REGIONAL RESIDENTIAL ELECTRICITY BILLS FOR 1000 Kw hr PER "TVA TODAY" MARCH 1975		ANNUALIZED COST OF SOLAR ENERGY (1000 SQ. FT. COLLECTOR SYSTEM @ $5/SQ. FT: 20 YR @ 8 1/4%)*
	¢/Kw hr	$/MM BTU	
NEW ENGLAND	4.60	13.48	5.25
NEW YORK CITY	6.40	18.75	5.20
WASHINGTON, D. C.	3.30	9.67	5.10
CHICAGO	2.80	8.20	5.10
TENNESSEE VALLEY AUTHORITY	2.00	5.86	4.35
LOS ANGELES	3.10	9.08	4.35

*THE SOLAR ENERGY SYSTEM WOULD PROVIDE 2/3 to 3/4 HEAT NEEDED.

A very large number of hardware options has been developed in the last few years under the impetus of government research and development. One circumstance of great interest to SMWIA is that the emphasis, so far, has been very heavily on hydronic systems rather than heated-air systems. This constitutes an unnecessary handicap to the widespread development of solar energy, in view of the advantages of air systems in many applications. These advantages include lighter roof loadings, elimination of elaborate anti-freezing methods, freedom from leak damages to houses and their contents, simpler and more rugged collector structures leading to reduced initial and maintenance costs.

The federal energy program also hopes to stimulate savings of almost a half billion barrels of oil a year by 1985 through energy conservation in heating and cooling buildings. While much of these savings will result from better glazing, sealing and insulation, about 10 percent of them should result from waste-heat recovery systems which are large users of sheet metal.

Among the energy conservation options to be considered are:

- The use of heat exchangers to transfer heat from exhaust air to fresh air in schools, hospitals and other buildings where health considerations require heavy air turnover,
- The replacement of constant-volume air systems by variable-volume systems,
- The recovery of heat from lights and electrical equipment for space heating,
- The recovery of heat from industrial processes for space heating and for further industrial use at lower temperature levels, and

- The distribution of heat within buildings which are not now equipped with balanced HVAC systems, to equalize temperatures.

These solar programs described above are estimated to require a capital expenditure of $7 billion between now and 1985; the program of heat recovery in commercial buildings to require $3.5 billion during the same period. These estimates suggest the size of the potential market for the sheet metal industry in these two areas.

Each component of a solar heating and cooling system and many components of conservation systems discussed in this report present an opportunity for sheet metal application. Where possible, SMWIA should strive to promote those total systems which would maximize these applications. In addition, two relatively new areas should be considered for assertion of SMWIA jurisdiction. Special sheet metal surface treatments should be considered, particularly vapor deposition of selective surfaces on absorber plates and corrosion inhibitors in aluminum roll. Heat pipes should also be considered as a possible new jurisdictional area since the technology is relatively new.

In the absence of a developed industrial base, most solar heating installations so far have been shop- or on-site-fabricated, using standard building-construction materials and components. The largest exception has been the use of fabricated components, such as rollbond collection panels. The federal agencies concerned with solar research, development, and demonstration have a clear policy of stimulating the

growth of an industrial capacity for producing solar components. Under this policy, substantial RD&D contracts have been given to major industrial firms. At the same time, the large firms have been reluctant to make major commitments to this development, in the absence of a guaranteed market and/or guaranteed government support. Clearly, the widespread application of SHACOB will require mass production and standardization of components and systems.

In order to make maximum contribution to the national need and also to serve its members, SMWIA should:

- Closely monitor developments in energy supply, government policies and technical developments;
- Influence government policies to achieve full and proper attention to heated-air systems and other developments of sheet-metal importance;
- Initiate and stimulate government-sponsored and private research and demonstration in the use of sheet metal in solar-energy and energy-conservation applications; and
- Encourage and operate programs to promote the use of new sheet-metal applications, and programs to disseminate information about them throughout the industry and the general public.

In order to develop, implement and coordinate these activities, SMWIA should establish a Study Committee with full-time staff support and with representation from:

Sheet Metal Workers International Association
Sheet Metal and Airconditioning Contractors National Association
Sheet Metal Workers Training Fund
Consultants (solar, conservation, marketing).

The initial program of demonstration projects should include those shown in Table 1-II.

TABLE 1-II

RECOMMENDED DEMONSTRATION ACTIVITIES

ACTIVITY	NUMBER OF UNITS
SOLAR	
Integrated Residential Systems	6
Boulder, Colorado Post Office	1
Unsolicited Commercial Demonstrations	4
Commercial Demonstrations, ERDA Phase 2	6
CONSERVATION	
Variable Volume Systems	10
Commercial Demonstrations	6
School Demonstrations	8
Heat Transfer Demonstrations	16

2.0 ENERGY SUPPLY AND DEMAND

The United States has built the world's highest standard of living, in part, on cheap and what seemed to be inexhaustible energy. Readily-available energy has helped shape our technology, our life-style, and the physical form of our communities. In recent years, our growth in per capita energy consumption, our population growth, and the reduction in the domestic production of energy have changed us from an energy exporter to a substantial importer. Figure 2-1 illustrates the widening gap. At the same time, world population growth and the effort of people everywhere to raise their standards of living toward ours have created expanding world-wide demands. This has made the United States, and all the energy-short countries, vulnerable to economic and political pressures from those countries having exportable energy surpluses.

These developments have required us to make a close and careful national examination of both the supply and the consumption of energy. As one of the most important consumption sectors, the heating and cooling of buildings will be undergoing considerable scrutiny; this study is designed to help SMWIA take part in that investigation.

2.1 Historic Projections

MITRE has conducted an analysis of 26 of the most recent or most often-cited of the scores of energy supply and demand projections which have been made.* The assumptions, scenarios and methods of

*A Compilation of Energy Supply and Demand Estimates, M74-99, The MITRE Corporation, August 1974.

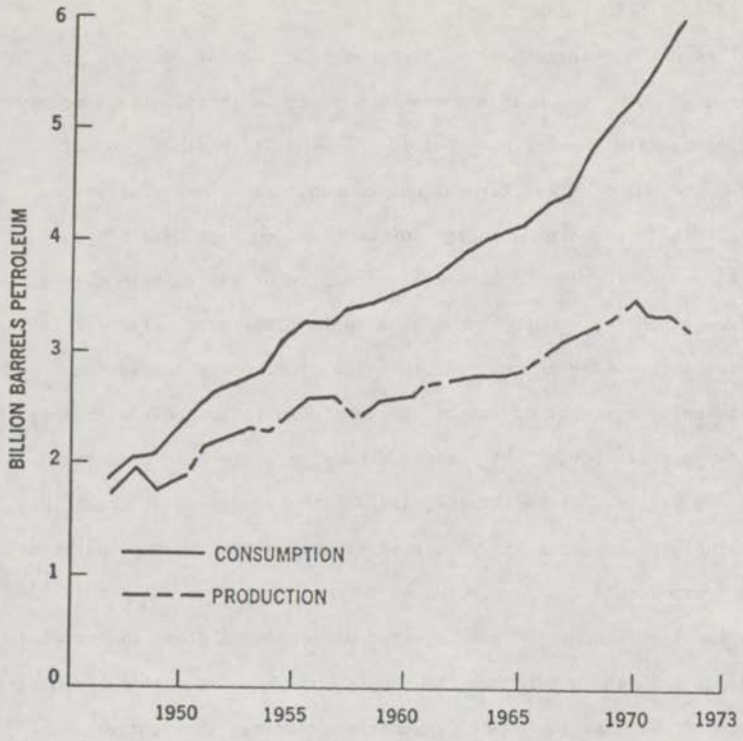


FIGURE 2-1
U.S. OIL PRODUCTION AND CONSUMPTION—1947-1973

these projections differ widely, and as a result the projections, shown in Figure 2-2, spread over a wide range, the largest shown for the year 2000 being almost three times as great as the smallest.* This illustrates the difficulty of making such projections, and emphasizes that any prediction more than a few years in advance must be used with considerable caution. Some of the projections presented here include estimates of the impact of demand-limiting measures, but most of them are simply historic projections based on past experience and estimates of future population and economic growth.

2.1.1 Demand by Sector

Figure 2-3, Average Demand by Sector, presents the averages computed in the 1974 MITRE study from the projections analyzed then. The projections entering into these averages, like those shown in Figure 2-2, are largely historic in nature.

2.2 Strategies and Impacts

The increasing dependence of the United States on foreign sources of energy, and our resulting vulnerability, were dramatically highlighted by the Arab oil embargo between October 1973 and March 1974. The Federal Government responded with the major Project Independence study, designed to develop methods of reducing our

*The unit of measure in Figure 2-2, one quadrillion British Thermal Units per year (10^{15} Btu/yr) is often abbreviated as "1 quad." 1 quad is approximately equal to 170 million barrels of crude oil per year.

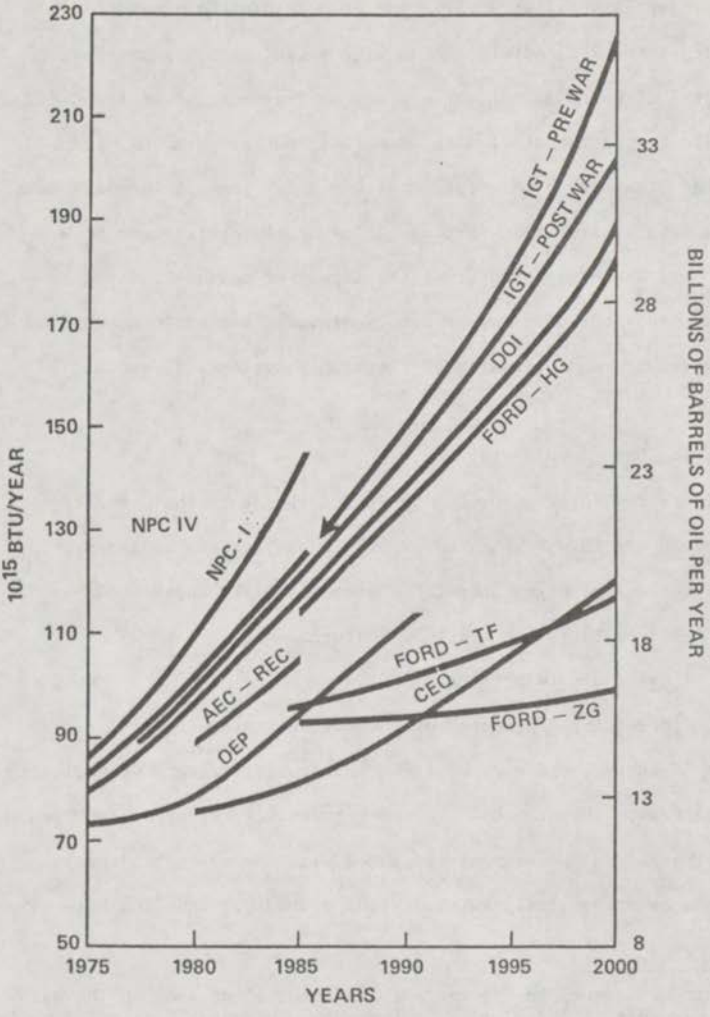


FIGURE 2-2
SELECTED ENERGY PROJECTIONS

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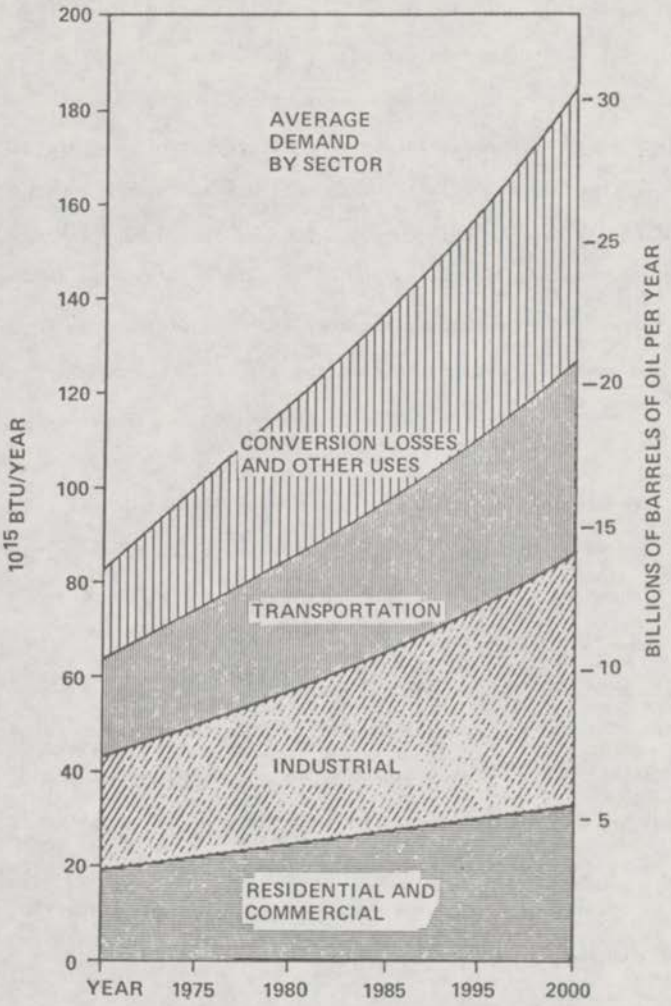

FIGURE 2-3
AVERAGE DEMAND BY SECTOR

2-5

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dependence on foreign oil, and with the establishment of the Energy Research and Development Administration (ERDA), which will operate a continuing program to refine and implement those methods.

Project Independence disclosed three categories of short-range options to reduce our vulnerability: accelerating domestic supply of conventional energy; energy conservation and demand management; and emergency programs such as rationing and energy storage. In the long run (after 1985) new energy sources, such as solar and geothermal, are expected to begin to make major contributions. Table 2-I lists some of the options presented in the Project Independence Blueprint.

Of these alternatives, the energy conservation and demand reduction category is of greatest immediate interest to the present study. Figure 2-4 shows an estimate of the contribution to the shortage which can be made by conservation.

2.3 Energy Consumption, Heating and Cooling of Buildings

The heating and air-conditioning of residential and commercial buildings in the United States accounts for about 20% of all the energy consumed. A 1972 analysis produced the projections of consumption by source shown in Table 2-II.* Those projections do not include the effects of any energy conservation or demand reduction measures which may be taken.

---

*Reference Energy Systems and Resource Data for Use in the Assessment of Energy Technologies, Associated Universities, Inc., Upton, New York, April 1972.

TABLE 2-I

ALTERNATIVE SHORT-RANGE ENERGY STRATEGIES

ACCELERATING DOMESTIC SUPPLY

- Lease Atlantic Outer Continental Shelf for Oil and Gas
- Reopen Pacific Outer Continental Shelf
- Increase Coal Production
- Deregulate Natural Gas
- Increase Nuclear Power
- Accelerate Synthetic Fuel Production

ENERGY CONSERVATION AND DEMAND REDUCTION

- Demand Reductions in Response to Increased Prices
- More Efficient Automobiles
- Incentives to Reduce Auto Miles Traveled
- Improved Thermal Efficiencies in Buildings
- Changing Fuels to Optimize Utilization
- Increased Energy Efficiencies in Industrial Processes

EMERGENCY PROGRAMS

- Rationing or Other Shortage Allocation
- Storage to Overcome Interruptions

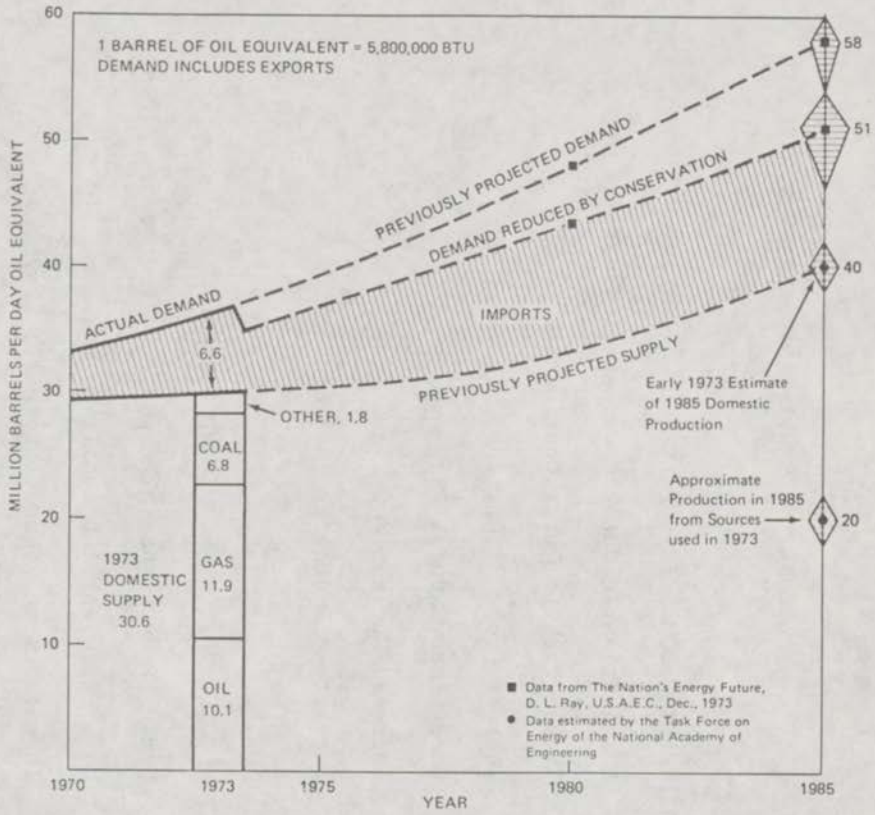

FIGURE 2-4
U.S. ENERGY SUPPLY AND DEMAND

TABLE 2-II

ENERGY USED IN HEATING AND COOLING RESIDENTIAL AND COMMERCIAL BUILDINGS

(10^{15} Btu/Yr)

		1977	1985	2000
Space Heating	Gas	4.74	4.69	5.14
	Oil	5.72	5.89	6.75
	Electricity	0.97	1.77	2.89
	Total	11.43	12.35	14.78
Air Conditioning	Gas	0.15	0.20	0.19
	Electricity	0.72	1.06	1.72
	Total	0.87	1.26	1.91
Total, Heating and Air Conditioning		12.30	13.61	16.69

Project Independence Blueprint proposes to save about 2 quads of the 13.61 quads projected for 1985 by an intensive program of conservation, and estimates that another 0.6 quads can be supplied by solar energy, instead of by the conventional sources shown in Table 2-II, under an accelerated program of implementation. If realized, these 2.6 quads of savings would be the equivalent of more than half a billion barrels of oil per year.

3.0 SOLAR HEATING AND COOLING OF BUILDINGS (SHACOB)

The deliberate use of the sun to heat man's dwellings, and the control of sunshine to avoid overheating, are as old as dwellings themselves. South-facing windows or apertures with overhanging sunshades to admit heat from the low-lying winter sun while excluding that from the higher summer sun; the use of massive masonry and adobe walls or even caves; the use of blinds, shades, awnings and louvers; and the control of ventilation and the insulation of buildings are an integral part of human culture. In times and places where fuel has been readily available and cheap, these techniques have been less used, and we have tended to warm our buildings by pouring in more heat and to cool them by brute force.

In addition to these so-called "passive" uses of solar energy, a number of active systems have been developed through the years which collect solar heat in air or a liquid and pump it to points of storage or use. Numerically, most of these have been used for producing domestic hot water. Israel and the Near East, Australia and Japan make substantial use of solar-heated water. Florida had tens of thousands of solar water heaters, until cheap electricity and plentiful natural gas drove them out.

Up until about 1973, a few dozen buildings had been built in the United States using active solar collection systems, but each one was one-of-a-kind, and no effort had been made to develop a mass-production industry. With the coming of the energy crisis, renewed

interest was generated, and the Federal government began to support a substantial solar heating and cooling effort.

3.1 Programs, Barriers, and Incentives

3.1.1 MITRE Study for NSF

In 1973, MITRE performed a study for the National Science Foundation (NSF) presenting a "Minimum" program of $78 million and an "Accelerated" program of $192 million for research, development and demonstration in solar heating and cooling of buildings.* This study was used as backup material for the programs developed by NSF, and later by the Energy Research and Development Administration (ERDA); and for the legislation in this area adopted by Congress.

3.1.2 Federal Legislation in 1974

Four major pieces of energy R&D legislation affecting solar energy were passed by Congress and signed into law by the President during 1974.

3.1.2.1 SHACOB Demonstration. The Solar Heating and Cooling Demonstration Act of 1974 (Public Law 93-409) authorized appropriations of $60 million over the fiscal years 1975-1979. It directed the Administrator of NASA and the Secretary of Housing and Urban Development to carry out a development and demonstration program for solar heating and combined solar heating and cooling systems in residential buildings. The program was to be transferred to the new ERDA when established.

*Solar Energy Research Program Alternatives, MTR-6516, The MITRE Corporation, McLean, Virginia, December 1973.

Priority under this Act was given to location of projects in enough different geographic locations to assure a realistic demonstration of the technology in rural and urban areas and under varied climatic conditions.

3.1.2.2 ERDA. The Energy Reorganization Act of 1974 (Public Law 93-438) established the Energy Research and Development Administration and transferred to it: (1) all the energy research functions of the Atomic Energy Commission; (2) from the Department of the Interior, the Office of Coal Research, the research from the Bureau of Mines in fossil fuels, and research into underground electric transmission; (3) from the National Science Foundation, the geothermal and solar heating and cooling programs; and (4) from the Environmental Protection Agency, the research and development program for an alternative automobile power system.

3.1.2.3 Solar Energy Research, Development and Demonstration. The Solar Energy Research, Development and Demonstration Act of 1974 (Public Law 93-473) stated the finding of Congress that an intensive research, development and demonstration program was required whose cost might reach $1 billion in the end. $75 million was authorized for fiscal year 1976, with an additional $2 million for drawing up a comprehensive plan.

This Act provided for the establishment of a Solar Energy Research Institute and a Solar Energy Information Data Bank to assemble and distribute information on solar energy technologies.

The technologies to be developed are: (1) direct heat for industrial processes, (2) thermal-electric energy conversion, (3) bioconversion of organic matter to fuel or energy, (4) photovoltaic and other direct energy conversion processes, (5) ocean thermal difference energy conversion, (6) wind energy conversion, (7) solar heating and cooling of buildings, and (8) energy storage.

3.1.2.4 Nonnuclear Energy R&D. The Federal Nonnuclear Energy Research and Development Act of 1974 (Public Law 93-577) directs the Administrator of ERDA to formulate and carry out a comprehensive Federal nonnuclear energy research and development program based on the following principles:

- Energy conservation, including both improvement in efficiency of energy production and reduction in energy waste;
- Consideration of environmental and social consequences;
- Consideration of impact on water resources;
- Heavy emphasis on technologies using renewable or essentially inexhaustible energy sources; and
- Consideration of net energy production at the commercial application stage.

In addition to the conventional Federal arrangements for performing research (grants, contracts, loans, Federal purchase, incentives), the Act authorizes the establishment of joint Federal-industry experimental demonstration or commercial corporations.

No funding level is specifically set, but the Administrator is directed to produce a comprehensive plan to be funded by annual and special appropriations.

3.1.3 National Plan for Solar Heating and Cooling

An interim plan, dated March 1975, for solar heating and cooling of residential and commercial buildings has been prepared by an interagency task force headed by ERDA.* Based on the legislation described, it includes these major strategic elements:

- Residential Demonstrations;
- Commercial Demonstrations;
- Development in Support of the Demonstrations;
- Research and Development;
- Collection and Dissemination of Information; and
- Government Policies and Actions to Accelerate Widespread Utilization.

Figure 3-1 presents the summary schedule for the solar heating and cooling demonstration program for both residential and commercial applications.

Interim performance criteria have been completed and published for residential applications.** Figure 3-2 shows a typical cycle for the residential demonstration program. This cycle will be repeated at approximately six-month intervals to permit new developments and

*National Plan for Solar Heating and Cooling, Interim Report, March 1975, ERDA-23.

**Interim Performance Criteria for Solar Heating and Cooling and Combined Heating/Cooling Systems and Dwellings, Prepared for the U.S. Department of Housing and Urban Development by the National Bureau of Standards, January 1, 1975, GPO Stock Number 003-003-01388, $1.90.

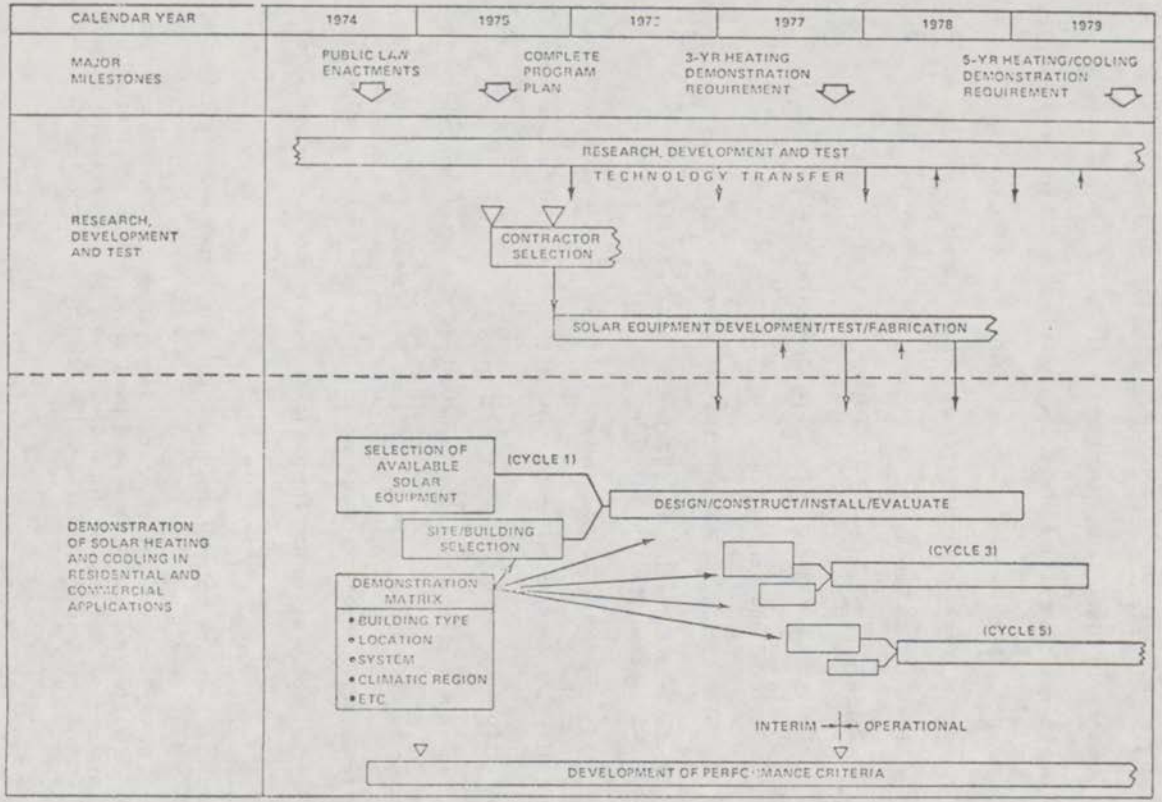

FIGURE 3-1
SUMMARY SCHEDULE FOR SOLAR HEATING AND COOLING PROGRAM

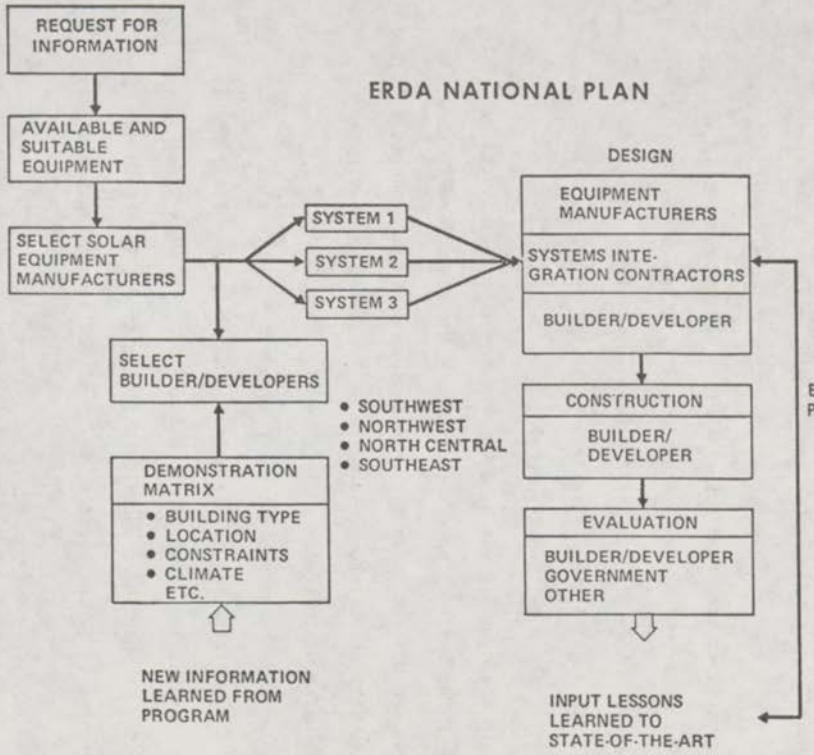

FIGURE 3-2
TYPICAL CYCLE–RESIDENTIAL DEMONSTRATION PROGRAM

lessons learned in the earlier cycles to be incorporated in the later cycles.

A Request for Proposals has been issued, and proposals are now being received, from among which a contractor will be selected to perform a study to recommend types of solar heating systems to be installed in different types of residences in different parts of the United States. This study is expected to be completed about October 1, 1975. Its results will be presented in the matrix indicated in Figure 3-1 and Figure 3-2.

Within the next few weeks, a Request for Information will be issued by ERDA, inviting manufacturers of solar heating components, subsystems and systems to submit descriptions of their products. These descriptions will form the basis of a catalog of available equipment which will be widely distributed.

NASA will procure and test solar system components singly and combined into systems, and will determine which systems are suitable for such location-building type combinations. HUD will issue Requests for Proposals for specific building types, locations and solar systems, to be responded to by local builders in each locality selected.

In addition to the five-cycle residential program described above, HUD will issue a Request for Proposals during June 1975, addressed to contractors who are ready to go with existing, tested

solar heating systems and specific buildings. Opportunity will also be provided for proposals to build passive solar-heated buildings. This procurement will not be delayed to wait for the completion of the location-building type matrix, but will be pursued as soon as possible.

A first step in the program of commercial demonstration was taken in 1974, when three contractors performed Phase 0 feasibility studies. Industrial firms then responded in January 1975 to a request for proposals for performance of Phase 1 tasks. A contract has been awarded to a team composed of Intertechnology Corporation and General Electric to design a number of commercial-type demonstrations in Federally-owned buildings, in cooperation with the Department of Defense, the General Services Administration, the Postal Service, and the Department of Health, Education and Welfare. A separate contract has been announced to retrofit solar heating equipment in the Post Office at Boulder, Colorado. The program in commercial-type buildings includes retrofit activities, in addition to new buildings. A substantial program in solar grain-drying and other solar energy uses in agriculture is being carried out between the National Science Foundation and the Department of Agriculture.

Table 3-I presents a summary of Federal funding estimates for three levels of demonstration between fiscal years 1975 and 1979. Level I is consistent with the $60 million authorized by PL 93-409, plus additional supporting R&D, while Levels II and III are more consistent with the approaches recommended in the National Plan.

TABLE 3-I

SUMMARY OF FUNDING ESTIMATES

	Approximate Number of Residential Units	Approximate Number of Commercial Units	Preliminary Funding FY 1975-79 (Millions of Dollars)
Level I	350	50	109
Level II	1,000	200	208
Level III	2,000	400	306

It has been estimated that this level of demonstrations will stimulate the number of installations (combined public, and private, shown in Table 1-I, earlier in this report).

3.1.4 Barriers

The most important barriers to the widespread use of solar energy for heating and cooling buildings include:

- High cost and questionable reliability of components in the absence of a developed industry;
- Construction industry fragmented and resistant to innovation;
- Conservative attitudes of lending agencies, insurers, code authorities, tax laws;
- Initial costs are high; many building operators do not use life-cycle costing;
- Sun rights, union jurisdictions, local building codes and laws; and
- Architects and builders must learn to design buildings as integrated energy-saving units, not collections of components.

3.1.5 Incentives

3.1.5.1 Federal. The National Plan presents a summary of incentives and action options available to help overcome barriers. This is shown in Table 3-II.

The House of Representatives has passed a bill to provide a $2,000 credit against income tax to any homeowner who installs solar heating equipment in his principal residence by spending $8,000. Smaller expenditures would result in lower credits or deductions. The bill also provides a tax credit of 30% of the cost of insulation

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TABLE 3-II

SUMMARY OF INCENTIVES AND ACTION OPTIONS

Barriers to Innovation	Types of Incentives	Action Party/Agency	Specific Action Steps	Parties Affected
1. High first costs are a disincentive to the consumer	* Income tax deduction	Federal and State Governments	Develop effective tax deduction formula	Greater incentive for high income groups than low
	* Income tax credit	Federal and State Governments	Allow a tax credit of some % of installed costs or mortgage payments	Home owner, all income groups
	* Direct subsidy	Federal and State Governments	Direct assistance in the purchase of solar equipment	General public
	* Assure that mortgage money is available	Federal Government	Influence the Federal Home Loan Bank Board, FNMA, and GNMA	Financial institutions; homebuyers
	* Guaranteed and insured loans	Federal Government	Raise the limit on FHA-insured mortgages to cover solar systems	Financial institutions; homebuyers
	* Low interest Federal borrowing	Federal Government	Provision of low-interest loans	Homebuyers
2. Solar systems make a home more expensive and perhaps burden to sell	* Similar to those under 1. for the purchase of a solar equipped house	Federal and State Governments	As above	Homebuyers and sellers
3. It may be difficult and/or expensive to insure a solar equipped building	* Government insurance	Federal Government	Legislation to provide government insurance	Financial community, Homebuyers, Insurance Ind.
4. If construction materials purchased by builders are taxed, the cost of the solar system to the consumer will be increased	* Sales tax exemption or reimbursement for materials used in solar system installation	State and local governments	Change in tax law	Construction Ind. Homeowner

TABLE 3-II

SUMMARY OF INCENTIVES AND ACTION OPTIONS

(Concluded)

Barriers to Innovation	Types of Incentives	Action Party/Agency	Specific Action Steps	Parties Affected
5. The solar system increases the price of a home and hence the property taxes	* Tax exemption	State and local governments	Develop provisions which are fair and equitable	Homebuyers, owners, and sellers
6. Solar systems in commercial buildings may yield an unfavorable rate of return	* Investment tax credit	Federal and State Governments	Extension of the investment tax credit to the cost of solar installations	Investors
	* Accelerated depreciation	Federal Government	Work out a suitable formula	
7. The potential manufacturers may be skeptical about entering the business due to high initial production costs	* Accelerated depreciation of capital equipment	Federal Government	Tax ruling	Manufacturers and indirectly consumers
8. Insufficient R&D	* Government grants and contracts	Federal and State Governments	Increase government R&D funds	Research community manufacturers

installed, up to a maximum credit of $150.

Other Federal incentives such as those shown in Table 3-II are still in the discussion stage.

3.1.5.2 State and Local. Introduced into the various state legislatures during the past year have been close to 75 separate pieces of solar-related legislation; the State of Connecticut alone had 13 bills introduced and the State of Oregon 9. Most of the pending legislation deals with economic incentives to the consumer to encourage the use of solar heating and cooling systems, and is focused primarily on providing exemptions and deductions on real estate, property, sales, use, or income taxes. The three incentives that have been most frequently proposed are: (1) the property tax exemption in which any equipment that is part of a solar energy system would be excluded from property taxation; (2) the sales tax exemption for solar equipment; and (3) a deduction in the property tax assessment for installation of solar energy systems. Only one state, Oregon, is proposing a direct tax credit for costs incurred in installing solar energy systems, allowing the taxpayer to actually reduce his or her tax liability by a certain amount, and only one state, Connecticut, proposes economic assistance to producers of solar equipment.

Low-interest loans have also been proposed as an incentive to encourage homeowners to install solar heating and cooling systems.

In Oregon, a bill currently under consideration will allow veterans to apply for loans from the Oregon War Veterans fund, and in North Dakota, the legislation, if passed, would provide loans from state-owned banks.

Bills pertaining to building codes and standards may also encourage the installation of solar energy systems; Florida recently passed a law requiring that no building be constructed without provision for future installation of solar hot water heating equipment.

To date, six states have made into law seven pieces of legislation relating to solar energy. In Florida, in addition to the building standards previously cited, the legislature has provided for the establishment of a state Solar Energy Center to coordinate research, development, and information exchange; California has passed a similar bill. Indiana will now allow a tax deduction from the assessed value of real property equipped with a solar energy system, while North Dakota allows a tax exemption for such systems. New Mexico will be providing funds for solar energy promotion, and Virginia will be establishing a Solar Energy Center at the Science Museum of Virginia in Richmond.

A listing of all pending and passed state legislation by type of incentive is provided in Table 3-III.

3.2 Cost Effectiveness

To be competitive in the marketplace, a solar system must supply heating and/or cooling in a way that is satisfactory to the consumer

TABLE 3-III

PENDING AND PASSED LEGISLATION: INCENTIVES ENCOURAGING USE OF SOLAR ENERGY SYSTEMS

STATE	INCENTIVES												
	TAX EXEMPTIONS						TAX DEDUCT.						
	Real Property	Sales	Use	Income	Personal Property	Unspecified	Income	Property Assessment	Unspecified	Tax Credit	Low-interest Loans	Financial Assistance To Producers Of Solar Eq.	Building Codes & Standards
Arizona						X							
California	X						X						X
Colorado						X							
Connecticut	X	X			X	X		X				X	X
Florida													(X)
Hawaii						X			X				
Illinois	X												
Indiana								(X)					
Iowa							X						
Maine		X											
Maryland						X							
Massachusetts	X												
Michigan		X	X					X					
Minnesota								X					
New Jersey	X												
New Hampshire	X												
New York	X							X					X
North Dakota	(X)	X	X								X		
Oregon	X			X						X	X		
Pennsylvania		X											
South Dakota	X												
Texas						X			X				
Vermont	X				X								X
Virginia							X						
Washington		X	X										
West Virginia						X							
Wisconsin						X							

X Pending

(X) Passed into Law

at a price he considers at least competitive with his available alternatives. This cost effectiveness depends on these factors:

- Mechanical reliability and effectiveness of the proposed solar system and its conventional alternatives;
- Initial and operating costs of the proposed solar system and its conventional alternatives;
- Financing considerations: cost of money, life-cycle costing;
- Available useful solar radiation; and
- Thermal loads on the building.

Each of these factors varies from building to building and across a wide choice of system alternatives. MITRE has performed a detailed analysis* of these factors and their impact on the competitiveness of solar applications in various parts of the United States. The approach and results of this study are summarized below.

3.2.1 Regional Considerations

The effects of climate on heating and cooling loads, the variation of solar radiation from place to place, and the variations in the cost and availability of alternative fuels dictate a regional approach to the analysis.

Eight regions have been identified in the analysis. One or two cities are selected to represent each region.** The regions and cities are:

• Northeast	Boston, Massachusetts
• Southeast	Washington, District of Columbia Charleston, South Carolina

* Unpublished

** The cities are representative only. Care must be exercised in extrapolating results from one city to another as rapid changes can occur over quite short distances.

- South Florida — Miami
- North Central — Bismarck, North Dakota; Madison, Wisconsin
- South Central — Fort Worth, Texas
- Mountain — Grand Junction, Colorado
- Pacific Northwest — Seattle, Washington
- Pacific Southwest — Los Angeles, California

The regions are shown in Figure 3-3.

Heating and cooling demands for the ten representative cities are presented in Table 3-IV for heating related to a base of 65°F and cooling related to a base of 70°F.*

3.2.2 Baseline SHACOB Systems

The baseline solar systems used in the MITRE analysis are:

System 1. Solar powered heat exchanger with conventional furnace backup; conventional vapor compression air conditioner.

System 2. Solar powered heat exchanger with conventional furnace backup; solar absorption air conditioner.

It should be noted that intensive development is being conducted on heat-pump systems, including solar-assisted heat pumps. While no detailed cost and performance figures were available for this study, these developments promise very useful options, and should be closely monitored.

*NOAA Publication #84, Heating and Cooling Degree-Days; NOAA, September 1973.

FIGURE 3-3
REGIONS AND REPRESENTATIVE CITIES

TABLE 3-IV

HEATING AND COOLING DEGREE-DAYS

	BOSTON	WASHINGTON	MADISON	BISMARCK	CHARLESTON	MIAMI	FORT WORTH	LOS ANGELES	SEATTLE	GRAND JUNCTION
HEATING										
January	1088	871	1473	1708	487	74	614	347	828	1209
February	972	762	1274	1442	389	56	448	277	678	907
March	846	626	1113	1203	291	19	319	264	657	729
April	513	288	618	645	54		99	177	474	387
May	208	74	310	329				121	295	146
June	36		102	117				54	159	21
July			25	34				19	56	
August	9		40	28				16	62	
September	60	33	174	222				36	162	30
October	316	217	474	577	59		65	62	391	313
November	603	519	930	1083	282		324	159	633	786
December	988	834	1330	1463	471	65	536	267	750	1113
TOTAL	5639	4224	7863	8851	2033	214	2405	1799	5145	5641
COOLING										
January						98				
February						145				
March						88				
April					6	170	13			
May		4			99	289	81			
June	76	240	147	10	319	338	396			189
July	138	292	40	128	325	403	451	22	40	343
August	160	254	36	142	302	376	301	164	46	310
September	87	186	99	3	231	326	235	68		11
October					132	288	93	15		
November						149				
December						205				
TOTAL	461	976	322	283	1414	2875	1570	269	86	853

3.2.3. Building Types

Four building types were selected for analysis:

1. Single-family house,
2. Multi-family low-rise apartment building,
3. Low-rise office building,
4. Retail store.

The principal characteristics of these buildings, including dimensions and heating and cooling loads, are given in Table 3-V.

3.2.4 Financing Considerations

Life-cycle costs of the two baseline solar systems described above were compared with the costs for conventional heating and cooling systems. This was done by converting all capital costs to annualized costs and then comparing annual costs in constant 1975 dollars.

The calculation of annualized costs is very sensitive to the discount rates selected. In this analysis, it was assumed that home mortgage rates would average about 8-1/4% over the 20-year life of the solar equipment, and that inflation would average 3-1/2% per year. In the case of commercial applications, it was assumed that a rate of return on capital invested of less than 10% was insufficient, 10% to 11% was marginal, while over 11% was economically viable.

3.2.5 Results of Analysis

Tables 3-VI through 3-IX present those regions of the country in which solar heating and domestic hot water or solar heating,

TABLE 3-V

BUILDING CHARACTERISTICS

	SINGLE-FAMILY	MULTI-FAMILY	OFFICE	RETAIL STORE
Dimensions-feet	25x36	36x200	100x100	40x130
Number of floors	3	3	3	1
Floor height - feet	9	9	11	16
Heating demand - 10^3 Btu/degree day	30	380	310	157
Cooling demand - 10^3 Btu/degree-day:				
Boston	73	808	681	428
Washington	65	719	607	381
Madison	65	719	607	381
Bismarck	57	631	531	334
Charleston	79	874	737	464
Miami	75	830	700	440
Fort Worth	57	630	532	334
Los Angeles	59	653	551	346
Seattle	98	1085	915	574
Grand Junction	34	376	317	199

TABLE 3-VI

PROJECTED SHACOB FEASIBILITY IN SINGLE FAMILY HOMES

Region	City	1977	1980	1985
N.E.	Boston	H + C + HW	H + C + HW	H + C + HW
S.E.	Washington	H + C + HW	H + C + HW	H + C + HW
N.C.	Madison	H + HW	H + HW	H + HW
N.C.	Bismarck	H + HW	H + HW	H + HW
S.E.	Charleston	H + HW	H + HW	H + HW
S.FLA.	Miami	-	-	-
S.C.	Forth Worth	H + HW	H + C + HW	H + C + HW
P.S.W.	Los Angeles	H + HW	H + HW	H + HW
P.N.W.	Seattle	H + HW	H + HW	H + HW
M.	Grand Junction	H + C + HW	H + C + HW	H + C + HW

TABLE 3-VII

PROJECTED SHACOB FEASIBILITY IN MULTI-FAMILY LOW RISE BUILDINGS

Region	City	1977	1980	1985
N.E.	Boston	H + C + HW (F)[1]	H + C + HW (F)	H + C + HW (F)
S.E.	Washington	H + C + HW (F)	H + C + HW (F)	H + C + HW (F)
N.C.	Madison	H + C + HW (F)	H + C + HW (F)	H + C + HW (F)
N.C.	Bismarck	H + C + HW (F)	H + C + HW (F)	H + C + HW (F)
S.E.	Charleston	H + HW (M)[2]	H + HW (M)	H + HW (F)
S.FLA.	Miami	(I)[3]	(I)	(I)
S.C.	Fort Worth	(I)	(I)	H + C + HW (M)
P.S.W.	Los Angeles	H + C + HW (F)	H + C + HW (F)	H + C + HW (F)
P.N.W.	Seattle	H + HW (F)	H + HW (F)	H + HW (F)
M.	Grand Junction	H + C + HW (F)	H + C + HW (F)	H + C + HW (F)

1. (F) - Feasible
2. (M) - Marginal
3. (I) - Infeasible

TABLE 3-VIII

PROJECTED SHACOB FEASIBILITY IN OFFICE LOW RISE BUILDINGS

Region	City	1977	1980	1985
N.E.	Boston	H + C + HW (M)[1]	H + C + HW (M)	H + C + HW (F)[2]
S.E.	Washington	H + C + HW (M)	H + C + HW (M)	H + C + HW (M)
N.C.	Madison	H + C + HW (M)	H + C + HW (F)	H + C + HW (F)
N.C.	Bismarck	H + C + HW (M)	H + C + HW (F)	H + C + HW (F)
S.E.	Charleston	(I)[3]	(I)	(I)
S.FLA.	Miami	(I)	(I)	(I)
S.C.	Fort Worth	(I)	(I)	(I)
P.S.W	Los Angeles	H + HW (F)	H + HW (F)	H + C + HW (F)
P.N.W.	Seattle	H + HW (M)	H + C + HW (M)	H + C + HW (M)
M.	Grand Junction	H + C + HW (M)	H + C + HW (F)	H + C + HW (F)

1. (F) - Feasible
2. (M) - Marginal
3. (I) - Infeasible

TABLE 3-IX

PROJECTED SHACOB FEASIBILITY IN RETAIL STORES

Region	City	1975	1980	1985
N.E.	Boston	H + C + HW (F)[1]	H + C + HW (F)	H + C + HW (F)
S.E.	Washington	H + C + HW (M)[2]	H + C + HW (M)	H + C + HW (M)
N.C.	Madison	H + HW (F)	H + HW (F)	H + HW (F)
N.C.	Bismarck	H + C + HW (F)	H + C + HW (F)	H + C + HW (F)
S.E.	Charleston	(I)[3]	(I)	H + HW (M)
S.FLA.	Miami	(I)	(I)	(I)
S.C.	Fort Worth	(I)	(I)	(I)
P.S.W.	Los Angeles	H + HW (F)	H + HW (F)	H + HW (F)
P.N.W.	Seattle	H + C + HW (M)	H + HW (F)	H + HW (F)
M.	Grand Junction	H + C + HW (F)	H + C + HW (F)	H + C + HW (F)

1. (F) - Feasible
2. (M) - Marginal
3. (I) - Infeasible

cooling and domestic hot water will be viable in the years 1977, 1980 and 1985. The decision takes into account the projected regional fuel costs of electricity presented in the Project Independence Blueprint assuming a cost of oil of $11 per barrel.

3.3 Inventories, Projections, and Market Penetrations by Time Period and Region

The subject of market penetration by solar heating and cooling of buildings is complex, taking into consideration many factors which are in a large part non-quantifiable. Generally, the analysis can be broken down into two parts: market potential and the effects of relative cost benefits, institutional constraints and possible incentives which will determine the share of this potential market which is actually captured.

G.E.'s Phase 0 report presents a market penetration curve that was derived from an analysis of historical data on the market penetration of various HVAC innovations. This curve reflects a market penetration scenario consistent with ERDA's SHACOB subprogram under the Direct Solar Energy Conversion Program:

1975-1981 Development of hardware, performance data, standards and specifications.

1981-1985 Market development and support by the government.

1982-2000 Commercialization.

Table 3-X presents projected regional market penetrations by solar heating and cooling for various building types. In making these calculations, estimated regional construction inventories were

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TABLE 3-X

SHACOB PENETRATION SUMMARY

	BUILDINGS # UNITS			SOLAR COLLECTORS MILLION SQUARE FEET		
	1975-1980	1980-1990	1990-2000	1975-1980	1980-1990	1990-2000
Northeast	8,000	122,800	772,600	20.3	343	2261
Southeast	10,000	146,800	935,400	14.5	232	1536
S. Florida	0	0	0	0	0	0
N. Central	5,200	133,800	519,300	10.5	209	1220
S. Central	1,400	23,300	149,400	1.6	27.6	180
Mountain	500	7,800	45,600	1.0	18.1	109
Pacific N.W.	700	11,500	70,900	1.0	19.2	121
Pacific S.W.	2,800	53,200	334,700	2.7	54	389
TOTAL	28,500	446,700	2827,900	51.6	880	5817
Single Family	25,700	392,400	2452,600	25.4	384	2397
Multi Family	1,660	31,200	22,900	17.2	321	2294
Motel Lo-Rise	44	1,170	5,100	0.8	23.4	101
Office Lo-Rise	406	8,300	66,500	3.0	59	473
Retail Store	730	13,500	79,900	2.1	35.6	210
Retail Mall	8	152	900	3.0	58	342

derived from the projections presented in G.E.'s Phase 0 study. These projections were constructed from an analysis of Basic Economic Areas which provided a population/economic growth pattern base.

The market penetration curve derived by G.E. through analysis of historical data estimated a capture potential of 55% between 1975 and 1980, 60% between 1980 and 1990, and 65% between 1990 and 2000. The penetration of the potential market was estimated to be 0.55% between 1975 and 1980 (0.3% of the total construction inventory), 3.92% between 1980 and 1990 (2.35% of the total), and 21.7% between 1990 and 2000 (14.1% of the total).

It is assumed by MITRE, that, if the projected rate of return for the solar heating and cooling system or solar heating system alone, where applicable, (as estimated by our present analysis) is less than 10%, the market penetration estimated by G.E. will not be realized. If the estimated rate of return is 10% to 11%, the market penetration estimated by G.E. will be halved. If the estimated rate of return is greater than 11%, the market penetration estimate presented by G.E. will be fully realized.

The estimates do not include the market potential of collectors used exclusively for the heating of water for home and commercial use. It is possible that in some regions where solar heating and/or cooling present a marginal cost benefit, solar hot water heaters may be viable. A. D. Little estimates a total U. S. market potential in solar hot water heaters for commercial and residential use in 1980 to

be approximately 344,200 units (if oil is selling at $11/bbl) with the greatest proportion of the market appearing in the Southern Atlantic, Middle Atlantic, and West South Central states.

3.3.1 Institutional Considerations

As mentioned earlier, the share of the potential market that is ultimately captured by solar heating and cooling will depend greatly on regional institutional incentives and constraints. These factors are difficult to define let alone to project. Generally, the factors fall into three categories: industrial, private, and public. A considerable number of interrelationships exist between these categories. The industrial constraints lie within the method of organizing the new industry. In production of collectors, manufacturing linkages must be constructed. A developing industry may choose to institute forward or backward linkages in forming a production scheme. Forward linkages are achieved when a company which is producing some component part of a final product moves into the business of assembling the final product. Backward linkages occur when a company which assembles a finished product moves into the business of producing the constituent parts to be applied to the final product. Forward linkages already seem to be developing as large national glass and metal manufacturers have already entered the industry on a limited scale. Small regional producers have also entered the industry and are in a large part characterized by

fabrication of secondary materials into finished collectors; however, some of these producers are beginning to manufacture some collector components such as absorber plates. Thus, the industry is presently being developed through forward and backward linkages. This phenomenon poses many problems. The fragmentary nature of this condition makes any nationally-unified industrial effort difficult. The situation also confuses the task of defining union jurisdictions because production is being staged in two different schemes. The problem of union jurisdiction is difficult enough because of the unique interface of components in a solar heating and cooling system. Cooperation with existing industries (i.e., construction, HVAC) which are themselves somewhat fragmented and resistant to innovation, must also be developed in order that distribution may proceed unhindered. It may be some time before effective integration exists nationally; however this integration may proceed at different rates in different regions and thus may play a part in causing different penetration rates between regions.

Public acceptance will also vary from region to region and will have its effect on the penetration rate. Public awareness of solar technology and the cost benefits which may be realized through the use of solar systems will depend on the publicity efforts of the industry and the information dissemination programs of the government under ERDA.

Finally, public acceptance will be influenced by the appearance of the collectors. A person will be less likely to buy collectors if they will severely downgrade the appearance of his building.

Legislation which may be beneficial or detrimental to the rate of penetration may also differ from region to region. Although many state and federal government entities are becoming aware of the implications of SHACOB, positive action is required by the solar industry and interested citizens in order to assure the implementation of laws that will induce the development of the industry as well as insure the value of collectors and rights of people wishing to use them. Tax incentives may be offered, sun rights need to be defined, building codes and zoning laws need to be modified. The attitudes of lenders and insurers will also need to be changed.

3.4 Technological Developments

This section presents a survey of the state-of-the-art in the development of solar hardware. It is a snapshot of a rapidly-changing situation and includes some components and systems which are fully developed and ready for routine application, some which are highly experimental, and some which are still in the category of unproved concepts. The sources of the information also vary, from rigorously documented engineering reports to informal and undocumented announcements by inventors or developers. The succeeding section, Present Suitability of Systems, selects from among these systems those which are now suitable for commercial application.

A SHACOB system can be generally broken down into three system components: Collector, Storage, Conversion and Auxiliary. Although this section will discuss each section separately, it is important to remember that the SHACOB system must be designed with the total synergistic effects of building and system in mind, as well as the mutual interactions between components of the solar system itself. Some designs may involve a high dependence of the SHACOB system on the building type and design, whereas others will provide convenient application of the SHACOB system to virtually all types of buildings.

3.4.1 Collectors

Collectors may have either liquid or air as a heat transfer medium. The basic liquid medium collector contains a metal plate with tubes connected or integral to remove the collected heat. This plate, has a solar absorbing surface of black paint or a thin durable film with selective radiation properties, is placed in a casing and is covered by one or more sheets of transparent material. The container is properly insulated to minimize heat losses through the back and sides. Before discussing variations from this basic design, let us consider the variations within these bounds.

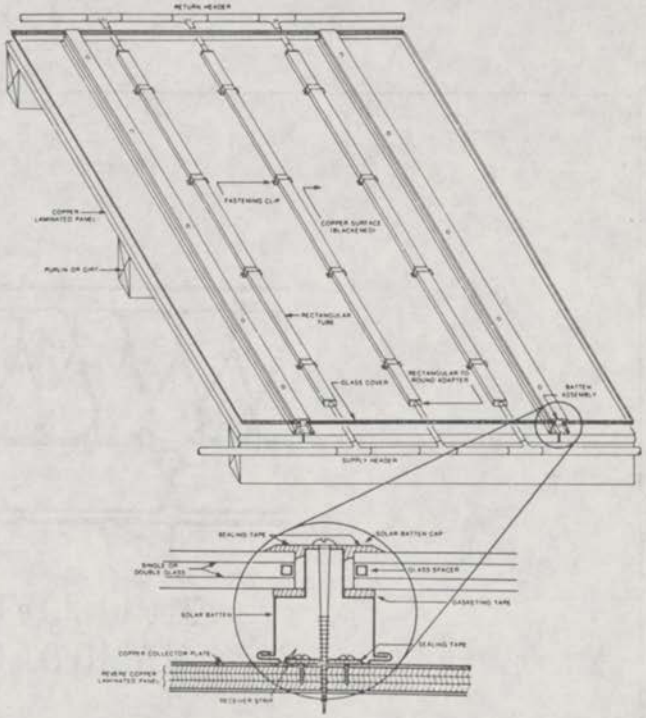
The plate may have the tubes connected to it in some manner or the tubes may be integral to the plate. Several methods exist in bonding the tubes to the plate. If soldering or welding is chosen to form the bond, a 40% bond (40% of the length of tubing which comes in contact with the plate being soldered or welded) will normally

result in a "fin efficiency factor" 90% of that associated with an isothermal surface. Several companies now have thermal adhesives which are claimed to have thermal transfer characteristics approaching those of welding or soldering with lower fabrication costs. The durability of these materials in solar collectors has not yet been established.

The Revere Copper collector plate (see Figure 3-4) utilizes a rectangular-shaped tube which allows for a greater amount of tube area to come into contact with the plate. These tubes are held with fastening clips in combination with a thermal adhesive. A tube-on-plate collector is pictured in Figure 3-5.

As mentioned previously, a plate may be formed with the tubes or water passages as an integral part. One such absorber plate type is the "rollbond" plate used in PPG's baseline solar collector (see Figure 3-6) and in numerous other experimental and semi-commercial collectors. The absorber is made by printing a tube pattern (with a special stop-weld material) on a copper or aluminum sheet, bonding another sheet of the same metal by a rolling process, and expanding the unbonded pattern into tubes by a hydraulic or pneumatic process. Other designs which integrate tube and plate are pictured in Figures 3-7 and 3-8.

In order to maximize the amount of thermal radiation absorbed and minimize the amount of thermal radiation emitted, the plate may be treated with a selective coating. A selective coating will absorb



SOLAR BATTEN
FIGURE 3-4
REVERE SOLAR COLLECTOR

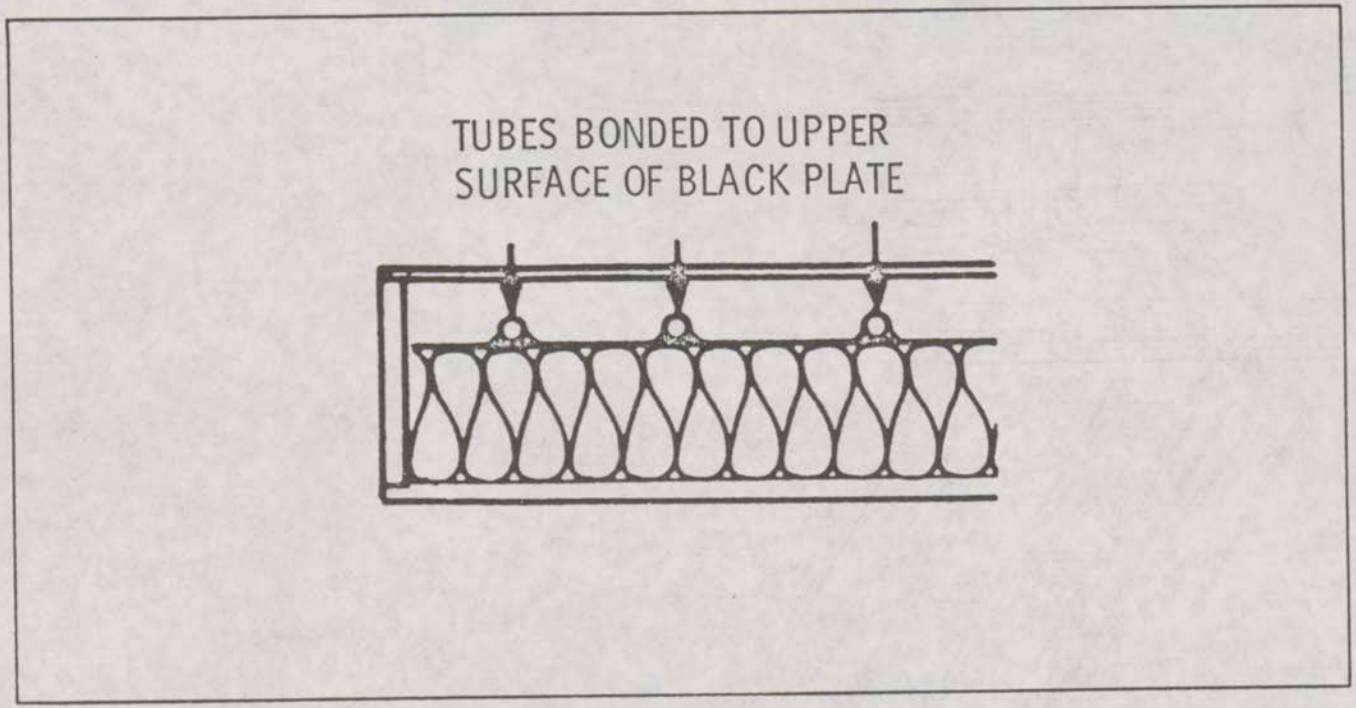


FIGURE 3-5

TUBE-ON-PLATE COLLECTOR

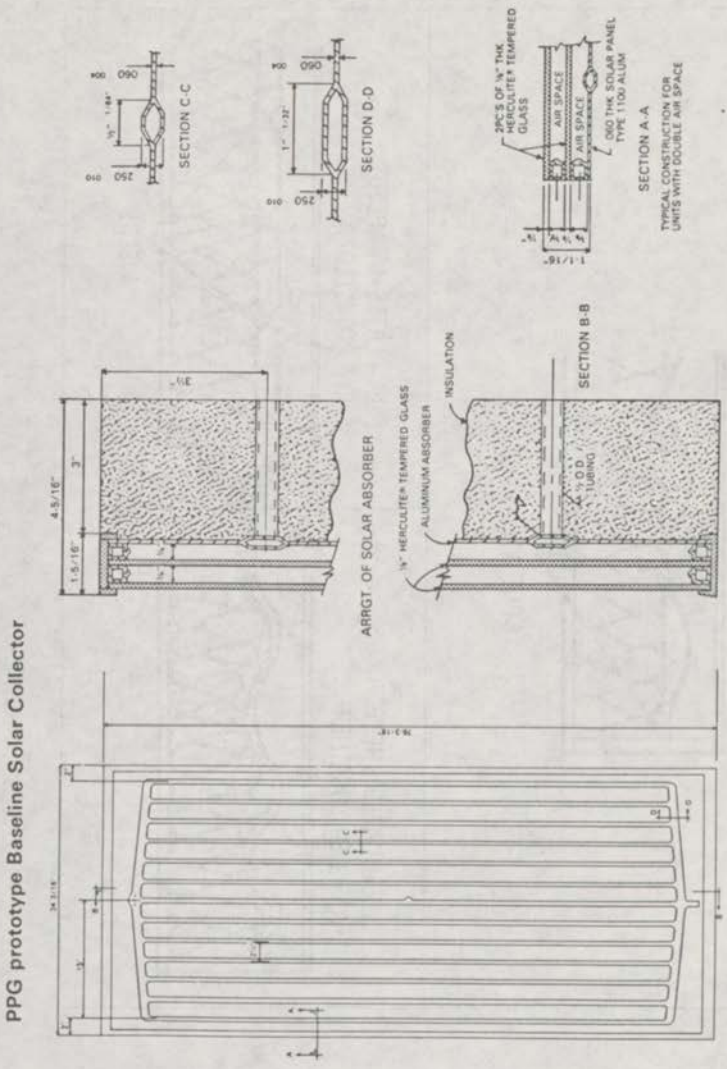


FIGURE 3-6

PPG BASELINE SOLAR COLLECTOR

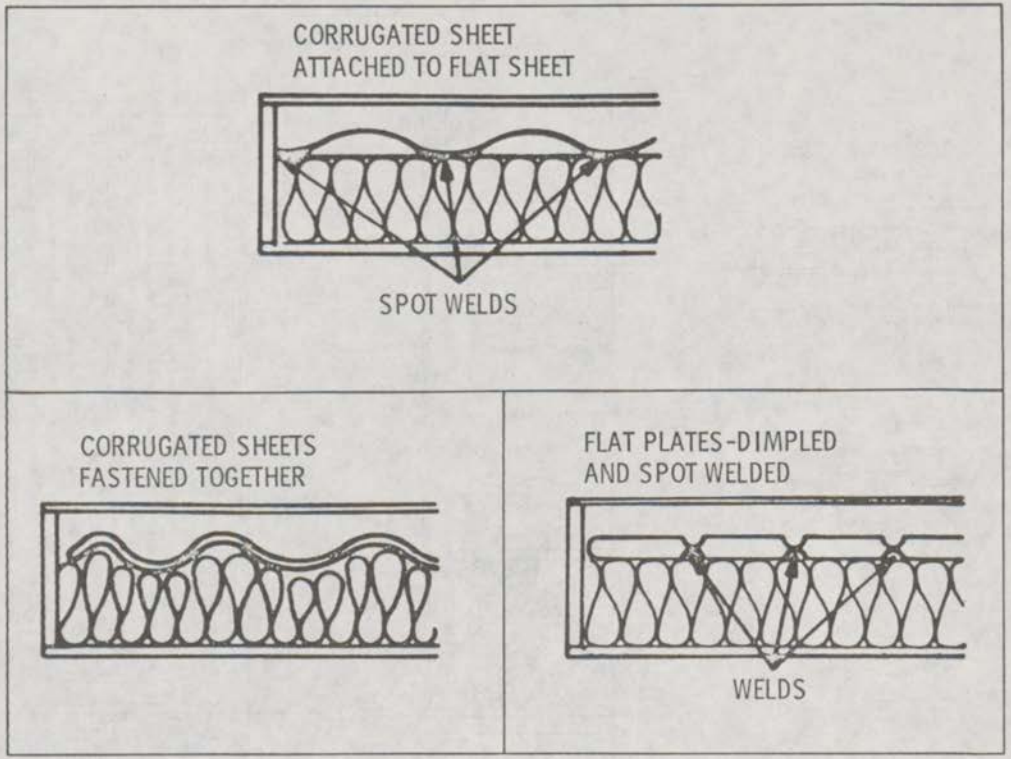


FIGURE 3-7

TUBE-IN-PLATE DESIGNS

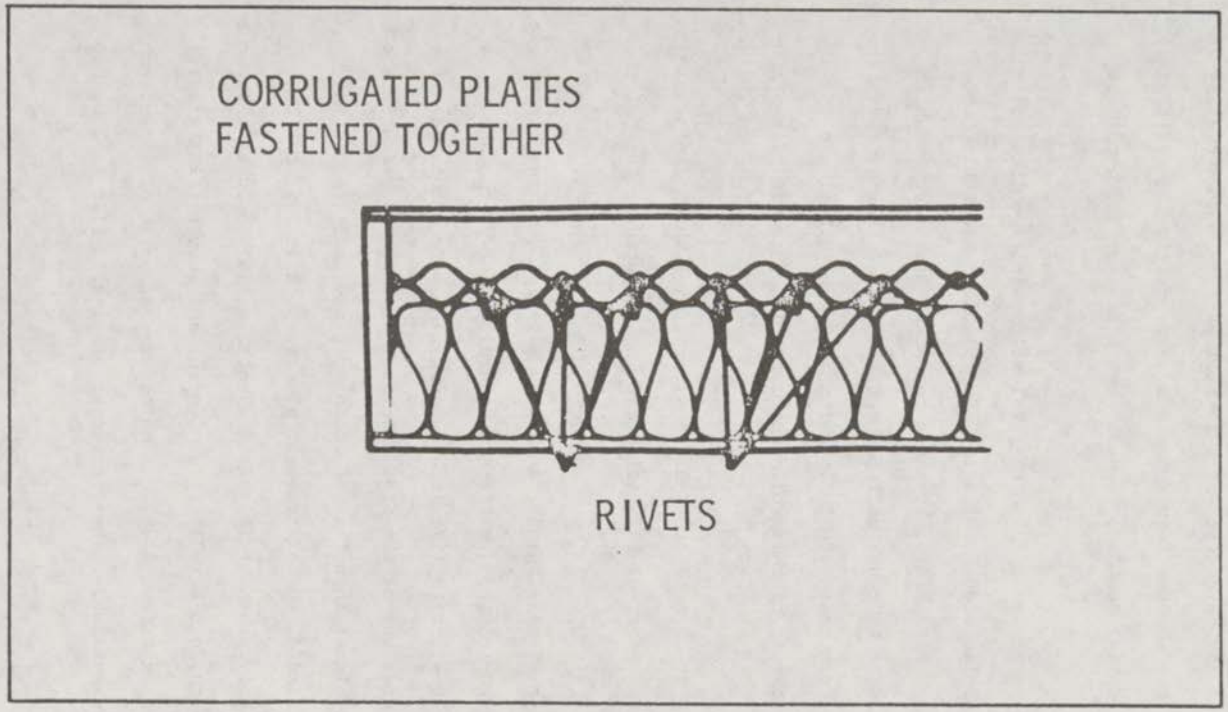


FIGURE 3-8

ANOTHER TUBE-IN-PLATE DESIGN

solar radiation and re-radiate only a small part of the energy absorbed. When the end use requirements do not justify the additional costs of a selective coating, an absorbent black surface should be used.

The plate surface may also be physically selective like Roland Winston's parabolic trough collector (See Figure 3-9). "Directional selectivity" may be achieved by the arrangement of V-grooves which are of proper size to cause multiple reflections of thermal radiation when received from near normal directions. The high cost and directional selectivity of this collector limit its potential for SHACOB use.

There are other collector design alternatives which can be used according to the particular location and the expected end use of the captured heat.

The number of glazing sheets and the material used in glazing are important design-related questions. Generally, one or two sheets of ordinary double-strength (1/8-inch) window glass are recommended for use in most locations of the U.S. The cost of tempered glass is not prohibitively higher than that of ordinary glass, and its use may well be justified. Several types of plastic such as Teflon film, tedlar film, polycarbonate films and sheets, cellulose acetate butyrate films and sheets, and acrylic films (Korad) and sheets (Plexiglas), have been used experimentally, but no commercial units or long-term experience are available. The first cost of plastic film is low, but

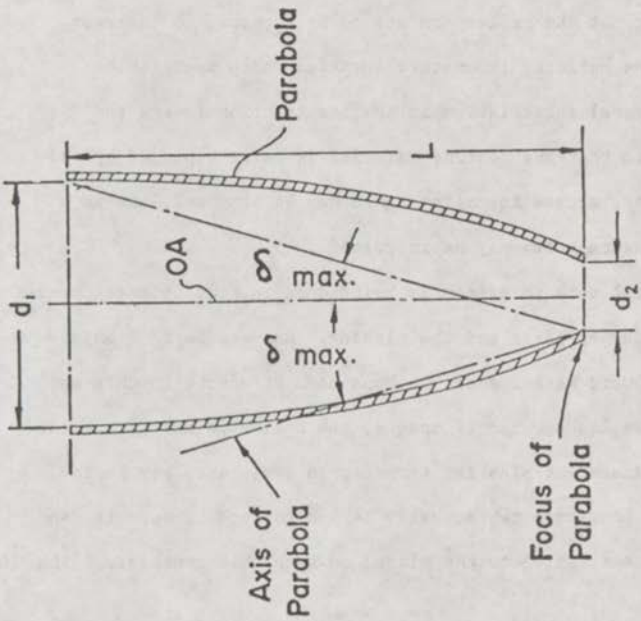


FIGURE 3-9

THE WINSTON IDEAL LIGHT COLLECTOR GEOMETRY

short service life and limited resistance to temperature and ultraviolet radiation are serious drawbacks. Heavier plastics are as costly as glass, but may prove superior in service where hail and other hazards exist. The requirements of the location and end use will dictate the decision. Table 3-XI summarizes the number of glazing sheets that should usually be used for several purposes, with or without a selective absorber.

Whether or not the collectors are to be integral to the roof structure of the building is another question which needs to be answered. Integral installation in new construction lowers the material cost in that the roofing material is being replaced by collectors; however, access for maintenance may be hindered, and as a result, maintenance costs may be increased.

Experimental work is presently being done in convection suppression between the absorber plate and the glazing. Convection is a major component in upward heat losses. A honeycomb structure in this space may reduce these losses, but if opaque, the collector must track the sun, and if transparent plastic, temperature resistance may be inadequate. The honeycomb may actually be a hindrance because it can reduce solar transmission to the plate; no such collectors are being marketed.

An alternative to the closed tube collectors described above is the Thomason system which allows water to flow in open troughs on top of the absorber plate. (See Figure 3-10). High heat loss due to

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TABLE 3-XI

GUIDE TO NUMBER OF GLAZING SHEETS

COLLECTION TEMPERATURE ABOVE AMBIENT TEMPERATURE ($F_C - F_A$) °F	TYPICAL APPLICATIONS	NUMBER OF COVER PLATES	
		BLACK-PAINTED ABSORBER ε = .9 OR .95	SELECTIVE ABSORBER ε = .2
-10 TO +10	HEAT SOURCE FOR HEAT PUMP AIR HEATING FOR DRYING	NONE	NONE
10 TO 60	SUMMER WATER HEATING AIR HEATING FOR DRYING SOLAR DISTILLATION SPACE HEATING IN NON FREEZING CLIMATES	1	1
60 TO 100	WINTER WATER HEATING WINTER SPACE HEATING	2	1
100 TO 150	SUMMER AIR CONDITIONING STEAM PRODUCTION IN SUMMER REFRIGERATION	3	2

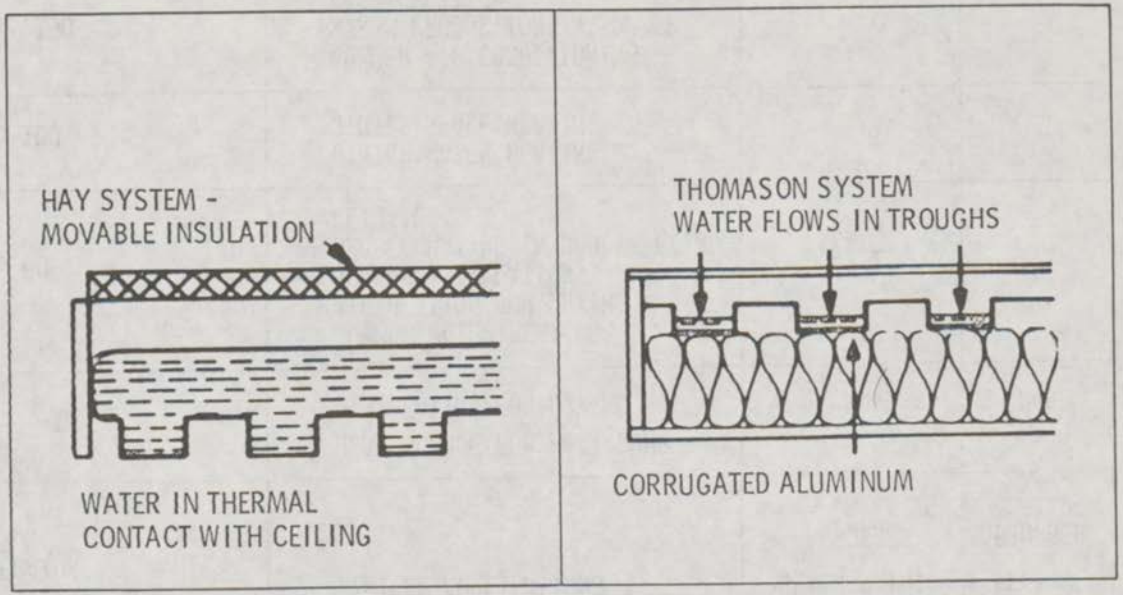


FIGURE 3-10

NON-TUBE LIQUID SOLAR COLLECTORS

evaporation and condensation between absorber and cover results in collection efficiencies considerably below those obtained with tubular-type collectors.

The Hay "Skytherm" system, mentioned above, integrates all system components into one. Water is stored in black plastic bags on the roof of the structure. The sun heats the water on winter days and the heat is stored for nighttime use; an insulated cover at night prevents re-radiation to the night sky. Heat is conducted into the house through the metal ceiling. During the summer, the bags remain covered during the day and are uncovered at night and wetted, thus achieving a cooling effect through evaporation and radiation to the night sky. The coolness is stored in the water bags for daytime use (See Figure 3-10). This system is limited to use in mild climates and on flat-roofed buildings.

Another recent innovation, now under limited production and test by Owens-Illinois, is an all-glass collector which employs a selectively-coated absorber tube in a vacuum, entirely eliminating convective losses. This collector, which can be produced on automatic machinery, promises both lower costs and higher output temperatures than other collectors. It should be extremely useful for absorption air-conditioner applications, where temperatures over 200°F are required for efficient operation. An evacuated tubular collector employing a metal absorber is being developed by Corning Glass Works.

When air is used as a heat-transfer medium, there are numerous

design options. Some differentiation exists as to how the air actually comes into contact with the absorber. The most simple design beyond a passive system could be characterized by an unglazed metal absorbing plate (selectively coated or black) with air passing beneath. Not much farther advanced in complexity is a Trombe system (See Figure 3-11) in which a heat-absorbing vertical wall is covered with glazing. The air between the wall and the glazing is heated by the warmed wall and it circulates through the house by convection.

The most widely used air collector is essentially a blackened metal air duct (with an air passage 1/2 inch or so in thickness) overlaid by two sealed glass covers and protected from bottom heat loss by adequate insulation. This collector is manufactured by the Solaron Corporation.

Experimental air heating systems have involved other collector types such as the matrix type (Figure 3-12) in an Arizona house and in experiments at the University of Wisconsin, the overlapped glass plate type (two Colorado houses), the Vee-corrugated type (experimental units in Australia) and the finned-plate type (University of Delaware house). Most of these collectors can operate at efficiencies somewhat higher than the commercial unit described above, but higher costs also are involved.

Omitted from this report are descriptions of numerous collector concepts, proposals and units actually being offered for sale which are clearly so inefficient, fragile, costly or otherwise unsuitable

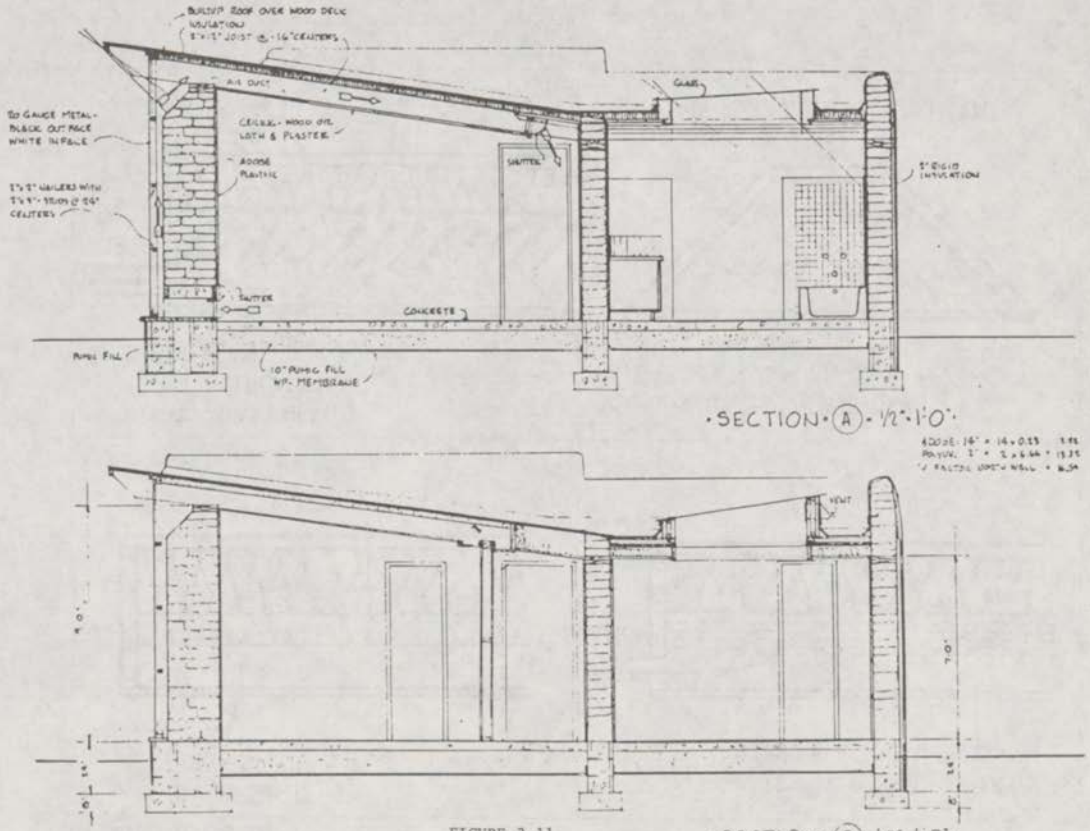


FIGURE 3-11
TROMBE HOUSE

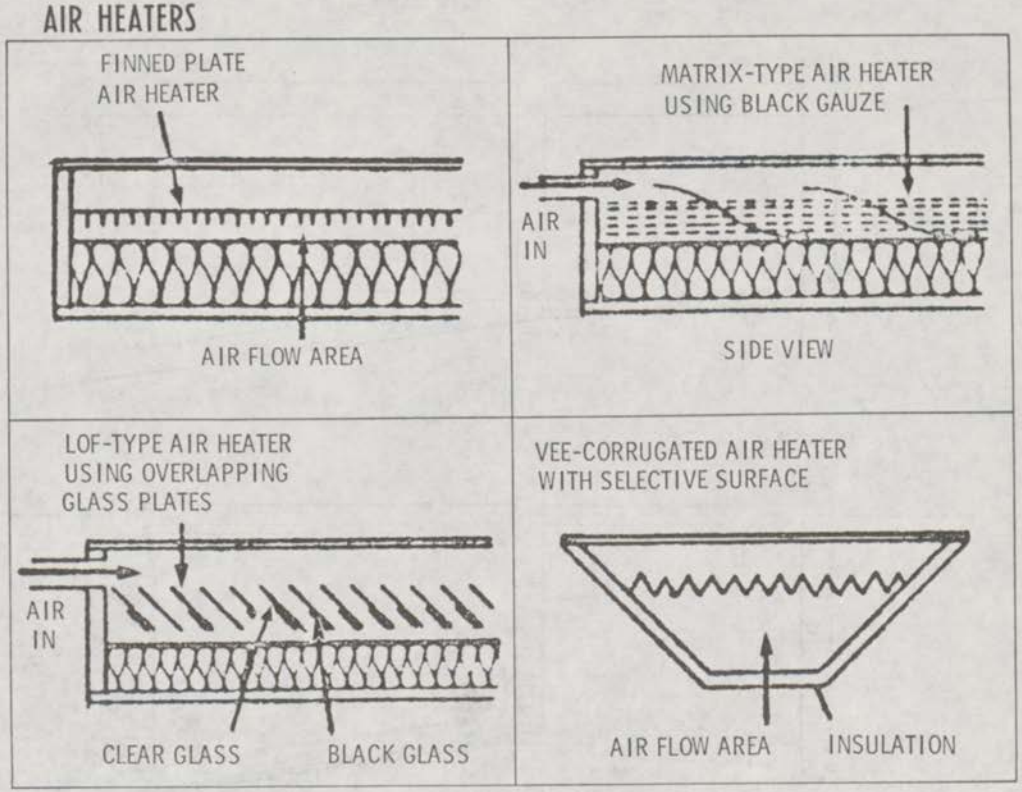


FIGURE 3-12
VARIOUS SOLAR AIR HEATER DESIGNS

for general use that commercialization cannot be anticipated. This field seems to attract a substantial number of technically naive enthusiasts who promote unproved concepts through the popular media. It is also attracting some groups which, through various marketing plans, are offering systems which cannot possibly provide the heating performance claimed. Contractors have the final responsibility for system effectiveness, and must insist on well-engineered dependable systems.

3.4.2 Storage.

Storage Technology is not limited to SHACOB considerations. Over and above the requirements which are obvious in solar applications, this field of knowledge can be applied to conservation (daily and yearly thermal flywheel effects can be created) and to reducing problems posed by high peak demands.

Two types of storage methods are potentially usable: sensible heat storage, and change of state storage, but only sensible heat storage in water and gravel is being extensively used.

3.4.2.1 Sensible Heat Storage. Sensible heat storage occurs when heat is supplied to a material so that its temperature rises and the heat is retained. Water is a practical storage medium for solar heat and has been used in all of the liquid systems built to date and currently used. Its high heat capacity, negligible cost and practical liquid temperature limits are advantageous, but its corrosive properties, freezing characteristics, and cost of containment are drawbacks.

No other liquid has a satisfactory combination of properties for SHACOB. If a liquid-type solar collector is used, water is without doubt the practical medium for heat storage.

Earthy materials (including rocks and pebbles) are most commonly indicated as the prime sensible heat storage media for SHACOB if air collectors are employed. Gravel is inexpensive and easy to obtain. Its advantages in comparison with water are:

- Lower cost installation mainly because of low-cost containment;
- Air may be more easily used as the heat transfer medium;
- Absence of freezing hazards and costs of prevention;
- Absence of corrosion in collection and storage units;
- Absence of damage associated with liquid leakage;
- Capability of storage at temperatures above 212°F, without pressurization.

A disadvantage with pebble-bed storage is the larger space required. In order to store 200,000 Btu at 100-160°F, approximately 17,500 pounds (175 cubic feet) of rocks are required, while for the same amount of heat storage capacity, approximately 3,300 pounds (53 cubic feet) of water are required. The volume required for pebble-bed storage is thus about three times that for water storage.

3.4.2.2 Change of State Storage. When heat is applied to many materials, they melt and, upon freezing, give up the heat. The heat that is given off, the heat of fusion, is generally greater than the sensible heat which can be held by the liquid or solid form of the material over the temperature range normally involved in SHACOB.

There are many materials which have melting points between 120° and 400°F with which there is no disassociation into components. If the particular material falls within this category, is relatively inexpensive, and is not severely hazardous, it could be considered for heat-of-fusion storage. Included within this category are several waxes and organic solids such as naphthalene, beeswax, stearic acid (tallow), and amorphous paraffin wax (vaseline).

Another class of compounds will evolve heat, when, after being heated, the temperature begins to drop and the compound changes from an anhydrite form into a crystalline form. This heat of hydration may be derived from such compounds as Glauber's salt or Plaster of Paris (Gypsum). However, the number of cycles which may be achieved is limited to some extent as the crystalline solid becomes increasingly harder to redissolve.

In order to store 200,000 Btu at 100°-160°F, approximately 1,740 pounds (19 cubic feet) of Glauber's salt would be required or approximately 3,900 pounds (29 cubic feet) of tallow.

In applying any change of state heat storage media, a storage vessel is required that can be heated or cooled by the heat transfer medium and from which the heat or coolness can be transported to use while the heat storage medium remains in the vessel.

Although change of state storage is attractive in theory, no materials have been identified which are cost-competitive with water and pebbles. At present, therefore, this type of storage is a

speculative possibility, with doubtful present applicability to SHACOB.

3.4.3 Conversion and Auxiliary

A solar heated building may draw heat directly from the output of the solar collectors when the sun is shining, or from storage while solar heat is being stored. If adequate heat is not available from the collectors, heat is supplied either from the storage unit or from the auxiliary heating system or from both together. In order to heat a building, a collector must supply heat at a temperature significantly greater than the desired space temperature, so if the temperature of the collector fluid or storage is not sufficient, auxiliary energy must be supplied.

The most commonly used auxiliary heater is a conventional furnace. Gas-fired warm air furnaces, gas-fired and oil-fired hot water boilers, and electric resistance duct heaters have been used. The modes of use vary with the type of system. All-liquid (hydronic) systems can be conveniently supplemented by use of a hot-water boiler. All-air systems or systems employing liquid solar collection and storage with heat exhange to air are advantageously supplemented with warm-air furnaces or electric resistance units.

In a few experimental solar installations, heat pumps have been used. In addition to the multiplying capability of the heat pump in reducing electric input (compared with resistance heating), this unit can make use of any heat supplied by the collectors even though the temperature may be below the desired space temperature; thus low

temperature collector outputs, which may be achieved with greater efficiency than high temperatures, are not wasted. The collector output, in effect, warms the heat pump's reservoir resulting in a higher coefficient of performance in the heat pump and a considerable savings in energy. Offsetting this advantage, however, is the fact that nearly all of the midwinter solar heat collection is at such a low temperature that electric power is needed for virtually all of the heat supplied to the building. The most cost-effective combination of solar supply and heat pump auxiliary has yet to be determined.

The heat supplied from the collectors can also be used to produce cooling. Several methods of using solar energy to produce cooling are being developed at present, most notably, absorption refrigeration, vapor compression refrigeration, and desiccant or molecular sieve cooling. These three methods require additional cooling components. Another method, night sky radiation and evaporation cooling, is integrated with other system components, but does not actually use solar energy.

Extensive analysis is currently being applied to absorption air-conditioning as a solar cooling option. The water-lithium bromide absorption unit manufactured by Arkla Industries has been installed in several solar heated and cooled buildings. A slightly modified commercial unit with a three-ton rating is operated with solar heated water at input temperatures of 175°F to 200°F, providing two to three tons of cooling at a COP of 0.6 over this temperature range.

Farber at the University of Florida has experimented with ammonia-water absorption units for several years, but performance is not

comparable with lithium-bromide units, and ammonia presents hazards for household use.

Design changes in lithium-bromide units are leading to reduced temperature requirements, so solar cooling by absorption refrigeration may become a practical option.

The Institute of Gas Technology is currently developing a desiccant or molecular sieve type cooling unit which applies the Munters principle.

Solar-powered heat engines which can be coupled with compressors are also being examined. A solar operated Rankine cycle engine has been used to power a conventional type vapor compression unit to produce cooling, but at low COP. Teagen and Sargent have experimented with various refrigerant-type working fluids for application in the cycle using a four-cylinder reciprocating engine. This system requires an input temperature of 120°C and will achieve a COP of 0.4. Although this COP is low compared to conventional vapor compression units, it approaches the COP of an absorption cooling unit (~0.6). However, an input temperature of 120°C is difficult to achieve with a conventional flat-plate collector. This combination is not presently available for practical SHACOB use.

The operation of a solar-assisted heat pump can be reversed to produce cooling. Figures 3-13 and 3-14 depict the solar-assisted heat pump in both modes of operation. In the cooling mode, water from storage, previously heated by receiving heat from the buildings, is run through the collector at night and is cooled through night sky radiation. The cooled water is then returned to the heat pump, the

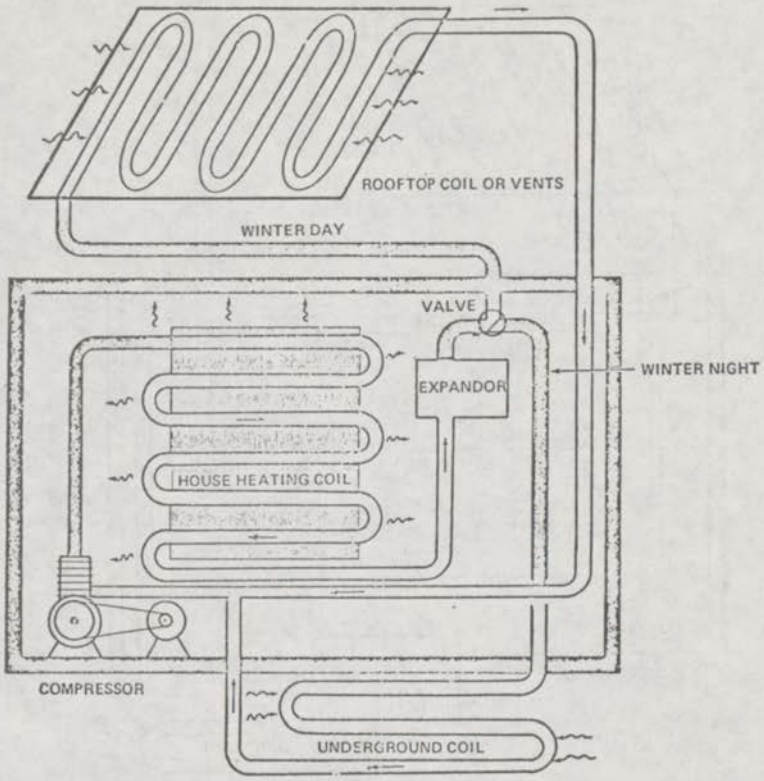


FIGURE 3-13
WINTER-TIME OPERATION - SOLAR HEAT PUMP

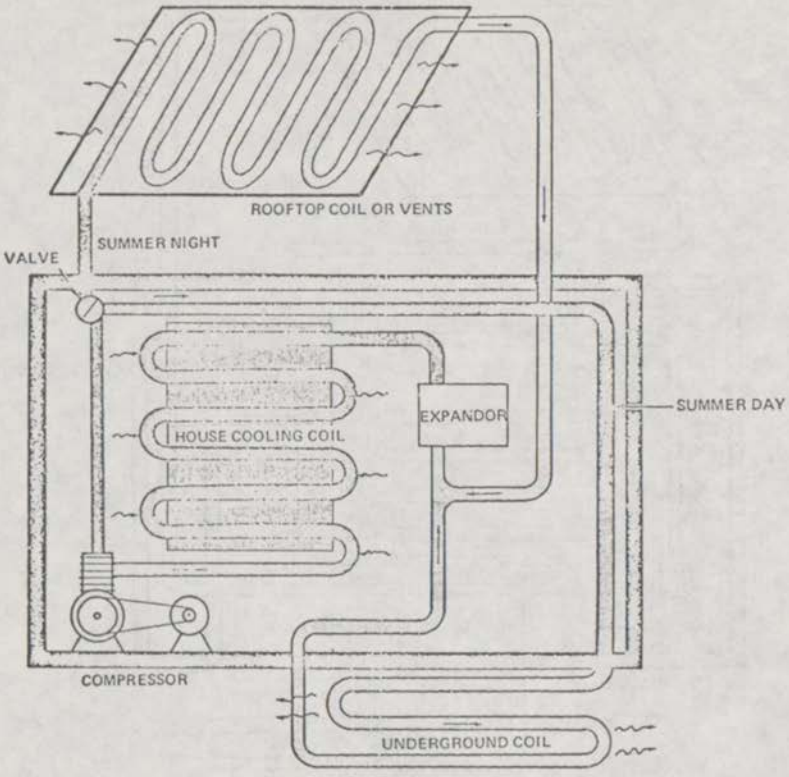


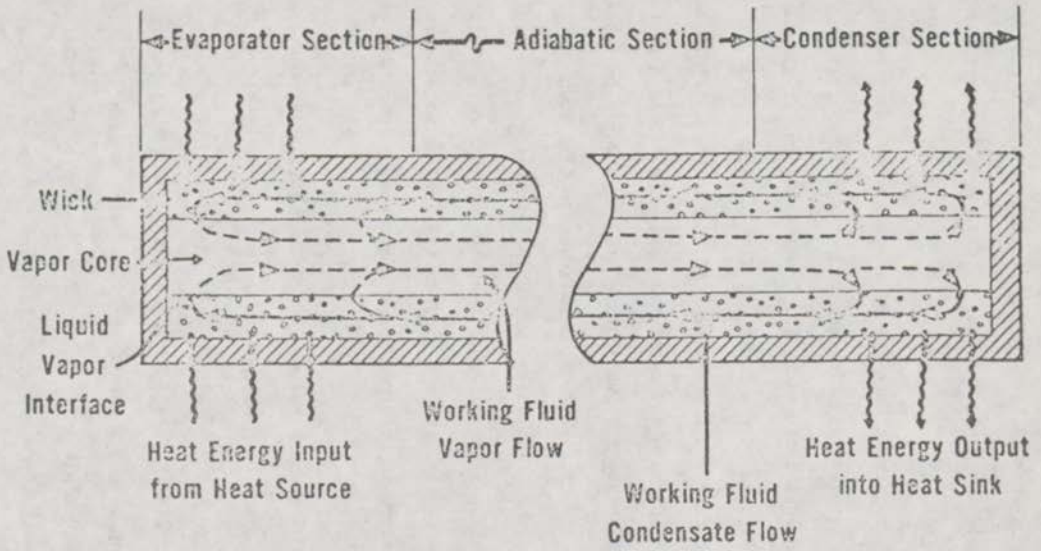
FIGURE 3-14
SUMMER TIME OPERATION - SOLAR HEAT PUMP

heat pump does not work as hard, a higher coefficient of performance (COP) is realized, and Btu's are saved. This mode of operation requires an unglazed collector.

The cooling feature of the Hay Skytherm system operates on the principles of night-sky radiation and evaporative cooling. In summer operation, the roof ponds (which are contained in plastic envelopes) are exposed to the night sky for cooling. During the day, the ponds are covered and the coolness stored in the water is conducted into the building through the metal ceiling. The Thomason system also utilizes night sky and evaporative cooling. Water is pumped from storage to the roof where it is allowed to flow down the unglazed north slope. The cooled water is then returned to storage. Supplemental cooling is supplied to the stored water by a small refrigeration unit. As with any evaporative cooling method, relatively low humidity is required for the successful operation of both of these systems.

In the hot air-pebble bed system, in suitable climates, cool night air can be used to cool the pebble bed, and this stored "coolness" used to cool the building during the day.

A heat pipe (See Figure 3-15) is a sealed length of tubing with a tightly-fitting wick. The tube is filled with a working fluid which will move, through capillary action, from one end of the tube to the other when there is a temperature difference between the two ends. At the warmer end the fluid vaporizes and absorbs heat. The vapor



Taken from NASA Technical Brief No. 71-10109

FIGURE 3-15

HEAT PIPE

then returns through the center of the wick to the cool end where it condenses and gives off heat. In this manner, a highly-efficient transfer of energy is achieved. Because there are no moving parts, maintenance is minimal.

This device has been proposed for use in SHACOB systems, and is used in some heat-recovery systems.

3.5 Present Suitability of Systems

The rapid pace of development and the large number of individuals and firms involved makes a thorough evaluation of available technology difficult and transitory. The following discussion of some of the technology receiving most attention may well miss some systems which are already or soon will be available for general use.

3.5.1 Domestic Hot Water Systems

Solar systems for production of domestic hot water have been in general use in Australia, Japan, Israel and the Near East for many years. From about 1936 to 1941, installation of these heaters was at a peak in Florida, reaching a total number of installations perhaps approaching 100,000. First World War II and then the advent of natural gas and cheaper electricity, combined with lifestyles which used more hot water and expected more convenience, put an end to the Florida industry. It is showing signs of revival in the current energy situation.

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In Australia and Israel, installation of solar hot water systems is routine. Several firms in the United States are now offering systems either for self-installation or for the use of the trade. This application is economically marginal in most parts of the United States, but as the areas of expensive fuel and power spread, solar water heaters will undoubtedly be produced and installed in increasing numbers. It should be noted that no systems are known to be usable where a freezing problem exists.

3.5.2 "Tailor-Made" Systems

A number of very careful and imaginative architects and engineers in the United States have designed and built single buildings, or small numbers of buildings, which use solar energy for space heating and hot water production.* These buildings often incorporate "passive" features, such as careful control of shading, consideration of the thermal storage capacity of floors and walls, and ventilation control. Nearly all of these buildings use solar collectors designed for the particular application and fabricated on the job. Some of these have been designed and built for specific clients, while some have been built as experimental projects with evaluation procedures incorporated. Only about a dozen buildings have been provided with commercially-manufactured solar equipment that has been sold, with guarantees, to the general public, for routine, non-experimental use; nearly all of these have been supplied by one manufacturer.

*See: Arizona State University College of Architecture Research Report 1975, "Solar-Oriented Architecture," AIA Research Corp. and National Bureau of Standards.

These systems represent a very important set of developments and will result in an expanding feature of the solar industry. Most of them are of such recent vintage that thorough technical and economic evaluations are not yet available.

3.5.3 Skytherm

The Skytherm system, developed by Harold Hay, was discussed briefly earlier in this report. It consists of a plastic-enclosed pool of water contained above a metal ceiling on the flat roof of a single-level house. An insulated cover which is opened and closed by automatic thermostatic control permits the water to be warmed by the sun or cooled by night-sky radiation and evaporation, as appropriate. The water pool exchanges heat with the living space below through the metal ceiling.

Two buildings have been constructed using the Skytherm technology. The most recent one, at Atascadero, California, has just been given an extensive technical evaluation by the California Polytechnic University, and has received a good rating.

The suitability of this system is sharply limited to climatic zones which do not present a freezing problem, and which have moderate temperature ranges. It also requires a flat-roofed building.

3.5.4 Thomason System

Half a dozen houses have been built by Harry E. Thomason, and a large number of sets of his plans have been sold for do-it-yourself use. This system, also mentioned earlier, uses an ordinary corrugated roof with water trickling down the corrugations as a collector, with

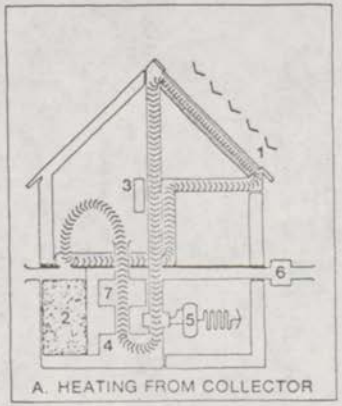
a glass cover to reduce re-radiation and evaporation. Warm water is collected and stored in a tank, typically surrounded by a pebble bed, and air is heated by contact with the tank wall and circulated through the house.

This system has a simplicity which has appealed to many people, and aggressive promotion has made it a familiar option. Doubts have been expressed by solar specialists as to the efficiency and economic viability of this system, which have not been resolved because of the failure of its developer to submit it to independent evaluations.

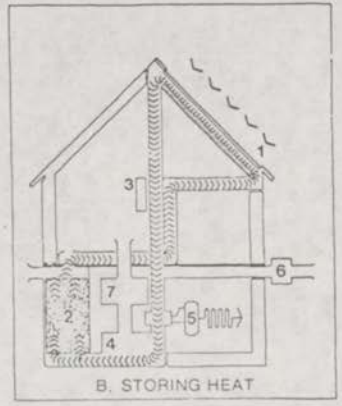
3.5.5 Solaron System

The Solaron System (see Figure 3-16) is of particular interest in the context of the present study. It is based on the experience of G.O.G. Löf, who has lived for 17 years in a house heated by a similar system. Löf is one of the few responsible investigators who gives substantial attention to hot air systems as contrasted with hot liquid systems.

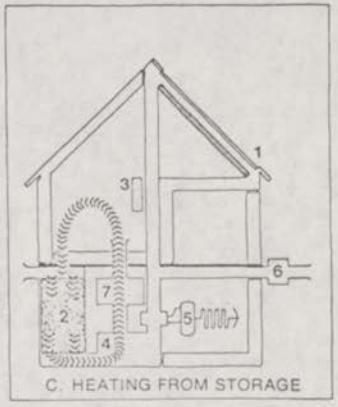
Air is warmed by contact with a blackened steel plate exposed to the sun, covered by two glass plates. The warm air is used directly to heat the building through standard ductwork and controls. A heat exchanger uses heat from the air stream to heat domestic water. A bed of dry pebbles accepts and stores heat from the winter sun or coolness from the summer night air. This stored heat or coolness is used to heat the building during winter nights and sunless days, and to cool the building in summertime. An auxiliary heating unit provides



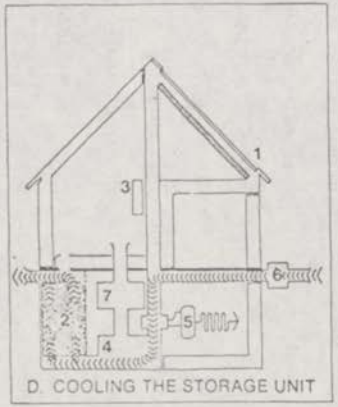
A. HEATING FROM COLLECTOR



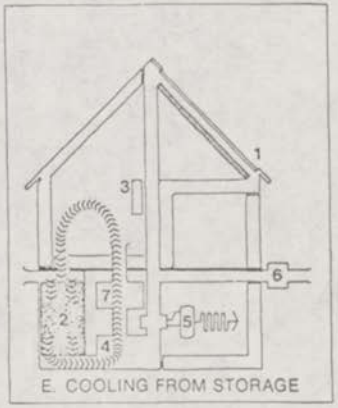
B. STORING HEAT



C. HEATING FROM STORAGE



D. COOLING THE STORAGE UNIT



E. COOLING FROM STORAGE

LEGEND

1. SOLAR COLLECTOR
2. DRY STORAGE UNIT HOT AND COLD
3. CONTROL UNIT
4. AIR HANDLING MODULE
5. HOT WATER UNIT
6. DAY-NIGHT EXCHANGE COOLER
7. AUXILIARY UNIT

SOLARON SYSTEM OPERATIONAL MODES

FIGURE 3-16

backup, as required.

The company manufactures the collectors, storage unit, air handling system and controls. Standard conventional components are procured and the whole system is installed by experienced HVAC contractors. About 50 Solaron installations are in various stages of design, construction and completion.

3.6 Current Status of Utilization

The use of solar energy for heating and cooling buildings will have to increase dramatically in order to realize the 0.6 quad savings by 1985 projected by Project Independence Blueprint; a recent survey of buildings in the U.S. which utilize solar heating or cooling systems listed only 136 buildings that are in existence, under construction, or planned for the near future.*

The distribution of the buildings by regions in the U.S. is shown in Table 3-XII. The Mountain Region shows the greatest number of solar buildings (55, or 41%), due primarily to the extensive construction of solar buildings in Colorado (28) and New Mexico (22). The New England and Mid-Atlantic Region has the second largest concentration (24%) of solar-heated buildings.

The buildings and their solar energy systems vary widely in design and construction, from complex engineering designs to rather basic

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*1974 Solar Directory, Carolyn Pesko, Editor, Environmental Action of Colorado, Denver, Colorado, 1975.

TABLE 3-XII

DISTRIBUTION OF CURRENT SOLAR HEATED/COOLED BUILDINGS IN THE UNITED STATES

REGION	NUMBER OF BUILDINGS	PERCENTAGE
MOUNTAIN Colorado (28) New Mexico (22) Arizona (3) Nevada (2) Montana (0) Idaho (0) Wyoming (0) Utah (0)	55	41
NORTHEAST New Hampshire (7) New York (6) Vermont (5) Pennsylvania (5) Connecticut (4) Massachusetts (3) Maine (2) Rhode Island (1)	33	24
NORTH CENTRAL Minnesota (5) Ohio (3) Michigan (3) Illinois (3) Nebraska (2) Wisconsin (1) Missouri (1) Kansas (1) Indiana (0) South Dakota (0) North Dakota (0) Iowa (0)	19	14

TABLE 3-XII (Concluded)

REGION	NUMBER OF BUILDINGS	PERCENTAGE
SOUTHEAST Virginia (5) Delaware (2) Maryland (2) Georgia (2) Florida (2) New Jersey (1) West Virginia (1) Alabama (1) D.C. (1) Kentucky (0) Tennessee (0) North Carolina (0) Mississippi (0) South Carolina (0)	17	13
PACIFIC & PACIFIC NORTHWEST California (9) Oregon (1) Washington (0)	10	7
SOUTH CENTRAL Arkansas (1) Texas (1) Louisiana (0) Oklahoma (0)	2	1

do-it-yourself projects. They also vary considerably in type; the majority of the 136 buildings (over 59%) are single-family residences. These are followed by small commercial buildings (18%); academic buildings (8%); large commercial buildings (7%); and multiple-family residences (6%). To date, there has been no record of industrial facilities employing solar heating and cooling systems.

Most of these solar-heated buildings employ active solar energy systems; only 5% of the 136 buildings rely on passive solar heating. Water-type solar heating systems are the most prevalent; 45% of the buildings are so equipped, as compared to 17% for air-type systems, while about 5% of the buildings employ some mix of both types.

Information on the type of auxiliary heat was provided on only 42 of the 136 buildings. Of these, 59% of the buildings use conventional backup systems - 19% use electricity, 19% use gas, and 21% use oil as the auxiliary heat source. Thirty-three percent of the buildings on which data were available rely on wood stoves, fireplaces, or non-conventional energy sources such as windpower, and 7% have no auxiliary heat system at all.

3.7 Sheet Metal Considerations in Solar Systems

3.7.1 Applications Areas

Each component of a solar heating and cooling system discussed earlier in this report presents an opportunity for sheet metal application (see Figure 3-17). Where possible, SMWIA should strive to promote those total systems which would maximize these applications.

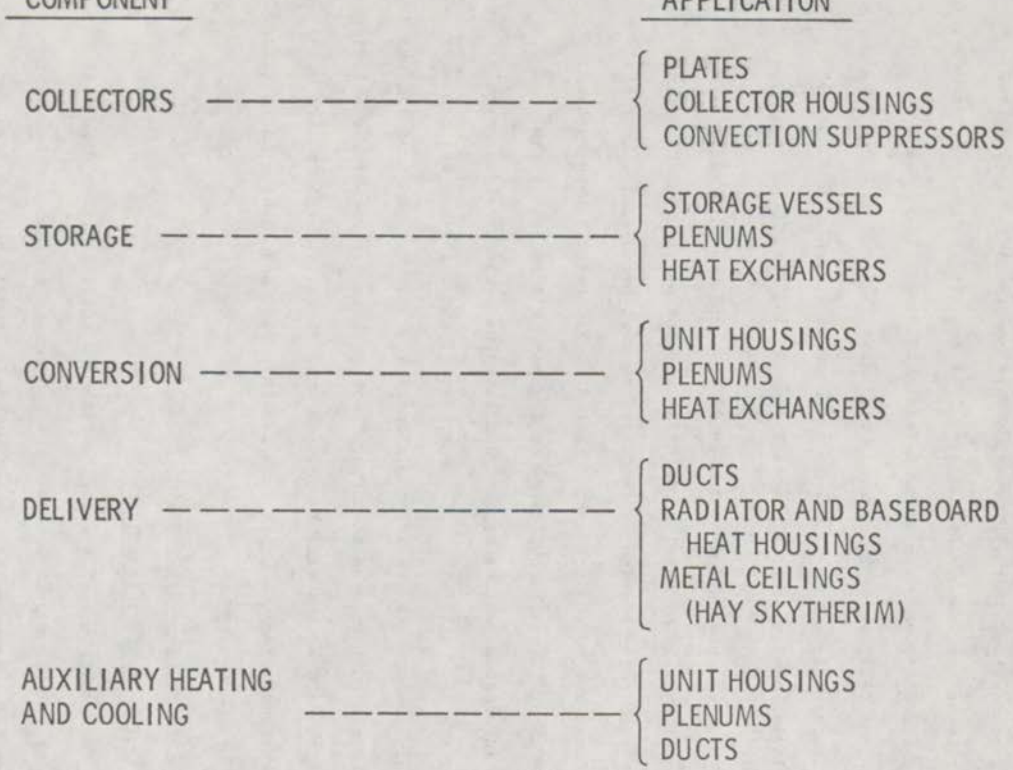

FIGURE 3-17
SHEET METAL APPLICATIONS IN SHACOB

In addition to those applications listed in Figure 3-19, two relatively new areas should be considered for assertion of SMWIA jurisdiction. Special sheet metal surface treatments should be considered, particularly vapor deposition of selective surfaces on absorber plates and corrosion inhibitors in aluminum roll. Heat pipes should also be considered as a possible new jurisdictional area since the technology is relatively new.

3.7.2 Air vs. Water

Practically every active solar heating and cooling system uses either air or water (usually mixed with anti-freeze and corrosion inhibitors) as a transfer fluid to absorb heat in a solar collector and to distribute heat through a building. In the case of water, it also serves as a storage medium. Since the solar heating industry as we know it largely grew by evolution from solar water heating techniques, many space heating systems are simply enlarged water-heating systems. This has resulted in a mental set on the part of many workers in the field which inhibits them from even considering hot-air systems. We have noted earlier in this report that 45% of the solar-heated houses included in the 1974 Solar Directory used water systems, while only 17% used air systems, with 5% mixed and the remainder passive systems. Almost all of the federally-supported research and demonstration activities have involved water systems.

These historic effects have resulted in a slighting of air systems, in spite of their obvious advantages, including:

- Lighter roof loadings
- Elimination of freezing problems
- Freedom from leak damage to houses and contents
- Freedom from corrosion of metals by water
- Simpler and more rugged construction, leading to lower initial and maintenance costs.

3.7.3 Industrial vs. On-Site Fabrication

In the absence of a developed industrial base, most solar heating installations so far have been shop or on-site fabricated, using standard building-construction materials and components. The largest exception has been the use of fabricated components, such as rollbond collection panels. The federal agencies concerned with solar research, development and demonstration have a clear policy of stimulating the growth of an industrial capacity for producing solar components. Under this policy, substantial R, D & D contracts have been given to major industrial firms. At the same time, the large firms have been reluctant to make major commitments to this development, in the absence of a guaranteed market and/or guaranteed government support.

It is clear that widespread application of SHACOB will require mass production and standardization of components and systems.

4.0 CONSERVATION

Project Independence Blueprint (PIB) estimates that about 2.3 quads per year of energy (the equivalent of almost half a billion barrels of oil) can be saved by 1985 by an accelerated energy conservation program in residential and commercial buildings. A major portion of this saving can be accomplished by improvements in heating, ventilating and air conditioning, both by retrofitting existing buildings and by raising the thermal efficiency standards of new construction.

The principal areas in which savings can be made are in the use of insulating glass (or storm windows and doors), improved sealing and caulking, and improved ceiling insulation. Of particular interest to this study, however, is PIB's estimate that a 6% reduction in the heating load of existing commercial buildings can be accomplished by the use of heat recovery schemes. This last saving could amount to about 0.2 quad per year of energy (the equivalent of about 30 million barrels of oil).

4.1 Incentives

PIB analyzes the impacts and costs of three major incentives to help accomplish the savings discussed above:

- Subsidy such as a 25% tax credit for retrofit of existing homes, expiring in 1980;
- Subsidy such as a 15% investment credit for energy reduction investments in existing commercial buildings expiring in 1980; and

- National thermal efficiency standards for new residential and commercial buildings.

By 1985 (assuming the energy cost levels implied by oil at $11 a barrel), these three measures are estimated to achieve an annual saving of 2.0 quads of energy (about 300 million barrels of oil) at a cost to the Federal government of on the order of $1 billion per year. Capital costs to the owners of the buildings (after the tax credits described) would average about $450 per home owners and from $250 to $2000 per 1,000 square feet of building space for owners of commercial buildings.

4.2 Technology

4.2.1 Variable Volume Systems

A variable-volume HVAC system is one that distributes air at a constant temperature and varies the volume of air supplied to each building space in accordance with its heating or cooling requirements. Properly designed and operated, it can perform the HVAC function at a substantial saving in energy and cost over a constant-volume system.

Existing constant-volume systems can be converted to variable-volume by substituting variable-volume fans and valves, and by minor changes in controls and ductwork. Particular attention is invited to equipment manufactured by MITCO Corporation. The cost of these changes if often very small as compared with the benefits.

4.2.2 Heat Recovery in Schools

An important sheet metal use in energy conservation is in waste-heat recovery*, a particularly good example of which is in schools.

*Designing Sophisticated HVAC Systems for Optimum Energy Use, ASHRAE Journal, February 1973.

Between the lighting and the dense human occupancy, a schoolroom often produces so much heat gain that it requires cooling even when outdoor temperatures fall below 20°F.* Health regulations typically require high-volume exhaust from classrooms. As a result, large quantities of heated air are withdrawn; a heat wheel or heat exchanger can transfer the heat from the exhaust air to fresh air input.

Two nationwide efforts are under way to accelerate the application of conservation technology to the schools. The Educational Facilities Laboratories (EFL) began early in 1975 to develop a program to analyze energy conservation needs for school districts throughout the nation. When the program becomes operational, a district may submit details of each of its facilities to EFL, and EFL will analyze the data and recommend in each case the most cost/beneficial energy conservation measures which might be taken. In another effort, the Interstate Energy Conservation Leadership Project has been funded by the U.S. Office of Education to prepare a package of energy conservation plans to be disseminated to schools throughout the nation. This project is still in the first year, and the package is not yet available.

4.2.3 Heat Transfer

A number of buildings are in use which do not have balanced HVAC systems, either because they are not large enough or because of faulty design decisions. In some cases, these buildings have hot and cold

*The Economy of Energy Conservation in Educational Facilities, Educational Facilities Laboratories, 1973.

rooms, because of sun exposure, type of occupancy or wind cooling. Often these buildings are heated on one side and air-conditioned on the other, sometimes both at once. Simple heat-transfer ductwork, perhaps with thermal storage, can help balance these buildings, running parallel with the existing partial HVAC systems.

4.3 Industrial Conservation

This study has been deliberately focused on the opportunities for solar heating and cooling of buildings, and for energy conservation in buildings. It is also true, however, that substantial energy savings are possible through careful thermal design of industrial processes and through recovery and beneficial use of heat energy which has often been wasted in the industrial methods adopted during periods of cheap energy.*

A study of this area of application, similar in depth to the present study would, in all probability, disclose additional opportunities for energy conservation through the use of sheet metal.

*Energy Consumption in Manufacturing, The Conference Board, 1974. Efficient use of Fuels in Process and Manufacturing Industries, Institute of Gas Technology, April 1974.

5.0 BUILDING SELF-SUFFICIENCY

Considerable careful analysis has recently been given to the possibility and desirability of making individual buildings or small groups of buildings much more self-sufficient in energy and other resources. The American Institute of Architects has proposed a strategy whereby as much as possible of the energy required for building operation would be generated on site by solar and wind energy collection and by conversion of solid wastes, with the energy inputs from utilities minimized.* The exchange of heat energy with the environment can be controlled by architectural design and by storage of surplus heat either in the fabric of the building or in special thermal storage units. Such integrated systems can eliminate the costs involved in transmission of energy and materials and in the overhead of the institutions required to furnish them.

The Holifield Laboratory of ERDA has built and is testing two houses each equipped with an underground tank holding between 1000 and 2000 cubic feet of water. Heat is transferred from house to tank in the summer and from tank to house in the winter, using an electric-driven heat pump. By spring, the water in the tank is frozen, and by fall it is melted and warmed. The heat pump, operating at a steady rate between end points whose temperatures are relatively

*Energy and the Built Environment: A Gap in current Strategies and A Nation of Energy Efficient Buildings by 1990, American Institute of Architects, May 1974.

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stable, works at high efficiency - preliminary tests show coefficients of performance of 5 to 6. The system is designed to supply space heating and cooling, and service hot water.

Numbers of installations have been designed in which heat storage over the daily cycle can cool houses in the daytime and warm them at night using a minimum of outside purchased energy and permitting that energy minimum to be purchased off-peak when it is cheaper and puts less strain on generating facilities.

5.1 Institutional Arrangements

In particular cases when the optimum system design for energy self-sufficiency is for more than one dwelling, such as in multi-family buildings or clusters of houses, or even entire communities, several institutional options are available. Cooperative or condominium energy systems are possible or "mini-utilities" organized on a community basis. It is also possible that ordinary regulated public utilities might own the decentralized energy collection and distribution system and provide heating and cooling as utility services for a fee. This last arrangement is also applicable to single-family dwellings.

These arrangements permit the location of energy facilities at optimum points in the community. Also, they may provide useful options for financing the capital investment in energy systems.

6.0 SMWIA STRATEGIES

In light of the changing energy situation, SMWIA should undertake several activities in order to ensure continued employment opportunities and benefits for its members.

6.1 Monitoring Developments

SMWIA should maintain a continuing program of monitoring developments in the nation's energy posture and government energy policies, as well as in energy technology and its social, environmental and economic implications. These developments should be analyzed and evaluated for their likely impacts on the sheet metal industry, and strategies evolved for dealing with them.

6.2 Inputs to Government Policies

Each of the four pieces of solar energy legislation described earlier in this report, as well as every other major piece of legislation and government regulation, went through a process of change and compromise as it evolved, usually involving public hearings and always offering opportunities for interested parties to make inputs. Both the National Plan for Solar Heating and Cooling and the Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings are currently in interim form, and interested persons and groups have been urged to make comments and suggestions for improvement. State and local laws, ordinances and regulations evolve through similar processes.

SMWIA should have a systematic scheme for reviewing such proposed policies and taking advantage of the opportunities presented for affecting their final form in areas of concern to SMWIA and its members.

Specifically, SMWIA should undertake an immediate campaign designed to overcome the bias being shown in favor of water systems as against air systems in the solar heating and cooling programs of the federal government.

6.3 Jurisdictional Negotiations

As one result of SMWIA's activity in monitoring developments, it should foresee technological innovations where questions of union jurisdiction might arise. A solid understanding in advance of such developments would help ensure that new areas logically falling within SMWIA jurisdiction would be so assigned. Early settlement of jurisdictional problems would benefit SMWIA and also help to reduce the possibility of delay in the introduction of useful innovations into the construction industry.

6.4 Research and Technology

SMWIA should encourage the inclusion of hot-air and other sheet-metal related technology in government and other research programs. In the case of particularly promising concepts, SMWIA should sponsor development itself.

6.5 Demonstration Projects

SMWIA should be continually alert for innovations which combine a requirement for sheet metal with the possibility of a contribution

to solving energy problems. Some such innovations will probably be seen to depend for their widespread adoption on a demonstration of their feasibility and acceptability. In such cases, SMWIA should take the initiative in seeing that suitable demonstration projects are undertaken.

A specific initial program of such demonstration projects is proposed in the next section of this report.

6.6 Information and Training

SMWIA should cooperate fully with government, industry, professional engineering and architecture associations, and other programs and media for the dissemination of information and understanding about successful innovations involving the use of sheet metal in the energy field. This should include, but by no means be confined to, the results of SMWIA-generated demonstration projects. The objective of this activity is the encouragement of prompt and widespread adoption of useful sheet-metal applications.

New developments in sheet metal applications should be incorporated in training programs in order that their widespread use can be accelerated. Specifically included should be the activities of the Sheet Metal Workers Training Fund and the solar educational and training program for craftsmen, contractors, architects and engineers to be developed by Colorado State University under the sponsorship of the Department of Commerce.

To coordinate and guide these efforts, SMWIA and SMACNA should establish a joint committee on information dissemination and training, with suitable consultants. This committee would determine the need for

and content of training programs, manuals, and publications, and institutional advertising programs.

7.0 RESEARCH AND DEMONSTRATION

This section recommends and discusses some research and demonstration projects for SMWIA to initiate, and describes the institutional arrangements suitable for each.

7.1 Research

7.1.1 Hardware

SMWIA should monitor the announcements of new developments by NSF, ERDA and private organizations in the areas listed below, in order to be able to exploit developments of sheet-metal importance, and to foresee requirements for jurisdictional negotiation;

- Heated-air solar collectors,
- Air-operated thermal storage devices,
- Air-to-air and water-to-air heat exchangers, and
- Air-to-air and water-to-air heat pumps.

7.1.2 Surveys

SMWIA should undertake thorough surveys of certain areas of activity which promise opportunities for expanded sheet-metal work. These include:

- Opportunities for retrofit installation of variable-volume HVAC systems,
- Names, addresses and capabilities of developers of air-operated solar components and systems,
- Federal agencies and procurement offices, especially within the Department of Defense and the General Services Administration, which are prepared to issue contracts for building or retrofitting commercial-type buildings with solar heating and cooling systems.

- Buildings without balanced hot-air systems in which better heat distribution would lead to more uniform temperatures, and

- Opportunities for using sheet metal in systems for recovery and use of waste heat in industrial processes.

7.2 Demonstration

Table 7-I lists demonstration activities which are recommended, together with the date and sponsorship of each.

7.2.1 Integrated Solar Systems for Residences

HUD will issue an RFP in June 1975 for solar heating systems for residences, aimed at firms or consortiums which are prepared to construct new residences on a turnkey basis with integral solar systems. These may include passive solar features (solar architecture). These will be built for and sold to private customers. The RFP will spell out the details of the federal contribution and cost-sharing.

While it is probable that a variety of solar air-heated options will be available in the future, the Solaron Corporation is believed to be the only realistic option at this point. SMWIA should encourage the formation of a number of teams to bid on single residences in each of several parts of the country. Each team should consist of:

- SMWIA
- Solaron Corporation
- A SMACNA member firm in that locality
- A local architect
- A local builder
- An independent evaluating contractor.

The areas recommended are:

TABLE 7-I

DEMONSTRATION ACTIVITIES

ACTIVITY	START DATE	SPONSORSHIP	NUMBER OF SYSTEMS
Solar			
Integrated Systems for Residences	June 1975	HUD	6
Retrofit Boulder, Colorado Post Office	June 1975	USPS	1
Request for Information	June 1975	ERDA	
Program Opportunities Notice		HUD	
Bidders Conference	June 1975	HUD	
PON Issued	January 1976	HUD	
Unsolicited Commercial Demonstrations	September 1975	NASA	4
Phase 2 Commercial Demonstrations	January 1976	NASA	6
Conservation			
Variable Volume Systems	June 1975	SMACNA	4
	January 1976	ERDA	6
Commercial Demonstration	January 1976	ERDA	6
School Demonstration	September 1975	SMACNA	2
	January 1976	ERDA	6
Heat Transfer for Temperature Balance	September 1975	SMACNA	4
	January 1976	ERDA	12

- New England
- Southeast
- North Central
- South Central
- Pacific Southwest
- Pacific Northwest.

The specific locations should be selected in consultation with Solaron and SMACNA on the basis of climatic suitability, population density (to maximize the transferability of results), and availability of SMACNA members willing to participate.

7.2.2 Boulder Post Office

During June of 1975, the United States Postal Service will issue an RFP for bids to retrofit the Boulder, Colorado, post office with a solar heating system. This is a particularly important project because it will set the pattern for possible use of solar heating in up to 40,000 postoffice buildings.

SMWIA should initiate a bid on this project by a team including Solaron and a local SMACNA contractor.

7.2.3 Request for Information

During June of 1975, ERDA will advertise for all persons and firms interested in producing solar components, systems and subsystems to submit details of their products for inclusion in a catalog. This catalog will be widely disseminated throughout the country, and will be used as the basis for selecting hardware for all federal government solar heating and cooling programs.

It is important to the sheet metal industry that as many qualified producers of air-operated equipment as possible be included in this

catalog. SMWIA should use its survey of developers, recommended earlier, to locate and encourage producers to respond to the ERDA request.

7.2.4 Program Opportunities Notices

HUD is about to contract with an R&D firm to prepare a matrix of locations and building types where solar systems are appropriate. Based on this matrix and the responses to the Request for Information described in the preceding section, HUD will issue Program Opportunities Notices for contractors and builders to secure solar equipment to install on buildings which conform to the descriptions in the matrix. A conference will be held in June 1975 for firms interested in being included in this program.

SMWIA should make sure that the sheet metal industry is properly represented at this conference, to protect its opportunities to be included in this program.

7.2.5 Unsolicited Commercial Demonstrations

ERDA will accept, in Fiscal Year 1976, a limited number of unsolicited proposals for commercial-type solar-heated buildings which generally fit the objectives of the National Plan for Solar Heating and Cooling. The major effort in commercial buildings will be deferred until the completion of the Phase I study described in the next section.

SMWIA should initiate four unsolicited proposals for early submission to ERDA. In each case, the project team should include:

- SMWIA
- Solaron Corporation
- A SMACNA contractor
- An independent evaluating contractor.

Two of these proposals should be for retrofitting existing school buildings with hot-air solar systems. The Federal government has now funded the retrofitting of 5 school buildings with hot-water solar systems, but none with air.

The two remaining unsolicited proposals should be for retrofitting super-market type post exchange buildings on military posts with solar hot-air systems. The use of Federally-owned buildings eliminates the legal difficulty of transferring ownership of the resulting systems to a private firm, while the selection of a supermarket-type building opens up the possibility of extending the application to a large number of similar buildings in the country.

7.2.6 Phase 2

ERDA has awarded a Phase 1 study contract for commercial buildings to a team consisting of Intertechnology Coporation and General Electric. This study will produce detailed specifications for a number of Phase 2 projects to build actual demonstration buildings. SMWIA should use its best efforts to ensure that air-operated systems are included in the Phase 1 study and that such systems are proposed during Phase 2, which should start early in calendar year 1976.

7.2.7 Variable-Volume Systems

The conversion of existing constant-volume HVAC systems to variable-volume systems presents an opportunity for substantial energy savings and also for substantial sheet-metal work. SMWIA should initiate a cooperative program involving SMACNA and the manufacturers of variable-volume components, designed to expand this conversion through a survey

to locate possible candidates for conversion and through aggressive advertising and promotion. Particular attention should be paid to associations of building operators, including the physical plant managers of colleges and universities and the public school districts throughout the country.

7.2.8 Commercial Building Conservation

ERDA has not yet developed a detailed plan for sponsoring demonstrations of building conservation techniques. This process could probably be expedited by the receipt of a few well-constructed unsolicited proposals within the next six months. SMWIA should initiate such proposals for approximately 6 commercial buildings in the same sections of the country as were recommended in Section 7.2.1, above, and with similar team members, except with a highly-qualified general HVAC engineer with a background in energy conservation added, and MITCO Corporation substituted for Solaron in cases involving variable-flow systems.

7.2.9 School Demonstration

The potential for energy conservation in school buildings is so large that an expedited program is recommended in this area, not waiting for ERDA to get ready to assume sponsorship. SMWIA should initiate one project in the East and one in the West for installing heat-recovery systems in the public schools. Schools should be selected in cooperation with the Educational Facilities Laboratories. Fundings should be by school district involved and by the sheet metal industry, with an effort made to secure backing from the Federal Office of Education.

This program should permit the expansion by early calendar year 1976 into a larger program funded by ERDA. The larger program should include six schools, with the geographical distribution and project organization similar to those recommended for commercial buildings in Section 7.2.8, above.

7.2.10 Heat Transfer

This section is directed to an expansion of the use of ductwork to distribute excess heat (from the sun, human bodies, and electrical equipment) through buildings which do not already have balanced air HVAC systems. SMWIA should initiate four such projects in various parts of the country with fundings from the building owners and the sheet metal industry.

Each project would be sold (with some help from SMWIA promotion) by a local SMACNA contractor to a cooperative building owner. SMWIA would add to the normal commercial contract the services of an independent evaluating contractor who could assess the system and publish a rigorous scientific report. This report could be used as the basis for a proposal early in 1976 to ERDA for sponsorship of an expanded demonstration of approximately twelve buildings of different types in different parts of the country.

APPENDIX B

MATERIAL SUBMITTED BY THE BUREAU OF STANDARDS

DESIGN AND EVALUATION CRITERIA FOR ENERGY CONSERVATION IN NEW BUILDINGS

NBSIR 74–452

February 27, 1974

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

Prepared for:
NATIONAL CONFERENCE OF STATES
ON BUILDING CODES AND STANDARDS

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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

February 27, 1974

National Conference of States for
Building Codes and Standards
c/o Mr. Bernard E. Cabelus, Chairman
State of Connecticut Delegate
State Office Building
Hartford, Connecticut 06115

Dear Mr. Cabelus:

The "Design and Evaluation Criteria for Energy Conservation in New Buildings" was developed in response to the July 12, 1973 request of the National Conference of States on Building Codes and Standards to provide the technical basis for a performance-type standard. Although this document is comprehensive in its technical scope, it is not practical at this time to develop a single document which would be universally applicable to all types of buildings in a uniform manner.

It is our recommendation that this document be used as the basis for the development of a consensus standard to apply to new construction for all building types except those excluded in the following paragraph. It is also our recommendation that the States be advised not to use the document in its present form for regulatory purposes.

The following recommendations are made with respect to:

1. Residential buildings including manufactured housing (one- and two-family) --

   - The Federal Housing Administration's Minimum Property Standard 51b should be used as an interim standard.

   - A consensus standard for one- and two-family housing should be developed using this document as a guideline to expand the scope covered by MPS 51b. It should include such factors as: air infiltration, usage of glass, illumination levels, and electrical distribution systems. It should seek to eliminate wasteful practices in heating, ventilation, air conditioning, and service water systems.

   - As an interim measure, the States should investigate the possibility of initiating a voluntary labeling program for buildings which meet the requirements of this document.

2. Mobile Homes --

   - The Coordinating Committee of the National Mobile Home Standard should be requested to sponsor and appoint a new subcommittee to develop an energy conservation supplement to ANSI A119.1. This supplement should be completed by July 1, 1974, using this document as a guideline.

3. Industrial buildings, monument buildings, short-term periodic use buildings such as vacation shelters, or buildings containing special laboratories --

   - Instead of using this document, special energy conservation measures applying to these buildings should be developed which take into consideration the special conditions which prevail.

As indicated in your November 19, 1973 letter to Dr. Richard Roberts, Director of the National Bureau of Standards, performance standards cannot be utilized without changes in the structure of the building regulatory system. It is recommended that NCSBCS at its February 27, 1974 meeting study what tasks need to be done to make performance standards workable and designate appropriate organizations to carry out the identified tasks. The completion of these tasks should be scheduled so that the regulatory system is capable of handling a performance-type standard when the consensus standard based on this document has been completed.

Sincerely,

F. Karl Willenbrock

F. Karl Willenbrock, Director
Institute for Applied Technology

ERRATA SHEET NO. 1

March 8, 1974

NBSIR 74-452, Design and Evaluation Criteria for
Energy Conservation in New Buildings
February 27, 1974

The following corrections should be incorporated into the referenced pages and paragraphs of NBSIR 74-452.

1. Page 9, Definition for Full-Load Energy Utilization Efficiency

Add the following missing equation, after line 5:

$$\eta_{fl} = \frac{\text{Output}}{\text{Thermal Input} \times C_1 + \text{Electrical Input} \times C_2} (100), \text{ percent.}$$

2. Page 21, 5.0.5 Floors, Foundation Walls, and Slabs-on-Grade - Heating

Change line 4:

From: ". . . opaque wall areas . . ."

To: . . . thermal transmittance values of Table 5.2 for Gross Exterior Wall Area . . ."

3. Page 30, 5.0.8 Orientation on Site - Cooling

Change Paragraph number

From: "5.0.8"

To: "5.0.15"

4. Page 62, 6.4.11 Special Zones

Change line 8

From: ". . . and rise of . . ."

To: ". . . and use of . . ."

5. Page 67, 6.5.7 Cooling Efficiency - Electric Motor-Driven Cooling Systems

Change line 4

From: ". . . ratio of system to net . . ."

To: ". . . ratio of net system . . ."

6. Page 69, 6.5.9 subparagraph 2

Change line 9

From: ". . . shut off. The heating input shall be provided: (1)..."

To: " . . . shut off the heating input, shall be provided (1) ... "

7. Page 75, Formula for COP

Change numerator

From: "not . . ."

To: "net . . ."

8. Page 84, 9.2 CRITERION

Insert paragraph number and heading into line 1, as follows:

"9.2.1 Heat Removed/Recovered from Luminaires -- Where the heat . . ."

9. Page 97, first paragraph

Change line 10

From: ". . . component . . ."

To: ". . . components. . ."

10. Page 98, Simplified and Reliable Energy Calculation Procedures

Change line 7

From: ". . . designs. What . . ."

To: ". . . designs are necessary. What . . ."

J. L. Heldenbrand

J. L. Heldenbrand
Project Manager
Building Environment Division
Center for Building Technology, IAT
National Bureau of Standards

USCOMM-NBS-DC

ERRATA SHEET No. 2
September 23, 1974

NBSIR 74-452, Design and Evaluation Criteria
for Energy Conservation in New Buildings
February 27, 1974

The following revised section should be inserted in place of pages 94 and 95 of NBSIR 74-452. The purpose is to clarify the discussion relative to real discount rates and real fuel price increases. Equation (1) has also been reduced to a simpler format. In the original equation, required brackets around the first term (1 + P) were missing.

PROCEDURE FOR DETERMINING ECONOMIC EFFICIENCY

In order to avoid the possibility that any requirement of these criteria might be counterproductive in an economic efficiency sense, it may become necessary to determine whether a requirement is economically efficient. To determine economic efficiency, the present worth of life-cycle energy savings must be compared to the present worth of the extra life-cycle costs incurred to achieve the energy savings. This section describes one acceptable method for calculating the present worth of energy savings and extra costs, and it specifies a relationship between these two magnitudes in order for economic efficiency to be determined.

For the purpose of these calculations, the building life (L) and the real annual discount rate (D) must be assumed. The life-cycle energy savings, resulting from the use of a required subsystem rather than a specific alternative, consist of the estimated yearly difference in electrical and fossil fuel consumption valued at present prices, which grow, in real terms, at an annual rate of P. The extra life-cycle costs consist of additional initial costs, additional maintenance operations, and replacement costs through the life of the building. Real discount rates and real rates of fuel price increases (i.e., rates of change apart from general price increases) are used to eliminate the need to estimate the rate of general inflation.

A given requirement in the document should be considered economically efficient if the present worth of energy savings (B) is greater than the present worth of the extra costs (C). A requirement should be considered economically inefficient if the present worth of energy savings (B) is less than the present worth of the extra costs (C). The calculation of B and C is described as follows:

$$B = \frac{1 + P}{D - P} \cdot \left[1 - \left(\frac{1 + P}{1 + D}\right)^{L}\right] \cdot S \qquad D \neq P \qquad (1a)$$

$$B = L \cdot S \qquad D = P \qquad (1b)$$

where

S = the annual value of energy saving by incorporating a subsystem or component required in the document rather than using a specific alternative.

$S = p_1 s_1 + p_2 s_2$, etc.,

where

p_1 = the present unit price of fuel 1, and s_1 = the number of units of fuel 1 saved annually.

Simply stated, B is equivalent to the present value of a stream of dollar energy savings over L years which grow at the real rate of fuel price increase, P, while being discounted to present value at the real discount rate, D.

$$C = I + \left[\frac{1 - \frac{1}{(1 + D)^L}}{D} \right] (M + O) + \sum_{y=1}^{L} \frac{R_y}{(1 + D)^y} \qquad (2)$$

where

D = real annual discount rate in decimal form.

P = annual rate of change in the real price of energy in decimal form.

I = extra initial cost incurred by incorporating a subsystem or component required by these criteria rather than using a specific alternative.

L = building life in years.

M = extra annual maintenance cost at present prices.

O = extra annual operations cost at present prices.

R_y = extra replacement costs in year y at present prices.

I, M, O and R_y may be negative. A negative value indicates that the particular cost component of the required subsystem is lower than that for the alternative being considered. If this is the case, the negative sign should be retained in the computation.

In selecting specific values for D and L, lower values of L and higher values of D will reduce B, thereby increasing the chance that the requirement will appear to be economically inefficient. It is recommended that a building life of no less than 30 years be used (12 years for mobile homes) and a discount rate of no more than .08 be used.

As increasingly costly energy sources are utilized, e.g., North Sea and North Slope oil rather than Oklahoma oil, the real price of energy can be expected to rise during the life of the building (barring an innovation such as the commercial generation of electricity by fusion at favorable cost). Therefore, it appears overly conservative to say that P equals zero. As an attempt to capture the effect of rising real energy prices, it is suggested that P be assumed to equal .01. This assumption means that the nominal price of energy is expected to rise annually at a rate one percent greater than the general level of prices over the appropriate lifetime.

USCOMM-NBS DC

NBSIR 74-452

DESIGN AND EVALUATION CRITERIA FOR ENERGY CONSERVATION IN NEW BUILDINGS

Jim L. Heldenbrand, Editor

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

February 27, 1974

Prepared for
National Conference of States on Building Codes and Standards

U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

FOREWORD

This document is a set of design and evaluation criteria for energy conservation in most types of new buildings. The National Conference of States on Building Codes and Standards (NCSBCS) requested that the National Bureau of Standards (NBS) develop such a document with the intent that it could serve as a basis for a national standard developed through the voluntary consensus process.

Development of these design criteria required engineering value judgments in their preparation. Two Administration energy policy directives have served as quantitative goals for the engineering judgments that guided the formulation of these criteria: these are found in the President's 1971 and 1972 Energy Messages to Congress. In 1971, the President directed the Secretary of Housing and Urban Development to reduce maximum permissible energy loss by "about one-third for a typical 1200 square foot home--and by even more for larger (federally insured) homes." In the following year, the President directed the Secretary to "issue revised insulation standards for apartments and other multifamily structures not covered by the earlier revision. The new rules will cut maximum permissible (energy) loss by 40 percent." A third Administration statement appeared part way through the criteria's development which reinforced its conservation orientation. This was Atomic Energy Commission Chairman Dixy Lee Ray's report to the President (December 1, 1973) on a plan to commit $10 billion to Federal energy research and development in fiscal 1975-79. In that report, entitled The Nation's Energy Future, conservation is central to the Federal Government's energy self-sufficiency strategy. Moreover, the Ray report ranks conservation of energy as the highest federal research and development priority.

The design and evaluation criteria focus on building subelements and service system arrangements. Special provisions offer added flexibility for both conventional and innovative designs. The technical portions of the document are organized into four complementary sections: requirements, criteria, evaluation and commentary. Existing standards and procedures promulgated by organizations such as the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), the American Society for Testing and Materials (ASTM) and the American National Standards Institute, Inc. (ANSI) are referenced whenever possible. The evaluation statements describe how to verify that candidate solutions meet the stipulated criteria. Finally, the commentary statements convey the intent of the criteria and, in a number of cases, explain how the criteria were selected.

We believe adherence to the criteria contained herein will result in significant energy savings while maintaining an acceptable level of habitability, thus advancing several national goals.

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February 27, 1974

DESIGN AND EVALUATION CRITERIA FOR
ENERGY CONSERVATION IN NEW BUILDINGS

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1/ Wherever the term "document" is used in this publication it refers to these design and evaluation criteria unless the immediate context indicates another meaning.

TASK GROUP FOR DEVELOPMENT OF ENERGY DOCUMENT

The energy document is the result of work by personnel of the National Bureau of Standards Center for Building Technology augmented by a group of advisors who met frequently over a period of three months. The following persons comprised the Task Group.

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*Participation in the preparation of this document does not imply endorsement by the advisors or the organizations who designated them.

BACKGROUND OF PROJECT

Temporary shortages of gas, oil, and electricity have occurred during the last two years in various areas of the country. These shortages have caused temporary shutdowns of schools, offices, manufacturing, food processing, and military installations, and brought about requests to State and City executives for guidelines in the use of energy resources. Several State governments have initiated independent legislative action to control the use of limited energy resources in new buildings, thus raising the possibility that a wide variety of different requirements could be imposed on the building and equipment industries.

In an effort to provide uniformity in the requirements placed on building design by the various State and local governments, the National Conference of States on Building Codes and Standards (NCSBCS) in July 1973 requested the National Bureau of Standards (NBS) to develop an interim standard for energy conservation in new buildings which would be available for consideration by the States during their 1973-74 legislative sessions. Although NBS does not promulgate or establish engineering Standards[1/], it strongly supports the concept of voluntary consensus standards. NBS agreed to develop design and evaluation criteria for energy conservation in new buildings which would be made available to a suitable organization for sponsorship through the consensus process. Toward this end NBS prepared alternative plans for expeditious promulgation of their criteria through the consensus process by such a sponsor.

NBS established a Task Group in the Center for Building Technology to develop the document. With the concurrence of NCSBCS, NBS invited three professional societies who are concerned in a broad way with the design of buildings and energy-using equipment, and NCSBCS itself to name advisors to work with the NBS Task Group. After receiving a preliminary draft, ASHRAE has offered to sponsor this document through to a national consensus voluntary standard. NCSBCS will act on this proposal at their meeting in Salt Lake City on February 27, 1974.

1/ Exceptions to this generalization are the voluntary product standards and the limited number of mandatory standards covered by Congressional directives.

PROCEDURES USED IN DEVELOPMENT OF THE DOCUMENT

NCSBCS requested that the document be performance oriented where practicable. Since the term "performance" is subject to various interpretations, a number of different approaches were studied. The following two categories of objectives for the energy document were developed by NBS and approved by NCSBCS, and the various performance approaches were rated for their ability to attain these objectives:

ESSENTIAL OBJECTIVES

1. Be available by January 1974.
2. Effect significant energy savings.
3. Be applicable to a range of building construction, occupancies, climates, and equipment.
4. Be amenable to consistent interpretation.
5. Be compatible with existing health, safety, and environmental regulations.
6. Be useful as a design guide.
7. Be an improvement over existing documents.
8. Merit a high level of voluntary compliance.

DESIRABLE OBJECTIVES

1. Maximize energy savings.
2. Be an acceptable basis for a voluntary consensus standard.
3. Reflect due consideration of cost implications.
4. Permit design flexibility and choice of materials and equipment within given constraints.
5. Maintain acceptable standards of space, environmental conditions, and convenience.
6. Clearly differentiate requirements for each type of occupancy.
7. Suggest methods of preconstruction evaluation.
8. Include provision for different (emergency) conformance levels.

The approach which rated the highest probability of attaining the above objectives can be described as a "framework of performance statements supported by performance requirements for subelements," and was followed in preparing this document.

The timeframe within which the document was developed permitted the use of state-of-the-art technology only. A public workshop was held on November 12 and 13, 1973, after announcement in the Commerce Business Daily and the issuance of written invitations to State officials and to a broad selection of professional and industrial associations for its provisions. During the preparation of this document, meetings were held at NBS between the Task Group and officials of various industry associations representing types of energy resources, mechanical equipment for buildings, the housing and mobile home industries, and building materials, to obtain their views and recommendations of building requirements. In advance of making the resulting design and evaluation criteria available for sponsorship through a consensus review process an opportunity was provided to selected industry, professional and government groups to review a working draft. In addition NBS contracted for economic and technical impact analyses of the draft document from nine architectural and engineering firms and industry associations. These comments and analyses have received consideration in the preparation of this document.

Design requirements were developed for only those features of energy-using equipment for which enough technical information was available to support a definitive criterion. Other parameters can be covered now by guidelines to designers on an advisory basis, and may be incorporated into future revisions of the document as the experience and technology of energy conservation expands.

APPLICATION

As illustrated in Figure 1, the document provides three paths to acceptance of a building's design energy requirement. Path 1 is basic since it provides the most direct approach and also provides the basis of comparison for establishing acceptable levels of energy usage for the alternative approaches afforded by Path 2 and Path 3.

By choosing only Path 1 in Figure 1, the building designer chooses to comply with the performance statements of Chapters 5 through 9 of this document.1/ These chapters contain a set of detailed performance requirements and criteria directed toward the saving of energy through design of building envelopes with good thermal resistance and low air leakage, and utilization of energy-saving practices in the design of mechanical and electrical systems. Provisions for acceptance of alternative designs for the building envelope are also included in Chapter 5. Conformance with Chapters 5 through 9 will result in energy conservation in buildings, and will provide design guidelines suitable for most building applications without the necessity for analysis of annual energy use.

In choosing Path 2 in Figure 1, the designer must perform a dynamic energy analysis on the building and service systems selected in Path 1. The resulting computed annual energy consumption becomes a reference energy budget. An alternative building design which does not necessarily meet each and every subelement requirement will be acceptable if an energy analysis of that design shows that the calculated annual energy use is equal to or less than the reference energy budget. Details regarding the Path 2 approach are given in Chapter 10 and illustrated in Figure 10-1.

Path 3 provides the designer with an allowable increase in total design annual energy consumed by the total building system, as a bonus for substituting solar or wind powered energy for part or all of the energy otherwise generated from mineral energy sources such as fossil fuel and uranium. The reference energy budget is based on a building designed to meet the requirements of Path 1. The basis for claiming an energy bonus is a dynamic energy analysis to establish both the reference energy budget and the annual design energy contribution provided by the solar or wind powered energy source. Details regarding the Path 3 approach are given in Chapter 11 and are illustrated in Figure 11-1 and the Commentary on Chapter 11.

1/ Chapters 1 through 4 apply to all three paths.

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Center for Building Technology

THREE PATHS TO APPROVAL OF ENERGY-BASED DESIGN

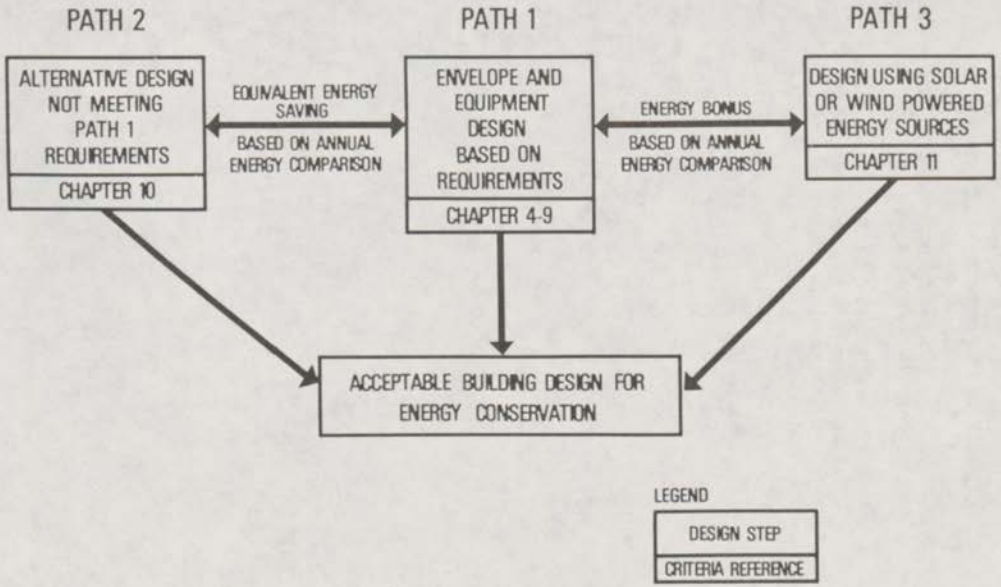

Figure 1

DESIGN CRITERIA WITH EVALUATION AND COMMENTARY STATEMENTS

The Requirement and Criteria statements contained in this document are supplemented where necessary with Evaluation and Commentary statements.

The Evaluation statements are intended to identify suggested procedures for evaluating a building design for conformance with the Criteria. The Commentary statements provide examples and sample calculations to illustrate design options and procedures and, in some instances, provide rationale for the Criteria.

Where no Evaluation or Commentary statement is given, the Criteria statement is presumed to be self-explanatory.

CHAPTER 1

OBJECTIVE

These design and evaluation criteria contain performance-oriented requirements for energy conservation in buildings. This document[1/] was prepared in response to a request by the National Conference of States on Building Codes and Standards to the National Bureau of Standards. It is intended to be the forerunner of a consensus standard to be promulgated by a national standards organization.

The document is performance-based to the extent permitted by present building design technology. The performance concept is applied at the subelement or subsystem level to synthesize an energy-efficient total system. The detailed performance requirements and criteria are directed toward the design of building envelopes with good thermal resistance and low air leakage, and toward requiring practices in the design of mechanical and electrical systems which conserve energy. Design flexibility is achieved by providing for acceptance of alternative design solutions that can be shown to save equivalent amounts of energy without following each and every detailed requirement. Such alternative designs, as well as those based on subelement requirements, must be supported by drawings, specifications, and calculations to demonstrate compliance.

The draft design and evaluation criteria can be made effective only by the application of its provisions in the design process, by review and evaluation of design proposals, and by the inspection of resulting construction. It is not the intent of this document to require tests and measurements of the completed building and its service systems to demonstrate compliance with its provisions except where explicitly stated.

1/ Wherever the term "document" is used in this publication, it refers to these proposed design and evaluation criteria unless the immediate context indicates another meaning.

CHAPTER 2

SCOPE

These design criteria are applicable to the design and construction of most new buildings for human occupancy except to buildings or portions thereof that are primarily an envelope over an industrial process; to buildings designed as monuments, to buildings intended for short-term periodic use, such as vacation shelters, or to portions of buildings containing special laboratories.

It is the intent of these design criteria to cover principally the features of a building and its equipment that determine its use of energy, and is not intended to abridge any safety or health requirements. The operation and use of buildings is not covered by this document, although some of the equipment requirements will inherently promote more efficient operation.

CHAPTER 3

DEFINITIONS

The following definitions are stipulated for the purposes of this document:

Building -- Any combination of materials, whether portable or fixed, which comprises a structure affording facilities or shelter for assembly, education, business, mercantile, institutional, or residential occupancies, as well as those portions of factory and industrial, and hazardous and storage occupancies which are used for office space. The word building shall be construed herein as if followed by the words "or part or parts thereof and all energy-significant equipment therein" unless the context clearly requires a different meaning. Unless otherwise stipulated, the term buildings as used in this document includes mobile homes and manufactured buildings.

Coefficient of Performance (COP) -- For cooling systems, the ratio of the rate of net heat removal to the rate of energy input, in consistent units. For heat pumps in the heating mode, the ratio of the rate of heat delivered to the rate of energy input, in consistent units.

Engineered System -- A system assembled at the point of application largely from standard components and packaged subsystems to meet a unique set of design requirements for a specific application, as contrasted with a mass produced system identified and sold as an integral product identified by a model number.

Energy Converting Equipment -- Equipment used principally to convert energy from one form to another, such as furnaces, electric motors, etc.

Energy Processing Equipment -- Equipment used principally to exchange energy, such as condensers, heat exchangers, etc. Specifically excluded are piping, ducting, and electrical distribution components.

Energy-Significant Equipment -- Means (1) central, unitary, or room space conditioning equipment, including but not limited to energy converting/processing equipment used in engineered systems and energy converting/processing packaged subsystems, and (2) service water-heating equipment.

Full-Load Energy-Utilization Efficiency (η_{fl}) -- The energy-utilization efficiency of energy-significant equipment, when operated at full-load rated capacity, computed as a ratio of useful output divided by energy input, including any auxiliaries, and converted to a percentage figure, as follows:

Where: Output = Useful effect (e.g., heating or cooling, shaft output energy, moisture added or removed, etc.) converted to Btu/hr.

Thermal Input = Thermal equivalent input of energy to direct fired equipment, in Btu/hr.

Electrical Input = Input to electrically energized equipment or components of equipment, in kw.

C_1 = 1.15 for off-cycle draft (exfiltration) losses on fuel burning equipment lacking devices to minimize air flow through the combustion chamber during burner off-cycles. C_1 = 1.0 for equipment utilizing such controls.

C_2 = 12,000 Btu/hr (kw) for electrical generation and transmission to load.

HVAC System -- A system that provides either collectively or individually the processes of comfort heating, ventilating, and/or cooling within or associated with buildings.

Manufactured Building -- Any building which is of closed construction and which is made or assembled in manufacturing facilities, on or off the building site; also any building of open construction for which certification under this document is sought by the manufacturer and which is made or assembled in manufacturing facilities away from the building site for installation, or assembly and installation on the building site. The term does not mean "mobile home."

Mobile Home -- A factory-assembled, movable dwelling designed and constructed to be towed on its own chassis, comprised of frame and wheels, usually used without a permanent foundation, and distinguishable from other types of dwellings in that the standards to which it is built include provisions for its mobility on that chassis as a vehicle.

New Energy -- Energy obtained by increasing the output of the basic energy conversion process as contrasted to energy recovered from or wasted by a primary energy-utilization system.

Opaque Areas -- All exposed areas of a building envelope which enclose conditioned space, except openings for windows, skylights, doors, and building service systems.

Recovered Energy -- Energy utilized which would otherwise be wasted (or rejected) from an energy-utilization system.

Reheat -- Sensible heat added to condition a zone to overcome cooling produced by expenditure of energy within the HVAC system serving that zone.

Solar Energy Sources -- Sources of thermal or photoelectric energy derived directly from conversion of incident solar radiation.

Test Year -- A year of hourly weather data recommended by the ASHRAE Technical Committee on Weather Data and Design Conditions for the purpose of energy consumption analysis. It is a weather year chosen from past weather in a given locality in terms of frequency, duration, and severity of hot and cold spells and in terms of overall energy requirements for heating and cooling buildings. In the absence of ASHRAE recommendations the designer may designate a test year for the locality concerned.

Thermal Break -- A relatively poor conductor of heat used to interrupt the path of heat flux between the inner and outer surfaces of a building element.

Total Energy System -- A system in which electric power is generated on or near the building site by means of engines or turbines, with exhaust and jacket heat recovered and used for space heating, water heating, absorption air conditioning, and/or process applications. For the purposes of this document, a qualifying total energy system shall have a minimum annual energy-utilization efficiency of 50 percent, including energy inputs to necessary auxiliary equipment. Combination electric generating and district heating or district cooling plants which have a minimum annual energy-utilization efficiency of 50 percent are also defined as total energy systems for the purpose of this document.

Unheated Space -- Means a ventilated crawl space, an unheated attic, basement or garage, or the outdoors. A basement or unheated portion thereof within which a heating system is located, shall be considered heated space if no insulation is provided at the basement ceiling, and shall be considered unheated space if insulation is provided at the basement ceiling. In mobile homes, spaces shall not be considered unheated which fall within an insulated envelope which provides one-half or more or the total resistance to the flow of heat, as required by Chapter 5.

Unitary Air Conditioner -- Means one or more factory made assemblies which normally include an evaporator or cooling coil, a compressor and condenser combination, and may include a heating function as well. Where such equipment is provided in more than one assembly, the separated assemblies are to be designed to be used together.

Zone -- With respect to the temperature control requirements in this document, a zone is defined as a portion of the space within a building which, recognizing the nature of its heating/cooling loads, could be satisfactorily controlled to desired temperature limits under varying outdoor conditions by the operation of a single automatic temperature control at an appropriate location within the zone. For actual temperature control criteria, refer to 6.4.2 and 6.4.3.

COMMENTARY

Full-Load Energy Utilization Efficiency -- This definition is provided in conjunction with paragraphs 6.3 and 6.4 to give system designers an interim basis for selection of efficient equipment. Efficiency information is needed for design of efficient systems, regardless of the nature of the energy source. Under the section on "New Information Needed for Energy Conservation Criteria" it is recognized that part-load efficiency data are not widely available at present for all types of energy-significant equipment. A requirement for part-load efficiency data should be incorporated in the criteria as soon as standard test procedures can be developed, in order to a) refine energy calculations affecting the design and selection of systems and equipment, and b) to avoid competitive pressures to optimize equipment efficiency at a load condition (such as 100% of design-rated load) which may not be typical of seasonal operation.

Referring to the constants used in the definition for Full-Load Energy-Utilization Efficiency, it is recognized that there are different values for energy conversion and transmission processes using direct-fired equipment. Because these factors are not all well documented at the present time, and because the order of magnitude of their values is nearest to unity, a value of one is assigned to C_1. Where off-cycle exfiltration is a factor, a 15-percent loss is assigned, pending receipt of better data. The C_2 figure of 12,000 Btu/kw hr was computed from national fuel consumption and energy production figures based on "Electric Power Statistics," Federal Power Commission, 1972, rounded to the nearest 1,000. It is necessary to use constants representing national averages to simplify the manufacturer's task of answering requests for the efficiency information stipulated in 6.4 or of publishing such data in sales literature or catalogs. This approach provides a simple yet fair method of including relative comparisons of efficiency among the considerations for deciding between competitive equipment.

CHAPTER 4

GENERAL PERFORMANCE REQUIREMENTS

The following general performance requirements shall be the basis for the more detailed statements of requirements and criteria which make up this performance document.

4.0 REQUIREMENT

Buildings and their service systems shall be designed to use energy efficiently while maintaining an acceptable thermal and visual environment and preserving their essential functional characteristics. The constraints put on energy use shall allow flexibility in the choice of materials and subsystems in the design process.

4.1 REQUIREMENT

The thermal resistance and air tightness of the exterior envelope of a building shall be designed to conserve energy under the applicable climate and occupancy conditions.

4.2 REQUIREMENT

The service systems in buildings used for heating, cooling, ventilation, domestic water heating, and lighting shall be designed for the efficient use of energy whether the energy conversion to useful effect occurs in the building or at some other location.

4.3 REQUIREMENT

Waste heat shall be recovered for useful purposes wherever practicable.

CHAPTER 5

EXTERIOR ENVELOPE REQUIREMENTS

5.0 REQUIREMENT

A building which is heated or cooled for comfort purposes shall be designed to restrict the flow of heat through the building exterior envelope.

CRITERIA (DESIGN CONDITIONS)

5.0.1 Combined Heating/Cooling -- A building designed to be both heated in winter and cooled in summer shall meet the higher of the summer and winter thermal resistance values for ceilings and roofs, opaque walls, foundation walls, slabs-on-grade, and the air leakage criteria requiring the greater airtightness. The winter design criteria shall be used to determine the area, heat transmission factors, and air leakage of doors and windows; water-vapor condensation control, and properties of caulking and sealants. The summer design criteria shall be used to determine shading requirements for windows. The preceding guidelines for selecting design criteria shall apply when establishing the reference energy budget for comparison with alternative designs provided for in Chapters 10 and 11.

EVALUATION

The design requirements for heating and cooling will be compared, where appropriate, to select the criteria which require the greater insulation resistance and airtightness.

COMMENTARY

This criterion is provided to require the designer and evaluator to design to the greatest need. For example, buildings in warm climates should restrict heat gain to minimize cooling loads, while buildings in cold climates should restrict heat loss to minimize heating loads. This criterion also requires more insulation in the coldest climates where it is most needed.

CRITERIA

5.0.2 Design Temperatures -- For the purpose of determining the thermal resistance to the flow of heat, indoor and outdoor design temperatures shall be used as specified below and in the ASHRAE Handbook of Fundamentals, 1972.

Design Temperatures, dry-bulb, °F

	Indoor		Outdoor*
Heating	70 °F	Heating -- see Column 4, subheading	97-1/2%
Cooling	78 °F	Cooling -- see Column 6, subheading	2-1/2%

* See next page.

* For locations in the United States and Canada, values given in Table 1, page 669, 1972 American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Handbook of Fundamentals, shall be required.

EVALUATION

Engineering examination of design temperatures used in calculations.

CRITERIA (HEATING)

5.0.3 Opaque Ceilings/Roof - Heating -- The heat flow through opaque areas of roofs or ceilings facing heated interiors shall not exceed the values of q/A (Btu/hr ft^2 of ceiling area) given in Table 5.1 for regions classified by heating degree-days when calculated at the indoor and outdoor design temperatures specified in 5.0.2.

$$q/A = U(t_i - t_o) \quad (1)$$

$$U = \frac{q/A}{t_i - t_o} \quad (2)$$

where q/A = heat flux, Btu/hr ft^2.
U = overall coefficient of heat transmission or thermal transmittance, air to air, Btu/hr ft^2 °F.
t_i = indoor design temperature, °F.
t_o = outdoor design temperature, °F.

5.0.3.1 Degree-day Values -- For locations in the United States and Canada, yearly total heating degree-days values given in Table 2, page 433, American Society of Heating, Refrigerating and Air Conditioning Engineers 1973 Systems Handbook shall be required. For degree-day values falling between the values tabulated in Table 5.1, intermediate values of q/A for ceilings and roofs may be read from Figure 5.1.

Table 5.1

Maximum Heat Flow Through Opaque
Areas of Roofs or Ceilings at Design Conditions

Heating Degree-days	q/A, Btu/hr (ft^2 Roof or Ceiling Area)
0	4.2
1,000	3.7
2,000	3.5
3,000	3.5
4,000	3.5
5,000	3.5
6,000	3.5
7,000	3.6
8,000	3.6
9,000	3.7
10,000	3.8
12,000	4.0
14,000 or greater	4.4

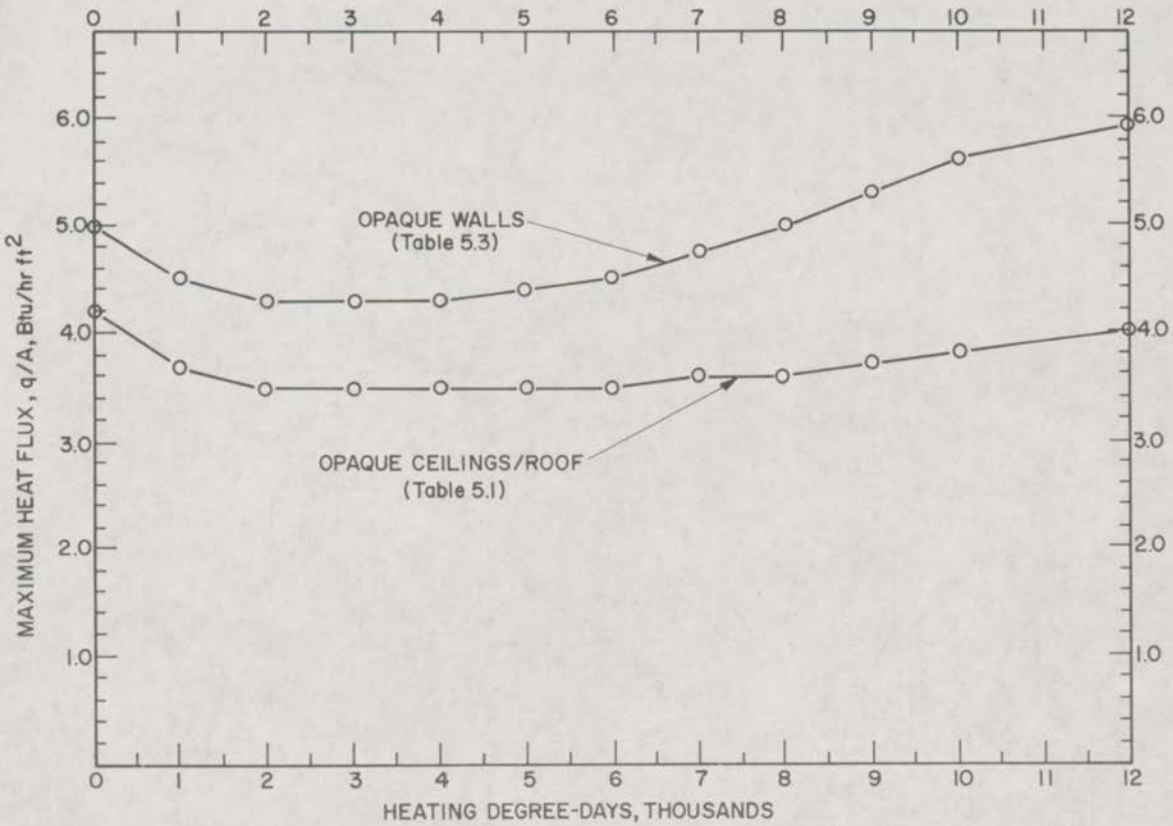

Figure 5.1 MAXIMUM HEAT FLUX FOR OPAQUE AREAS OF CEILING/ROOFS AND WALLS

EVALUATION

Engineering examination and evaluation of heat flow computations or test results. Design values of the thermal resistance of building materials as given on pages 357-363, ASHRAE 1972 Fundamentals Volume shall be used for evaluation.

COMMENTARY

A limit is placed on the heat flow through ceiling surface areas. The required overall thermal resistance of the ceiling/roof construction for each geographic area of the U. S. can be determined by the procedure used in the illustrative examples given in Appendix 1 to Chapter 5. A plot of q/A vs Heating Degree-days is shown in Figure 5.1. Design values of the thermal resistance of building materials to be used for evaluation are given on pages 357-363, ASHRAE 1972 Fundamentals Volume.

Heating energy used in a building correlates more closely with heating degree days than with design temperature difference. Degree days are not precisely related to design temperature differences referenced in handbooks. Therefore the criteria for heat flux through building elements was made to correlate with heating degree days and the thermal resistance was adjusted to meet the heat flux criteria at design temperature conditions. A building in a city having a greater design temperature difference but the same degree days as for an identical building in another city will have greater thermal resistance. This will result in somewhat less annual energy usage. The rationale for this approach is to maintain approximately equivalent comfort conditions for cities having lower extremes of design temperature.

CRITERIA

5.0.4 Gross Exterior Walls (Including Opaque Wall, Window, and Door Areas - Heating -- The combined thermal transmittance value (U value) for the gross area of exterior walls consisting of opaque wall areas, window areas, and door areas, all facing a heated interior, shall not exceed the values given in Table 5.2 for regions as classified by heating degree-days (see 5.0.3.1) when calculated at the indoor and outdoor design temperatures specified in 5.0.2. For degree-day values falling between the values tabulated in Table 5.2, intermediate values of the combined thermal transmittance of exterior walls, U_o, shall be read from Figure 5.2.

Table 5.3 provides guidelines for using equation (3) to select combinations of opaque wall, fenestration, and door areas and thermal resistances to satisfy the requirements of Table 5.2. The thermal transmittance values for window areas and door areas, and the amount of wall, window, and door area and its distribution in the periphery of the exterior walls of the building are at the option of the designer, providing the criteria for combines thermal transmittance are satisfied. For additional options see 5.0.9. For degree-day values falling between the values tabulated in Table 5.3, intermediate values of q/A for opaque walls shall be read from Figure 5.1.

Table 5.2

U_o Values, Gross Exterior Wall Area, Btu/hr ft^2 °F

Heating Degree-days	One- and Two-Family Living Units and Mobile Homes	All Other Buildings
0	0.60	0.63
500	0.48	0.51
1,000	0.36	0.40
2,000	0.29	0.37
3,000	0.27	0.36
4,000	0.25	0.34
5,000	0.22	0.32
6,250	0.20	0.30
7,500	0.18	0.28
10,000	0.17	0.27
12,000	0.16	0.26

Table 5.3

Guidelines for Maximum Heat Flow Through Opaque Areas of Walls at Design Conditions

Heating Degree-days	q/A, Btu/hr (ft^2 Opaque Wall Area)
0	5.0
1,000	4.5
2,000	4.3
3,000	4.3
4,000	4.3
5,000	4.4
6,000	4.5
7,000	4.8
8,000	5.0
9,000	5.3
10,000	5.6
12,000	5.9
14,000	6.0

For convenience of the user of this document, the heat flux (q/A), thermal resistance (R), and thermal transmittance (U) values meeting the design criteria of Tables 5.1 and 5.3 for 243 U. S. cities are tabulated in Appendix 2, along with corresponding degree-day and winter design temperature data from the ASHRAE Fundamentals and Systems Volumes, 1972 and 1973, respectively.

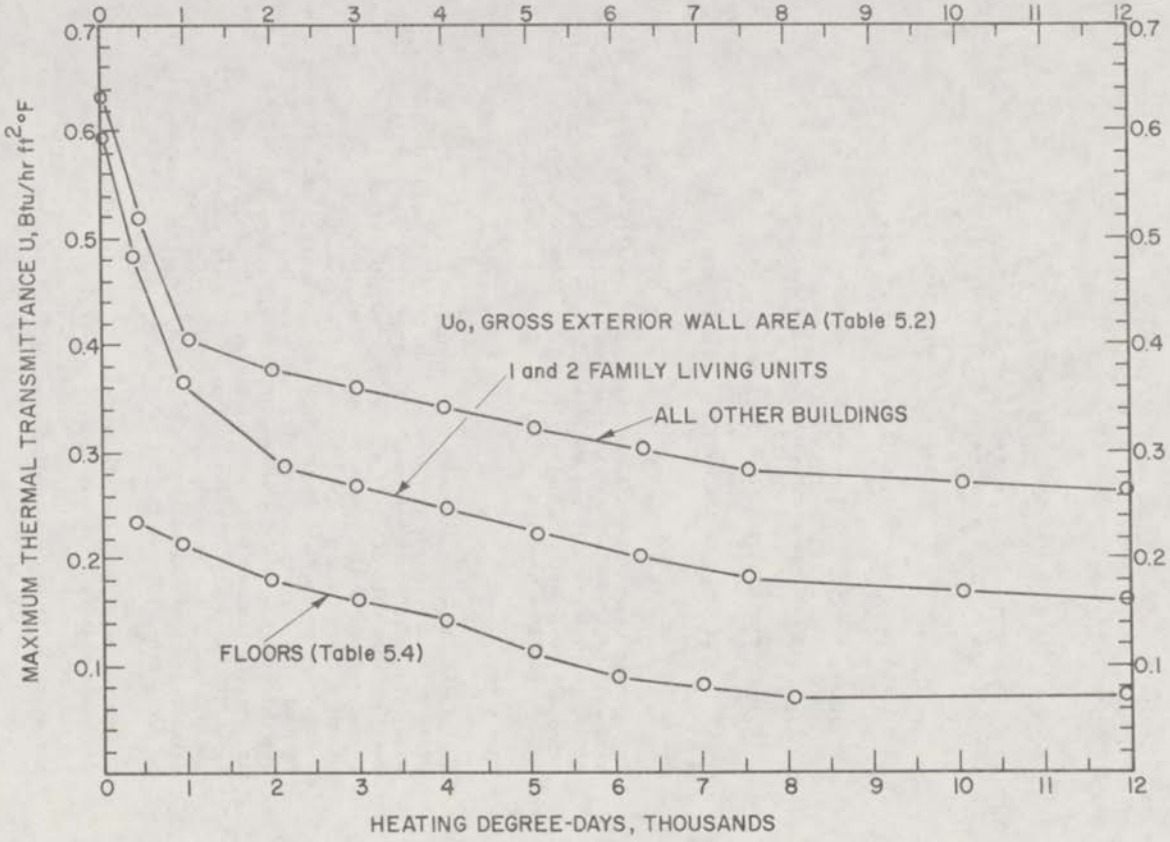

Figure 5.2 MAXIMUM THERMAL TRANSMITTANCE FOR GROSS EXTERIOR WALLS AND FLOORS FACING UNHEATED SPACES

The following formula shall be used to determine acceptable combinations of wall, window, and door areas, and thermal properties to meet the requirements of Table 5.3.

$$U_o A_o = U_{wall} A_{wall} + U_{window} A_{window} + U_{door} A_{door} \quad (3)$$

where: U_o = the average thermal transmittance of the gross wall area and A_o = a unit area of gross wall

U_{wall} = thermal transmittance of opaque wall area

A_{wall} = ratio of opaque wall area to gross wall area

U_{window} = thermal transmittance of window

A_{window} = ratio of window area to gross wall area

U_{door} = thermal transmittance of door

A_{door} = ratio of door area to gross wall area.

EVALUATION

Engineering examination and evaluation of overall U_o-value computations. Design values of the thermal resistance of building materials, thermal transmission for windows and slab doors as given on pages 357-363, Tables 8 and 9 on page 370, ASHRAE Fundamentals Volume, shall be used for evaluation.

COMMENTARY

A limit is placed on the thermal transmittance (U_o - value) of the gross wall area around the periphery of the building, including the wall, window and door areas. The required thermal transmittance for the gross wall area for each geographic area of the U. S. can be determined by the procedure used in the illustrative examples given in Appendix 1 to Chapter 5. A plot of U_o vs Heating Degree-days is shown in Figure 5.2. Design coefficients of thermal transmission for windows and slab doors are given in Tables 8 and 9, respectively, on page 370 of the ASHRAE 1972 Fundamentals Volume and for the thermal resistance of building materials on pages 357-363. All of the thermal resistance values required by Tables 5.1, 5.2, and 5.3 can be met throughout the United States, except Alaska, without using oversized studs and joists, by using available plastic or dense fibrous insulation.

The objective of Table 5.3 is twofold: (1) to provide criteria for designers wishing to prepare energy conserving designs without performing the trade-off analysis permitted in applying Table 5.2 and paragraph 5.09; and (2) to simplify the first trial step of a

trade-off analysis for those designers using the alternative criteria of Table 5.3 or paragraph 5.0.9. The thermal resistance of the opaque wall construction for each geographic area of the U. S. can be determined by the procedure used in the illustrative examples given in Appendix 1 to Chapter 5. A plot of q/A vs Heating Degree-days is shown in Figures 5.1.

CRITERIA

5.0.5 Floors, Foundation Walls, and Slabs-on-Grade - Heating

Floors/Heated Spaces -- For floors that face heated areas both above and below the floor line, there is no requirement for thermal resistance of the floor area, except that the peripheral edges of the floor must contain thermal resistance equivalent to that of the opaque wall areas above or below the floor and the thermal resistance must be continuous vertically. If the above thermal resistance criteria for the peripheral edge of a conventional structural floor system cannot be met, the peripheral edge shall be considered a part of the gross exterior wall area which is to be designed to meet the combined thermal transmittance values in Table 5.2.

Floors/Unheated -- For floors that face unheated spaces, the required maximum thermal transmittance is given in Table 5.4. For degree-day values falling between the values tabulated in Table 5.4, intermediate values of the maximum thermal transmittance, U, shall be read from Figure 5.2.

Table 5.4

Maximum Thermal Transmittance (U-Value) for Floors Facing Unheated Spaces

Heating Degree-days	Maximum U-value, Btu/hr ft^2 °F
0	no requirement
500	0.23
1,000	0.21
2,000	0.18
3,000	0.16
4,000	0.14
5,000	0.11
6,000	0.09
7,000	0.08
8,000 or greater	0.07

Foundation Walls--Foundation walls and the windows and doors therein enclosing heated space and exposed to outdoor air shall contain thermal resistance equal to that required for gross exterior walls as specified in 5.0.4. The thermal resistance of foundation wall enclosing heated space below grade shall be not lower than 50% of that required for gross exterior walls above grade.

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Slab-on-Grade -- For slab-on-grade floors the thermal resistance of the insulation around the perimeter of the floor shall be equal to 50% of the thermal resistance of the opaque wall area above the floor and shall extend downward below the grade line to the footing or the design frost line, or an equivalent distance horizontally inward from the edge under the floor.

EVALUATION

Engineering examination and evaluation of U-value and thermal resistance computations. Design values of the thermal resistance of building materials to be used for evaluation are given on pages 357-363, ASHRAE 1972 Fundamentals Volume.

COMMENTARY

Heated space is considered to be space that is heated for human occupancy or for prevention of physical damage from freezing. The meaning of "unheated space" is given in Chapter 3, Definitions. The "U" value approach is used for Table 5.4, rather than q/A, because the temperature difference at design conditions across floors over unheated spaces is more uncertain than the design indoor-outdoor temperature difference.

CRITERIA

5.0.6 Air Leakage Control

5.0.6.1 Overall Air Leakage -- The natural (not mechanically forced) leakage of air between indoors and outdoors shall not exceed 0.7 air change per hour for one- and two-family dwellings and 0.5 air change per hour for all other buildings and mobile homes.

Compliance with the overall air leakage requirement shall be determined by calculations from certified data furnished by the manufacturer or supplier on doors, windows, and exterior walls, and supplemented by calculations using the crack method given in the ASHRAE Handbook of Fundamentals, at the appropriate prevailing design wind conditions for the area of application. The 0.5 air change-per-hour criterion for all buildings other than one- and two-family dwellings and mobile homes contains an allowance for chimney effect in tall buildings.

5.0.6.2 Windows and Storm Windows -- Windows shall be designed to limit air leakage into or from the building. The air infiltration rate of aluminum, steel, and wood windows shall not exceed the rates specified in the following applicable national and industry standards, when tested at a pressure differential of 1.567 lb/ft^2, equivalent to the impact pressure of a 25 mph wind.

ANSI A134.1-1972 Specifications for Aluminum Prime Windows
ANSI A134.3-1972 Specifications for Aluminum Combination Vertically-sliding or Horizontally-operating Storm Windows for External Application.
AAMA 303.2-Jan. 1973 Specifications for Aluminum Mobile Home Windows (proposed ANSI 134.5)
Steel Window Institute Recommended Specifications for Steel Windows - 1973
NAAMM Standard SW-1-71 Specifications for Metal Windows
NWMA Industry Standard for Wood Window Units I.S. 2-73

Compliance with the criteria for air leakage of all types of windows shall be determined by ASTM E283-73, Standard Method of Test for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors.

5.0.6.3 Doors -- All exterior doors shall be designed to limit air leakage into or from the building when in the closed position.

The air infiltration rates of aluminum and wood sliding glass doors shall not exceed the rates specified in the following national and industry standards, when tested at a pressure differential of 1.567 lb/ft^2.

ANSI A134.2-1972 Specifications for Aluminum Sliding Glass Doors.
NWMA I.S. 3-70 Industry Standard for Wood Sliding Patio Doors.

The air infiltration rate of swinging doors shall not exceed 1 cfm per foot of crack in the closed position, when tested at a pressure differential of 1.567 lb/ft^2.

Compliance with the criteria for air leakage of all types of doors shall be determined by ASTM 283.73, Standard Method of Test for Rate of Air Leakage through Exterior Windows, Curtain Walls, and Doors.

5.0.6.4 Exterior Walls -- Panelized exterior walls shall be designed to limit air leakage at all joints between adjacent panels and at the joints between panels and other building elements.

The air infiltration rate of the exterior walls, excluding window elements, shall not exceed 3 $ft^3/hr\ ft^2$ of area, when tested at a pressure differential of 1.567 lb/ft^2.

Compliance with the criteria for air leakage of all types of exterior walls shall be determined by ASTM E238-73, Standard Method of Test for Rate of Air Leakage through Exterior Windows, Curtain Walls, and Doors.

5.0.6.5 Caulking and Sealants -- Caulking, sealants, or gasketing meeting the requirements of the specifications cited in the following paragraphs shall be used at the joints around all window and door frames, at the joints between walls and foundations, at the joints between walls and roof, around the frames of all other openings in the exterior envelope, and at the penetration of utility services through walls, floor, and ceiling.

The properties of the sealants, caulking, and gaskets must meet the requirements of the following ASTM and Federal Government Specifications, as applicable, when tested as specified therein:

FS-TT-S-00227E (Com-NBS) Nov. 4, 1969
Interim Fed. Spec. "Sealing Compound: Elastomeric Type, Multi-Component (For Caulking, Sealing, and Glazing in Buildings and Other Structures)."

FS-S-00230C (Com-NBS) Feb. 2, 1970
Interim Fed. Spec. "Sealing Compound: Elastomeric Type, Single Component (For Caulking, Sealing, and Glazing in Buildings and Other Structures)."

FS-TT-C-00598C (Com-NBS) June 23, 1970[1/]
Interim Fed. Spec. "Caulking Compound, Oil and Resin Base Type (For Building Construction)."

FS-TT-S-001657 (Com-NBS) Oct. 8, 1970
Interim Fed. Spec. "Sealing Compound: Single Component, Butyl Rubber Based, Solvent Release Type For Buildings and Other Types of Construction)."

FS-TT-001543A (Com-NBS) June 9, 1971
Interim Fed. Spec. "Sealing Compound: Silicone Rubber Base (For Caulking, Sealing, and Glazing in Buildings and Other Structures)."

ASTM C509-70
"Standard Specification for Cellular Elastomeric Preformed Gasket and Sealing Material."

ASTM C542-71a
"Standard Specification for Lock-Strip Gaskets."

ASTM C570-72[2/]
"Oil and Resin-Base Caulking Compound for Building Construction."

1/ Same as ASTM C570-72

2/ Same as FS-TT-C00598C (Com-NBS) June 23, 1970

EVALUATION

Engineering examination and evaluation and test results data. Evaluation against materials and assemblies specifications as published by the Federal Government and the American Society for Testing and Materials. The crack method as given in the 1972 ASHRAE Handbook of Fundamentals shall be used as the basis for engineering evaluation.

COMMENTARY

The air leakage into and out of a building in winter is a significant portion of the energy requirement necessary to maintain indoor temperature. The process creating natural air leakage consists of the buoyancy or chimney pressure difference of the dense cold outdoor air and the lighter warmer indoor air plus the effect of wind velocity pressure on the building. The air leakage limitation specified is based on what is attainable in construction practice including allowance for exhaust fan openings fitted with self-closing devices when the fan is not in use. This criteria is not intended to cover purposely designed forced ventilation systems in buildings.

Weatherstripping and caulking are required to minimize the loss of heat energy from air infiltration and to protect the exterior envelope from the elements.

CRITERIA

5.0.7 Condensation Control - Heating -- The design of the building envelope shall provide protection against cold weather water-vapor condensation on or in roofs, attics, walls, windows, doors, and floors. For opaque areas of ceilings, roofs, floors, and walls containing dry thermal insulation, a continuous vapor barrier, having a water vapor permeance not exceeding 0.5 perm (grains/hr ft^2 (in.-Hg)) is required on the winter-time warm side of the insulation.

Slab-on-grade floors shall have a vapor barrier with lapped joints under the slab not exceeding 0.1 perm.

A vapor barrier not exceeding 0.1 perm shall be required to cover the ground area of a crawl space beneath floors.

Ceiling, roof, floor, and wall constructions shall contain thermal breaks to prevent excessive heat transmission through framing members.

EVALUATION

Engineering examination and evaluation of the design and design calculations. ASTM Recommended Practice E 241-68 for general design information, ASTM Test Methods E 96-66 (Procedures A - dry cup) for materials such as paper, plastic films and other sheet materials that are less than 1/8 inch thick, and C355-64 (dessicant method) for

materials greater than 1/8 inch thick such as fiberboards, gypsum and plaster products on wood products, shall be used to evaluate vapor barriers, when applicable. A simulated service test or comparison with systems known to be effective shall be used to evaluate complete wall, floor, ceiling or roof systems.

COMMENTARY

The purpose of these criteria is to prevent indoor water vapor from condensing on cool surfaces whose temperatures are below the dew-point temperature of the indoor air and to prevent condensation within the construction of indoor water vapor that permeates through indoor surfaces.

CRITERIA

5.0.8 Orientation and Shape Analysis - Heating -- The proposed design shall show that energy conservation was among the considerations taken into account in determining building orientation and shape. The design submittal shall show that the following factors have been considered in the orientation analysis: (a) compass orientation of the building on the site; (b) aspect ratio (ratio of length to width); and (c) the number of stories for a given floor area requirement.

EVALUATION:

Engineering evaluation of heat loss and energy calculations.

COMMENTARY

The intent of these criteria is to require analysis of the options available to the designer and owner of the building to conserve energy by taking into account prevalent solar and wind conditions. For example, if the predominant cold winds come from the north, the north wall of the building can be designed to reduce the heat flux, while the east, south, and west facades can be positioned to take advantage of winter solar heat and designed for minimum solar heat gain through windows in summer. The length-to-width ratio and the number of stories for a given building can sometimes be used as flexible design parameters. Subject to site constraints and user needs, the shape of the building that defines the amount of facade area can be varied and the energy consumption examined to select a minimum and yet allow the functional requirements of the building to be satisfied.

CRITERIA

5.0.9 Alternative Building Envelope Heat Transmission Design Criteria - Heating -- Alternate designs and methods of construction that show total building heat loss at design conditions to be equal to or less than designs developed to satisfy all of the above criteria shall be acceptable if submitted as certified by a registered engineer or architect. For the purpose of computing the total building heat loss of the building used as a basis for comparison, the heat transmitted through the ceiling/roof shall be based on the assumption of 100 percent opaque ceiling/roof area (not containing skylights or saw-tooth shaped roofs containing windows). The design heat loss calculation for any alternative building envelope or subelement construction proposed under this criterion shall be determined for the same indoor and outdoor design temperatures, common occupancy and use schedules, and equivalent useful floor area, perimeter, and building volume as for the design complying with all of the preceding criteria in this Chapter.

EVALUATION

Engineering evaluation of heat loss and energy consumption calculations.

COMMENTARY

The intent of these criteria is to allow a separate performance approach where maximum flexibility and innovation can be used that would result in overall conservation of energy from a process of trading off savings in one area of the building against losses that exceed the above criteria in other areas of the building. When this approach is used it is usually done with the aid of a computer where many options or changes can be examined rapidly and simultaneously for the building as a whole.

CRITERIA (COOLING)

5.0.10 Opaque Ceilings/Roof and Wall - Cooling -- The heat flow through opaque surface areas of roof/ceilings or walls facing cooled interiors shall not exceed 2.0 Btu/hr/ft^2 of ceiling or wall area when calculated at an indoor design temperature of 78 °F and an outdoor sol-air temperature calculated as follows:

$$t_{ea} = t_{oa} + \frac{\alpha}{h_o}\left(\frac{I_{DT}}{24}\right) - \frac{\varepsilon \Delta R}{h_o} \qquad (4)$$

where:

α = absorptance of the surface for solar radiation

h_o = coefficient of heat transfer by radiation and convection of the outer surface, Btu/hr ft^2 °F

1/ Reference equation 42 of Chapter 22, ASHRAE Handbook of Fundamentals, 1972.

t_{ea} = average sol-air temperature, °F

t_{oa} = average summer design outdoor temperature, °F

$t_{oa} = t_d - \Delta t/2$, where t_d is the summer design dry-bulb temperature listed in Table 1, page 669, 1972 ASHRAE Fundamentals Volume, Column 6 2 1/2%. Δt is the value given in Column 7, Outdoor Daily Range.

ϵ = hemispherical emittance of the surface.

The average equivalent temperature difference, t_ε, is

$$t_\varepsilon = t_{ea} - t_i \qquad (5)$$

where t_i is the indoor design temperature, 78 °F.

The minimum thermal resistance, R, of the opaque ceiling/roof or wall is

$$R = \frac{t_\varepsilon}{q/A} \quad . \qquad (6)$$

Inclusion of the effect of the mass (weight) of the roof or wall in addition to the above procedures shall be allowed in meeting the heat flow criteria.

$\bar{R}$ = the difference between the longwave radiation incident on the surface from the sky and surroundings, and the radiation emitted by a blackbody at outdoor air temperature Btu/hr ft^2.

α/h_o = 0.15 for light colored surfaces
0.30 for dark colored surfaces

I_{DT} = 1.15 times the maximum sum of the two half-day totals of solar heat gain factors for each wall as given in Tables 2 to 6, pages 388-392, 1972 ASHRAE Handbook of Fundamentals, Btu/hr ft^2.

$\epsilon\Delta\bar{R}/h_o$ = 7 °F for horizontal surfaces
= 0 °F for vertical surfaces.

EVALUATION

Examination and evaluation of engineering calculations.

COMMENTARY

The average equivalent temperature difference, t_ε, is used in the criterion instead of actual indoor air to outdoor air temperature differential to account for solar heating of outdoor surfaces to temperatures greater than the outdoor air temperature. The examples in Appendix 1 at the end of Chapter 5 will serve to illustrate the procedure for limiting the heat flux and determining the required overall thermal resistance and thermal transmittance (U-value).

CRITERIA

5.0.11 Window Heat Gain - Cooling -- The heat gain through transparent window areas of the exterior envelope shall be controlled during the cooling season in relation to the geographic location and the compass orientation of the building on its site. Plain glass without a shading device is not permitted (e.g., shades, venetian blinds, draperies, awnings, eyebrow reveals, or vertical/horizontal fins must be used). The windows shall be equipped with shading devices, interior or exterior, that will limit, during the cooling season, the maximum instantaneous combined solar and air-to-air heat transmission at design conditions to 70 Btu/hr ft^2 of transparent window area, as an average for the entire window.

EVALUATION

Engineering examination and evaluation of calculations. For evaluation of design, calculation procedures given on pages 386 through 410 of the 1972 ASHRAE Handbook of Fundamentals shall be used.

CRITERIA

5.0.12 Doors - Cooling -- Heating criteria apply (see 5.0.4. and 5.0.6.3).

EVALUATION

See Heating Evaluation, 5.0.4.

COMMENTARY

See Heating Commentary, 5.0.4.

CRITERIA

5.0.13 Floors, Foundation Walls, and Slabs-on-Grade - Cooling -- Heating criteria apply (see 5.0.5).

EVALUATION

See Heating Evaluation, 5.0.5.

COMMENTARY

See Heating Commentary, 5.0.5.

CRITERIA

5.0.14 Air Leakage Control - Cooling -- Heating criteria apply except that the natural (not forced) leakage of air from cooled spaces to the outdoors shall not exceed 0.5 volume air change per hour at design conditions for one- and two-family dwellings. (See 5.0.6.1)

EVALUATION

See Heating Evaluation following 5.0.6.5

COMMENTARY

See Heating Commentary following 5.0.6.5

CRITERIA

5.0.8 Orientation on Site - Cooling -- The proposed design shall show that energy conservation was among the considerations taken into account in determining building orientation and shape. The design submittal shall show that the following factors have been considered in the orientation analysis: (a) compass orientation of the building on the site; (b) aspect ratio (ratio of length to width); and (c) the number of stories for a given floor area requirement.

EVALUATION

See Heating Evaluation, 5.0.8

COMMENTARY

See Heating Commentary, 5.0.8

CRITERIA

5.0.16 Alternative Building Envelope Heat Transmission - Cooling -- Alternative designs and methods of construction that show design total building heat gains equal to or less than designs developed to satisfy all of the above criteria shall be acceptable if submitted as certified by a registered engineer or architect. The purpose of these criteria is to allow energy trade-offs that would result in equivalent overall conservation of energy, even though the criteria for selected subelements of the building may not precisely meet the specified requirements. For the purpose of computing the total heat gain of the basic building used for comparison, the heat gain through the ceiling/rood shall be based on the assumption of 100-percent opaque ceiling/roof area (not containing skylights or saw-tooth shaped roofs containing windows).

The design cooling load calculation for any alternative building envelope or subelement construction proposed under this criterion shall be determined for the same indoor and outdoor design temperatures, common occupancy and use schedules, and equivalent useful floor area, perimeter, and

building volume as for the design complying with all of the preceding criteria in this Chapter that are applicable to cooling.

EVALUATION

See Heating Evaluation, 5.0.9.

COMMENTARY

See Heating Commentary, 5.0.9.

APPENDIX 1
EXAMPLES ILLUSTRATING THE APPLICATION
OF CHAPTER 5 CRITERIA

5.0.3 Opaque Ceilings/Roof - Heating

1) Location, Duluth, Minnesota

Heating Degree-Days, 10,000 (from p. 43.5 ASHRAE 1973 Systems Vol)

Required q/A, 3.8 Btu/hr. ft^2 of ceiling area from Criteria 5.0.3.

Design Temperatures
Indoor , 70 °F (from Criteria 5.0.2)
Outdoor, -15 °F (from p.674 ASHRAE 1972 Fundamentals Volume)

Design Temperature Difference, [70 - (-15)] = 85°F

Overall Thermal Resistance, R

$$R = \frac{\text{Design Temperature Difference}}{q/A} = \frac{85}{3.8} = 22.37$$

Overall Thermal Transmittance, (U-value)

$$U = \frac{1}{R} = \frac{1}{22.37} = 0.0447 \text{ Btu/hr ft}^2 \text{ °F}$$

2) Location - Scranton/Wilkes-Barre, Pennsylvania

Heating Degree-Days - 6254

Required q/A - 3.52

Design Temperature Difference - [70 - 6] = 64

Overall Thermal Resistance - $\frac{64}{3.52} = 18.18$

Overall Thermal Transmittance - $\frac{1}{18.18} = 0.055$

3) Location - Atlanta, Georgia

Heating Degree-Days - 2961

Required q/A - 3.5

Design Temperature Difference - [70 - 23] = 47

Overall Thermal Resistance - $\frac{47}{3.5} = 13.43$

Overall Thermal Transmittance - $\frac{1}{13.43} = 0.074$

4) Location - San Diego, California

Heating Degree-Days - 1458

Required q/A - 3.59

Design Temperature Difference - [70 - 44] = 26

Overall Thermal Resistance - $\frac{26}{3.59} = 7.24$

Overall Thermal Transmittance - $\frac{1}{7.24} = 0.14$

5) Location - Key West, Florida

Heating Degree-Days - 108

Required q/A - 4.1

Design Temperature Difference - [70 - 58] = 12

Overall Thermal Resistance - $\frac{12}{4.1} = 2.93$

Overall Thermal Transmittance - $\frac{1}{2.93} = 0.34$

5.0.4 Gross Exterior Walls (Including Opaque Walls, Window, and Door Areas) Heating -- Table 5.2

1) Duluth, Minnesota, 10,000 heating degree-days

Single-Family

U_{wall} = 0.066 from Opaque wall criteria

Assume 10% single glass and 4% metal storm doors

$U_o \times 1 = 0.065 \times 0.86 + 1.13 \times 0.1 + 0.33 \times 0.04$
$= 0.057 + 0.113 + 0.013$
$= 0.183$ will not meet 0.17 Criteria

Assume 10% storm windows and 4% metal storm doors

$U_o \times 1 = 0.066 \times 0.86 + 0.56 \times 0.1 + 0.33 \times 0.04$
$= 0.057 + 0.056 \times 0.013$
$= 0.126$ will meet 0.17 Criteria

Assume U_{wall} = 0.11 10% storm windows and 4% metal storm doors

$U_o \times 1 = 0.11 \times 0.86 + 0.56 \times 0.1 + 0.33 \times 0.04$
$= 0.095 + 0.056 + 0.013$
$= 0.164$ will meet 0.17 Criteria

Assume 15% storm windows and 4% metal storm doors

$U_o \times 1 = 0.066 \times 0.81 + 0.56 \times 0.15 + 0.33 \times 0.04$
$= 0.053 + 0.084 + 0.013$
$= 0.15$ will meet 0.17 Criteria

Assume 20% storm windows and 4% metal storm doors

$U_o \times 1 = 0.066 \times 0.76 + 0.56 \times 0.2 + 0.33 \times 0.04$
$= 0.05 + 0.112 + 0.013$
$= 0.175$ will not meet 0.17 Criteria

All other buildings

Assume 10% insulating glass area and 1% insulated steel door

$U_o \times 1 = 0.066 \times 0.89 + 0.65 \times 0.1 + 0.59 \times 0.01$
$= 0.059 + 0.065 + 0.006$
$= 0.13$ will meet 0.27 Criteria

Assume 30% insulating glass area and 1% insulated steel door

$U_o \times 1 = 0.066 \times 0.69 + 0.65 \times 0.3 + 0.59 \times 0.01$
$= 0.046 + 0.195 + 0.006$
$= 0.247$ will meet 0.27 Criteria

Assume 30% single glass area and 1% insulated steel door

$U_o \times 1 = 0.066 \times 0.69 + 1.13 \times 0.3 + 0.59 \times 0.01$
$= 0.046 + 0.339 + 0.006$
$= 0.39$ will not meet 0.27 Criteria

Assume $U_{wall} = 0.16$, 10% single glass and 1% insulated steel door

$U_o \times 1 = 0.16 \times 0.89 + 1.13 \times 0.1 + 0.59 \times 0.01$
$= 0.142 + 0.113 + 0.006$
$= 0.261$ will meet 0.27 Criteria

Assume 50% insulating glass emissivity coating = 0.2 and 1% insulated steel door

$U_o \times 1 = 0.066 \times 0.49 + 0.38 \times 0.5 + 0.59 \times 0.01$
$= 0.032 + 0.19 + 0.006$
$= 0.23$ meets 0.27 Criteria

2) Scranton/Wilkes-Barre, Pennsylvania, 6254 heating degree-days

$U_{wall} = 0.072$ from opaque wall criteria

Single-Family

Assume 5% single-glass, 10% storm windows and 4% metal storm door

$U_o \times 1 = 0.072 \times 0.81 + 1.13 \times 0.05 + 0.56 \times 0.1 + 0.33 \times 0.04$
$= 0.058 + 0.057 + 0.056 + 0.013$
$= 0.184$ meets 0.20 Criteria

Assume $U_{wall} = 0.12$, 15% storm windows and 4% metal storm doors

$U_o \times 1 = 0.12 \times 0.81 + 0.56 \times 0,15 + 0.33 \times 0.04$
$= 0.097 + 0.084 + 0.013$
$= 0.194$ will meet 0.20 Criteria

All other buildings

Assume 30% insulating glass area and 1% insulated door area

$U_o \times 1 = 0.072 \times 0.69 + 0.65 \times 0.3 + 0.59 \times 0.01$
$= 0.050 + 0,195 + 0.006$
$= 0.251$ meets 0.30 Criteria

Assume 50% insulating glass area emissivity coating, 0.6, and 1% insulating steel doors

$U_o \times 1 = 0.072 \times 0.49 + 0.52 \times 0.5 + 0.59 \times 0.01$
$= 0.035 + 0.26 + 0.006$
$= 0.30$ meets 0.30 Criteria

Assume U_{wall} = 0.20, 10% single glass and 1% insulating steel doors

U_o x 1 = 0.20 x 0.89 + 1.13 x 0.1 + 0.59 x 0.01
= 0.178 + 0.113 + 0.006
= 0.297 meets 0.30 Criteria

3) Atlanta, Georgia, 2961 heating degree-days

U_{wall} = 0.091 from opaque wall criteria

Single-Family

Assume 15% single glass and 4% metal storm doors

U_o x 1 = 0.091 x 0.81 + 1.13 x 0.15 + 0.33 x 0.04
= 0.074 + 0.17 + 0.013
= 0.257 meets 0.27 Criteria

All other buildings

Assume 25% single glass and 1% insulated door area

U_o x 1 = 0.091 x 0.74 + 1.13 x 0.25 + 0.59 x 0.01
= 0.067 + 0.283 + 0.006
= 0.356 meets 0.36 Criteria

Assume U_{wall} = 0.27, 10% single glass and 1% insulated door area

U_o x 1 = 0.27 x 0.89 + 1.13 x 0.1 + 0.59 x 0.01
= 0.24 + 0.113 + 0.006
= 0.359 meets 0.36 Criteria

Assume 45% insulating glass and 1% insulated door area

U_o x 1 = 0.091 x 0.54 + 0.65 x 0.45 + 0.59 x 0.01
= 0.049 + 0.293 + 0.006
= 0.348 meets 0.36 Criteria

4) San Diego, California, 1458 heating degree-days

U_{wall} = 0.17 from opaque wall criteria

Single-Family

Assume 15% single glass and 4% wood doors

U_o x 1 = 0.17 x 0.81 + 1.13 x 0.15 + 0.49 x 0.04
= 0.137 + 0.169 + 0.02
= 0.32 meets 0.32 Criteria

All other buildings

Assume 20% single glass, 1% insulated door area

$U_o \times 1 = 0.17 \times 0.79 + 1.13 \times 0.2 + 0.59 \times 0.01$
$= 0.134 + 0.226 + 0.006$
$= 0.37$ meets 0.38 Criteria

Assume 40% insulating glass and 1% insulated door area

$U_o \times 1 = 0.17 \times 0.59 + 0.65 \times 0.4 + 0.59 \times 0.01$
$= 0.10 + 0.26 + 0.006$
$= 0.37$ meets 0.38 Criteria

5) Key West, Florida, 108 heating degree-days

$U_{wall} = 0.41$ from opaque wall criteria

Single-Family

Assume 25% single glass and 4% wood doors

$U_o \times 1 = 0.41 \times 0.71 + 1.13 \times 0.25 + 0.49 \times 0.04$
$= 0.29 + 0.283 + 0.02$
$= 0.59$ meets 0.60 Criteria

All other buildings

Assume 30% single glass and 1% insulated door area

$U_o \times 1 = 0.41 \times 0.69 + 1.13 \times 0.3 + 0.59 \times 0.01$
$= 0.283 + 0.339 + 0.006$
$= 0.628$ meets 0.63 Criteria

Assume 50% insulating glass and 1% insulated door area

$U_o \times 1 = 0.41 \times 0.49 + 0.65 \times 0.5 + 0.59 \times 0.01$
$= 0.20 + 0.325 + 0.006$
$= 0.53$ meets 0.63 Criteria

62-963 O - 76 - 33

5.0.4 Opaque Walls - Heating, Table 5.3

(1) Location - Duluth, Minnesota

Heating Degree-Days - 10,000 (from p. 43.5 ASHRAE 1973 Systems Volume)

Required q/A - 5.6 Btu/hr. ft^2 of wall area from Criteria 5.2.2

Design Temperatures

Indoor, 70 °F (from Criteria 5.1.2)
Outdoor, -15 °F (from p. 674 ASHRAE 1972 Fundamentals Volume)

Design Temperature Difference - [70 - (-15)] = 85 °F

Overall Thermal Resistance, R

$$R = \frac{\text{Design Temperature Difference}}{q/A} = \frac{85}{5.6} = 15.18$$

Overall Thermal Transmittance, (U-value)

$$U = \frac{1}{R} = \frac{1}{15.18} = 0.066$$

(2) Location - Scranton/Wilkes-Barre, Pennsylvania

Heating Degree-Days - 6254

Required q/A - 4.58

Design Temperature Difference - [70 - 6] = 64

Overall Thermal Resistance - $\frac{64}{4.58} = 13.97$

Overall Thermal Transmittance - $\frac{1}{13.97} = 0.072$

(3) Location - Atlanta, Georgia

Heating Degree-Days - 2961

Required q/A - 4.3

Design Temperature Difference - [70 - 23] = 47

Overall Thermal Resistance - $\frac{47}{4.3} = 10.93$

Overall Thermal Transmittance - $\frac{1}{10.93} = 0.091$

(4) Location - San Diego, California

Heating Degree-Days - 1458

Required q/A - 4.41

Design Temperature Difference - [70 - 44] = 26

Overall Thermal Resistance - $\frac{26}{4.41} = 5.9$

Overall Thermal Transmittance - $\frac{1}{5.9} = 0.17$

(5) Location - Key West, Florida

Heating Degree-Days - 108

Required q/A - 4.95

Design Temperature Difference -[70 - 58] = 12

Overall Thermal Resistance - $\frac{12}{4.95} = 2.42$

Overall Thermal Transmittance - $\frac{1}{2.42} = 0.41$

5.0.4 Opaque Ceilings/Roof and Wall - Cooling

1) Key West, Florida

From Table 1, p. 671, 1972 ASHRAE Handbook of Fundamentals

Latitude = 24° 3"
Design dry-bulb temperature, Δt_d = 89 °F
Outdoor daily range, Δt = 9 °F

From Table 2, p. 388, 1972 ASHRAE Handbook of Fundamentals

Horizontal Roofs, the maximum half-day total value occurs on June 21, and is equal to 1095

For walls, maximum half-day totals are:

North, 282 a.m. and 282 p.m. on June 21
East, 936 a.m. and 176 p.m. on June 21
South, 451 a.m. and 451 p.m. on September 21
West, 176 a.m. and 936 p.m. on June 21

$$t_{ea} = t_{oa} + \frac{\alpha}{h_o}\left(\frac{I_{DT}}{24}\right) - \frac{\epsilon \Delta R}{h_o}$$

For Roofs

light colored, $t_{ea} = (89 - \frac{9}{2}) + 0.15\left[\frac{1.15\ (1095 + 1095)}{24}\right] - 7$

$$t_{ea} = 93.2\ °F$$

$$\Delta t_t = t_{ea} - t_i$$
$$= 93.2 - 78$$
$$= 15.2$$

$$R = \frac{\Delta t_t}{q/A} = \frac{15.2}{2.0} = 7.6$$

$$U = 0.13$$

dark colored,

$$t_{ea} = (89 - \frac{9}{2}) + 0.3\left[\frac{1.15\ (1095 + 1095)}{24}\right] - 7 = 109.$$

$$\Delta t_{\ell} = t_{ea} - t_i$$
$$= 109 - 78$$
$$= 31$$

$$R = \frac{\Delta t_{\ell}}{q/A} = \frac{31}{2.0} = 15.5$$

$$U = 0.065$$

For walls

light colored

$$\text{North, } t_{ea} = (89 - \frac{9}{2}) + 0.15\left[\frac{1.15\ (282 + 282)}{24}\right] - 0 = 88.6\ ^{\circ}F$$

$$\Delta t_{\ell} = t_{ea} - t_i$$
$$= 88.6 - 78$$
$$= 10.6$$

$$R = \frac{\Delta t_{\ell}}{q/A} = \frac{10.6}{2.0} = 5.3$$

$$U = 0.19$$

$$\text{East, } t_{ea} = (89 - \frac{9}{2}) + 0.15\left[\frac{1.15\ (936 + 176)}{24}\right] - 0 = 92.5\ ^{\circ}F$$

$$\Delta t_{\ell} = t_{ea} - t_i$$
$$= 92.5 - 78$$
$$= 14.5$$

$$R = \frac{\Delta t_{\ell}}{q/A} = \frac{14.5}{2.0} = 7.25$$

$$U = 0.14$$

$$\text{South, } t_{ea} = (89 - \frac{9}{2}) + 0.15\left[\frac{1.15\ (451 + 451)}{24}\right] - 0 = 90.\ ^{\circ}F$$

$$\Delta t_{\ell} = t_{ea} - t_i$$
$$= 90 - 78$$
$$= 12$$

$$R = \frac{\Delta t_{\ell}}{q/A} = \frac{12}{2.0} = 6.0$$

$$U = 0.17$$

West, $t_{ea} = (89 - \frac{9}{2}) + 0.15 \left[\frac{1.15\ (176 + 936)}{24}\right] - 0 = 92.4\ °F$

$\Delta t_{\ell} = t_{ea} - t_i$
$= 92.4 - 78$
$= 14.4$

$R = \frac{\Delta t_{\ell}}{q/A} = \frac{14.4}{2.0} = 7.2$

$U = 0.14$

dark colored

North, $t_{ea} = (89 - \frac{9}{2}) + 0.30 \left[\frac{1.15\ (282 + 282)}{24}\right] - 0 = 92.7\ °F$

$\Delta t_{\ell} = 92.7 - 78 = 14.7$

$R = \frac{\Delta t_{\ell}}{q/A} = \frac{14.7}{2.0} = 7.35$

$U = 0.14$

East, $t_{ea} = (89 - \frac{9}{2}) + 0.30 \left[\frac{1.15\ (936 + 176)}{24}\right] - 0 = 100.5$

$\Delta t_{\ell} = t_{ea} - t_i$
$= 100.5 - 78$
$= 22.5$

$R = \frac{\Delta t_{\ell}}{q/A} = \frac{22.5}{2.0} = 11.25$

$U = 0.09$

South, $t_{ea} = (89 - \frac{9}{2}) + 0.30 \left[\frac{1.15\ (451 + 451)}{24}\right] - 0 = 97.5\ °F$

$\Delta t_{\ell} = t_{ea} - t_i$
$= 97.5 - 78$
$= 19.5$

$R = \frac{\Delta t_{\ell}}{q/A} = \frac{19.5}{2.0} = 9.75$

$U = 0.10$

West, $t_{ea} = (89 - \frac{9}{2}) + 0.30 \left[\frac{1.15\ (176 + 936)}{24}\right] - 0 = 100.3\ °F$

$\Delta t_{\ell} = t_{ea} - 78$
$= 100.3 - 78$
$= 22.3$

$R = \frac{\Delta t_{\ell}}{q/A} = \frac{22.3}{2.0} = 11.15$

$U = 0.09$

(2) San Diego, California

Latitude = 32° 4'
Design dry-bulb temperature, t_d = 83 °F
Outdoor daily range, Δt = 12 °F
Horizontal Roofs, max. half-day total = 1119 on June 21
For walls, max. half-day totals are:

North, 252 a.m. and 252 p.m. on June 21
East , 972 a.m. and 180 p.m. on June 21
South, 844 a.m. and 844 p.m. on December 21
West , 172 a.m. and 983 p.m. on May 21

$t_{ea} = t_{oa} + \frac{\alpha}{h_o}\left(\frac{I_{DT}}{24}\right) - \frac{\epsilon \Delta R}{h_o}$

For Roofs

light colored, $t_{ea} = (83 - \frac{12}{2}) + 0.15 \left[\frac{1.15\ (1119 + 1119)}{24}\right] - 7 = 86\ °F$

$\Delta t_{\ell} = t_{ea} - t_i$
$= 86 - 78$
$= 8\ °F$

$R = \frac{\Delta t_{\ell}}{q/A} = \frac{8}{2.0} = 4.0$

$U = 0.25$

dark colored, $t_{ea} = (83 - \frac{12}{2}) + 0.3 \left[\frac{1.15\ (1119 + 1119)}{24}\right] - 7 = 102\ °F$

$$\Delta t_{\ell} = t_{ea} - t_i$$
$$= 102 - 78$$
$$= 24\ °F$$

$$R = \frac{\Delta t_{\ell}}{q/A} = \frac{24}{2.0} = 12.0$$

$$U = 0.08$$

For walls

light colored

North, $t_{ea} = (83 - \frac{12}{2}) + 0.15 \left[\frac{1.15\ (252 + 252)}{24}\right] - 0 = 80.6\ °F$

$$\Delta t_{\ell} = t_{ea} - t_i$$
$$= 80.6 - 78$$
$$= 2.6$$

$$R = \frac{\Delta t_{\ell}}{q/A} = \frac{2.6}{2.0} = 1.3$$

$$U = 0.77$$

East, $t_{ea} = (83 - \frac{12}{2}) + 0.15 \left[\frac{1.15\ (972 + 180)}{24}\right] - 0 = 85.3\ °F$

$$\Delta t_{\ell} = t_{ea} - t_i$$
$$= 85.3 - 78$$
$$= 7.3\ °F$$

$$R = \frac{\Delta t_{\ell}}{q/A} = \frac{7.3}{2.0} = 3.65$$

$$U = 0.27$$

South, $t_{ea} = (83 - \frac{12}{2}) + 0.15 \left[\frac{1.15\ (844 + 844)}{24}\right] - 0 = 89.1\ °F$

$$\Delta t_{\ell} = t_{ea} - t_i$$
$$= 89.1 - 78$$
$$= 11.1$$

$$R = \frac{\Delta t_{\ell}}{q/A} = \frac{11.1}{2.0} = 5.55$$

$$U = 0.18$$

West, $t_{ea} = (83 - \frac{12}{2}) + 0.15 \left[\frac{1.15\ (983 + 172)}{24}\right] - 0 = 85.3\ °F$

$$\Delta t_{\ell} = t_{ea} - t_i = 85.3 - 78 = 7.3$$

$$R = \frac{\Delta t_{\ell}}{q/A} = \frac{7.3}{2.0} = 3.65$$

$$U = 0.27$$

dark colored

North, $t_{ea} = (83 - \frac{12}{2}) + 0.30 \left[\frac{1.15\ (252 + 252)}{24}\right] - 0 = 90.2\ °F$

$$\Delta t_{\ell} = t_{ea} - t_i$$
$$= 90.2 - 78$$
$$= 12.2$$

$$R = \frac{\Delta t_{\ell}}{q/A} = \frac{12.2}{2.0} = 6.1$$

$$U = 0.16$$

East, $t_{ea} = (83 - \frac{12}{2}) + 0.30 \left[\frac{1.15\ (972 + 180)}{24}\right] - 0 = 93.6\ °F$

$$\Delta t_{\ell} = t_{ea} - t_i$$
$$= 93.6 - 78 = 15.6$$

$$R = \frac{\Delta t_{\ell}}{q/A} = \frac{15.6}{2.0} = 7.8$$

$$U = 0.13$$

South, $t_{ea} = (83 - \frac{12}{2}) + 0.30\left[\frac{1.15\ (844 + 844)}{24}\right] - 0 = 101.2\ ^{\circ}F$

$\Delta t_{\ell} = t_{ea} - t_i = 101.2 - 78 = 23.2$

$R = \frac{\Delta t_{\ell}}{q/A} = \frac{23.2}{2.0} = 11.6$

$U = 0.09$

West, $t_{ea} = (83 - \frac{12}{2}) + 0.30\left[\frac{1.15\ (983 + 172)}{24}\right] - 0 = 93.6\ ^{\circ}F$

$\Delta t_{\ell} = t_{ea} - t_i = 93.6 - 78 = 15.6$

$R = \frac{\Delta t_{\ell}}{q/A} = \frac{15.6}{2.0} = 7.8$

$U = 0.13$

APPENDIX 2

HEAT FLUX, THERMAL RESISTANCE, AND THERMAL TRANSMITTANCE VALUES[1/] FOR CEILINGS, ROOFS, AND OPAQUE WALLS MEETING THE DESIGN CRITERIA OF TABLES 5.1 AND 5.3 FOR 243 U. S. CITIES

1/ The degree-day and winter outside design temperature in this Appendix are taken from ASHRAE Systems Volume (1973) and the ASHRAE Fundamentals Volume (1972), respectively.

APPENDIX 2

STATE	STATION	DEGREE DAY	DESIGN TEMP.	DESIGN ΔT	CEILING/ROOF Q/A	CEILING/ROOF R	CEILING/ROOF U	WALL Q/A	WALL R	WALL U
ALA.	BIRMINGHAM	2551	22	48	3.50	13.71	.07	4.30	11.16	.09
	HUNTSVILLE	3070	17	53	3.50	15.14	.07	4.30	12.33	.08
	MOBILE	1560	29	41	3.59	11.43	.09	4.39	9.34	.11
	MONTGOMERY	2291	26	44	3.50	12.57	.08	4.30	10.23	.10
ALASKA	ANCHORAGE	10869	-20	90	3.89	23.16	.04	5.73	15.71	.06
	FAIRBANKS	14279	-50	120	4.40	27.27	.04	6.00	20.00	.05
	JUNEAU	9075	-4	74	3.71	19.96	.05	5.32	13.90	.07
	NOME	14171	-28	98	4.40	22.27	.04	6.00	16.33	.06
ARIZ.	FLAGSTAFF	7152	5	65	3.60	18.06	.06	4.83	13.46	.07
	PHOENIX	1765	34	36	3.55	10.15	.10	4.35	8.28	.12
	TUCSON	1800	32	38	3.54	10.73	.09	4.34	8.76	.11
	WINSLOW	4782	13	57	3.50	16.29	.06	4.38	13.02	.08
	YUMA	974	40	30	3.71	8.08	.12	4.51	6.65	.15
ARK.	FORT SMITH	3292	19	51	3.50	14.57	.07	4.30	11.86	.08
	LITTLE ROCK	3219	23	47	3.50	13.43	.07	4.30	10.93	.09
	TEXARKANA	2533	26	44	3.50	12.57	.08	4.30	10.23	.10
CALIF.	BAKERSFIELD	2122	33	37	3.50	10.57	.09	4.30	8.60	.12
	BURBANK	1646	38	32	3.57	8.96	.11	4.37	7.32	.14
	EUREKA	4643	35	35	3.50	10.00	.10	4.36	8.02	.12
	FRESNO	2611	31	39	3.50	11.14	.09	4.30	9.07	.11
	LONGBEACH	1803	38	32	3.54	9.04	.11	4.34	7.37	.14
	LOS ANGELES	2061	43	27	3.50	7.71	.13	4.30	6.28	.16
	OAKLAND	2970	37	33	3.50	9.43	.11	4.30	7.67	.13
	SACRAMENTO	2502	32	38	3.50	10.86	.09	4.30	8.84	.11
	SAN DIEGO	1458	44	26	3.61	7.21	.14	4.41	5.90	.17
	SAN FRANCISCO	3015	37	33	3.50	9.43	.11	4.30	7.67	.13
	SANTA MARIA	2967	34	36	3.50	10.29	.10	4.30	8.37	.12
COLO.	COLORADO SPRINGS	6423	4	66	3.54	18.63	.05	4.63	14.26	.07
	DENVER	6283	3	67	3.53	18.99	.05	4.58	14.61	.07
	GRAND JUNCTION	5641	11	59	3.50	16.86	.06	4.46	13.22	.08
	PUEBLO	5462	-1	71	3.50	20.29	.05	4.45	15.97	.06
CONN.	BRIDGEPORT	5617	8	62	3.50	17.71	.06	4.46	13.90	.07
	HARTFORD	6235	5	65	3.52	18.45	.05	4.57	14.22	.07
	NEW HAVEN	5897	9	61	3.50	17.43	.06	4.49	13.59	.07
DEL.	WILMINGTON	4930	15	55	3.50	15.71	.06	4.39	12.52	.08
D.C.	WASHINGTON	4229	19	51	3.50	14.57	.07	4.32	11.80	.08
FLA.	DAYTONA BEACH	879	36	34	3.76	9.04	.11	4.56	7.46	.13
	FORT MYERS	442	42	28	3.98	7.04	.14	4.78	5.86	.17
	JACKSONVILLE	1239	32	38	3.65	10.40	.10	4.45	8.54	.12
	KEY WEST	108	58	12	4.15	2.89	.35	4.95	2.43	.41
	LAKELAND	661	39	31	3.87	8.01	.12	4.67	6.64	.15
	MIAMI	219	47	23	4.09	5.62	.18	4.89	4.70	.21
	MIAMI BEACH	141	48	22	4.13	5.33	.19	4.93	4.46	.22
	ORLANDO	766	37	33	3.82	8.65	.12	4.62	7.15	.14
	PENSACOLA	1963	32	38	3.61	10.53	.09	4.41	8.62	.12
	TALLAHASSEE	1485	29	41	3.60	11.38	.09	4.40	9.31	.11
	TAMPA	683	39	31	3.86	8.03	.12	4.66	6.65	.15
	WEST PALM BEACH	253	44	26	4.07	6.38	.16	4.87	5.33	.19
GA.	ATHENS	2929	21	49	3.50	14.00	.07	4.30	11.40	.09
	ATLANTA	2961	23	47	3.50	13.43	.07	4.30	10.93	.09

STATE	STATION	DEGREE DAY	DESIGN TEMP.	DESIGN ΔT	CEILING/ROOF Q/A	CEILING/ROOF R	CEILING/ROOF U	WALL Q/A	WALL R	WALL U
	AUGUSTA	2397	23	47	3.50	13.43	.07	4.30	10.93	.09
	COLUMBUS	2383	26	44	3.50	12.57	.08	4.30	10.23	.10
	MACON	2136	27	43	3.50	12.29	.08	4.30	10.00	.10
	ROME	3326	20	50	3.50	14.29	.07	4.30	11.63	.09
	SAVANNAH	1819	27	43	3.54	12.16	.08	4.34	9.92	.10
HAWAII	HONOLULU	0	62	8	4.20	1.90	.52	5.00	1.60	.63
	HILO	0	61	9	4.20	2.14	.47	5.00	1.80	.56
IDAHO	BOISE	5809	10	60	3.50	17.14	.06	4.48	13.39	.07
	LEWISTON	5542	12	58	3.50	16.57	.06	4.45	13.02	.08
	POCATELLO	7033	-2	72	3.60	20.00	.05	4.81	14.98	.07
ILL.	CHICAGO (O'HARE)	6639	0	70	3.56	19.64	.05	4.69	14.92	.07
	CHICAGO (MIDWAY)	6155	1	69	3.52	19.63	.05	4.55	15.18	.07
	CHICAGO	5882	1	69	3.50	19.71	.05	4.49	15.37	.07
	MOLINE	6408	-3	73	3.54	20.62	.05	4.62	15.79	.06
	PEORIA	6025	2	68	3.50	19.41	.05	4.51	15.09	.07
	ROCKFORD	6830	-3	73	3.58	20.37	.05	4.75	15.37	.07
	SPRINGFIELD	5429	4	66	3.50	18.86	.05	4.44	14.86	.07
IND.	EVANSVILLE	4435	10	60	3.50	17.14	.06	4.34	13.81	.07
	FORT WAYNE	6205	5	65	3.52	18.46	.05	4.56	14.25	.07
	INDIANAPOLIS	5699	4	66	3.50	18.86	.05	4.47	14.77	.07
	SOUTH BEND	6439	3	67	3.54	18.91	.05	4.63	14.47	.07
IOWA	BURLINGTON	6114	0	70	3.51	19.94	.05	4.53	15.44	.06
	DES MOINES	6588	-3	73	3.56	20.51	.05	4.68	15.61	.06
	DUBUQUE	7376	-7	77	3.60	21.39	.05	4.88	15.79	.06
	SIOUX CITY	6951	-6	76	3.60	21.14	.05	4.79	15.88	.06
	WATERLOO	7320	-8	78	3.60	21.67	.05	4.86	16.09	.06
KANS.	DODGE CITY	4986	7	63	3.50	18.00	.06	4.40	14.32	.07
	GOODLAND	6141	4	66	3.51	18.78	.05	4.54	14.53	.07
	TOPEKA	5182	6	64	3.50	18.29	.05	4.42	14.49	.07
	WICHITA	4620	9	61	3.50	17.43	.06	4.36	13.98	.07
KY.	COVINGTON	5265	8	62	3.50	17.71	.06	4.43	14.01	.07
	LEXINGTON	5683	10	60	3.50	17.14	.06	4.37	13.79	.07
	LOUISVILLE	4660	12	58	3.50	16.57	.06	4.37	13.28	.08
LA.	ALEXANDRIA	1921	29	41	3.52	11.66	.09	4.32	9.50	.11
	BATON ROUGE	1560	30	40	3.59	11.15	.09	4.39	9.12	.11
	LAKE CHARLES	1459	33	37	3.61	10.25	.10	4.41	8.39	.12
	NEW ORLEANS	1385	35	35	3.62	9.66	.10	4.42	7.91	.13
	SHREVEPORT	2184	26	44	3.50	12.57	.08	4.30	10.23	.10
MAINE	CARIBOU	9767	-19	89	3.78	22.24	.04	5.53	15.19	.07
	PORTLAND	7511	0	70	3.60	19.44	.05	4.90	14.28	.07
MD.	BALTIMORE	4454	15	55	3.50	15.71	.06	4.37	12.60	.08
	FREDERICK	5087	11	59	3.50	16.86	.06	4.41	13.38	.07
MASS.	BOSTON	5634	10	60	3.50	17.14	.06	4.46	13.49	.07
	PITTSFIELD	7578	-1	71	3.60	19.72	.05	4.92	14.44	.07
	WORCESTER	6969	1	69	3.60	19.18	.05	4.79	14.40	.07
MICH.	DETROIT	6232	0	62	3.52	17.60	.06	4.57	13.57	.07
	ESCANABA	8481	-3	73	3.65	20.01	.05	5.14	14.19	.07
	FLINT	7377	3	67	3.60	18.61	.05	4.88	13.74	.07
	GRAND RAPIDS	6794	6	64	3.59	17.83	.06	4.77	13.42	.07
	LANSING	6969	6	64	3.59	17.82	.06	4.77	13.41	.07

STATE	STATION	DEGREE DAY	DESIGN TEMP.	DESIGN ΔT	CEILING/ROOF Q/A	CEILING/ROOF R	CEILING/ROOF U	WALL Q/A	WALL R	WALL U
	MARQUETTE	8393	-4	74	3.64	20.33	.05	5.12	14.46	.07
	MUSKEGON	6696	8	62	3.57	17.37	.06	4.71	13.17	.08
	SAULT STE. MARIE	9048	-8	78	3.70	21.05	.05	5.31	14.68	.07
MINN.	DULUTH	10000	-15	85	3.80	22.37	.04	5.60	15.18	.07
	MINNEAPOLIS	8383	-10	80	3.69	21.99	.05	5.11	15.69	.06
	ROCHESTER	8295	-13	83	3.63	22.87	.04	5.09	16.31	.06
MISS.	JACKSON	2239	24	46	3.50	13.14	.08	4.30	10.70	.09
	MERIDIAN	2289	24	46	3.50	13.14	.08	4.30	10.70	.09
	VICKSBURG	2041	26	44	3.50	12.57	.08	4.30	10.23	.10
MO.	COLUMBIA	5040	6	64	3.50	18.29	.05	4.40	14.53	.07
	KANSAS CITY	4711	8	62	3.50	17.71	.06	4.37	14.18	.07
	ST. JOSEPH	5484	3	67	3.50	19.14	.05	4.45	15.06	.07
	ST. LOUIS	4900	8	62	3.50	17.71	.06	4.39	14.12	.07
	ST. LOUIS	4484	11	59	3.50	16.86	.06	4.35	13.57	.07
	SPRINGFIELD	4900	10	60	3.50	17.14	.06	4.39	13.67	.07
MONT.	BILLINGS	7049	-6	76	3.60	21.11	.05	4.81	15.80	.06
	GLASGOW	8996	-20	90	3.70	24.33	.04	5.30	16.98	.06
	GREAT FALLS	7750	-16	86	3.60	23.89	.04	4.95	17.37	.06
	HAVRE	8700	-15	85	3.67	23.16	.04	5.21	16.31	.06
	HELENA	8129	-13	83	3.61	22.97	.04	5.04	16.47	.06
	KALISPELL	8191	-3	73	3.62	20.17	.05	5.06	14.43	.07
	MILES CITY	7723	-15	85	3.60	23.61	.04	4.94	17.19	.06
	MISSOULA	8125	-3	73	3.61	20.21	.05	5.04	14.49	.07
NEB.	GRAND ISLAND	6530	-2	72	3.55	20.26	.05	4.66	15.45	.06
	LINCOLN	5864	0	70	3.50	20.00	.05	4.49	15.60	.06
	NORFOLK	6979	-7	77	3.60	21.40	.05	4.79	16.06	.06
	NORTH PLATTE	6684	-2	72	3.57	20.18	.05	4.71	15.30	.07
	OMAHA	6612	-1	71	3.56	19.94	.05	4.68	15.16	.07
	SCOTTSBLUFF	6673	-4	74	3.57	20.74	.05	4.70	15.74	.06
NEVADA	ELKO	7433	-7	77	3.60	21.39	.05	4.89	15.76	.06
	ELY	7733	-2	72	3.60	20.00	.05	4.95	14.56	.07
	LAS VEGAS	2709	26	44	3.50	12.57	.08	4.30	10.23	.10
	RENO	6332	7	63	3.53	17.83	.06	4.60	13.70	.07
	WINNEMUCCA	6761	5	65	3.58	18.18	.06	4.73	13.75	.07
N.H.	CONCORD	7383	-7	77	3.60	21.39	.05	4.88	15.79	.06
N.J.	ATLANTIC CITY	4812	18	52	3.50	14.86	.07	4.38	11.87	.08
	NEWARK	4589	15	55	3.50	15.71	.06	4.36	12.62	.08
	TRENTON	4980	16	54	3.50	15.43	.06	4.40	12.28	.08
N.M.	ALBUQUERQUE	4348	17	53	3.50	15.14	.07	4.33	12.23	.08
	PATON	6228	2	68	3.52	19.30	.05	4.57	14.88	.07
	ROSWELL	3793	19	51	3.50	14.57	.07	4.30	11.86	.08
	SILVER CITY	3705	18	52	3.50	14.86	.07	4.30	12.09	.08
N.Y.	ALBANY	6875	0	70	3.59	19.51	.05	4.76	14.70	.07
	BINGHAMTON	7286	2	68	3.60	18.89	.05	4.86	14.00	.07
	BUFFALO	7062	6	64	3.60	17.78	.06	4.81	13.30	.08
	NEW YORK(CENT.PK.)	4871	15	55	3.50	15.71	.06	4.39	12.54	.08
	NEW YORK(LA GUARDIA)	4811	16	54	3.50	15.43	.06	4.38	12.33	.08
	NEW YORK(KENNEDY)	5219	21	49	3.50	14.00	.07	4.42	11.08	.09
	ROCHESTER	6748	5	65	3.57	18.18	.05	4.72	13.76	.07
	SCHENECTADY	6650	-1	71	3.56	19.92	.05	4.69	15.12	.07

STATE	STATION	DEGREE DAY	DESIGN TEMP.	DESIGN ΔT	CEILING/ROOF Q/A	CEILING/ROOF R	CEILING/ROOF U	WALL Q/A	WALL R	WALL U
	SYRACUSE	6756	2	48	3.68	19.02	.05	4.73	14.39	.07
N.C.	ASHEVILLE	4042	17	53	3.50	15.14	.07	4.30	12.31	.08
	CHARLOTTE	3191	22	48	3.50	13.71	.07	4.30	11.16	.09
	GREENSBORO	3805	17	53	3.50	15.14	.07	4.30	12.33	.08
	RALEIGH	3393	20	50	3.50	14.29	.07	4.30	11.63	.09
	WILMINGTON	2347	27	43	3.50	12.29	.08	4.30	10.00	.10
	WINSTON-SALEM	3595	17	53	3.50	15.14	.07	4.30	12.33	.08
N.D.	BISMARK	8851	-19	89	3.69	24.15	.04	5.26	16.94	.06
	DEVILS LAKE	9901	-19	89	3.79	23.48	.04	5.57	15.98	.06
	FARGO	9226	-17	87	3.72	23.37	.04	5.37	16.21	.06
	WILLISTON	9243	-17	87	3.72	23.36	.04	5.37	16.19	.06
OHIO	AKRON-CANTON	6037	6	64	3.50	18.27	.05	4.51	14.19	.07
	CINCINNATI	4810	12	58	3.50	16.57	.06	4.34	13.36	.07
	CLEVELAND	6351	7	63	3.54	17.82	.06	4.61	13.68	.07
	COLUMBUS	5660	7	63	3.50	18.00	.06	4.47	14.11	.07
	DAYTON	5622	6	64	3.50	18.29	.05	4.46	14.34	.07
	MANSFIELD	6403	3	67	3.54	18.92	.05	4.62	14.50	.07
	SANDUSKY	5796	8	62	3.50	17.71	.06	4.48	13.84	.07
	TOLEDO	6494	5	65	3.55	18.31	.05	4.65	13.98	.07
	YOUNGSTOWN	6417	6	64	3.54	18.07	.06	4.63	13.84	.07
OKLA.	OKLAHOMA CITY	3725	15	55	3.50	15.71	.06	4.30	12.79	.08
	TULSA	3860	16	54	3.50	15.43	.06	4.30	12.56	.08
OREGON	ASTORIA	5186	30	40	3.50	11.43	.09	4.42	9.05	.11
	EUGENE	4726	26	44	3.50	12.57	.08	4.37	10.06	.10
	MEDFORD	5008	23	47	3.50	13.43	.07	4.40	10.68	.09
	PENDLETON	5127	10	60	3.50	17.14	.06	4.41	13.60	.07
	PORTLAND	4635	29	46	3.50	13.14	.08	4.36	10.54	.09
	ROSEBURG	4491	29	41	3.50	11.71	.09	4.35	9.43	.11
	SALEM	4754	25	45	3.50	12.86	.08	4.38	10.28	.10
PENN.	ALLENTOWN	5810	5	65	3.50	18.57	.05	4.48	14.51	.07
	ERIE	6451	11	59	3.55	16.64	.06	4.64	12.73	.08
	HARRISBURG	5251	13	57	3.50	16.29	.06	4.43	12.88	.08
	PHILADELPHIA	5144	15	55	3.50	15.71	.06	4.41	12.46	.08
	PITTSBURGH	5987	9	61	3.50	17.43	.06	4.50	13.56	.07
	READING	4945	9	61	3.50	17.43	.06	4.39	13.88	.07
	SCRANTON	6254	6	64	3.53	18.15	.06	4.58	13.99	.07
	WILLIAMSPORT	5934	5	65	3.50	18.57	.05	4.49	14.47	.07
R.I.	PROVIDENCE	5954	10	60	3.50	17.14	.06	4.50	13.35	.07
S.C.	CHARLESTON	2033	27	43	3.50	12.29	.08	4.30	10.00	.10
	COLUMBIA	2484	23	47	3.50	13.43	.07	4.30	10.93	.09
	FLORENCE	2387	25	45	3.50	12.86	.08	4.30	10.47	.10
	GREENVILLE-SPARTENBURG	2980	23	47	3.50	13.43	.07	4.30	10.93	.09
S.D.	HURON	8223	-12	82	3.67	22.64	.04	5.07	16.18	.06
	RAPID CITY	7345	-6	76	3.60	21.11	.05	4.87	15.61	.06
	SIOUX FALLS	7839	-10	80	3.60	22.22	.04	4.97	16.10	.06
TENN.	BRISTOL	4143	16	54	3.50	15.43	.06	4.31	12.52	.08
	CHATTANOOGA	3254	19	51	3.50	14.57	.07	4.30	11.86	.08
	KNOXVILLE	3494	17	53	3.50	15.14	.07	4.30	12.33	.08
	MEMPHIS	3232	21	49	3.50	14.00	.07	4.30	11.40	.09
	NASHVILLE	3578	16	54	3.50	15.43	.06	4.30	12.56	.08

STATE	STATION	DEGREE DAY	DESIGN TEMP.	DESIGN ΔT	CEILING/ROOF Q/A	R	U	WALL Q/A	R	U
TEXAS	ABILENE	2624	21	49	3.50	14.00	.07	4.30	11.40	.09
	AMARILLO	3985	12	58	3.50	16.57	.06	4.30	13.49	.07
	AUSTIN	1711	29	41	3.56	11.52	.09	4.36	9.41	.11
	BROWNSVILLE	600	40	30	3.90	7.69	.13	4.70	6.38	.16
	CORPUS CHRISTI	914	36	34	3.74	9.08	.11	4.54	7.48	.13
	DALLAS	2363	24	46	3.50	13.14	.08	4.30	10.70	.09
	EL PASO	2760	25	45	3.50	12.86	.08	4.30	10.47	.10
	FORT WORTH	2405	24	46	3.50	13.14	.08	4.30	10.70	.09
	GALVESTON	1274	36	34	3.65	9.33	.11	4.45	7.65	.13
	HOUSTON	1396	32	38	3.62	10.49	.10	4.42	8.60	.12
	LAREDO	797	36	34	3.80	8.94	.11	4.60	7.39	.14
	LUBBOCK	3578	15	55	3.50	15.71	.06	4.30	12.79	.08
	MIDLAND	2591	23	47	3.50	13.43	.07	4.30	10.93	.09
	PORT ARTHUR	1447	33	37	3.61	10.25	.10	4.41	8.39	.12
	SAN ANGELO	2235	25	45	3.50	12.86	.08	4.30	10.47	.10
	SAN ANTONIO	1546	30	40	3.59	11.14	.09	4.39	9.11	.11
	VICTORIA	1173	32	38	3.67	10.37	.10	4.47	8.51	.12
	WACO	2030	26	44	3.50	12.57	.08	4.30	10.23	.10
	WICHITA FALLS	2832	19	51	3.50	14.57	.07	4.30	11.86	.08
UTAH	SALT LAKE CITY	6052	9	61	3.61	17.40	.06	4.52	13.51	.07
VT.	BURLINGTON	8269	-7	77	3.43	21.23	.05	5.08	15.16	.07
VA.	LYNCHBURG	4166	19	51	3.50	14.57	.07	4.32	11.81	.08
	NORFOLK	3421	23	47	3.50	13.43	.07	4.30	10.93	.09
	RICHMOND	3865	18	52	3.50	14.86	.07	4.30	12.09	.08
	ROANOKE	4150	18	52	3.50	14.86	.07	4.31	12.05	.08
WASH.	OLYMPIA	5234	25	45	3.50	12.86	.08	4.42	10.17	.10
	SEATTLE-TACOMA	5145	24	46	3.50	13.14	.08	4.41	10.42	.10
	SEATTLE	4429	32	38	3.50	10.86	.09	4.34	8.75	.11
	SPOKANE	6655	4	66	3.57	18.51	.05	4.70	14.05	.07
	WALLA WALLA	4805	16	54	3.50	15.43	.06	4.38	12.33	.08
	YAKIMA	5941	10	60	3.50	17.14	.06	4.49	13.35	.07
W.VA.	CHARLESTON	4476	14	56	3.50	16.00	.06	4.35	12.88	.08
	ELKINS	5675	5	65	3.50	18.57	.05	4.47	14.55	.07
	HUNTINGTON	4446	14	56	3.50	16.00	.06	4.34	12.89	.08
	PARKERSBURG	4754	12	58	3.50	16.57	.06	4.38	13.26	.08
WISC.	GREEN BAY	8029	-7	77	3.40	21.37	.05	5.01	15.37	.07
	LA CROSSE	7589	-8	78	3.40	21.67	.05	4.92	15.86	.06
	MADISON	7863	-5	75	3.40	20.83	.05	4.97	15.08	.07
	MILWAUKEE	7635	-2	72	3.40	20.00	.05	4.93	14.61	.07
WYO.	CASPER	7410	-5	75	3.40	20.83	.05	4.88	15.36	.07
	CHEYENNE	7381	-2	72	3.40	20.00	.05	4.88	14.77	.07
	LANDER	7870	-12	82	3.40	22.78	.04	4.97	16.49	.06
	SHERIDAN	7683	-7	77	3.40	21.39	.05	4.94	15.60	.06

CHAPTER 6

HEATING, VENTILATING, AND COOLING SYSTEM REQUIREMENTS

HEATING AND COOLING LOADS

6.0 REQUIREMENT

Heating and cooling loads shall be determined for the purpose of sizing heating, ventilating and air conditioning, (HVAC) systems and components for efficient utilization of energy.

CRITERIA

Note: The following items, 6.0.1 through 6.0.2.6, refer only to parameters for use in calculating heating/cooling loads. For equipment and system requirements refer to 6.1 through 6.5.

6.0.1 Procedures -- Heating and cooling loads shall be determined in accordance with procedures described in the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Handbook of Fundamentals, Chapters 21 and 22, or procedures for which similarity to ASHRAE procedures can be demonstrated.

6.0.2 Design Parameters -- The following design parameters shall be used in the heating and cooling load determination: (If for special cases other design conditions are selected, heating and cooling load calculations shall be based on the selected conditions.)

6.0.2.1 Outdoor Design Conditions -- Winter and summer outdoor design conditions shall be the 97-1/2 and 2-1/2 percent values, respectively, as given in Chapter 33, Weather Data and Design Conditions, of the ASHRAE Handbook of Fundamentals, 1972.

6.0.2.2 Indoor Design Conditions -- Winter indoor design conditions shall be 70 °F dry-bulb temperature, with humidification, if provided, to not more than 30% relative humidity. Summer indoor design conditions shall be 78 °F dry-bulb temperature, with controlled dehumidification, if provided, to not less than 60% relative humidity.

COMMENTARY

ASHRAE procedures will be used to determine the adequacy of submitted calculations.

The winter and summer design temperature levels selected for load calculations were chosen to discourage oversizing in the selection of HVAC equipment.

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CRITERIA

6.0.2.3 General Ventilation -- For load design of all building types except one- and two-family dwelling units, mechanical ventilation with outside air, for the purpose of meeting normal respiratory and odor control needs shall be taken as 5 cfm[1/] per person for certain spaces or two air changes for other spaces (see 6.0.2.4 and 6.4.15 for description and criteria).

6.0.2.4 Special Ventilation -- For load design, mechanical ventilation capacity in excess of 5 cfm per person (or two air changes per hour) for the purpose of controlling smoking contaminants, toxic gases, or other contaminants, shall be the actual amount included in the design (see 6.4.15).

EVALUATION

Examination and evaluation of engineering calculations.

CRITERION

6.0.2.5 Infiltration -- For load design, infiltration shall be taken as 0.7 air change per hour for one- and two-family dwellings and mobile homes, and 0.5 air change per hour for all other buildings. (see 5.0.6.1)

EVALUATION

See Evaluation for 5.0.6.

CRITERION

6.0.2.6 Heat Gains -- Internal heat gains shall be included in both heating and cooling loads as appropriate.

EVALUATION

Examination and evaluation of engineering calculations.

COMMENTARY

In buildings that have a reasonably steady internal heat release of appreciable magnitude from sources other than the heating system, a computation of this heat release under design conditions should be made for deduction from the total of the computed heat losses.

1/ Wherever the term cfm is used in this document it shall be interpreted as standard cubic feet per minute, unless the immediate context indicates another meaning.

EQUIPMENT EFFICIENCY

6.1 REQUIREMENT

Manufacturers of building equipment defined as energy-significant equipment shall make available to prospective building owners or their representatives the full-load energy-utilization efficiency of such equipment, taken by itself.

CRITERIA

6.1.1 Full-load Efficiency -- The manufacturer shall make available to prospective purchasers the full-load energy-utilization efficiency (η_{fl}) of the specific models to be furnished based on equipment in new condition. Furnishing of certified test data is deemed to satisfy the requirements of this paragraph.

6.1.2 Rounding-Off -- For the purpose of publication, the energy-utilization efficiency shall be rounded off to the nearest even whole number within a range of two percentage points, e.g., 72 $\pm$ 1 percent.

COMMENTARY

The "two percent" criterion effectively allows an actual spread of up to four percent and is an arbitrary value based on engineering judgment.

CRITERIA

6.1.3 Procedure -- A document shall be furnished to prospective equipment purchasers, upon request, summarizing the methods used to determine the efficiency, or referencing a national consensus voluntary standard test procedure. Publication of such test methods or references by commercial data services or trade organizations is deemed to satisfy the requirements of this paragraph.

6.1.4 Availability of Data -- Where the data specified in 6.1.1 are not immediately available, the manufacturer shall obtain and furnish the data specified in 6.1.1.

6.1.5 Multi-Mode Operation -- Where equipment is designed for multi-mode operation (e.g., multi-speed forced warm air furnace with provision for a cooling coil), full-load energy-utilization efficiency (η_{fl}) data shall be provided for each separate mode of operation applicable to the proposed system.

6.1.6 Full-Load Efficiency Data -- Full-load efficiency data shall be furnished as required under 6.1.1 for each different basic model and subtype numbered energy-significant equipment, except that a typical unit may be selected to represent a group of units, each of which meets all the following criteria:

(1) The function, capacity, and performance characteristics are similar.

(2) The basic model numbers are the same.

(3) The units are all manufactured at the same plant.

(4) The units are sold to the same class of market. Examples of different classes of market include residential, commercial, contractor, retail, etc.

6.1.7 Identify Test Model -- Where full-load energy-utilization efficiency data are published for a group of similar units based on testing or analysis of a typical unit, the actual unit type number tested or analyzed shall be clearly identified.

6.2 REQUIREMENT

Energy-significant equipment used in building systems shall be designed for efficient utilization of energy.

CRITERION

6.2.1 Minimum Full-Load Energy-Utilization Efficiency -- No equipment shall be specified in the design of new buildings which has a full-load energy-utilization efficiency less than the equivalent of that presently specified in nationally recognized voluntary standards.

EVALUATION

Verification that selected energy-significant equipment meets full-load efficiency requirements of applicable national consensus standards.

6.3 REQUIREMENT

Energy-significant equipment which requires periodic routine maintenance actions to maintain efficient operation shall be furnished complete with the necessary maintenance information.

CRITERION

6.3.1 Required Maintenance Actions -- Required routine maintenance actions shall be clearly stated as required and incorporated on a permanent label affixed to a normally visible, external surface of the equipment. The label may be limited to identifying required actions explained in greater detail in a service manual. The label should identify by title and/or publication number the service manual for that particular model and type of product.

SYSTEM REQUIREMENTS

6.4 REQUIREMENT

HVAC systems shall be energy-efficient.

CRITERIA

6.4.1 System Design Heating/Cooling Capacity -- The heating system(s) for spaces in buildings intended to provide comfort for human occupancy shall be designed with capacity to heat such spaces to 70 °F at the winter outdoor design temperature (see 6.0.2.1). Similarly, the cooling system(s), if provided, shall be designed with capacity to cool such spaces to 78 °F at the summer outdoor design temperature (see 6.2.2.1). Heating/cooling systems shall be capable of functioning to accomplish the requirements for the control system in 6.4.2, 6.4.3, 6.4.4, 6.4.5 and 6.5.9, as applicable.

EVALUATION

Review of HVAC system plans and specifications. Comparison of system capacity design and building load calculations.

COMMENTARY

The design criteria of Chapter 6 do not limit the operation of HVAC systems in buildings to the design indoor temperatures specified in the criteria. For special cases such as hospitals or homes for the elderly, requiring higher indoor temperatures, designers may wish to size systems toward the high end of the 120 percent capacity range allowed in 6.4.10.

CRITERIA

6.4.2 Temperature Control -- Each space heating/cooling system shall be provided with at least one readily adjustable automatic control for the regulation of interior temperature. Each separate zone served by space heating/cooling system shall be equipped with readily adjustable automatic control or conveniently located manual means for temperature regulation as required in 6.4.1, 6.4.3, and 6.5.9. Automatic comfort space temperature controls shall be capable of being set to control heating at least from 55 °F to 70 °F and to control cooling (if cooling is provided) at least from 78 °F to 85 °F. For space (or zone) temperatures between 70 °F and 78 °F the automatic control system shall be capable of being set such that neither heating or cooling is provided. Combination, separate or multiple heating/cooling thermostats used to control heating and cooling in any one room or zone shall be interlocked or the systems otherwise controlled to avoid simultaneous heating and cooling in any one room or zone except for reheat as allowed in 6.4.7. Means for shutting off the heating or cooling to each zone shall be provided at a convenient location, either within the zone or at an appropriate central building supervisory monitoring station.

COMMENTARY

Central supervisory/monitoring systems can be used to meet the requirements of 6.4.2.

CRITERIA

6.4.3 Multiple-Zone Temperature Control

6.4.3.1 Single-Family Dwelling Units, Attached or Detached, and Mobile Homes -- At least one automatic temperature control as required in 6.4.2 shall be provided for each single-family dwelling unit and mobile home. Each separate heating/cooling system in a single-family dwelling unit shall be equipped with an automatic temperature control. Each separate zone in a single-family dwelling unit or mobile home shall be provided with either a readily adjustable automatic temperature control or sufficient conveniently located manually-adjustable devices capable of being adjusted to both partially restrict and shut off the heating or cooling input to the rooms or spaces in that zone. For single-family dwelling units or mobile homes, there shall be at least one separate zone in each cumulative full story height of the complete dwelling unit, excluding non-conditioned basements and garages. Intermediate floor levels in split-level construction are not considered full stories under this criterion.

6.4.3.2 Multi-Family Occupancies -- For multi-family occupancies, each individual living unit shall be considered separately for zoning purposes and shall be provided with automatic space temperature control as required in 6.4.2. For any single living unit, there shall be at least one separate zone in each cumulative full story height of the complete living unit, and each zone shall be provided with controls as required in 6.4.3.1. Intermediate floor levels in split level construction are not considered full stories under this criterion. Spaces other than living units in multi-family buildings shall be treated as in 6.4.3.3.

6.4.3.3 Other Buildings -- For other buildings, each space or group of spaces to be conditioned for comfort and having different demands for heating or cooling (because of varying solar loads, changing occupancies, or other internal heat gains) shall be considered as a separate zone, and shall be provided with automatic space temperature control as required in 6.4.2. Each floor shall be considered as at least one zone. For buildings greater than 2000 ft^2 of floor area per story, at least each cumulative 2000 ft^2 of floor area or fraction thereof of conditioned space(s) on each floor adjacent to each major orientation of exterior exposure shall be considered as a separate zone and shall be provided with automatic space temperature control as required in 6.4.2. At least each cumulative 3000 ft^2 of floor area or fraction thereof of conditioned space(s) on each floor having no exterior exposure shall be considered as a separate zone and shall be provided with automatic space temperature control as required in 6.4.2.

EVALUATION

Review of control systems plans and specifications.

COMMENTARY

Areas or spaces within a building having different and varying demands for heating and cooling (called zones) each need a means for controlling its temperature to prevent overheating (or overcooling) which could be caused by having the system control in another space. In addition, large open spaces require multiple zoning to provide ability to operate the heating and cooling in only those areas being utilized. Multiple zone control can be accomplished by modulating or varying the heating or cooling effect being delivered to each zone or by using separate systems for each zone. The 2000 ft^2 of floor area adjacent to an exterior exposure would accommodate, for example, 13 offices 10 ft by 15 ft or equivalent spaces.

CRITERIA

6.4.4 System Design for Humidity Control -- This document does not require that heating/cooling systems be designed for or equipped with controls for maintaining selected relative humidities in spaces or zones to provide comfort for human occupancy.

If the heating system is equipped with means for adding moisture to maintain selected relative humidities in spaces or zones during heating operation, the capacity of the humidifying function shall be designed to produce relative humidities not higher than 30 percent at winter design conditions, and the system shall be equipped with automatic humidity control(s) capable of being set to control indoor relative humidity to 30 percent or lower.

If automatic control of indoor space humidity is provided as a part of the cooling system design, the minimum indoor design relative humidity shall be 60 percent. Means for raising humidity during cooling operation is not required. The automatic humidity control system shall be capable of being set such that cooling apparatus shall not operate for the sole purpose of lowering the space (or zone) relative humidity below 60 percent. See 6.4.7 Reheat for limitations on use of new and recovered energy. The control system shall be capable of being set such that neither the humidifying or dehumidifying functions of the HVAC system shall operate for the sole purpose of space (or zone) humidity control in the range from 30 to 60 percent relative humidity.

6.4.5 Control Set-Back -- All heating and cooling systems shall be equipped with manually adjustable automatic timing or other devices capable of reducing the energy for heating and cooling during periods of non-use or alternate uses of the building spaces or zones served by such systems. Buildings designed for continuous manual or automatic supervisory control are considered to meet this criterion. The change in setting required to reduce the heating or cooling effect (set-back) shall not cause energy to be expended to produce the set-back conditions.

COMMENTARY

"Set-back" as used in 6.4.5 means the ability to change the automatic temperature control setting to a value which will reduce the heating or cooling produced during periods of reduced needs. Night set-back during the heating season (e.g., a thermostat setting change from 70 °F to 55 °F), should not cause the cooling system to operate to cool the building to the set-back temperature of 55 °F. Similarly, under cooling conditions a set-back of the thermostat should not cause the heating system to raise the indoor temperature.

6.4.6 Simultaneous Heating/Cooling -- HVAC systems serving one or more rooms or zones in a building shall be so arranged that no one room or zone can be heated and cooled simultaneously by the HVAC system except for reheat as permitted in 6.4.7.

COMMENTARY

Separate heating and cooling systems should be interlocked or otherwise controlled to prevent simultaneous operation for one room or zone. See Criterion 6.4.7 for limitation on reheat.

CRITERIA

6.4.7 Reheat -- Energy for reheat to accomplish either humidity or temperature control in any HVAC system shall be limited to the following conditions:

a. The total amount of new energy for either humidity or temperature control used for reheat shall not exceed 5 percent of the cooling system design capacity.

b. Recovered energy shall not be used for reheat for control of temperature in excess of 10 percent of the cooling system design capacity.

c. Recovered energy may be used as needed for humidity control in accordance with 6.4.4.

EVALUATION

Review of HVAC system plans and specification.

COMMENTARY

Use of excessive amount of either new or recovered energy for reheat purposes for temperature control only (as opposed to reheat for required humidity control purposes) is wasteful, and can be eliminated by suitable distribution design. Use of small amounts of energy for reheat for either temperature or humidity control in isolated areas may be more economical than providing a separate system.

CRITERIA

6.4.8 Energy Recovery -- Each air exhaust-makeup system having more than 4000 cfm capacity which imposes non-beneficial heat gains or losses on space conditioning systems shall employ energy recovery equipment if either the winter or summer outdoor design temperature is 15 °F or more lower or higher, respectively, than the indoor design temperature. This equipment shall be capable of recovery of at least 50 percent of the potential heating or cooling effect in the exhaust air, whenever the temperature difference between the exhaust air and makeup air is 10 °F or greater. This requirement does not include contaminant-laden process exhaust systems such as kitchen range hoods. Energy recovery systems shall be capable of intermittent operation to accommodate beneficial outdoor air conditions and the exhaust-makeup system shall be designed to operate in accord with the design requirements whether the energy recovery system is functioning or not.

COMMENTARY

Possible proximity of the air intakes and outlets can create a need in design to assure the effective separation of the two air streams.

CRITERIA

6.4.9 Cooling with Outdoor Air -- Each HVAC system with cooling capacity greater than 120,000 Btu/hr in buildings not equipped with internal/external zone heat recovery equipment shall be designed to use outdoor air for cooling whenever cooling is needed at an outdoor temperature of 65 °F or lower, and when the enthalpy of the outdoor air is lower than that of the indoor air.

6.4.10 System Sizing -- HVAC systems and subsystems for a building shall be selected such that the aggregate capacity at design conditions shall not be more than 120 percent of the design heating, cooling, humidifying, and dehumidifying loads, standby equipment not included. The cooling equipment in heat pumps may exceed the 120 percent requirement. The heating equipment in heat pumps shall not exceed the 120 percent requirement.

EVALUATION

Examination of HVAC system plans and specifications. Comparison of load requirements and system capacity data.

COMMENTARY

The 20-percent over-design in system capacities indicated by this criterion is an allowance for additional capacity that may be needed following night-time change in thermostat setting and weather conditions above or below design levels. Generally, excessive oversizing of system capacities results in less efficient operation. Standby equipment as used in 6.4.10 refers to equipment designed and intended for use when primary equipment is off-line due to maintenance or repair.

In order to minimize inefficiencies due to oversized system designs, it shall be a design objective that the HVAC system be sized so as to be capacity limited at the stated design conditions. At outdoor temperature extremes, the conditioned space temperature may drift from the normal control point, and at or near extreme conditions, the heating/cooling system may recover slowly after temperature control setting change.

CRITERIA

6.4.11 Special Zones -- Individual zones in large buildings or groups of buildings served by a central HVAC system which (1) must maintain zone operation when main building loads are minimal or are shut down, or (2) comprise unusual heating or cooling loads different from main building loads, shall be served by the central system only if the central system is designed to accommodate efficiently this special zone conditioning by such means as efficient capacity reduction of refrigerating units and boilers, adequate distribution zoning and zoning control, and rise of multiple subsystem elements (compressors, heaters, fans and pumps, etc); otherwise, these special zones shall be equipped with separate space conditioning systems. For cumulative special zone loads equal to one-half or more of the total system design load, the system shall be energy efficient to at least 85 percent of the full-load efficiency (see 6.4.13).

EVALUATION

Examination of plans and specifications with particular regard to system design related to special zones and capacity reduction. Comparison of computed load requirements with selected equipment performance data.

CRITERION

6.4.12 System Performance Instrumentation -- Central heating and cooling systems in buildings of more than 10,000 ft^2 of floor area shall be equipped with instruments or other indicating devices from which a deter-

mination can be made of need for adjustment or service to maintain energy-efficient operation.

EVALUATION

Examination of plans and specifications

COMMENTARY

The indicating devices envisioned by this criterion include but are not limited to pressure gages, water level devices on boilers, flow meters for various critical fluids, thermometers for flue and other temperatures, etc.

CRITERIA

6.4.13 Half-Load Efficiency -- HVAC systems operating at 1/2 rated load at design conditions shall have an efficiency not less than 85 percent of the system efficiency at full load operation at design conditions. HVAC systems shall be designed and equipped with means for operating at highest available system efficiencies as loads are reduced.

EVALUATION

Certification by designer or manufacturer of HVAC systems or major subsystems.

CRITERION

6.4.14 Interzone Heat Recovery -- Each HVAC system with a cooling capacity greater than 240,000 Btu/hr and which simultaneously provides heating to one or more zones and cooling to one or more different zones shall be designed to recover heat rejected by the cooling unit whenever the heat rejected is equal to at least 50 percent of the heat required by that system at that time. In such systems, new energy shall be used only for supplemental heating needed in excess of the recoverable heat.

EVALUATION

Comparison of design heating/cooling loads and system design capacities. Examination of plans and specifications.

CRITERIA

6.4.15 Ventilation by Mechanical Means -- Outdoor air for mechanical ventilation designed as a part of an HVAC system, for the purpose of meeting normal respiratory and odor control needs in conditioned offices, stores, meeting rooms, auditoriums, schools, living units and similar spaces, shall be limited to 5 cfm per person. Outdoor air for mechanical ventilation of conditioned corridors, lobbies, stairways, halls, laundries, storage areas and similar public spaces in multi-family and other buildings

shall be limited to 2 air changes per hour for normal respiratory and odor control needs. Special ventilating capacity in excess of 5 cfm per person (or 2 air changes per hour) for the purpose of controlling smoking contaminants, toxic gases, or other contaminants in the two classes of conditioned spaces listed above shall be equipped with volume or cyclic controls capable of remote adjustment if necessary, so that the ventilation rate can be readily adjusted to the amount needed for actual occupancy conditions and shut off when not required.

These ventilation-limiting requirements do not apply to intermittently-operated locally-controlled ventilation units such as kitchen vent fans, range hoods, bathroom fans, or to attic ventilating fans, or to the sizing of ventilation systems using outdoor air for temperature control in the occupied spaces, or to ventilation of non-conditioned spaces.

ASHRAE Standard 62-73, Standards for Natural and Mechanical Ventilation, recommends special ventilation rates.

All mechanical ventilation systems shall be equipped with conveniently located means for volume reduction or shut-off when ventilation is not required.

COMMENTARY

If outdoor air ventilation rates in conditioned spaces greater than shown are desired, consideration can be given to use of heat recovery apparatus to minimize adverse loads on the space conditioning system (see 6.4.8.) The criteria values for outdoor ventilation rates were were selected to save energy and yet provide needed ventilation. For unusual non-toxic odor control, consideration should be given to odor removal devices in lieu of increased ventilation rates.

COMPONENT AND SUBSYSTEM REQUIREMENTS

6.5 REQUIREMENT

Components of HVAC systems shall be energy-efficient.

CRITERIA

6.5.1 Fluid Transport Thermal Losses/Gains -- See 6.5.2 and 6.5.3 for minimum insulation requirements. In addition, the non-beneficial heat gain/loss to/from each separate subsystem of piping and ductwork transporting liquids, vapors, or gases used for space heating/cooling shall be limited to 3 percent of the heating/cooling thermal transfer design capacity for the fluid in that subsystem. In any case, the aggregate total non-beneficial gain/loss shall not exceed 5 percent of the total system design capacity including all piping, ductwork, and unit casings, etc., forming the entire heating/cooling system within the building. A subsystem is a section of the entire system which contains only one type of transfer fluid, such as hot or chilled water, steam, refrigerant, brine, air, etc. Non-beneficial heat gain/loss means heat transfer into/from non-conditioned space(s) or heat transfer into/from conditioned space(s) in excess of or opposition to the energy requirement of that space.

EVALUATION

Examination of plans and specifications. Review of heat loss/gain calculation.

COMMENTARY

A simple heating/cooling system may have only air ducts to consider under 6.5.1. More complex systems may have chilled water lines, steam or hot water lines, primary and secondary air ducts, etc, for which the several subsystem losses or gains must be determined for comparison with the design heating/cooling loads served by that subsystem, and the total losses/gains compared with the total system design capacity.

CRITERIA

6.5.2 Thermal Resistance of Ducts, Plenums, and Other Enclosures for Air Systems-Heating -- Air ducts and other surfaces installed in non-heated spaces (e.g., attics, garages, crawl spaces, etc.) shall be thermally insulated to provide a surface-to-surface thermal resistance of not less than $R = \Delta T/20$ hr ft^2 °F/Btu, where ΔT is the maximum temperature difference between the air in the duct or enclosure and the surrounding air, or shall be insulated to a value of R = 4 hr ft2 °F/Btu, whichever is greater.

COMMENTARY

Examination and evaluation of engineering calculations.

CRITERIA

6.5.3 Thermal Resistance and Condensation Control, Ducts, Pipes and Surfaces - Cooling -- For air ducts and surfaces installed in non-cooled spaces, the thermal resistance criteria of 6.5.2 shall apply. Additionally, all ducts, pipes, and cool surfaces shall be insulated sufficiently to prevent surface condensation under operating conditions. The insulation shall be protected by a vapor barrier, maximum permeance 0.1 perm, and all joints shall be sealed against vapor penetration.

EVALUATION

Engineering examination and evaluation of the design and design calculations. ASTM recommended practice E241-68 for general design information, ASTM Test Methods E96-66 (Procedures A, dry cup) for materials such as paper, plastic films and other sheet materials that are less than 1/8-inch thick shall be used for the purpose of evaluation.

COMMENTARY

Access doors and similar removable panels in duct system enclosures should be tight fitting (see 6.5.4) and insulation at joints of such doors should be adequately sealed to minimize moisture entering the insulation.

6.5.4 Duct Air Leakage -- The entire duct system for HVAC systems shall not leak more than 5 percent of the design air flow at design duct pressure.

EVALUATION

Review of duct plans and specifications. Tests patterned after SMACNA procedures.

COMMENTARY

Medium and high pressure ducts are customarily designed for duct leakage of 1 percent or less. Duct air leakage in any system defeats the intended function of the system. Leakage in non-conditioned areas is a total loss and in addition, leakage even in conditioned areas may prevent adequate delivery to intended locations.

CRITERION

6.5.5 Automatic Ignition -- Automatically controlled gaseous or liquid fuel-fired devices providing space heating shall be equipped with means for fuel ignition which operates only when the burner is required to operate. Automatic ignition devices shall conform to life safety standards, such as:

ANSI Z21.20 Automatic Burner Ignition and Safety Shut-off Devices
ANSI Z226.1 Primary Safety Controls for Gas and Oil Fired Appliances

EVALUATION

Certification or listing of selected ignition devices.

6.5.6 Off-Cycle Air Flow Heat Loss -- Combustion heating equipment with greater than 250,000 Btu/hr input shall be equipped with devices to minimize air flow through the combustion chamber during burner off-cycles. These devices shall be safety listed. All vented fireplaces shall be equipped with tight closing dampers or other comparable draft closures.

EVALUATION

Examination of proposed heating system design. Certification or listing of stack or combustion chamber off-cycle air flow control devices.

6.5.7 Cooling Efficiency - Electric Motor-Driven Cooling Systems -- Electric motor-driven cooling systems rated at standard rating conditions as listed in ARI 210-67 and including all system fan and pump motors shall have a ratio of system to net cooling capacity to energy input of not less than 8.0 Btuh/watt for cooling capacities of 60,000 Btuh or greater and 7.0 Btuh/watt for cooling capacities less than 60,000 Btuh. All cooling systems with rated output greater than 240,000 Btuh shall have a ratio of system capacity to energy input of not less than 8.5 Btuh/watt.

EVALUATION

Certification of selected equipment.

COMMENTARY

The term "Btuh/watt" is used here as a means of expressing efficiency of electric motor-driven cooling equipment because of its adoption by the industry. As used it means (Btu/hr)/watt, where "Btu/hr" is the net cooling capacity of the complete system at its defined rating condition, and "watt" is the electrical input rate to the complete system at the same conditions. The values of "Btuh/watt" do not include correction for electric power generation, transmission and distribution efficiency for either the compressor motor or for other auxiliary electrically-operated elements. If electric power generation transmission and distribution requires 12000 Btu/kwh, the values of 7.0, 8.0 and 8.5 "Btuh/watt" indicate net cooling capacity-to-energy source input COP values of 0.58, 0.67, and 0.71 respectively. Net cooling as used here includes both sensible and latent heat.

CRITERIA

6.5.8 Cooling Efficiency - Heat-Operated Cooling Systems -- Heat-operated cooling systems with a COP of less than 0.5 at standard rating conditions including all system auxiliaries, and fan and pump motors (determined in accordance with Appendix 2 of Chapter 6) shall not be used to provide more than 25 percent of the design cooling requirement unless recovered energy, solar energy or energy derived from waste processes is used as the principal energy source.

EVALUATION

Comparison of selected system performance data and efficiency of energy source. Review of calculated overall system COP.

COMMENTARY

Pending availability of standard industry rating procedures for determining the overall system net cooling capacity-to-system energy input COP, a procedure is given in Appendix 2 of Chapter 6. Net cooling as used here includes both sensible and latent heat. Using the procedure in Appendix 2, as an example, a heat-operated cooling system with a unit COP of 1.0 or more, energized by a steam supply of at least 70 percent efficiency, and with system control, condenser and cooling circuit power inputs equal to not more than 20 percent of the chiller capacity would satisfy the requirement of 6.5.8 for use of "new" energy.

6.5.9 Electric Resistance Heating— This document does not limit the use of electric resistance heating systems as the principal means of comfort space heating in the following buildings:

-all buildings in geographic areas having 2000 heating degree-days or less annually

-buildings utilizing electric energy for heating which is generated either by solar or wind-produced energy, by combustion of waste materials, by recovery of waste energy, or by a total energy system conforming to the definition in Chapter 3.

-buildings smaller than 500 ft^2 of floor area.

-mobile homes

For all other buildings the use of electric resistance heating as the principal means for comfort space heating shall be limited to the following conditions:

1. Buildings shall have a design heat loss at least 15 percent lower than permitted in Chapter 5

2. In addition to the minimum temperature control requirements for any heating system in 6.4.2 and 6.4.3, (a) one or more readily-adjustable automatic temperature controls as required in 6.4.2 shall be provided for control of each zone described in 6.4.3.1, 6.4.3.2, or 6.4.3.3 as applicable, and (b) at least one readily-adjustable automatic temperature control as required in 6.4.2, or sufficient readily-adjustable manual devices capable of being set to both partially restrict and shut off. The heating input shall be provided: (1) in each separate heated room or other enclosed spaces of more than 100 ft^2 of floor area which has one or more exterior walls, and (2) in each heated room or other enclosed space of more than 500 ft^2 of floor area, having no exterior walls. If in response to 2(b), each separate heated space in a zone is provided with automatic control, 2(a) is satisfied, and a separate zone control is not required.

EVALUATION

Examination of plans and specification.

COMMENTARY

Electricity is a highly refined source of heat which, in typical generating plants, has already lost about two thirds of the available potential energy of the fuel used in the generating process by the time it reaches the electric heating load in a building. Because of this loss in energy potential, logic indicates that a highly refined form of energy should be applied more carefully at the point of use. 6.5.9 (2) is intended to eliminate unnecessary input of this highly refined heat energy when solar or other heat gains reduce the demand for heating.

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Central electric resistance warm air or hydronic systems can satisfy the automatic zone temperature control requirements by using individual automatically-controlled heat outlets or fixtures in all the spaces in a zone.

The rationale for not recommending a differential reduction of heat loss even greater than 15 percent for electric resistance heating is based on the following:

(1) The thermal resistance criteria in Chapter 5 may already be equal to or greater than previously existing guidelines for electrically heated buildings, and the technical/esthetic feasibility of requiring thermal resistance differential requirements much greater than 15 percent is in doubt for some climatic regions.

(2) The criteria of 6.5.9 do not limit using forms of electrically energized heating other than the resistance type. In many applications, an electric driven heat pump system uses electricity more efficiently than does electric resistance heat, and its use should be encouraged.

(3) Depending upon the application, anywhere from one-fifth to one-half of the source potential energy is lost in direct heat conversion systems using fossil fuels. The 15 percent criteria brings the efficiency of electric resistance heat within the same general area as that of the low end of the range for fossil fuels.

The exception made for mobile homes is based on two factors:

(1) Dimensional space and weight limitations due to transportation requirements.

(2) Mobile homes typically use central forced warm air heating systems because this type of system is adaptable to various fuels used at different installation sites. The specific site (and fuel) is unknown at the time of manufacture. Under these conditions, it is usually unfeasible for the mobile home manufacturer to use those forms of electric resistance heating that readily lend themselves to zone control.

CRITERIA

6.5.10 Heat Pumps -- Electric motor driven vapor compression heat pumps with supplemental electric resistance heat shall be sized to provide by compression at least 60 percent of the calculated annual heating requirement for the building or space served. A control shall be provided which can be set to prevent use of supplemental electrical resistance heat at outdoor temperatures above 32 °F. Air-source heat pumps shall have seasonal performance factors (S.P.F.), including supplemental heating of:

Design Temperature, °F	S.P.F.
> 35	> 2.25
20 to 35	> 2.0
0 to 20	> 1.5
-20 to 0	> 1.25

$$S.P.F. = \frac{X}{Y+Z}$$

where:
X = heat delivered to space during heating season, kWh.
Y = energy to motors during the heating season, kWh.
Z = supplemental heat during heating season, kWh.

EVALUATION

Comparison of calculated annual heat loss and certified seasonal performance factors. Review of design calculations, plans, and specification.

COMMENTARY

Heat pump seasonal performance factors (S.P.F.) can be computed as shown below from building heat loss, heat pump performance characteristics, including supplemental heat, and seasonal heating hours below 65 °F for outdoor air temperature increments of 5 °F. Engineering Weather Data AFM 88-8, Chapter 6, lists heating season hours at 5 °F intervals for many locations in the U. S. This information is also available from the U. S. Weather Bureau. Using data such as is furnished by several heat pump manufacturers, the analytical procedure may consist of a summation by 5 °F increments of the building heat loss, the varying steady-state heat pump performance characteristics and hours of operation, and hours of required supplementary heat operation. A computerized dynamic analysis is not necessarily required. The S.P.F. shall take into account all system energy requirements, including defrost operation and supplementary heat. Specifically, the items, X, Y, and Z necessary for determining S.P.F. can be calculated in tabular form from the following information:

A - Outdoor temperature range, °F
outdoor air temperature increments of 5 °F below 65 °F
B - Seasonal heating hours for A, hrs
C - Average building heat loss for A, Btu/hr
D - Heat pump capacity for A, Btu/hr
E - Percent running time for heat pump, %
If C>D, E = 100; otherwise E = 100 x C/D
F - Rate of energy input to heat pump for A, kW
G - Energy input to heat pump, kWh
G = B x E x F/100
H - Energy input to building from electric resistance heaters, kWh.
If C<D, H = 0; otherwise H = B x (C-D)/3412.
J - Energy input to building from heat pump, kWh.
J = E x D/341200

Summing over the outdoor air temperature increments gives

$Y = \Sigma G$
$Z = \Sigma H$
$X = \Sigma J + \Sigma H$

for substitution in the definition for S.P.F.

The purpose of the control to prevent use of supplemental electric resistance at outdoor temperature above 32 °F is to eliminate unnecessary use of the less efficient supplemental heating at times when the heat pump can supply adequate heating. It also assures that failure of the heat pump will be detected if it occurs. The temperature of 32 °F will permit use of supplemental heating to prevent freezing damage in the event of heat pump failure. The 32 °F temperature is not intended as a balance point requirement for determining heat pump size.

APPENDIX 1

LISTING OF STANDARDS FOR HVAC
EQUIPMENT WHICH INCLUDE EFFICIENCY

ANSI Z21.11 - 1971

Gas-Fired Room Heaters
Volume I (Z21.11.1) Vented Room Heaters - Efficiency 70 percent based on total volume of gas.
Volume II (Z21.11.2) Unvented Room Heaters - 1971 -
Performance - No number for efficiency.

ANSI Z21.13 - 1972

Gas-Fired Steam and Hot Water Boilers
Shall have a thermal efficiency of 75 percent based on total heating value of the fuel.

ANSI Z21.34 - 1971

Gas-Fired Duct Furnaces
Thermal efficiency of 75 percent based on total heating value of fuel.

ANSI Z21.43 - 1968

Unvented Gas-Fired Infrared Radiant Heaters
Radiant efficiency of at least 35 percent.

ANSI Z21.44 - 1971

Gas-Fired Gravity and Fan Type Sealed Combustion System Wall Furnaces
Gravity type - Efficiency 70 percent based on total heating value of fuel.
Fan type - Efficiency 75 percent based on total heating value of fuel.

ANSI Z21.47 -

Gas-Fired Gravity and Forced Air Central Furnaces
Thermal efficiency gravity 70 percent based on total heat value of gas.

ANSI Z21.48 - 1976 (48a - 1968

Gas-Fired Gravity and Fan Type Floor Furnaces
Gravity type - Efficiency 65 percent based on total heating value of fuel.
Fan type - Efficiency 70 percent based on total heating value of fuel.

ANSI Z21.51 - 1971

Vented Gas-Fired Infrared Radiant Heaters
Efficiency - shall have a radiant efficiency of at least 35 percent.

ANSI Z21.52 - 1971

Gas-Fired Single Firebox Boilers
Steam and hot water boilers shall have efficiency 75 percent based on total heating value of fuel.

ANSI Z21.53 - 1967

Gas-Fired Heavy-Duty Forced Air Heaters

Shall have thermal efficiency of not less than 75 percent based on total heating value of fuel.

ANSI Z91.1 - 1972

Oil-Powered Central Furnaces
Performance - Output capacity in Btu/hr 0.75 times input.

APPENDIX 2

PROCEDURE FOR DETERMINING COEFFICIENT OF PERFORMANCE (COP) FOR HEAT-OPERATED COOLING SYSTEMS MEETING THE REQUIREMENTS OF 6.5.8

At the present no standard industry rating conditions have been promulgated for heat-operated cooling units. Unit performance shall be based on the following rating conditions which shall be considered "standard" for this document:

Leaving chilled-water temperature	44 °F
Chilled water ΔT across chiller	10 °F
Temperature of condensing water entering unit	85 °F
Condenser water flow	3.6 gpm/ton of condenser load
Steam inlet pressure (single effect)	12 psig
Entering hot water temperature (single effect)	270 °F
Hot water ΔT across unit (single effect)	40 °F
Steam inlet pressure (double effect)	123 psig or 144 psig
Entering hot water temperature (double effect)	370 °F
Hot water ΔT across unit (double effect)	40 °F
Outdoor air Temperature, DB	95 °F
Outdoor air temperature, WB	75 °F
Indoor air temperature, DB	80 °F
Indoor air temperature, WB	67 °F

The COP of the proposed system based on the above conditions shall be determined by:

$$COP = \frac{\text{net refrigerating effect}}{\text{rate of total energy input}}$$

where the net refrigerating effect is the rate of heat removal from the chilled water passing through the chiller minus the power input to all cooling circuit fans and pumps, and the rate of total energy input is the sum of all power used by the unit accessories, the condenser water cooling process pumps, fans, etc plus the product of the rate of fuel consumption and the higher heating value of the fuel used as the source of heat energy to the absorption unit itself, all expressed in consistent units. For the COP determination, energy input to all auxiliary devices (other than the absorption unit) such as controls, fan and pump motors shall be based on the power input to the various devices. Where steam or hot water is used as the unit energy source, the rate of energy input to the unit shall be based on the fuel used to produce the steam or hot water. If the unit is direct-fired, the rate of energy input to the unit shall be the product of the rate of fuel consumption and the higher heating value of the fuel.

CHAPTER 7

SERVICE WATER HEATING REQUIREMENTS

7.0 REQUIREMENT

Hot water for domestic and sanitary purposes shall be generated and delivered in a manner conducive to saving energy.

CRITERIA

7.0.1 Insulation -- All service hot water storage tanks and pipes containing heated water shall be insulated. Minimum insulation values for storage tanks and piping shall be R=6 and R=4, respectively.

EVALUATION

Review of system plans and specifications.

COMMENTARY

The heat loss of domestic hot water systems due to intermittent use and from the piping or recirculating systems is significant, and adds to the cooling loads in spaces requiring cooling.

CRITERIA

7.0.2 Pump Operation -- Circulating service hot water systems shall be so arranged that the circulating pump(s) can be turned off when the portion of the building served by that pump is not in use.

7.0.3 Combination Service Water Heating/Space Heating Boilers -- Service water heating equipment shall not be dependent on year-round operation of boilers otherwise required only for winter space heating if the boiler capacity is more than 120 percent of the design service water heating demand load.

COMMENTARY

A boiler may operate at low efficiencies during summer months if used to provide domestic hot water under conditions where the water heating load is small in relation to the space heating load.

CRITERIA

7.0.4 Temperature Control -- Service water heating systems shall be equipped with automatic temperature controls capable of adjustment to the lowest acceptable temperature setting for the intended use. These settings shall be 120 °F or less for domestic dishwashing/clothes washing machines and 180 °F or less for commercial application.

7.0.5 Electric Resistance Service Water Heating -- For systems serving more than four single-family living units, service water heaters shall not use electric resistance heating unless 1) electricity is used as the principal means for heating the building, or 2) the electric power used for water heating is generated either by solar or wind-produced energy, by combustion of waste materials, by recovery of waste energy, or by a total energy system conforming to the definition in Chapter 3.

CRITERIA

7.0.6 Fossil-Fuel-Fired Service Water Heating -- Fossil-fuel-fired service water heaters with input heating capacities greater than 250,000 Btu/hr shall be equipped with automatic ignition (which operates only when the burner is required to operate) and off-cycle air-flow heat-loss control devices. Each of these devices shall be safety listed.

APPENDIX 1

LISTING OF STANDARDS FOR SERVICE WATER
HEATING EQUIPMENT WHICH INCLUDE EFFICIENCY

ANSI A21.10 - 1971

Gas Water Heaters
Volume I (Z21.10.1) Automatic Storage Type Water Heaters With Inputs Less Than 75,000 Btu/hr - Performance Test.
Volume II (Z21.10.2) Side-Arm Type Water Heaters
Volume III (Z21.10.3) Circulating Tank, Instantaneous and Large Automatic Storage Type Water Heaters - Thermal efficiency of not less than 70 percent based on the gas input.

CHAPTER 8

ELECTRICAL DISTRIBUTION AND
POWER FACTOR REQUIREMENTS

8.0 REQUIREMENT

The electrical distribution system in a building shall be designed for efficient distribution of energy from the service entrance to the outlets, and shall not impose inefficient conditions on the electric utility distribution system.

CRITERIA

8.0.1 Power Factor -- In each building having one or more electric services aggregating 600 amperes or more, a graphic (recording) power factor meter shall be provided during the first year of operation and the power factor shall be continuously monitored. If the power factor falls below 0.9 lagging for periods accumulating one-half hour in any 24-hour period, power factor corrective devices shall be installed to raise the power factor to 0.9 or higher. If after the initial power factor correction additional reactive loading is introduced in the building, the power factor shall be continuously monitored again for a period of one year, and additional correction performed to meet the above criterion.

It is recommended that the electric utility be responsible for installation, upkeep, and removal of the graphic power factor meter.

COMMENTARY

Low power factor causes greater losses in transmission and distribution of electricity. Typically, most commercial and public buildings during the non-air conditioning season have a power factor of at least 0.9, unless the power factor is reduced by reactive loads such as fluorescent lighting units and elevator motors. Where the loads of the building are such that they create a power factor at the building service of less than 0.9 lagging, capacitance corrective devices can be placed at those loads or at the feeders to those loads. Power factor correction at the generating plant does not prevent the losses associated with transmission of the reactive power component through the distribution network.

CRITERION

8.0.2 Power Factor Correction for Cooling Equipment -- In a building which is wholly or partly cooled with one or more units aggregating 120,000 Btuh or higher, power factor correction devices shall be provided so that the power factor of the entire air conditioning system, including fans, shall be not less than 0.9 lagging at any load condition.

EVALUATION

The designer shall indicate on the plans a calculation of the lagging kilovars of the air conditioning equipment, the corrective leading kilovars provided, and the resultant power factor of not less than 0.9.

COMMENTARY

Power factor improvement, especially during periods of peak summer load, will reduce peak demand in the public utility peak power output and reduce losses in the transmission and distribution system.

CRITERIA

8.0.3 Service Voltage -- In each building having one or more electric services aggregating 600 amperes or more, the service voltage shall be nominally 277/480 volts, 3-phase, 4-wire, or 480 volts, 3-phase, 3-wire. In such buildings, the portion of the lighting system defined as "efficient" under 9.1.1 shall be served directly at 277 volts or higher, and transformers shall be used only to serve appliance loads, or other loads not designed to operate at 277 volts. Manufacturers shall make available to prospective building owners or their representatives data on the full-load efficiency of such transformers.

EVALUATION

Verify by inspection of the plans submitted for approval.

COMMENTARY

Higher service voltages mean lower losses in the distribution of electricity.

CRITERION

8.0.4 Voltage Drop -- In any building, the combined voltage drop in feeders and branch circuits shall not exceed 3 percent of the service voltage.

EVALUATION

The plans submitted for approval shall have a tabulation of feeders and branch circuit voltage drops. The voltage drop summation of the longest and the most heavily loaded feeder and branch circuits should not be more than 3 percent of the service voltage.

COMMENTARY

Articles 210-6(d) and 215-3 of the National Electric Code define the size of the feeders and branch circuits so that the total voltage drop does not exceed 5 percent of the service voltage. The energy lost in the distribution system principally goes into I^2R losses in the feeders, branch circuits, transformers and switch gear, and is converted into heat which is generally not credited to useful effect, and adds to the comfort cooling load.

The above criterion reduces the voltage drop loss by up to 2 percent, and to that extent, energy will be conserved.

CRITERION

8.0.5 Light Switching -- In any space requiring two or more branch circuits for lighting, switching shall be provided for each circuit or for portions of each circuit, so that a portion of the lighting system adequate for custodial or maintenance purposes or for effective complementary use of natural and artificial lighting may be operated without switching on/off all of the lighting in that space.

EVALUATION

The plan examiner shall look at the diagrams to make sure that there is enough switching provided. He should determine that there is at least one switch in each room.

CRITERION

8.0.6 Electric Meters -- In any multi-tenant building, the electric energy to each tenant shall be metered separately for energy consumed in his portion of the building. It is recommended that each tenant also be billed separately for the energy he uses. Condominiums shall be included as multi-tenant buildings. Hotels, college dormitories, and other transient facilities are excluded from the provisions of this paragraph.

EVALUATION

Examine plans to determine that each tenant has his own meter.

COMMENTARY

There is some evidence that a significant reduction in energy usage occurs when tenants pay directly for the energy they consume.

CHAPTER 9

LIGHTING REQUIREMENTS

9.0 REQUIREMENT

In any space within a building, the permissible level of maintained illumination shall be based upon the use for which the space is intended.

CRITERIA

9.0.1 Task Lighting -- The design criteria for the level of illumination in the immediate area of a specific task shall be no greater than that recommended by the Illumination Engineering Society in the IES Lighting Handbook, 5th ed., for that task.

9.0.2 Local Lighting -- Task illumination shall be produced by luminaires arranged to illuminate the immediate task area, and such luminaires shall be individually switched. This requirement shall not apply where room occupancy is such that the averaged occupied space is 50 ft^2 or less per occupant.

9.0.3 General Lighting -- The general level of illumination in a space surrounding the task area shall be not more than 1/3 of the task level. Where more than one task level occurs in a space, the general level shall be not more than 1/3 of the average level of task illumination in the adjacent task spaces.

9.0.4 Noncritical General Lighting -- In the areas within corridors, stairways, toilets, lobbies, and the like, where no specific visual task occurs, the level of illumination shall be no more than 1/3 of the average level of general illumination in the adjacent task spaces, but not less than OSHA recommended levels for safety.

9.0.5 Lighting Calculations

9.0.5.1 Compliance with the requirements and criteria of 9.0 and 9.1 shall be determined by calculation of maintained illumination, following the procedure recommended by the Illuminating Engineering Society in the IES Lighting Handbook, 5th ed.

9.0.5.2 The following initial reflectances shall be used in calculation of maintained illumination:

1) Ceilings, 80%
2) Walls, 50%
3) Floors, 20%

COMMENTARY

Where higher reflectances are provided, increased lighting levels will be permitted in proportion. Where lower reflectances are provided, no increase in wattage will be permitted for the purposes of bringing lighting levels up to those specified above.

9.0.5.3 The following shall be used in calculating Light Loss Factors:

1) Area atmosphere to be "clean"
2) Time between cleaning, 12 months
3) Lamp burnout factor = 1.0
4) All recoverable factors = 1.0

9.0.5.4 Coefficients of utilization shall be no lower than those given in the IES Lighting Handbook, 5th ed., for the existing conditions and type of luminaires.

9.1 REQUIREMENT

Only efficient lamps shall be used for general illumination and local task illumination, except as provided below in 9.1.3 and 9.1.4.

CRITERION

9.1.1 Efficient Lamps -- Lamps shall be defined as those which produce at least 40 lumens per watt input, including ballast losses, at the rated initial output, defined herein as "efficient lamps". This definition is used in 9.1.4 as a basis for determining lighting load.

COMMENTARY

Some lamps in common use operate with a relative efficiency as low as 1/4 that of other commonly available lamps. The objective of the criteria of 9.1.1 is twofold:

1) To provide a basis for computing the total wattage allowed for lighting under 9.1.4.

2) To restrict the use of inefficient lamps to special usages (9.1.3) and in a trade-off mode with more efficient lamps as provided under 9.1.4.

CRITERIA

9.1.2 Other Lamps -- To the extent that lamps producing less than 40 lumens per watt are used, the general lighting in the space shall be reduced by an equal number of watts.

9.1.3 Exceptions -- The criteria of 9.1.1 and 9.1.2 shall not apply to the following:

1) Private residences, except for kitchens, bathrooms, and laundry areas.

2) Private apartments in apartment houses, except for kitchens and bathrooms in the apartments, and public spaces such as lobbies, halls, stairways, laundry and utility rooms, and basement areas generally.

3) Small spaces, such as closets, requiring only one lamp of not over 60 watts.

4) Auditoriums and stages where dimming is essential to the use of the space.

5) Projectors.

6) Portable devices.

7) Luminaires for medical and dental diagnostic, surgical, or therapeutic purposes.

8) Highlighting applications, such as localized lighting of work stations, sculpture exhibits, art exhibits, and individual items of display merchandise.

9) Specialized lighting applications (color matchings; where electrical interference cannot be tolerated).

9.1.4 Lighting Alternatives -- The total watts used in a building for interior lighting purposes shall be no more than that which would have been required had all spaces been illuminated with efficient lamps, efficient luminaires, and reflectances, as defined above. Performance specifications of lamps and luminaires shall be that given in the fifth edition of the IES Lighting Handbook.

9.2 REQUIREMENT

Use of luminaires providing for heat removal or heat recovery shall be encouraged.

CRITERION

Where the heat from lamps is in part removed by a heat transfer medium which does not enter the occupied spaces, each Btu so removed may be offset by 1/2 Btu of additional permitted energy input to the lighting system for illumination purposes, provided that at least 50% of energy so removed can be recovered for useful heating purposes elsewhere or for reheat in humidity-control equipment, and provided that the remainder of the energy removed is not transmitted as additional load to the cooling system.

EVALUATION

The evaluator may determine from standard procedures when available, or manufacturers' recommendations when industry or national standards are not available, the total Btu exhausted from luminaires.

COMMENTARY

All energy used for lighting ends up as heat, and energy saved by removing this load from the air conditioning load should be rewarded. The criteria of 9.5 is not intended to encourage the use of more energy in lighting for the purpose of heating building space.

9.3 REQUIREMENT

The energy expended for exterior lighting shall be minimized by basing the maximum level of maintained illumination upon the use for which the space is intended and by using efficient light sources as defined in 9.1.1.

CRITERIA

9.3.1 Lighting Levels

9.3.1.1 Maintained levels of illumination for exterior lighting shall be no greater than that recommended by the Illuminating Engineering Society in the IES Lighting Handbook, 5th ed., for that area classification.

9.3.1.2 Signs and facade lighting, 500 watts, or 1% of total interior lighting load of the building, whichever is greater.

9.3.1.3 Continuous burning gas lamps shall not be used to provide illumination or decoration.

9.3.2 Lighting Calculations -- Calculation of illumination shall follow the procedure recommended by the Illuminating Engineering Society (IES) Lighting Handbook, fifth edition.

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CHAPTER 10

ENERGY REQUIREMENTS FOR BUILDING DESIGNS BASED ON DYNAMIC ANALYSIS

10.0 REQUIREMENT

Alternative building designs shall be accepted that can be shown to save equivalent amounts of energy without following each and every detailed requirement of Chapters 5 through 9 of this standard.

CRITERIA

10.0.1 Equivalent Annual Energy Consumption -- Under the provisions of this chapter the designer may propose any design of building and energy-saving systems for which the integrated annual energy use is equal to or less than the corresponding annual energy use of a similar system designed to meet the requirements of chapters 1-9 of this standard. Comparison of the two designs shall be based on annual energy profiles of both systems covering heating, ventilating, cooling, lighting, and service water systems. The criteria for this comparison process are illustrated in Figure 10-1.

10.0.2 Documentation -- Building owners or their representatives who desire to use an alternative building design based on dynamic analysis shall provide detailed technical data and analyses as necessary to verify that the design complies with the requirements of this chapter. This report shall include details of the annual energy consumption analysis for the building service systems prepared by a registered professional engineer or architect, recognized as an expert in the design of the type of structure and systems submitted.

10.0.3 Basis for Comparison -- The building and service system design selected as a basis for the reference energy budget shall meet the requirements of Chapters 1 through 9 of this document and shall be one that is commonly employed for the proposed type of occupancy and geographical location.

10.0.4 Commonality -- The comparative analysis for evaluation shall include the building exterior envelope design, common climatic data, common operational occupancies and schedules, common energy systems characteristics, common efficiency assumptions, and comparable building shape and height.

10.0.5 Analysis Procedure -- The energy consumption analysis for the design forming the basis of comparison and for all energy-using systems considered as alternatives under the provisions of this chapter shall be conducted according to the following procedure:

10.0.5.1 The building heating and cooling load analysis that is used as the basis for the energy consumption analysis shall be performed in accordance with the procedures recommended by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Task Group On Energy Requirements in the document entitled "Procedures for Determining Heating and Cooling Loads for Computerized Energy Calculation", or equivalent.

10.0.5.2 The simulation of the building and its systems shall cover the entire range of operation for a test year. Simulation of the HVAC system shall be performed in accordance with the ASHRAE Task Group publication entitled "Proposed Procedures for Simulating the Performance of Components and Systems for Energy Calculation". Operational characteristics of the building, including temperature and humidity levels, lighting schedule, occupancy schedule, and schedule of outside air being introduced through the ventilation system shall be included. The simulation of the compponent equipment shall include operation at part-load as well as full-load conditions. Manufacturers' data shall be used where available and all thermal performance characteristics of the energy-significant components as well as thermal characteristics of the building shall be given in the report specified in 10.0.2.

10.0.5.3 The particular computer program or calculation procedure that is used to estimate annual energy consumption shall be reviewed and evaluated by the registered professional engineer or architect referenced in 10.0.2. An analysis procedure which deviates from the criteria of 10.0.5.1 and/or 10.0.5.2 shall be allowed provided that it is approved.

COMMENTARY

These criteria allow maximum flexibility to the designer to provide performance solutions without necessarily complying with the detailed criteria for the building envelope, mechanical, electrical, lighting, service water, or other systems within a building.

Center for Building Technology

OPTIONAL DESIGN APPROACH FOR CONVENTIONAL ENERGY SOURCES USING DYNAMIC ANALYSIS AND COMPARATIVE ENERGY BUDGETS

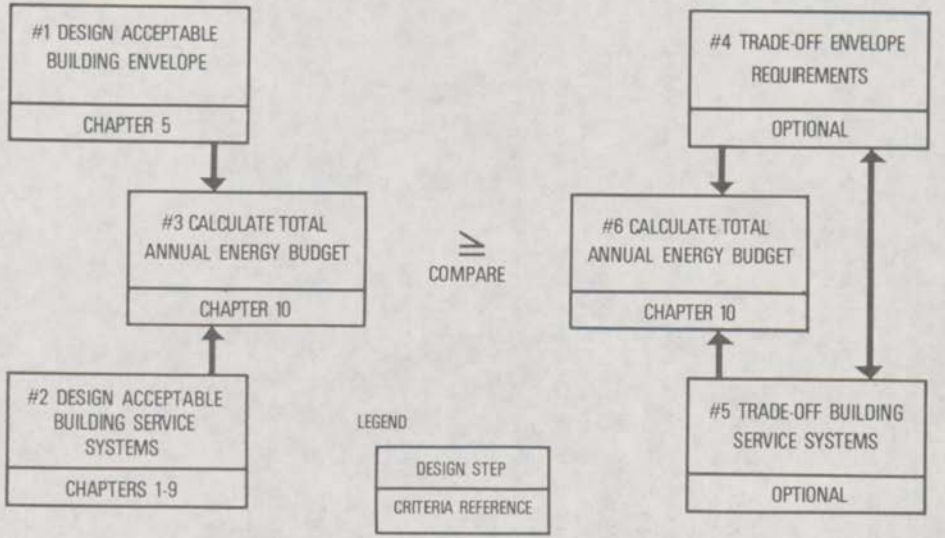

Figure 10-1

CHAPTER 11

REQUIREMENTS FOR BUILDINGS UTILIZING SOLAR OR WIND POWERED ENERGY SOURCES

11.0 REQUIREMENT

An energy bonus shall be granted to buildings designed to reduce usage of mineral or hydroelectric energy sources by using solar or wind powered energy sources to supply part of all of the building energy requirements.

CRITERIA

11.0.1 Energy Estimate -- The computed annual energy consumption of a building and its service systems when employing part or all solar or wind powered energy sources according to the Criteria of this chapter shall be allowed to exceed the reference energy budget obtained by computing the annual energy consumption of a system employing only mineral or hydroelectric energy sources by the amount of 50 percent of the energy obtained from solar or wind powered sources. The criteria for claiming such an energy bonus is given in this chapter and the steps illustrated in Figure 11-1. Windows shall not be considered a solar energy source for the purposes of this chapter. Use of windows to make more effective use of solar energy can be recognized under Chapter 10.

11.0.2 Documentation -- Building owners or their representatives desiring to claim the energy bonus that is permitted in 11.0.1 shall provide a report giving detailed technical data and analysis as necessary to verify that the design complies with the requirements of this chapter. This report shall include details of the energy consumption analysis for the building service systems prepared by a registered professional engineer or architect, recognized as an expert in the design of the type of structure and systems submitted.

11.0.3 Basis for Comparison -- The building and service systems design using mineral or hydroelectric energy source(s) and selected as a basis for the reference energy budget shall meet the requirements of Chapters 1 through 9 of this document and shall be one that is commonly employed in the proposed type of occupancy and geographical location.

11.0.4 Commonality -- In designing the service systems using part or all solar or wind energy sources, only those components of the building and service equipment that must be modified to utilize such energy may be different from those used to calculate the total annual energy budget. Common climatic data, common occupancies and use schedules, and common efficiency assumptions for identical components shall be used in the two cases.

11.0.5 Analysis Procedure -- The energy consumption analysis for both the mineral or hydroelectric and the solar or wind powered energy-using systems shall be conducted according to the following procedure.

11.0.5.1 The building heating and cooling load analysis that is used as the basis for the energy consumption analysis shall be performed in accordance with the procedures recommended by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Task Group on Energy Requirements in the document entitled "Procedures for Determining Heating and Cooling Loads for Computerized Energy Calculation," or equivalent.

11.0.5.2 The simulation of the building and its systems shall cover the entire range of operation for a test year. Simulation of the HVAC system shall be performed in accordance with the ASHRAE Task Group publication entitled "Proposed Procedures for Simulating the Performance of Components and Systems for Energy Calculation". Operational characteristics of the building, including temperature and humidity levels, lighting schedule, occupancy shcedule, and schedule of outside air being introduced through the ventilation system shall be included. The simulation of the component equipment shall include operation at part-load as well as full-load conditions. Manufacturers' data shall be used where available and all thermal performance characteristics of the energy-significant components as well as thermal characteristics of the building shall be given in the report specified in 11.0.2.

11.0.5.3 The particular computer program or calculation procedure that is used to estimate annual energy consumption shall be reviewed and evaluated by the registered professional engineer or architect referenced in 11.0.2. An analysis procedure which deviates from the criteria of 11.0.5.1 and/or 11.0.5.2 shall be allowed provided that it is approved by the organization using this document.

COMMENTARY

The intent of Chapter 11 is to encourage the development and use of solar or wind powered energy sources so as to conserve extracted energy sources and reduce pollution. For example, assume a design that meets the criteria of Chapters 1 through 9 and that has an annual consumption of energy from mineral sources of 100 units. The designer can elect to use the criteria of Chapter 11 instead of Chapters 1 through 9 and design his building to supply, say, 50 units of the energy requirement from solar energy sources. Using the formula in Figure 11-1, block #6, he will then be permitted to design his building and service systems to consume a total of 125 units of energy annually with 75 coming from mineral fuel and 50 units coming from solar energy. The net saving will be 25 units of mineral fuel and the building will be allowed a bonus of 25 units of energy over and above the reference energy budget of 100 units.

The rationale for Chapter 11 and the related definition of solar energy sources is as follows:

1) All forms of extracted energy sources commonly in use today are in short supply, will apparently remain so for the near future, and have finite limits of economic recovery and ultimate depletion.

2) The AEC has stated that nuclear electrical power generation cannot reasonably be expected to carry a major fraction of the electric energy load until after the turn of the century.

3) Limitations on the total quantity of thermally generated energy as we know it today will ultimately be determined by the effects of various forms of pollution, including thermal pollution. The effects of thermal and other forms of pollution are already measurably significant.

4) Conserving energy is an essential element of the Federal Government's goal to achieve energy self-sufficiency.

It follows that the Nation's finite energy sources and particularly those in short supply should be conserved and used in the most efficient manner available, and that extra incentives are neither needed nor should be used to stimulate the exploitation of energy sources which add pollution to the air or waterways.

Center for Building Technology

ENERGY BONUS FOR CONSERVING MINERAL ENERGY SOURCES

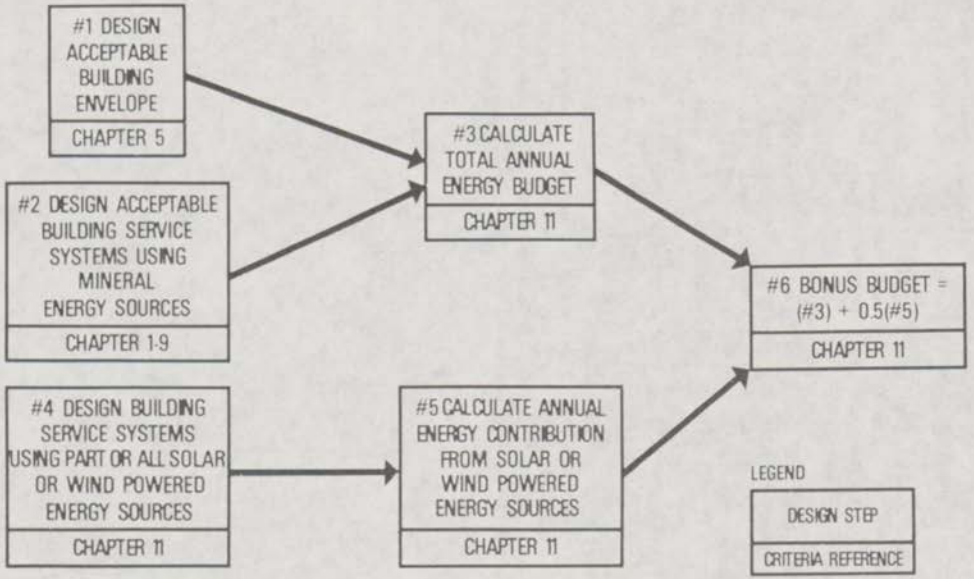

Figure 11-1

CONVERSION FACTORS TO METRIC (S.I.) UNITS

Physical Quantity	Symbol	To convert from	to	Multiply by
Length	x	inch	meter	$2.54^{*} \times 10^{-2}$
		$foot_2$	meter	$3.048^{*} \times 10^{-1}$
Area		$inch_2$	m_2	$6.4516^{*} \times 10^{-4}$
		$foot_2$	m_3	9.290×10^{-2}
Volume		$inch_3$	m_3	1.639×10^{-5}
		$foot_3$	m^3	2.832×10^{-2}
Temperature		Fahrenheit	Celsius	$t_c = (t_F - 32)/1.8$
Temperature difference		Fahrenheit	Kelvin	$K = (\Delta t_F)/1.8$
Pressure		inch Hg (60 F)	Pa	3.377×10^{2}
Mass		lbm	kg	4.536×10^{-1}
Mass/unit area	M	lbm/ft^2	kg/m^2	4.882
Moisture content rate		lbm/ft^2 week	$kg/m^2 s$	8.073×10^{-6}
Density	ρ	lbm/ft^3	kg/m^3	1.602×10^{1}
Thermal conductivity	k	$Btu/hr\ ft^2(F/inch)$	W/mK	1.442×10^{-1}
U-value	U	$Btu/hr\ ft^2 F$	$W/m^2 K$	5.678
Thermal resistance	R	$F/Btu/hr\ ft^2$)	$K/(W/m^2)$	$1.761. \times 10^{-1}$
Heat Flow	q/A	$Btu/hr\ ft^2$	W/m^2	3.155
Heat flow		Btu/hr	W	2.931×10^{-1}
Heat flow		ton (of refrigeration	W	3.517×10^{3}
Water vapor:				
--permeability (perm-inch)	μ	$\frac{\text{grain}}{\text{hr } ft^2(\text{in.Hg/in.})}$	kg/Pa.s.m.	1.459×10^{-12}
--permeance (perm)	p,P	$\frac{\text{grain}}{\text{hr } ft^2(\text{in.Hg})}$	$kg/Pa.s.m^2$	5.745×10^{-11}
Illumination		foot candle	lm/m^2	1.076×10^{1}
Flow		gpm	m^3/s	6.309×10^{-5}
Flow		cfm	m^3/s	4.719×10^{-4}
Wind velocity		mph	knots	8.696×10^{-1}
Wind velocity		mph	m/s	4.470×10^{-1}
Pressure		lbf/ft^2	Pa	4.788×10^{1}
Pressure		psi (gage)	Pa (gage)	6.895×10^{3}
Cooling efficiency		Btu/hr kW		2.931×10^{-4}
Cooling efficiency		Btuh/watt		2.931×10^{-1}

* Exact value: others are rounded to fourth place.

PROCEDURE FOR DETERMINING ECONOMIC EFFICIENCY

In order to avoid the possibility that any requirement of these criteria might be counterproductive in an economic efficiency sense, it may become necessary to determine whether a requirement is economically efficient. To determine economic efficiency, the present worth of life-cycle energy savings must be compared to the present worth of the extra life-cycle costs incurred to achieve the energy savings. This section describes one acceptable method for calculating the present worth of energy savings and extra costs, and it specifies a relationship between these two magnitudes in order for economic efficiency to be determined.

For the purpose of these calculations, the building life (L) and the annual discount rate (D) must be assumed. The life-cycle energy savings, resulting from the use of a required subsystem rather than a specific alternative, consist of the estimated yearly difference in electrical and fossil fuel consumption valued at present prices, which grow, in real terms, at an annual rate of P. The extra life-cycle costs consist of additional initial costs, additional maintenance operations, and replacement costs through the life of the building.

A given requirement in the document should be considered economically efficient if the present worth of energy savings (B) is greater than the present worth of the extra costs (C). A requirement should be considered economically inefficient if the present worth of energy savings (B) is less than the present worth of the extra costs (C). The calculation of B and C is described as follows:

$$B = \left[1 + P\left[\frac{(1 + D)^{L} - (1 + P)^{L}}{(1 + D)^{L}\,(D - P)}\right]\right] S$$

where

S = the annual value of energy saving by incorporating a subsystem or component required in the document rather than using a specific alternative.

$S = p_1 s_1 + p_2 s_2$, etc.,

where

p_1 = the present unit price of fuel 1, and s_1 = the number of units of fuel 1 saved annually.

$$C = I + \left[\frac{1 - \frac{1}{(1 + D)^{L}}}{D}\right](M + O) + \sum_{y=1}^{L} \frac{R_y}{(1 + D)^{y}}$$

D = annual discount rate in decimal form.

P = annual rate of change in the real price of energy in decimal form.

I = extra initial cost incurred by incorporating a subsystem or component required by these criteria rather than using a specific alternative.

L = building life in years.

M = extra annual maintenance cost at present prices.

O = extra annual operations cost at present prices.

R_y = extra replacement costs in year y at present prices.

I, M, O and R_y may be negative. A negative value indicates that the particular cost component of the required subsystem is lower than that for the alternative being considered. If this is the case, the negative sign should be retained in the computation.

In selecting specific values for D and L, lower values of L and higher values of D will generally reduce the difference between B and C thereby increasing the chance that the requirement will appear to be economically inefficient. It is recommended that a building life of no less than 30 years be used (12 years for mobile homes) and a discount rate of no more than .08 be used.

As increasingly costly energy sources are utilized, e.g., North Sea and North Slope oil rather than Oklahoma oil, the real price of energy can be expected to rise during the life of the building (barring an innovation such as the commercial generation of electricity by fusion at favorable cost). Therefore, it appears overly conservative to say that P equals zero. As an attempt to capture the effect of rising real energy prices, it is suggested that P be assumed to equal .01. This assumption means that the nominal price of energy is expected to rise annually at a rate one percent greater than the general level of prices.

NEW INFORMATION NEEDED FOR ENERGY CONSERVATION CRITERIA

ENERGY ANALYSIS DATA

The amount of energy consumed by building service systems is strongly affected by the dynamic interplay of structure heat transfer characteristics and mechanical systems for heating and cooling, both of which are usually changing with respect to time depending upon the outdoor weather conditions and the use patterns of the building spaces such as lighting, energy consuming equipment and occupancy.

Even with similar mechanical systems in similar types of building in the same general locality, the energy consumption between buildings may differ considerably depending upon the design of the central system and the specific types of system components used.

Accurate evaluation of building energy consumption, therefore, requires detailed mathematical simulation of the system dynamics. Such a simulation technique has been illustrated in a document entitled, "Proposed Procedures for Simulating the Performance of Components and Systems for Energy Calculations", published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Although the methodology to perform dynamic simulation analysis is well defined, the validity of such calculation is limited by the lack of adequate technical information such as the following:

Part-Load Efficiency Data -- Most of the HVAC equipment manufacturers publish efficiency data for major energy consuming components in terms of output capacity and input power requirement at a specified design point so that consulting engineers can select equipment to meet the heating and cooling load of the building under steady state design conditions. The efficiencies of components are commonly available only at a specific design point, often 100 percent of design rated load, which seldom occurs during the course of building operation throughout the year. During most of the year the equipment operates under part load conditions. Yet the energy efficiency data for the part load condition are seldom available from the manufacturer. In some cases such data are not easy to obtain and may require considerable one-time expenditure. In order for energy analysis to become an effective adjunct of building design, however, part load efficiency data is essential.

Control Characteristics -- The dynamic response of a heating and cooling system with respect to changing requirements in the space is influenced by the manner in which the system and its equipment are controlled. If the control is out of phase with the space heating and cooling needs,

much of the energy used to heat and cool the space will be wasted. This phenomena is especially acute for the terminal reheat system and double duct system whereby the primary energy is used to simultaneously heat and cool the supply fluid to attain the desirable condition. The parameters that describe the performance of the control function are usually expressed in such terminology as throttling range, time constant, transfer function and LaPlace transform, details of which are found in most control textbooks. Availability of this type of information for different types of controls would make it possible to estimate the energy consumption of system component as reflected in the drooping of the modulating control or the cycle frequency, percent-on time and anticipation characteristics of the on-off controls. However, very little information has been made available by the manufacturers as to these parameters, nor are comprehensive algorithms available to take these factors into account for the energy analysis.

Air Distribution To Multiple Zones From Central Fan-Plants-- The amount of chilled or heated air to be delivered to the various zones from a central fan plant is in many instances very much different from that predicted by zone heat balance equations. Present engineering practice for air distribution design is aimed at the sizing of the air duct, and not suitable for evaluating the air delivery performance under actual operating conditions. Moreover, a large amount of fan power is wasted by overpressurizing supply air and subsequent throttling of it through dampers. More comprehensive and accurate methodology for designing and evaluating the air distribution system, such as that based upon network analysis, is available and its use should be encouraged.

Standard Weather Data For The Energy Analysis -- Weather data required for the energy analysis is not the same as the steady state design weather data used for the selection of heating and cooling equipment and system design. The design weather data are basically specified as preventive measures so that occupants can be protected from the results of inadequate capacity of heating and cooling equipment. Such weather design criteria are not suitable for the dynamic evaluation of energy consumption by the equipment, since extreme weather conditions seldom prevail during the year. The weather data needed for energy analysis must satisfy the following requirements:

- Must contain coincidental values of temperature, humidity, wind data and solar radiation data including percent of sky cover by clouds.
- Must be conducive to dynamic analysis of building thermal performance and system responses.
- Must be readily obtainable and usable for each locality.
- Must be consistent.

Engineering Data For Nonconventional Systems -- Design and performance analyses data are needed for nonconventional systems, such as solar and/or wind power utilization systems, engine driven heat pumps, and heat-operated refrigeration cycles (Rankine, absorption, adsorption and fuel-cell).

Simplified And Reliable Energy Calculation Procedures -- Although the energy calculation methods based upon the dynamic simulation of buildings and building service systems fulfill a need, they require considerable effort and a comprehensive computer program which may not be warranted in many applications of small or simple buildings. Simple energy estimate methods and versatility for evaluating different mechanical systems or innovative designs. What is needed is an energy analysis procedure more comprehensive than the degree day method yet less difficult to use than dynamic analysis. One such attempt was made recently at the National Bureau of Standards to estimate heating and cooling load(1). Approaches similar to this effort need to be further developed so that the energy consumption of less complicated buildings may be determined by a simple arithmetic manipulation of climatic factors, energy usage patterns and indoor conditions with respect to energy response factors, which will be predetermined for several typical buildings by the detailed dynamic analyses.

TESTING PROCEDURES

Most of the testing procedures published today for the HVAC equipment are for the rating or safety labeling/listing of equipment under specified design conditions. Due to standby losses (standing pilots, stack losses, compressor crankcase heaters, circulating pumps, etc.) energy converting equipment may operate with higher efficiency under the design test condition, than the part load conditions typical of day by day operation. In addition, conventional testing procedures are usually under steady loading conditions whereas the actual load is usually fluctuating. For the purpose of energy-based evaluation of building service systems and equipment, new testing procedures must be developed for evaluating efficiency performance under realistic operating conditions. General requirements for energy based testing may be stated as follows:

1. For the purpose of evaluating energy utilization efficiency, equipment shall be subjected to standardized, non-steady load conditions which represent the changing climatic and internal building load patterns common to the building.

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(1) Kusuda, T., Tsuchiya, T., Powell, F.J., "Prediction of Room Temperature by Using Equivalent Thermal Mass Response Factors", Proceedings for the 5th Symposium on Temperature, National Bureau of Standards, Wash., D. C. 1971.

2. Accurate instrumentation for determining integrated energy consumption as well as the peak power demand should be used.

3. Methodology to translate the test results to actual operating condition through mathematical simulation must be prescribed.

INFILTRATION

One of the greatest causes of building energy waste is due to unwanted air leakage, which is usually affected by the way the buildings are constructed and by the outdoor weather conditions, particularly the temperature and wind. Yet the present technology for estimating the heat gain and heat loss due to infiltration is relatively weak as compared to other modes of heat transfer such as conduction and solar radiation.

Methods of testing and evaluating building air infiltration under field conditions are presently available, but such methods need to be further developed and reduced to consensus standard procedures.

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BUILDING SCIENCE SERIES 64

U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards
in cooperation with
FEDERAL ENERGY ADMINISTRATION/Energy Conservation and Environment

Retrofitting Existing Housing For Energy Conservation: An Economic Analysis

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
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[3] Located at Boulder, Colorado 80302.
[4] Part of the Center for Building Technology.

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Retrofitting Existing Housing for Energy Conservation: An Economic Analysis

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In cooperation with
The Federal Energy Administration
Frank Zarb, Administrator
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Energy Conservation and Environment
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Demonstration Program

U.S. DEPARTMENT OF COMMERCE, Frederick B. Dent, *Secretary*
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, *Director*

Issued December 1974

Foreword

This study is a product of the continuing economic research being sponsored by the Office of Energy Conservation at the National Bureau of Standards in cooperation with the Federal Energy Administration. The study is significant in that it provides a methodology for determining economically optimal levels of investment in energy conservation for reducing energy use in residential space heating and cooling.

Economists, architects, home builders, planners and others will find in the conclusions which are drawn from the model, derived from basic principles of economics, proof that more investment in thermal improvements for both existing and new buildings makes good sense in terms of long term energy and dollar savings.

In view of its technical nature, this study is not intended to be a homeowner's guide to improvements for energy savings. It is the technical foundation for a consumers pamphlet, which is being published in conjunction with this study. The pamphlet is available from tne National Bureau of Standards and the Federal Energy Administration.

R.W. Sant, Assistant Administrator
Federal Energy Administration

R.W. Roberts, Director
National Bureau of Standards

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The author wishes to thank the many persons in the Center for Building Technology at the National Bureau of Standards who encouraged this research effort by the contribution of time and professional assistance. Dr. Harold Marshall and Mr. Joel Levy were especially helpful in formulating the economic model and in reviewing the several draft versions of this study. Mr. Douglas Burch and Dr. Tamami Kusuda, among many others in the Thermal Engineering Systems Section, spent many hours explaining the thermodynamic relationships needed to successfully implement the economic model as well as providing data to expedite its completion. Of course, the responsibility for all errors and omissions in the study rests with the author alone.

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Cover: The Bowman House, on the National Bureau of Standards' campus at Gaithersburg, MD, is used in the experimental validation of energy savings achieved by retrofitting an existing residence.

EXECUTIVE SUMMARY

Rising real energy prices serve as an incentive for energy consumers to become energy conservers. Energy conservation does not imply a life style of austerity, however, but rather a more effective utilization of energy resources. This is especially true in the case of space heating and cooling operations in residential buildings. Increased resistance to heat transfer in the building envelope, as well as a more efficient heating, ventilating, and air conditioning (HVAC) system, are direct and nearly perfect substitutes for energy consumption.

However, most of the nation's stock of housing units were constructed in a period of relatively low energy costs, lower HVAC requirements, and in a building market where first costs dominated design decisions. As a result, these buildings use considerably more energy than newer buildings designed to reflect higher energy costs and to minimize present-value life-cycle HVAC costs. Still, many energy conservation techniques (ECT's) which increase energy efficiency in new housing can be retrofitted into existing housing with a considerable savings potential in life-cycle HVAC costs. Homeowners in general are aware of many of these techniques, such as insulation, storm windows and doors, and weather stripping. However, opinions differ as to the extent to which these ECT's should be utilized. In general the homeowner is not able to cope with the complex thermal engineering and economic analysis necessary to determine the optimal size or allocation of an energy conservation budget for his own home.

The purpose of this Building Science Series report is to formulate an economic model, with thermal engineering input, to determine systematically that combination of ECT's which will maximize the potential present-value dollar savings in HVAC operations for existing housing, subject to varying climatic conditions, energy costs, and ECT costs. This model is then utilized to demonstrate the effect of climatic conditions and fuel prices on the optimal level of application of certain ECT's given prevailing ECT costs. The actual ECT's to be examined include:

(1) attic insulation,

(2) wall insulation,

(3) floor insulation,

(4) duct insulation in unheated areas,

(5) storm windows,

(6) storm doors, and

(7) weather stripping.

This study goes considerably beyond other economic studies of energy conservation in buildings because

1) no limit to the application of insulation was used where there are no physical constraints;

2) the energy savings potentials per dollar of investment from the various ECT's are compared in order to formulate a balanced energy conservation budget;

3) the model is quite sensitive to fuel prices and to projected rates of fuel price increases, as well as to climatic conditions, ECT costs, and discount rates; and

4) maximization of dollar savings to the homeowner is stressed.

The economic model formulated for use in this study utilizes marginal analysis to determine the optimal combination of the ECT's examined. Marginal analysis is especially useful in determining the efficient allocation of productive resources in order to maximize their output. Here the ECT's are considered to be productive resources, and net dollar savings (savings less costs) is the output to be maximized.

Two basic applications of marginal analysis are discussed: the first determines the optimal size and distribution of an energy conservation budget with no financial constraints; the second distributes a constrained budget among techniques in order to maximize dollar energy savings within the constraint.

Various empirical assumptions are made in order to apply the model to retrofitting existing housing. An allowance for physical constraints is incorporated into the model. A real (adjusted for inflation) discount rate of 1 percent is assumed, based on an after-tax alternative rate of return to the average homeowner. A 1 percent annual rate of real price increase is assumed for heating fuel and electricity. In effect this yields a minimum rate of return on investment equivalent to the rate of fuel price increases over the lifetime of the ECT's. The average rate of return will be considerably higher than this minimum rate of return, however, depending on how well the house was insulated before retro-

fitting, climate factors, and energy prices. A lifetime expectancy of 20 years is assumed for the ECT's (except for 10 years in the case of storm doors and weather stripping).

Calculations of energy savings are based on ASHRAE recommended procedures. Conductive heat gains and losses are calculated for applications of insulation; conductive and infiltrative heat gains and losses are calculated for storm windows and doors; and infiltrative heat gains and losses are calculated for weather stripping. Marginal energy savings and costs are calculated for each incremental inch of insulation, for various size storm windows, and for prime doors with varying glass content. Calculations are based on average seasonal loads rather than on design (extreme) conditions. The results are applicable to most housing designs if the ECT's considered can be retrofitted without structural modification.

Tabular results of this study show that the optimal level of investment in ECT's increases considerably as climate conditions grow more severe and more expensive heating and cooling energy forms are used. While government and industry recommendations for ceiling insulation currently call for six inches, this appears optimal in most geographical areas only when using low-priced natural gas. Ten to 12 inches of insulation is indicated as optimal for attics in oil-heated houses, except in the mildest climates, and 12 inches or more is indicated for most electrically heated and cooled houses. Insulation blown into existing walls is shown to be economically advantageous in many climates where higher fuel prices prevail (provided that this can be accomplished without damage to the structure). Insulation in floors over crawlspaces, garages, and unheated basements, as well as around exposed heating and cooling ducts, is shown to be economically rewarding in conjunction with attic and wall insulation, and often at considerably higher levels than currently recommended in promotional literature. Weather stripping, when installed by the homeowner, is found to be economical in all climates above 2000 degree days.

The conclusions of this research project contain several important points:

1) Most housing units in the U.S. today, especially older houses and those with added air-conditioning units, are underinsulated with respect to economic efficiency.

2) Homeowner-optimal levels of investment in energy conservation techniques are generally higher than current industry and government recommendations.

3) Energy conservation investment recommendations which reflect the variation in prices for different fuels will be of greater benefit to consumers than recommendations which consider climate variation only.

4) Artificially low or controlled energy prices encourage socially inefficient use (waste) of energy because economic incentives to conserve are reduced.

5) Building codes for energy conservation purposes should not substitute for consistent economic analysis. If such codes are viewed as maximums as well as minimums, they may be responsible for underinvestment in energy conservation.

Several recommendations are made as well:

1) Estimates of energy savings from high levels of insulation should be field validated.

2) More research is needed into suitable materials for retrofitting walls and their long-term effects on moisture transfer.

3) Economic benefits from other ECT's including forced-air ventilation, clock thermostats, and solar shading, should be examined.

4) Most importantly, the information derived from this study must be made available to homeowners in a manner which they can understand and implement. Such information is essential if they are to respond efficiently to increased fuel prices and scarcer energy resources. By doing so they will permanently reduce their demand for energy used in the space heating and cooling of buildings.

1. INTRODUCTION

While the energy "crisis" and spot fuel shortages may be temporary in nature, long range forecasts of rising energy prices[1] over and above the rate of general inflation signal the growing scarcity of energy in relation to other resources. These rising prices, more than any other factor, will convince energy consumers that they must become energy conservers. Energy conservation does not necessarily imply a new life-style of austerity, however. In many cases, rising energy prices will provide a significant incentive to increase the effectiveness of energy utilization with little or no decrease in our present standard of living.

This is especially true for space heating and cooling operations in buildings.[2] More efficient heating, ventilating, and air conditioning (HVAC) equipment and a building envelope[2] with increased resistance to heat loss and gain are direct and nearly perfect substitutes for energy consumption. As the cost of heating fuels and electricity rises, additional investments in such energy conservation techniques (ECT's) will become economically attractive, thereby encouraging a permanent reduction in energy consumption.

However, additional investments in ECT's generate increasingly smaller energy savings, and beyond a certain level such improvements no longer pay for themselves. For this reason it is important that the benefits and costs of the various ECT's considered be identified so as to select only those investments which are potentially profitable. Profitability, of course, is not the only incentive for increasing energy conservation efforts. Comfort factors and a desire to head off another "energy crisis" may also play an important role. But while all of these may provide an initial incentive to undertake such actions, ultimately economic considerations will give the best indicators as to how much to invest and in what priority order among the various ECT's available.

Currently there is little information available, especially for homeowners, regarding economically optimal investment levels of energy conservation techniques available for reducing space heating and cooling costs. And yet decision-making in energy conservation investments can be quite complicated. Among the many variables which must be considered simultaneously are climate factors, comfort requirements, fuel prices, and the costs and energy saving potentials of a wide variety of energy conservation techniques.

It is therefore important that information on the economic aspects of energy conservation, sensitive to localized climates and fuel prices, be developed for transmittal to homeowners. The homeowner who responds to his own best economic interests will, in most cases, increase his energy conservation efforts. In doing so, costly and time-consuming energy conservation legislation and enforcement could be avoided, and the national goal of energy self-sufficiency might be more easily achieved on a voluntary basis.

1.1 Purpose

The purpose of this study is to systematically estimate economically optimal combinations of selected energy conservation techniques for reducing HVAC operation costs in existing residences. Such combinations will be considered optimal in the sense that they maximize potential net dollar savings in space heating and cooling operations over the lifetime of the investment, in this case considered to be a maximum of 20 years. Such combinations will be economically balanced in that no further energy savings can be achieved by trading off one technique for another within the available energy conservation budget.

Improvements in the utilization of energy for residential space heating and cooling operations have a considerable impact potential on national energy demand. There are nearly 70 million existing residences in the U.S.[3] which make up nearly 20% of the annual energy consumption,[4] some 15 quadrillion Btu. Sixty percent of this is used for space heating and cooling alone.[5] Because the majority of these residences were built when energy was relatively inexpensive (and, in many cases, before air conditioning became commonplace), there were few incentives to encourage the conservation of energy. As a result there exists a considerable potential for reducing heating and cooling energy requirements in the major-

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[1] See Nordhouse, William V., "The Allocation of Energy Resources," Brooking Papers on Economic Activity, III, 1973.

[2] For the purpose of this study, "building envelope" refers to those surface areas which allow the transfer of heat into or out of a building, including roof, walls, floor, windows and doors, and heating ducts in unheated areas.

[3] U.S. Department of Commerce, Bureau of Census, Housing Division, 1970 Census of Housing, Table 32.

[4] Seidel, Marquis R.; Steven E. Plotkin; and Robert O. Reck; "Energy Conservation Strategies," Environment Protection Agency, Washington, D.C., July 1973, p. 13.

[5] Ibid., p. 13.

ity of U.S. housing. These potential reductions have been estimated to be as high as 20%[6] across the entire country and as high as 50% for many individual homes and geographical areas.[7] It should be recognized, however, that such potential reductions are largely a function of energy prices. If energy prices increase at a rate greater than that of ECT prices, the potential energy savings due to the reallocation of resources away from energy consumption and toward energy conservation will increase as well.

Rather than emphasizing energy conservation as a national priority, however, this study emphasizes energy conservation from the standpoint of the energy consumer. A concerted effort by government and industry has made most homeowners aware that there are a considerable number of actions that can be taken to reduce residential energy consumption.[8] Some of these require a substantial investment, however, which the homeowner may be hesitant to make if he is unsure of a sufficient return. In addition, failure to understand the economic trade-offs between the various ECT's will most likely lead to investments which do not maximize potential savings in terms of energy or dollars. This study provides economic information which can be used to complement current technical information regarding energy conservation for existing housing. With this economic information, the homeowner will be better able to respond fully and accurately to rising energy prices, reaping considerable economic benefits for himself.

1.2 Scope and Approach

The energy conservation techniques examined in this study are those suitable for retrofitting into existing residences, in many cases by the homeowner himself, which will reduce the heat loss or heat gain through the building envelope.[9] Only those ECT's which offer substantial potential energy savings and require a large initial investment on the part of the homeowner have been considered, however. This in general includes increased levels of insulation, storm windows and doors, and weather-stripping. The potential savings of these ECT's are examined under a wide range of climates and economic assumptions in order to provide as much useful data as possible. Marginal analysis, a well-known microeconomic analytical tool, is used to establish a methodology for systematically determining the optimal (i.e., most profitable) combination of ECT's under any given set of assumptions. Optimal combinations of ECT's are then estimated for different climate factors and energy prices, using ECT costs typical of mid-1974 price levels.

We believe that this study goes considerably beyond most other economic analyses of residential energy conservation opportunities in several ways:

1) It establishes a systematic methodology for determining the most profitable level of energy conservation investments available to the homeowner.

2) It does not limit the application of insulation to commonly accepted levels (except in the case of physical barriers).

3) It considers the profitability of the various ECT's vis-a-vis each other (i.e., in combination) rather than as discrete entities.

4) It is sensitive to current fuel prices, fuel price differentials, and projected fuel price increases for the major sources of energy use in space heating and cooling.

1.3 Organization

The general plan of this study is to briefly describe the ECT's to be considered, formulate an economic model for determining their most profitable combination, and calculate these optimal combinations for a wide variety of economic and climatic conditions. Specifically this study is organized as follows:

Section 2 will outline the ECT's to be considered and give some insight into options available to the homeowner in terms of materials and installation.

Section 3 will present the optimality conditions which must be met if net savings are to be maximized. Economic variables such as discount rates, fuel price rises, and institutional considerations will be discussed.

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[6] Ibid., p. 7.

[7] Ibid., p. 47.

[8] See for instance "7 Ways to Reduce Fuel Consumption in Household Heating . . . Through Energy Conservation," U.S. Department of Commerce, NBS, December 1972; "11 Ways to Reduce Energy Consumption & Increase Comfort in Household Cooling" (same reference); Technical Options for Energy Conservation in Buildings, NBS Technical Note 789, U.S. Department of Commerce, National Bureau of Standards, July 1973; and the "Builders Guide to Energy Conservation," NAHB, 1974.

[9] Heating and cooling equipment are assumed to be fixed in size for existing houses.

Section 4 will provide the basic approach used in calculating marginal energy savings for both winter heating and summer cooling.

Section 5 will present, in tabular form, the results of this analysis for a wide range of economic and climatic conditions. Some interpretation of the tables will be made in order to facilitate their understanding and make interpolation of the data possible.

Section 6 will include a short summary and some recommendations for further research.

Included in the appendices will be a more detailed discussion of the ECT's considered, ECT costs, climatic factors for various geographic locations, a more detailed methodology for computing marginal heat losses and gains from various envelope sections of a residential building, and a note on the computer programs used for calculating the optimal levels of investments.

2. RETROFITTING EXISTING HOMES

2.1 Why Existing Homes Need Retrofitting

The vast majority of existing buildings in the United States, whether residential, commercial, or public in nature, are wasteful thermal shelters in view of today's energy prices. If the real (i.e., adjusted for general inflation) price of electricity and heating fuels continues to increase during the coming years, as expected, the financial burden of heating and cooling these buildings will grow accordingly unless energy conservation measures are undertaken.

However, construction practices in the past were not necessarily irrational with respect to energy conservation. Until recently energy has always been considered a relatively abundant resource in the U.S., and real energy prices have been accordingly low -- in some cases actually declining. What is now considered to be inefficient energy utilization was not economically inefficient while energy prices reflected this abundance. On the other hand,consumers have been poorly informed about the potential for energy and dollar savings that can be realized from the many ECT's available. Consequently, they have failed to demand many of these features when purchasing a new home. Instead, a "first cost" design philosophy developed which stressed the minimization of construction costs rather than recurring operational costs. As a result, most existing buildings were never built with energy conservation in mind.

Neglect of energy conservation opportunities in existing and new housing cannot continue indefinitely. Homeowners in many parts of the country are receiving monthly fuel bills which are twice that of the previous years. As the cost of heating and cooling the home makes up an increasingly larger percentage of the costs of owning and maintaining a home, present and future homeowners will be forced to curtail their standard of living if they do not take adequate conservation measures. For unlike mortgage payments and investments in ECT's, dollars spent on heating and cooling the home are permanently foregone.

Many existing homes in the U.S., especially those built before 1960, have no more than three inches of insulation in the attic, no insulation in the walls or under floors over unheated areas, no storm windows or double-glazed windows, and no solar shading. FHA Minimum Property Standards (MPS) after 1959 began to require increased insulation in new houses that it insured after 1959,[10] especially in the colder climates, and have been responsible for upgrading much of the new housing stock since that time. However, there still exists a significant economic potential for further improvement in new and existing housing in most areas of this country today.

A recent study sponsored by the Oak Ridge National Laboratory[11] has shown that for most areas in the U.S., 6 inches of attic insulation, 3 1/2 inches of wall insulation, a foil insulator in the floor, and storm windows and doors have the greatest potential dollar return in new housing. Significantly, that study did not consider more than 6 inches of insulation in any application and was completed before the recent energy shortage and accompanying price rises took place. Results of this NBS study show that in many climatic regions even further insulation is easily economically justifiable (barring physical constraints) for existing housing and similar conclusions can be made for new housing as well.

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[10] These 1959 MPS required that the heat loss of a gas or oil heated house be no more than 50 Btuh per square foot of living area (40 Btuh for electrically heated homes). The current MPS have more than halved these allowances.

[11] Moyers, John C., "The Value of Thermal Insulation in Residential Construction: Economics and the Conservation of Energy," Oak Ridge National Laboratory, December, 1971.

2.2 Retrofitting Techniques

a. Selection of Techniques

While there are a large number of potentially profitable energy conservation actions that can be undertaken in the home, only a limited number of them will be examined here. We will not deal with clearly profitable conservation actions such as adjusting the furnace to increase its efficiency, caulking around window and door frames, sealing other cracks and openings which permit infiltration of outside air, and other such steps which have been outlined elsewhere. These usually have small economic costs and considerable economic benefits and should therefore be given the highest priority. Rather, this paper is concerned with investments in energy conservation which may take several years to pay for themselves, therefore requiring more specific knowledge as to potential energy savings which can be realized over their lifetime.

The retrofitting techniques which will be examined in this study are as follows:

1) attic insulation,
2) wall insulation,
3) floor insulation over unheated areas,
4) insulation of ducting in unheated spaces,
5) storm windows,
6) storm doors, and
7) weather stripping.

Most of these techniques might have been incorporated into the house at the time of construction at a lower cost than when retrofitting because walls, ceilings, and floors are more accessible, labor is better allocated, and materials can usually be purchased at a builder's discount during construction. Furthermore, savings due to such improvements would have accrued from the first day of occupancy. Retrofitting these techniques may still be profitable in varying degrees of application, however, as will be shown in the results of this benefit/cost study.

The following guidelines were used in deciding exactly which techniques would be considered. In general these energy conservation modifications will:

1) require a capital investment on the part of the homeowner which may take several years to recover;
2) reduce heat transfer through the envelope of a house; i.e., through the ceiling, walls, floors, windows, and doors;
3) be suitable for retrofitting into existing houses;
4) have resistances to heat transfer which can be reasonably estimated;
5) be acceptable to most homeowners;
6) not significantly alter the appearance of the house or reduce its market value; and
7) be available on the open market.

Other energy conservation techniques which may be considered as worthwhile but are not specifically treated in this study include the clock thermostat; a fan to substitute for air conditioning when the outside temperature falls below the inside temperature; heavy drapes; and solar shading, in the form of awnings, solar screens, or trees and taller shrubs.

b. Variations of Techniques Considered

For most of the ECT's examined in this study there are a wide variety of materials available that will reduce heat gain and loss through the various sections of the building envelope. Depending on actual physical and climatic conditions, some of these will be more suitable than others. Some discussion as to specific options, including variables which are not easily quantifiable, is presented in Appendix A. The actual materials considered in this study are as follows.[12]

1. Attic insulation (no limit to thickness)

   a. glass fiber--loose fill (R-2.2 per inch)
   b. glass fiber--blanket/batt (R-3.1 per inch)
   c. cellulose--loose fill (R-3.7 per inch)

[12] Resistance (R) values are approximately those claimed by the manufacturers. Thickness limits are due to physical constraints. It is not intended that structural modifications be made to increase physical space for insulation where more is indicated than can be practically installed in any envelope section.

2. Wall insulation (3 1/2" thickness limit)

   a. cellulose--loose fill (R-3.3 per inch)

   b. glass fiber--blanket batt (for open walls only) (R-3.1 per inch)

3. Floor insulation over unheated space (10" thickness limit)

   a. glass fiber blanket/batt (R-3.1 per inch)

4. Ducting insulation in unheated spaces (10" thickness limit)

   a. glass fiber duct wrap (R-4 per inch)

5. Storm windows

   a. triple track metal sash

6. Storm doors

   a. metal sash with screen inserts

7. Weather stripping

   a. doors

   b. windows

c. Prices

The prices used in this study are based on a considerable amount of data gathered from many sources during the spring and summer of 1974. These sources include retail firms which do considerable business in energy conservation materials and services, and the results of a survey run by the U.S. League of Savings Associations which contains price estimates for these ECT's collected from 35 cities in the U.S. Actual prices used are included in Appendix B.

It should be noted that prices for many of these ECT's vary by as much as a factor of two or more, even within the same marketing area. The distribution of prices generally reflects a concentration of rather competitive estimates at the lower end, however, and the actual prices used reflect this concentration. At the same time it should be stressed that the estimates used are for average working conditions (as defined by the contractors themselves) and may vary according to total job size. Homeowners are cautioned to get several estimates and to weigh the reputation of the contracting company carefully when choosing to contract for installation.

3. ECONOMICS OF RETROFITTING

This study is basically a benefit/cost analysis of energy conservation techniques suitable for retrofitting in existing residences. Its goal, however, is to do more than just identify potentially profitable ECT's. Rather it seeks to identify the most profitable combination of techniques available for a particular residential application. The criteria for determining an optimal solution will be discussed in this section, as well as other economic considerations that may play an important role in the analysis.

3.1 Marginal Analysis

Marginal analysis is a particularly useful microeconomic tool for examining potential energy conservation investments because it provides a systematic approach to the solution of profit maximization problems which involve variable-sized investment opportunities. While marginal analysis is often used in benefit/cost analyses, it has not been frequently utilized in energy conservation studies of this type. With its use, however, a considerable amount of useful information can be generated that was previously not available.

The term "marginal", as used in this study, refers to the last increment of some variable; for example, the last inch of insulation in an attic. Marginal savings (MS) are the dollar savings generated by that last increment. Marginal cost (MC) is the cost attributable to that last increment.[13]

Two basic applications of marginal analysis are made here in determining optimal investments in ECT's. The primary application is used to select the optimal combination of ECT's for a given set of climatic, architectural, and economic variables, in the sense that no other combination will generate greater net savings (i.e., total savings less total costs) over the life span considered. The secondary application of marginal analysis is used in selecting economically "balanced" combinations of ECT's for any given investment size, in the sense that no other combination will generate greater dollar energy savings for the same or lesser total cost. While the primary optimality criterion assumes an economically balanced combination of ECT's, it is important to note that this secondary, or alternative, application is significant in its own right. It enables the homeowner to maximize the potential dollar energy savings available from any given energy conservation budget.

a. Optimal Combination of ECT's

As stated above, the primary application of marginal analysis will help us determine that combination of ECT's which maximizes net savings in residential space heating and cooling operations. The basic criterion for the optimal combination is expressed as Condition I, namely, that for each ECT considered,

$$MS = MC, \tag{3-1}$$

where MS = marginal savings, or the savings generated by the last increment of an ECT, and

MC = marginal costs, or the cost attributable to that last increment.[14]

This condition simply states that investment in any given ECT should continue up to the point where the last dollar invested generates exactly one dollar in energy savings.[15] When this condition has been met for all techniques, no further investment will be profitable.[16]

Figure 3.1 illustrates an application of the optimal investment criterion for attic insulation. In Figure 3.1, the depth of this insulation is measured on the horizontal axis. Total savings (TS) and total cost (TC) are measured on the vertical axis of the upper part of Figure 3.1. While total costs increase at a constant rate as a function of insulation depth, total savings increase at a decreasing rate, rising considerably above the total cost curve at first, but eventually intersecting this curve at insulation thickness q_2, and thereafter falling below it. At any point on

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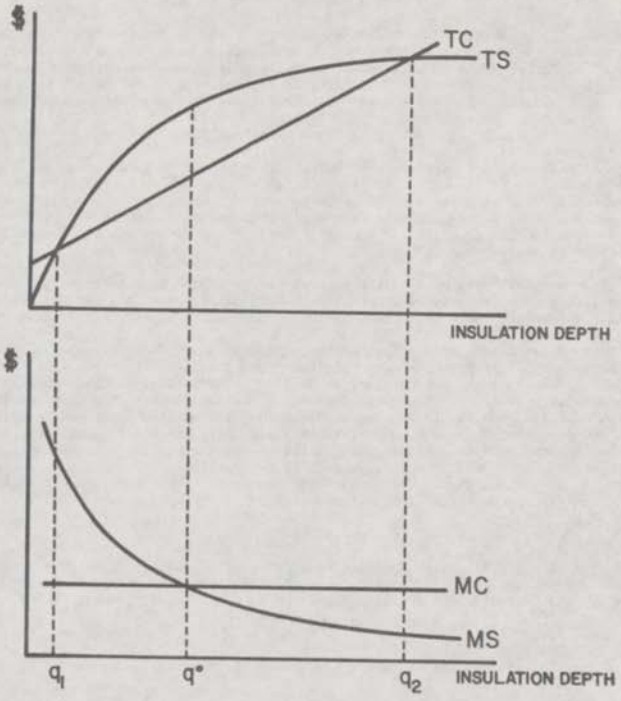
[13] It is important to distinguish between MC and MS and total cost (TC) and total savings (TS). MC and MS represent the rate of change (or first derivative) of the TC and TS functions at each increment; the summation of the MC of each increment (or the definite integral of MC) will result in TC; summation of MS of each increment will result in TS.

[14] Second order conditions require that, locally, MS minus MC be decreasing. Care must be exercised in distinguishing local optimals from global optimals. This will be discussed in Section 3.2.

[15] These dollar savings result from a stream of energy savings generated over the expected lifetime of the ECT's discounted to present value to reflect alternative investment opportunities over this period of time.

[16] In some cases it will not be possible to reach the point where MS = MC because of physical or other constraints. This will be discussed further in Section 3.2.



CONDITION I: MS=MC

OPTIMAL LEVEL OF INVESTMENT

Figure 3.1 Condition I assures maximum net dollar savings generated by investment in a given ECT.

the horizontal axis between q_1 and q_2, total savings are maximized only at that level of insulation where the difference between TS and TC is maximized. This will occur only where the slope of the TS curve is equal to the slope of the TC curve, i.e., at q^*. Moving to the lower diagram we see that this is precisely the point where the MS curve intersects the marginal cost curve; i.e., where MS = MC.[17]

The reason for requiring MS to equal MC is clear: At any point to the left of q^*, increases in the level of insulation will generate savings greater than costs so that net savings will be increased. At any point to the right of q^*, however, the cost of additional insulation is not covered by the incremental savings so that net savings are decreased. This leaves only q^* as the profit-maximizing level of insulation.

While the "optimal" combinations of ECT's presented in the tables of Section 5 reflect a wide range of climatic conditions and energy prices, they are all consistent in that they satisfy Condition I.

b. Balanced Combination of ECT's

Marginal analysis is particularly appropriate in the analysis of most ECT's precisely because the potential energy savings generated by any given technique generally decrease as more of that technique is utilized. As these savings decrease, it becomes more profitable to shift further investment into other techniques which generate greater marginal savings (per dollar invested). As we shall see, marginal analysis is quite useful in treating these economic "tradeoffs."

The second application of marginal analysis provides the criterion for selecting an economically balanced combination of ECT's for any given investment size, i.e., that combination which saves more energy dollars than any other for the same or less cost. This requires not only an absolute determination of the profitability of each energy conservation technique at each incremental level of application, but of their relative profitability, in relation to each other, at each incremental level of application as well.

The equilibrium condition for this balanced combination is expressed as Condition II:[18]

$$\frac{MS_1}{MC_1} = \frac{MS_2}{MC_2} = \frac{MS_3}{MC_3} = \ldots = \frac{MS_n}{MC_n} \qquad (3\text{-}2)$$

where MS_i = the marginal savings generated by the i^{th} technique,

MC_i = the marginal cost of the i^{th} technique, and

$i = 1, 2, 3, \ldots, n$ techniques.

When Condition II is satisfied, the last dollar spent on each technique will generate the same dollar energy savings. In order to remain within the implied budget constraint, any increase in one technique will require a decrease in one or more of the other techniques.

Condition II is shown graphically in Figure 3.2. Here the curved lines show marginal savings per dollar invested (MS/MC) for each technique. The horizontal axis represents the level of investment for each technique; as more is invested in each technique, MS/MC decreases monotonically. The horizontal line (B) running continuously through all the MS/MC functions is the budget line. It assures by construction that MS/MC will be equal for each technique. The higher B crosses the vertical axis, the higher is MS/MC, and the lower is the total budget. The lower B, the higher the total budget. The quantity of each technique considered is determined by the intersection of B with each MS/MC curve; thus q_1 is the quantity of the first technique obtained, q_2 of the second, etc. The budget, or total investment size (B) is then equivalent to

$$B = q_1AC_1 + q_2AC_2 + q_3AC_3 + \ldots + q_nAC_n, \qquad (3\text{-}3)$$

where AC_i = the average cost of the i^{th} technique at level q_i.

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[17] This is a straightforward extension of the fact that MS and MC are the first derivatives of the TS and TC functions, respectively.

[18] An important assumption in this criterion is that the savings and cost functions of the various ECT's be independent of each other. This will be discussed further at the end of this Section.

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CONDITION II:

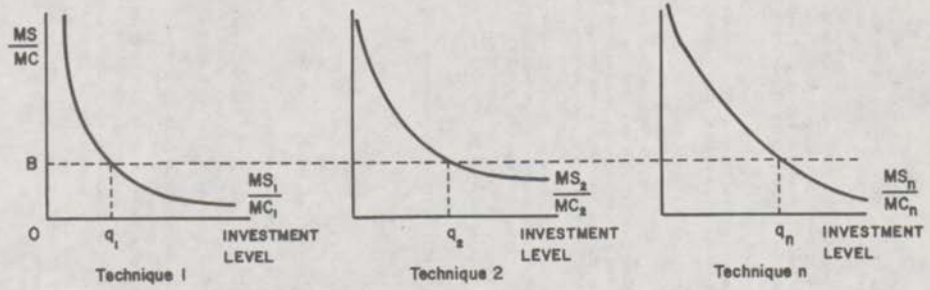
$$\frac{MS_1}{MC_1} = \frac{MS_2}{MC_2} = \frac{MS_3}{MC_3} \cdots = \frac{MS_n}{MC_n}$$

Where:

MS_i = Marginal Energy Savings (in dollars) of the i^{th} technique.

MC_i = Marginal Cost of the i^{th} technique.

i = 1,2,3,....n number of technique.



OPTIMAL COMBINATION OF INVESTMENTS

Figure 3.2 Condition II assures an optimal distribution of a energy conservation budget among ECT's.

As the budget increases, the budget line moves downwards and additional levels of investment in each ECT are determined.[19]

A graphical demonstration of the desirability of equal dollar savings per dollar of investment at the margin is given in Figure 3.3. Here technique 1 at q_1^* and technique 2 at q_2^* are generating equal savings per dollar at the margin. Suppose now that we wish to increase the investment level in technique 1 to $\bar{q}_1$. This will require an equivalent decrease in investment for technique 2 in order to remain within the budget constraint. The cross-hatched area for technique 1 shows the increase in savings due to the increased investment and the cross-hatched area for technique 2 shows the concurrent decrease in savings. Note that this increase is not sufficient to offset the decrease. Again, only at that point where MS/MC is equal for each technique will the combination be economically balanced.

As a further example, consider two alternative ECT's, say attic installaion and floor insulation (over an unheated crawlspace) in a given house. Assume that the fixed labor cost of installing insulation in the floor is twice that of the attic (because of poor accessibility) but the materials cost and variable cost of installation for each additional inch is the same in both cases. Furthermore, let us assume that equal dollar energy savings will accrue from equal applications of each technique. How does one distribute a limited budget between these two ECT's?

One might intuitively feel that more attic insulation should be installed than floor insulation since the total cost of the attic insulation (labor plus materials) is less than that of floor insulation for the same level of application. This may at first appear reasonable because the net savings generated by attic insulation in this case are potentially greater than those due to the insulation in the floor. But to satisfy Condition II, equal amounts of both should be installed. Only in this way will MS/MC be equal for both.[20]

A numerical example of this problem is shown in Table 3.1. Marginal costs per square foot for each increment are shown together with the marginal savings generated. If 6 inches are used in both applications, for example, the MS/MC ratio is 2.5 (.05/.02) for both and thus Condition II is satisfied. The total cost of the attic insulation at this point is $.17 per square foot and the total cost for floor insulation is $.22. (We assume here that our budget is limited to $.39 per square foot for the two ECT's together.) Thus for a total budget of $.39 we save $4.84 ($2.42 x 2). But suppose we wish to add 7 inches of insulation to the ceiling and only 5 inches to the floor (in order to remain within the budget constraint). The budget remains at $.39 (now $.19 and $.20), but while the total savings generated by the attic insulation rise to $2.45, the savings from the floor insulation fall to $2.37, for a total savings of only $4.82. Total savings have thus declined by $.02 per square foot for failure to meet Condition II. Net savings have declined as well, since total costs have remained the same. As more attic insulation is substituted for floor insulation (in this case) the total savings fall quite rapidly, as can be seen by using 9 inches of attic insulation and 3 inches of floor insulation. In this case total savings fall by $.155 per square foot. Thus the more imbalanced the combination of ECT's, the greater the decline in net savings. It should now be clear why we cannot ignore MS and MC when selecting a combination of ECT's that will maximize savings.

As discussed at the outset of this section, Condition I implies that Condition II has been met. This can be shown quite simply because Condition I can be restated as

$$\frac{MS_1}{MC_1} = \frac{MS_2}{MC_2} = \frac{MS_3}{MC_3} = \ldots = \frac{MS_n}{MC_n} = 1 \qquad (3\text{-}4)$$

We now see that at the margin all ECT's are generating the same MS per dollar invested; in this case the last dollar invested in each technique generates exactly one dollar in savings. Again referring to Table 3.1, we can now determine the optimal level of investment in each technique where there is no budget constraint. Condition I is met only when 8 inches of insulation are installed in each location.

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[19] An exception to this will occur if there is some physical or cost constraint for a particular ECT, in which case its MS/MC ratio will remain above those of the other techniques. This will be discussed further in Section 3.2.

[20] Implicit in this assumption is a budget large enough to include first increments of both ECT's. If the budget falls short of this level, the entire budget will be allocated to that technique with the lower fixed cost.

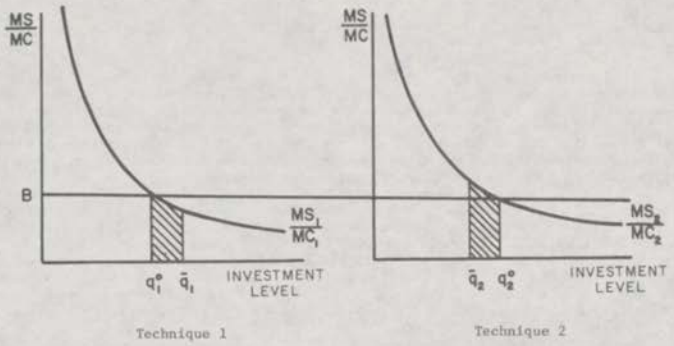

Figure 3.3 Violation of Condition II produces suboptimal results.

Table 3.1 Hypothetical Costs and Savings Due to Attic and Floor Insulation[1]

Inch	Cost/Ft.^{2}				Savings/Ft.^{2}	
	Attic		Floor		Attic = Floor	
	MC	TC	MC	TC	MS	TS
1	$.07	$.07	$.12	$.12	$1.50	$1.50
2	.02	.09	.02	.14	.50	2.00
3	.02	.11	.02	.16	.20	2.20
4	.02	.13	.02	.18	.10	2.30
5	.02	.15	.02	.20	.07	2.37
6	.02	.17	.02	.22	.05	2.42
7	.02	.19	.02	.24	.03	2.45
8	.02	.21	.02	.26	.02	2.47
9	.02	.23	.02	.28	.015	2.485

[1]Values are hypothetical as they will vary accordingly to climate, construction type, and market area. The marginal savings are the present value of the stream of dollar savings expected from each inch of insulation over its expected lifetime.

An important limiting assumption required of Condition II is that of the independence of the various ECT's included in the analysis. This means that the amount of energy savings generated by one technique cannot be influenced directly or indirectly by other ECT's, whether included in the model or not. (For example, setting back the thermostat will have some effect on the savings potential of all ECT's.) Where the savings generated by two or more techniques are interdependent, the model will give valid results provided that all interdependent techniques but the one to be examined are held constant at some level determined more or less outside the immediate analysis. (This can be done by an iterative approach if warranted.) While this may present some problems in a few instances, especially in building systems with a large number of potential ECT's and variable design parameters, the independence requirement is generally successfully met in the more limited applications found in residential retrofit. The more practical aspects of this assumption are discussed further in the following subsection.

3.2 Further Economic Considerations

A methodology for determining theoretically optimal levels of investment in energy conservation techniques has been presented. We now examine how well the model will perform in practical applications.

a. Discrete versus Continuous Investment Sizes

Up to this point, energy savings have been assumed to be generated by a continuously available range of investment levels for each technique.[22] In reality, no such continuity exists. Instead, energy conservation techniques are generally available in a finite number of sizes only. Furthermore, external constraints may limit the amount of any given technique that can be implemented. But this does not imply that feasible solutions are inefficient.

Insulation batts, as an example, come in a limited number of preformed sizes and shapes and may not conform to the exact amount of insulation specified in a continuous analysis. But in this discrete case the last available increment of insulation whose MS/MC ratio is closest to the optimal MS/MC ratio (without falling below it) provides the optimal "feasible" solution. This feasible solution is indeed optimal for in reality the marginal cost could be quite high for an increment that would exactly meet that level determined in a continuous analysis. This is because production and distribution costs associated with a very large number of sizes would be higher than that of a limited number of sizes.

Similar reasoning can be used in those cases where external constraints limit the use of a technique so that its MS/MC ratio cannot approach the continuously determined optimal level. A good example is insulation in walls. Most walls are limited to 3.5 inches of insulation by construction design, although more might be economically desirable if there were room for it. But the marginal cost of the next increment, given a 3.5" constraint, would be quite high since major redesign and reconstruction would be necessary. Again we have an optimal feasible solution.

b. Independence versus Interdependence of ECT's.

As discussed in subsection 3.1, independence of the various ECT's is required if the model is to be successfully used. It is important that we examine the ECT's considered in this study in order to determine how well they fit this assumption.

1) Reducing the thermostat setting in winter and raising it in summer will have a direct effect on the savings generated by all techniques, since the rate of heat transfer is a function of the inside-outside temperature differential. To the extent that a thermostat is set back in order to conserve energy per se, this new setting should be reflected in the calculations of energy savings. This may slightly reduce the optimal level of investment in other ECT's.[23] It should be noted, however, that in a well-insulated house the thermostat level may be reduced somewhat over that of a poorly insulated house, with no loss of comfort, due to draft reduction, a higher mean radiant temperature, and a more even distribution of heat thoughout the house. In this case, the savings due to the decreased thermostat setting should be internalized into the savings function. Since energy savings are the difference between energy use before and after retrofit, the original setting should be used to calculate previous energy use and the lower setting (if known) to calculate energy use after retrofit. (Marginal increments of insulation are unlikely to have any measurable effect on thermostat reduction, however, so that the lower temperature can be used in evaluating this last increment both before and after its use is considered.)

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[22] The methodology for estimating these energy savings will be discussed in Section 4.

[23] The reduction of a thermostat setting to reduce energy consumption in a well-insulated house will save considerably less energy than in a poorly-insulated house. For this reason thermostat setback may not be considered necessary from the standpoint of conservation in a well-insulated house.

2) The heat losses through the ceiling, walls, windows, floors, and doors are assumed independent in that a constant indoor temperature is assumed. While there may be some variation in temperature near these surfaces in a poorly-insulated house, these will approach the average room temperature as the house becomes better insulated, so that the accuracy of the calculations at the margin will be improved.

3) The effects of storm windows and weather stripping on air infiltration are certainly interdependent. However, by examining the effect of one while holding the other constant, the model will perform well. In this case storm windows can be considered as applied to weather stripped or nonweather-stripped windows. And weather stripping can be considered as being added to windows with or without storm windows. This same approach can be used for storm doors and weather stripping as well.

4) Savings generated by insulation around exposed heating and cooling ducts are sensitive to, among other variables, the amount of time which the furnace or air conditioner must operate in order to maintain the desired indoor temperature. As the house is better insulated this operating time will be shortened and therefore potential savings will decrease. For this reason the savings generated by duct insulation must be estimated after the investment levels in other ECT's have been determined and their effects on operation time evaluated. This will be discussed further in the section on duct insulation in Appendix A.

c. Local versus Global Optimal Solutions

Under certain conditions, it is possible that Condition I and Condition II might be met at several different levels as more of a given ECT is considered. This presents a problem in that while each of these levels may define a local optimum, where net savings are optimized in some local range, in general only one will be a global optimum, in that net savings are maximized for the entire range of application. It is important that under such circumstances the global optimum be identified.

Such a problem will not occur under the assumptions made earlier, where marginal savings decrease monotonically (i.e., at no point do marginal savings increase as more of any one technique is added), and at the same time marginal costs are constant or monotonically increasing. Under such conditions only one optimum will be found and it will be both a local and global solution.

While, in general, marginal savings meet this criterion, marginal costs sometimes behave differently. This is especially true of batt (or blanket) insulation. These batts are generally available in sizes from 2 to 6 inches thick, with installation charges being approximately the same for any size within this range. Each additional batt requires additional installation, however, giving rise to a marginal cost function similar to that in Figure 3.4. Under such conditions, Condition I (or II) might be met at several points, as shown in Figure 3.5, at 6 and 12 inches. The marginal cost of inches 7 and 8 rise above marginal savings so that a local optimal exists at the 6th inch. However, marginal costs fall and then rise again so that another local optimal exists at the 12th inch. A criterion is therefore needed for determining the globally optimal level.

We must examine the cumulative marginal costs and marginal savings between the 6th and 12th inches to determine if the sum of these marginal savings is greater than the sum of the marginal costs. Since these savings are indeed greater than costs, i.e., AEFG > ABCD in Figure 3.5, the additional 6 inches should be added and 12 inches is the global optimum. The criterion for determining the global optimum between two local optimum can be stated as follows: If the sum of the marginal savings (ΣMS) generated by the cummulative increments between the two local optima is greater than the sum of their marginal costs (ΣMC), the higher level is the global optimum. If $\Sigma MS < \Sigma MC$, the lower level is the global optimum. If $\Sigma MS = \Sigma MC$, both are equally preferable.

d. Present Value Determination

Since the appropriate investment size is a function of present value energy savings expressed in dollar terms, it is important that this present value be estimated as realistically as possible. But to do so requires knowledge of annual energy savings, energy prices now and in the years to come, discount rates, and the time period over which these dollar savings will accrue. Unfortunately, these are difficult to estimate accurately. Energy prices have risen sharply in the past year and it is estimated that they will continue to rise at rates which will vary from year to year and location to location. Homeowner discount rates, which are bounded on the lower side by the rate of return on alternative investments (opportunity cost) and on the upper side by the cost of borrowing[23], will vary from homeowner to homeowner. And the expected lifetime of the various modifications considered often depend on external conditions that are impossible to predict. Nevertheless, a general model can be formulated for estimating present value if one is willing to assume values for these variables.

[23] If the rate of return on investment (at the margin) is greater than the rate of interest for borrowing available for such investments, rational economic behavior would opt for borrowing, if funds for such investments were not otherwise available.

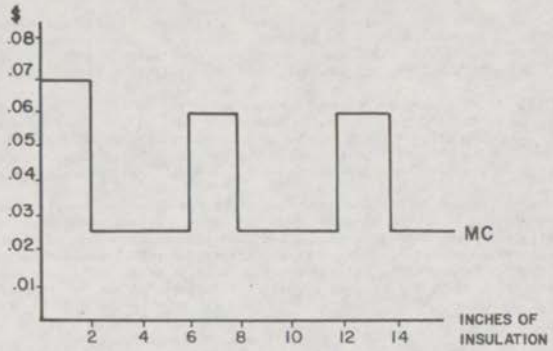

Figure 3.4 Marginal cost of batt insulation will increase when installation costs recur.

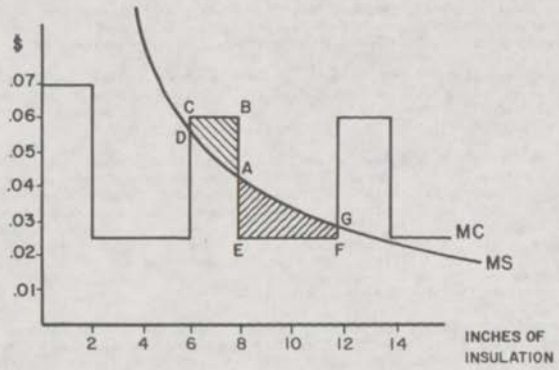

Figure 3.5 Net savings generated by the 9th through 12th inches are greater than net loss generated by the 7th and 8th inches.

Specifically, we are concerned with finding the present value of a stream of annual energy savings valued at (S) at today's energy prices, accruing over the lifetime (L) of the ECT. These energy savings, while constant in Btu terms, are growing in dollar terms because of price rises at some average annual rate (P). But at the same time these savings must be discounted to present value using an appropriate discount rate (D).

Thus present value can be expressed in terms of nominal (actual) price increases and discount rates as

$$P.V. = \sum_{t=1}^{L} \left(\frac{1 + P}{1 + D}\right)^{t} \cdot S. \qquad (3\text{-}5)$$

However, both price rises and discount rates are a function of two forces: a real rate of change (P' and D')[24] and the rate of inflation (I).[25] Because the I term appears (implicitly) in both the numerator and the denominator of equation (3-5), its effect cancels out,[26] leaving only the real terms to be estimated. This is of considerable value to us because the need to estimate the rate of inflation has been eliminated. Throughout the remainder of this report we will refer only to these real components, P' and D'. Equation 3-5 above then reduces to[27]

$$P.V. = \sum_{t=1}^{L} \left(\frac{1 + P'}{1 + D'}\right)^{t} \cdot S. \qquad (3\text{-}6)$$

Some discussion as to appropriate values for P', D', and L is now needed:

1) Estimates of projected rates of energy price increases for fossil fuels and electricity are available from several sources. Most of these are based on different sets of assumptions, however, and the estimates vary accordingly. While it is improbable that natural gas, fuel oil, and electricity will all increase in price at the same rate, it is difficult to predict relative changes with any accuracy now. A real rate of increase (over and above the rate of general inflation) of 1% for all energy sources is used in this study, based on the NBS draft proposal for "Design and Evaluation Criteria for Energy Conservation in New Buildings."[28] This may be considered conservative by some because of recent price increases many times this rate in some cases. This rate is meant to be representative of the long run rate of real price increases for the next 20 years, however, and in this respect it reflects price increases determined by long run market forces.

Although some energy prices, particularly those for electricity, have historically declined in real terms up until a few years ago, it is unlikely that such a pattern will continue before the end of the century for several reasons. First, environmental controls are growing stricter; second, more intensive extraction methods are now being used; third, many new oil fields are located in remote areas; and fourth, generating equipment and refining processes have been developed to the point where increasing their scale may no longer lower average cost significantly.

Controls on well-head prices for natural gas may be eased in the future, allowing natural gas prices to rise closer to their free-market level, which is substantially higher than current prices. Therefore, it may be wise to use a somewhat higher base price than currently being experienced when estimating the optimal investment level in energy conservation for natural gas heating.

2) Before estimating an "appropriate" discount rate for the "typical" homeowner, some insight into discount rates is needed.

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[24] Real energy price rises are due to those resources becoming scarcer relative to other resources, not inflation, which raises the nominal price of all resources. Real discount rates here refer to that rate of return required to attract an investment, apart from the need to recover purchasing power lost by inflation.

[25] When discrete (vs. continuous) compounding is used, $P = I + P' + I \cdot P'$ and $D = I + D' + I \cdot D'$

[26] This can be shown as follows:

$$\frac{1 + P}{1 + D} = \frac{1 + I + P' + I \cdot P'}{1 + I + D' + I \cdot D'} = \frac{(1 + P')(1 + I)}{(1 + D')(1 + I)} = \frac{1 + P'}{1 + D'}$$

[27] For ease of computation this can be expressed as

$$P.V. = \frac{1 + P'}{D' - P'} \left[1 - \left(\frac{1 + P'}{1 + D'}\right)^{L}\right] \cdot S \qquad D' \neq P' \quad (3\text{-}7a)$$

$$P.V. = L \cdot S \qquad D' = P' \quad (3\text{-}7b)$$

[28] U.S. Department of Commerce, National Bureau of Standards, February 27, 1974.

In order that energy conservation investments be considered in their proper economic priority, they must be compared with the next most profitable alternative investments available to homeowners after adjusting for risk, tax liabilities, and preference for short- over long-term investments. An appropriate discount rate will then reflect an "opportunity cost," i.e., the cost of foregone profit from the next best alternative. In this study the discount rate may also be viewed as the minimum rate of return needed to induce further investment in energy conservation.

It is quite important to note that returns on investment in ECT's are not subject to income taxation for homeowners as they arise from reduced expenditures of after-tax disposable income. (This is not true for enterprises because decreased costs imply increased, taxable, profits.) Therefore, for homeowners, alternative after-tax rates of return should be used in determining an appropriate discount rate for investments in energy conservation.

While such alternative investment opportunities will vary from homeowner to homeowner, the discount rate used in this study reflects rates of return from U.S. Government 3-5 year securities available between 1952 to 1970.[29] These securities represent low-risk investments available to homeowners and their rate of return is generally comparable to interest rates paid by regulated savings institutions. More importantly, the real rate of return over their lifetime (average of 4 years) could be tracked using the Consumer Price Index (CPI)[30] as the basis for the rate of inflation appropriate to the average homeowner.[31] This resulted in an average real rate of return of 1.6% before taxes (standard deviation = .75%) and an after-tax return of only .7% (25% tax on nominal returns). While these may be biased somewhat low because of index problems inherent in the CPI, they are representative of the magnitude of real rate of return on low-risk investments. Apparently these returns are quite small in comparison to nominal rates of return. For this reason a 1% real rate of return on investment may be sufficient to induce further homeowner investment into energy conservation. It might be noted that at the present rate of inflation it is quite difficult for the average homeowner to realize even this low real rate of return after taxes.

However, one must clearly understand that this is the potential rate of return to be realized at the margin, i.e., for the last increment of investment. The average annual rate of return on the total investment will usually be considerably higher, depending on the existing state of the house to be retrofitted. For example, where the addition of six inches of insulation will pay back its cost in three to five years or less, but continues generating savings over its entire lifetime, one can easily see that the actual rate of return on the total investment is quite high.

The marginal investment (that for the last increment) may also be viewed as requiring its full expected lifetime to be repaid (including interest at the discount rate). Each previous increment will take less and less time to be repaid, however, and the first increment may be paid back (in some cases) within a few months of retrofit. The average length of payback will then be considerably shorter than the expected lifetime, as can be seen by examining the tables in Section 5.

Because the marginal investment does require the full expected lifetime to be repaid, this may be considered a relatively long-term and illiquid investment (unless the house is sold before the last increment is completely amortized). For this reason such a marginal investment may not be as attractive to the homeowner as a short-term investment yielding the same rate of return. While the additional rate of return needed to induce such long-term investments may be somewhat higher than for a short-term invest-

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[29] Source: U.S. Department of Commerce, Social Economic Statistics Administration, Bureau of Economic Analysis, Business Statistics, 1972, p. 92.

[30] Ibid., p. 40.

[31] The following formula was used in computing the real after-tax rate of return, R, for each security issue in year t:

$$R_t = \frac{\left[(1 + r_t)^n - 1\right](1 - x) - 1\right]^{\frac{1}{n}}}{\prod_{t=1}^{n} (1 + I_t)} - 1$$

where R_t = real after-tax rate of return on investment for security bought in year t,

r_t = nominal interest rate of security issue purchased in year t,

I_t = inflation rate in year t,

n = lifetime of security, and

x = appropriate income tax bracket (in decimal form).

These real rates of return for the years 1952 to 1970 were then averaged to provide the 1.6% estimate before taxes and .67% after taxes.

ment, this difference is overshadowed by other considerations, especially the effect of high inflation rates on actual investment opportunities and the somewhat conservative estimate used in estimating the rate of fuel price increases.

A further note is required to cover the case of borrowing by the homeowner, where he may not have sufficient investment funds available for energy conservation improvements. In this case, the real discount rate should be no higher than his real cost of borrowing, recognizing that income tax credits from interest payments reduce the actual cost of borrowing and that he will be paying back cheaper dollars because of inflation. If the homeowner can borrow at 10% for home improvements[32] and he is in the 25% tax bracket, his nominal cost of borrowing is only 7.5%. If the rate of inflation is 7-8% over the life of the loan, the real rate of borrowing will actually approach zero, which is less than the real discount rate used here. Again a 1% real discount rate appears to be a reasonable assumption for marginal investments.

3) Since the real rate of fuel price increase has been considered equivalent to the homeowner's discount rate of 1%, the present value of future energy savings is simply the sum of these savings, at current prices, over the life of the specific ECT considered.[30] This, of course, leaves the estimated lifetime as a critical variable in the assessment of marginal savings generated by these various ECT's. For this reason we must now consider the appropriate lifetime over which energy conservation modifications to existing houses might be amortized. This is especially relevant to homeowners or prospective home buyers who do not foresee occupying their house long enough for the marginal investments (i.e., the cost of last increments of the various techniques) to be completely paid back in the form of energy savings.

As discussed in Section 2.1, there have been certain failures in the market for buildings to properly value energy conservation investments. Insufficient consumer information and a "first-cost - minimization philosophy" were cited as probable causes of this problem. As energy costs increase relative to other costs, however, and energy conservation rises in economic priority, these factors will diminish in effect. Energy consumers will become more conscious of the economic desirability of energy conservation and the market value of buildings will better reflect their energy usage (as reflected in fuel bills). In this respect a well-insulated house will be more likely to sell quickly and command a price higher than that of a poorly insulated home, making it considerably easier for a homeowner to recoup the unamortized portion of his investment if he is not intending to occupy the house throughout the lifetime of the ECT's.

Homeowners now have an increased incentive to invest in energy conservation modifications, for these investments can be more readily capitalized than in the past. It is not necessary that such expenditures be completely amortized in the length of time they expect to remain in the house. Investment decisions can more readily reflect the lifetime expectancy of the modifications.

While the expected useful lifetime of some ECT's, such as insulation may extend to the life of the building, any lifetime assumption over 20 years is likely to be unrealistic in view of large-scale uncertainties as to economic conditions beyond that time period, especially for energy prices. For this reason we conservatively chose 20 years as the appropriate time period for use in estimating the present value of future energy savings. When lifetime expectancies are clearly shorter than 20 years, as in the case of storm doors, more conservative lifetime estimates should be used.

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[32] This is approximately the FHA Title I rate available to homeowners for home improvements.

[33] See equation 3-7b in this subsection.

4. CALCULATION OF ENERGY SAVINGS

Estimation of BTU energy savings in this study are based largely on ASHRAE methodologies as found in the Handbook of Fundamentals.[35] While more sophisticated heating and air-conditioning load estimating methodologies are available, such as the NBS Load Determination (NBSLD) Program, the massive computational requirements of these programs, when applied to the large-scale computational requirements of this study, would have exceeded the available resources many times over.

4.1 Basic Assumptions

The general approach used in calculating heating and cooling loads and some important assumptions fundamental to the estimating process are presented in this section. The methodologies actually used in calculating these loads will be outlined in Appendix D.

Consistent with current ASHRAE procedures, degree days[36] below 65°F are used as the basis for heating loads, and summer cooling hours over 80°F are used for air-conditioning load requirements. While the degree day concept has been widely accepted as a useful determinant of annual heating loads, cooling hour estimates are not generally considered to be more than a rough approximation to the total air conditioning load. This latter methodology has been used before in similar studies,[37] however, and is used here because no better approximation, consistent with the large number of calculations required by this study, has been forthcoming.

Unlike much of the ASHRAE procedure, the purpose of these estimates is not to determine the heating and/or cooling load under design conditions for an entire building or for a zone within the structure in order to properly size heating and cooling equipment. Instead, we wish to estimate the net effect on the average yearly heating and cooling energy loads caused by a given change in the thermal resistance of a given envelope section. The most important assumption here is that the reduction of Btu losses or gains in any given envelope section has a corresponding effect on the reduction of the total heating or cooling load.

To the extent that such reductions in heat losses and gains are independent, as in the case of wall and ceiling insulation, the energy savings realized are additive. This is one of the basic assumptions on which the marginal analysis model is formulated. However, with some techniques these reductions are interdependent, as in the case of weather stripping together with storm windows and doors. In such cases one technique must be held constant while the other is varied. This latter approach is used on an ad hoc basis when dealing with such interdependent techniques in this study.

Furthermore, it is assumed that the marginal reduction of heating and cooling loads will have no significant effect on the efficiency of the mechanical heating and cooling system. In most cases overdesigned equipment may not be as efficient as properly-designed equipment. By reducing the Btu load in a residence with a fixed heating and cooling system we are in effect "creating" an overdesigned system. However, heating and cooling systems seldom operate under design (extreme) conditions. As a consequence, seasonal efficiencies for oil and gas fired furances generally range from 50 to 70%.[38] (Electric resistance heating units are considered to be 100% efficient regardless of utilization rate). At the margin there is unlikely to be a significant difference in the seasonal efficiency so that this should have little effect on optimal investment levels. The system efficiency used in the estimating procedure should reflect seasonal, rather than design, considerations.

4.2 Application of Marginal Analysis to Energy Conservation Techniques

Marginal analysis is particularly useful in evaluating energy conservation investments because savings generated by successive increments of most modifications generally decrease in magnitude and thus total savings are not proportional to investment size. This makes it quite difficult to determine optimal levels of investment without analyzing the savings and costs of each increment. As we have seen, marginal analysis gives us a consistent and straightforward approach to this problem.

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[35] ASHRAE, Handbook of Fundamentals, 1972

[36] Degree days are the sum of all average daily temperature differentials below 65°F over a year's time. A good correlation between this parameter and heating loads has been established over a long period of time.

[37] See J. C. Moyers, "The Value of Thermal Insulation in Residential Construction."

[38] See for instance, S. Stricker, "Measurement of Heat Output of Residential Furnaces," ASHRAE Transactions, Volume 76, Part II, 1970.

Decreasing marginal savings are most apparent where varying amounts of insulation are considered. The amount of heat which passes through a given section of insulation varies inversely with its depth. This results in smaller marginal energy savings generated by each additional inch.[39] Other energy conservation techniques may not be directly variable in increments in the same sense that insulation is. Some of these techniques can still benefit from the application of marginal analysis, however. Consider storm windows as an example: They come in a large range of sizes but vary little in cost up to a certain size (usually up to 100 united inches[40]). If each size window is ranked according to its savings/cost ratio, each window can be treated as a marginal investment and only those windows whose MS/MC ratio exceeds or equals the MS/MC ratio of other techniques is economically justifiable. This permits a great deal more flexibility in analyzing such techniques. Often storm windows have been found to be either economical or uneconomical, depending on climatic conditions or fuel costs. Now we may state that storm windows above a given size may be economical in certain areas even where storm windows on all windows may not be. As the climate grows more severe, or fuel prices increase, smaller and smaller windows will become cost effective. This will be demonstrated in the data generated in Section 5.

4.3 Measurement of Marginal Savings

There are three basic mechanisms through which heat transfer contributes to the heating and cooling loads of a building:

1) Conduction, or the flow of heat through mass in the direction of decreasing temperature.
2) Convection, or the flow of heat carried by a dynamic medium such as infiltrating air.
3) Radiation, or electromagnetic energy transmission which is converted to heat at its point of termination or absorption.

The retrofitting techniques considered in this study can effect direct reductions in the first two factors and indirectly reduce loads caused by the third. Solar shading is generally the most effective way to reduce radiation heat gain, especially through windows.

Hourly conductive heat losses and gains can be estimated using the following relationship:

$$H_{ch}/A = U \cdot (t_i - t_o), \qquad (4\text{-}1)$$

where H_{ch} = hourly conductive Btu heat loss ($t_i > t_o$) or heat gain ($t_o > t_i$);

U = coefficient of conductance (Btu's per hour per square foot per degree Fahrenheit temperature difference (Btuh ft^{-2} F^{-1});

A = area in square feet (ft^2);

t_i = average inside air temperature; and

t_o = average outside air temperature.

As the thermal resistance (R) of an envelope section is increased, the thermal conductance (U) decreases in inverse proportion ($U = 1/R$), reducing the thermal load resulting from that section. The marginal Btu savings (ΔH_{ch}) due to the increase in resistance is then given by

$$\Delta H_{ch}/A = (U_1 - U_2) \cdot (t_i - t_o) \qquad (4\text{-}2)$$

where U_1 = thermal conductance before R is increased,

U_2 = thermal conductance after R is increased.

Annual heating loads are found by taking the sum of the differences between inside and outside daily average temperatures (where $t_i > t_o$) during an annual heating season. When t_i is equated to 65°F, the degree day methodology for computing annual heating loads is consistent with the methodology outlined above:[41]

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[39] However, energy savings may still be significant. Every time that the total resistance of a thermal barrier is doubled, heat transfer through that barrier is halved.

[40] "United inches" equal height plus width in inches.

[41] Degree days are based on 65°F rather than 70°F as the 5°F temperature differential is considered to be provided by small solar radiation gains and internal heat sources other than direct heating and should therefore not be reflected in direct energy savings. For this reason all energy saving calculations, while reflecting a 70°F inside temperature, are based on 65°F.

$$H_{ca}/A = U \cdot DD \cdot 24, \quad (4\text{-}3)$$

where H_{ca} = annual Btu conductive heating load,

DD = annual degree days, and

24 = hours per day.

Annual cooling loads are found by using the average temperature difference between the inside and outside surface of the envelope section during the cooling hours.

$$C_{ca}/A = U \cdot CH \cdot (t_o - t_i), \quad (4\text{-}4)$$

where C_{ca} = annual Btu conductive cooling load, and

CH = annual cooling hours over 80°F

t_o = average outside temperature during cooling hours (sol air temperature equivalents used where appropriate.)

Marginal annual heating and cooling savings generated at any given envelope section are simply the difference between the loads before and after the last increment of thermal resistance is added.

Heating and cooling loads due to air infiltration in buildings are primarily a function of the cubic feet of air entering per hour and the temperature difference between the inside and outside air.

Direct reductions in these loads can be produced by installation of storm windows, storm doors and weather stripping. These loads are made up of two components, sensible heat and latent heat. Sensible heat loss (gain) is equivalent to the number of Btu required to heat (cool) the air, which enters by infiltration, to desired room temperature.

$$H_{sh} = 0.24 \cdot Q \cdot \rho \cdot (t_i - t_o), \quad (4\text{-}5)$$

where H_{sh} = sensible hourly Btu load,

0.24 = specific heat of air,

Q = volume of infiltrating air in cubic feet per hour,

ρ = density of air at t_o, pounds per cubic foot (≈ .075),

t_i = inside average air temperature, and

t_o = outside average air temperature.

The latent heat load is the Btu requirement for adding or removing moisture from the air. In winter this load is due chiefly to a humidifier, which is not considered in this study. In the summer this load is a complex function of humidity and internal moisture loads which are removed by the air conditioner. Because of the limited ability of home air conditioners to remove moisture from the air, it is not clear whether or not marginal decreases in infiltration will decrease the actual amount of latent heat removed. This is especially true where smaller equipment or less frequent utilization of equipment results from reduced sensible heat loads. For these reasons latent heat loads will not be considered in this study.

Degree days are utilized in estimating annual infiltration heat loads as well, so that the annual heat load due to infiltration (H_{sa}) is expressed by:

$$H_{sa} = 0.24 \cdot Q \cdot \rho \cdot DD \cdot 24, \quad (4\text{-}6)$$

and annual cooling load due to convection (C_{sa}) is expressed by

$$C_{sa} = 0.24 \cdot Q \cdot \rho \cdot CH \cdot (t_o - t_i). \quad (4\text{-}7)$$

Marginal heating and cooling loads are calculated using the difference between the infiltration rate before retrofit and after retrofit at any point in the building envelope.

The amount of fuel saved by increasing the thermal resistance or decreasing the rate of infiltration is a function of the load reduction, the Btu content of the fuel, and the efficiency of the mechanical equipment. The following Btu fuel contents were used in this study:

Natural gas = 100,000 Btu per therm,

#2 Heating Oil = 140,000 Btu per gallon, and

Electric Heating = 3,413 Btu per kWh.

Heating system efficiencies are typically between 50 to 70% for natural gas and fuel oil and 100% for electrical resistance heating. Air conditioners generally provide 6000-8000 Btu per kWh, having a coefficient of performance (COP) of approximately 2.

Annual marginal heating fuel savings (ΔF_h) are then estimated using

$$\Delta F_h = \frac{\Delta H_{ca} + \Delta H_{sa}}{B_h \cdot E_h} \tag{4-8}$$

where ΔH_{ca} = marginal annual Btu conductive heating load reduction,

ΔH_{sa} = marginal annual Btu infiltration heating load reduction.

B_h = Btu content per unit of heating fuel, and

E_h = efficiency of heating system.

Annual marginal cooling energy savings (ΔF_c) are estimated using

$$\Delta F_c = \frac{\Delta C_{ca} + \Delta C_{sa}}{3413\ \phi_c} \tag{4-9}$$

where ΔC_{ca} = marginal annual Btu conductive cooling load reduction,

ΔC_{sa} = marginal annual Btu infiltration cooling load reduction,

3414 = Btu per kWh

ϕ_c = Coefficient of performance

Algorithms for evaluating heat losses and heat gains from specific section of the building envelope are treated in Appendix D.

Annual marginal dollar savings (S) are then equivalent to $\Delta F_h \cdot P_1 + \Delta F_c \cdot P_2$, where

P_1 = price per unit of heating energy, and

P_2 = price per unic of cooling energy.

5. DISCUSSION OF RESULTS

5.1 General Observations

Using the general methodology outlined in Section 4 along with specific methodologies for the various techniques considered, as outlined in Appendix D, energy savings in eight different climatic regions were estimated for each inch of insulation up to 30 inches in attics, 10 inches below floors, 3.5 inches in walls, and 10 inches around exposed ducts, as well as for storm doors, storm windows, and weather stripping. These latter cases included savings generated by both loose and average fitting weather-stripped windows and doors.

The estimates generated using this methodology are based on a typical wood-frame residential structure.[1] However, the results are typical of a wide variety of construction types, with the exception of solid brick or masonry walls, slab floors on grade, and ceiling/roof systems with no attic space for additional insulation, in the cases of wall, floor, and attic insulation respectively. Again, insulation estimates are applicable only where no structural modifications are necessary.

Optimal combinations of ECT's have been estimated for five climatic regions ranging from 2,000 degree days to 10,000 degree days with no cooling requirements and for three regions with 500 to 1,500 cooling hours in addition to heating requirements. Although these regions are not typical of all U.S. climates, they represent a broad range of climatic conditions into which most housing requiring significant retrofitting can be interpolated.

In addition, these combinations were estimated for a wide range of current energy prices, enabling the reader to see the effect of these prices on the optimal levels of ECT investments determined as optimal. Note that the energy prices (including efficiency adjustments) used for heating fuels are varied by a factor of ten, i.e., from $.15 per 100,000 Btu, representative of low-priced natural gas to $1.50 per 100,000 Btu, representative of relatively high priced electric resistance heating. Cooling energy costs vary only by a factor of two because only electric energy is considered. (In addition, summer kWh costs are assumed to be $.01 greater than winter kWh costs due to higher peak loading charges.) At the same time climatic conditions are varied by a maximum factor of five (2000 to 10,000 degree days). The paired heating and cooling energy costs shown are meant to be representative of frequently encountered price relationships. In some cases, where cooling requirements are present, the cooling energy costs corresponding to the heating energy costs shown may be substantially different. In this case some judgment will be needed in interpreting the tables or the model will have to be rerun for the actual prices encountered.

ECT costs, on the other hand, were held constant at representative mid-1974 price levels because these costs vary little compared to climate factors and energy prices. The costs actually used are listed in Appendix B. These include an allowance for commercial installation except in the cases of weather stripping and duct insulation (for reasons discussed in Appendix A).

Tables 5.2A through 5.2H contain the tabularized results of this study for the ECT's considered, based on a lifetime expectancy of 20 years for all but storm doors and weather stripping, for which 10 years may be considered more appropriate. This in effect limits the payback period of the last increment of any technique to 20 years (or 10 where appropriate) although the payback period for the total investment may be as low as one year in some cases. Techniques which have an "all or nothing" application, such as blown-in wall insulation, may take up to 20 years to pay back completely in this case. It should be remembered that this payback includes an after-tax-equivalent annual dividend equal to the actual rate of energy price increases so that it is very likely equal to or better than most other low risk investments available to homeowners. After 20 years all savings are free and clear in these extreme cases.

Before examining these tables more closely, several general observations should be made:

1) Each table lists seven combinations of ECT's for a given climatic zone which are economically balanced in the sense that the MS/MC ratio is equal at the margin for each technique within a given combination (except where limited by physical constraints). More importantly, each combination is optimal at the indicated heating and cooling energy prices in the sense that MC = MS. Therefore dollar savings are maximized when the combination chosen reflects the energy prices encountered at the building site. However, any combination within a given climate will maximize dollar savings per dollar invested. This is important because these other combinations can serve as a guide to those who do not wish to invest up to the point where MS = MC but wish to maximize the return on the dollars that they do invest. In essence this implies that significant departure from these combinations will produce suboptimal results given that there are no physical constraints in the relevant range, and structural conditions and costs of retrofitting are similar to those assumed.

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[1] Walls and roof are assumed unshaded; doors assumed shaded.

2) It is important to note that, while fixed costs may vary, relatively similar marginal costs will give rise to these same optimal combinations of techniques. Thus in cases involving insulation, where installation charges are approximately constant over a given rnage of application (say from 2 to 6 inches), leaving marginal costs equal to incremental materials cost within that range, the optimal level of application will be the same whether it is commercially installed or installed by the homeowner himself, provided, of course, that the total cost (installation and materials costs) are not greater than total savings. Payback periods, however, may be considerably shortened if the homeowner installs these ECT's himself.

3) These estimates were derived using an annual discount rate representing a rate of return at the margin equal to the best alternative use of the marginal investment funds available to the average homeowner. The real discount rate used (1% compounded annually) is equivalent to the real assumed rate of energy price increases (1% compounded annually) over the appropriate lifetime (20 years).

4) These optimal investment levels are not based on an assumed building size or configuration.[41] Insulation levels were determined by examining the thermal transfer through a single square foot of the appropriate envelope section. Doors and windows were analyzed as discrete entities. Weather stripping was examined per foot of crack length. Thus these optimal levels, where applicable, are appropriate to any building size or design; however the payback period for the total retrofitting investment will be a weighted average of the payback periods for each ECT used. The weighting factors will be the percent of the total retrofitting investment applied to each ECT. In essence this means that the average payback period will vary from house to house, even in the same climate and fuel price market, because of design differences and the degree to which the various envelope sections require energy conservation modifications.

5) The energy savings on which these optimal combinations of ECT's are based were calculated assuming an average indoor temperature of approximately 70°F during winter heating and 75°F during summer cooling.[42] Higher average temperatures during the winter and lower average temperatures during the summer will result in higher levels of ECT investment; the reverse will lower these levels. The amount of change will vary from region to region, varying as a function of the percent change in the indoor-outdoor temperature differential.

6) Infiltration reductions due to weather stripping and storm windows and doors are subject to considerable variation depending on the actual leakage conditions of the primary windows and doors. Payback period for storm windows include an allowance for reduction of infiltration. Due to the wide variation in potential energy savings from weather stripping as well as the wide variation in costs, no payback periods for weather stripping are presented. Calculations using the ASHRAE crack methodology for estimating infiltration around windows and doors, as outlined in Appendix D, together with costs of materials based on $.15 per linear foot, show this ECT to be economically justified in all cases where a 20-year life is assumed. Where a 10-year life is assumed all but average fitting windows (or windows with existing storm windows) in the mildest climates with low fuel prices ($.15-.30 per therm output) are cost effective. Weather-stripping materials are available at costs considerably below $.15 per linear foot, however, so that this technique is considered cost effective in all climates and for all fuel prices.

7) The appropriate unit energy cost to use with the following tables is that rate, including all taxes and surcharges, at which the last unit saved by retrofitting would have been purchased. For natural gas and electricity, cost per unit often decreases as more is used per month. (Summer rates for electric power increase after a certain level of consumption in many areas now.) For this reason average costs for these fuels may not be representative of the cost per unit saved. Homeowners should request detailed price schedules from their utility companies which list the prices actually charged by "block" of fuel use, making sure that this includes all relevant taxes and surcharges, in order to determine the proper unit energy prices to use with these tables.

The cost per unit of fuel can be converted to cost per 100,000 Btu output (i.e., after efficiency considerations are made) using Table 5.1. Fuel costs equivalents are shown for a range of utilization efficiencies for gas and oil furnaces and electric resistance heating as well as for typical seasonal equivalent coefficients of performance (COP) for heat pumps and air conditioners. Cost per 100,000 Btu output is calculated for gas, oil, and electric resistance heating as follows:

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[41] Attic, crawlspace, and basement temperatures were calculated using a fixed-size house. Such temperatures are meant to be an average, however, and as such, representative of all such unheated areas.

[42] These temperatures were selected because the best data available for thermal load calculations are based on them. This study in no way suggests that they are appropriate thermostat settings for the homeowner.

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$$\text{Cost/100,000 Btu} = \frac{100{,}000 \text{ Btu}}{\text{(Btu content/unit) x efficiency}} \text{ x \$/unit.}$$

For heat pumps and electric air conditioners use:

$$\text{Cost/100,000 Btu} = \frac{100{,}000 \text{ Btu}}{\text{3413 Btu/kWh x COP}} \text{ x \$/KWH}$$

8) The effects of differential ECT marginal costs on optimal investment levels can be simulated by changing energy costs for any or all techniques. Because marginal/savings (MS) are directly proportional to energy prices, any percentage change in energy price will result in a corresponding percentage change in MS.

Since

$$\frac{MS/a}{MC} = \frac{MS}{aMC} = 1, \qquad \text{(Condition I met for new MC)}$$

where a = the adjustment factor for marginal cost, such adjustments can be simulated by dividing the appropriate energy price by this adjustment factor. This adjusted energy price can be used as a "reference" energy price for finding the optimal level of investment in the ECT under examination.[43]

As an example, consider the case of insulation used for winter heating savings (no cooling load) with a fuel priced at $.45/100,000 Btu delivered (efficiency considerations accounted for). Suppose that the variable costs of such insulation were raised by 10% (an adjustment factor of 1.1) over the costs shown in Appendix B. In this case a reference energy price of $.41 (.45/1.1) will simulate the effect of the cost differential. Note that relatively small changes in ECT costs (<20%) will have small practical effects on the optimal levels of investment.

5.2 Tabular Results

Tables 5.2A through 5.2H present the estimates of optimal energy conservation combinations for a variety of climates and a wide range of energy prices. In the case of attic and wall insulation, several insulating materials are examined: loose fill glass fiber (R-2.2 per inch), glass fiber batt/blanket (R-3.1 per inch), and loose fill cellulose (R-3.7 per inch in attics and R-3.3 per inch in walls). Insulation in ceiling and floors is examined in the case of no existing insulation and for an existing R-11 base (equivalent to 3.5 inches of glass fiber batt/blanket). Walls are assumed uninsulated; if any insulation exists, blown-in insulation is not practical and unlikely to be cost effective. Duct wrap for insulating heating and cooling ducts in unheated areas is examined. Insulation should be raised to the level shown. (Duct connections should be retaped first, if necessary). Data shown are for ducts in attic spaces. For crawlspaces, garages or unheated basements, the duct estimates for winter degree days only will provide a better guide than those tables showing both heating and cooling requirements.

Minimum storm window sizes that appear cost effective are shown in the tables; sizes 2' x 2' through 4' x 6' were examined for both loose and average fitting, weather-stripped, double-hung, wood-frame prime windows. Results do not appear to vary significantly for these two types of windows once weather stripped. Savings from storm windows over casement windows and fixed (non-openable) windows may be similar as well.

Payback periods are shown for a 3' x 5' window in order to give some indication of the payback period for average size windows. Both winter heating and summer cooling savings are considered.

Storm doors, on the other hand, are considered for winter heating savings only (screen inserts are generally more useful for natural ventilation during the non-heating months.) Energy savings due to the use of storm doors are based on an assumed wooden, weather-stripped prime door, 1.5" thick, size 3' x 6'8", with glass composition ranging from 0 to 50%. Again both loose and average fitting units were examined and found to be similar in savings potential. Results shown are for average fitting prime doors. Prime doors with window sections lose more heat than solid doors under similar thermal loading conditions so that energy savings generated by storm doors increase as the percentage of glass in the prime door increases. In some cases the application of storm doors to prime doors with glass components will be cost effective even while application to solid doors is not. (In Tables 5.2A-H, applications of storm doors which appear to be economical are marked with an x followed by the minimum percentage of glass in the prime door that makes their use justifiable from an economic standpoint.)

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[43] This will not provide exact solutions in those tables (5.2 F-H) which involve both heating and cooling loads because the two sets of energy prices used are not strictly proportional. Note that only changes in variable costs need be adjusted for; changes in fixed costs will have no effect on optimal levels unless they are so high as to eliminate all net savings.

Table 5.1

FUEL COSTS NORMALIZED TO 100,000 Btu OUTPUT

A. HEATING

Cost per 100,000 Btu delivered		$0.15	$0.30	$0.45	$0.60	$0.90	$1.20	$1.50
1. Natural gas (100,000 Btu/therm)								
$/therm	a. 50% efficiency	.075	.15	.23	.30	.45	----	----
	b. 70% efficiency	.105	.21	.32	.42	.63	----	----
2. #2 fuel oil (140,000 Btu/gallon)								
$/gallon	a. 50% efficiency	.105	.21	.32	.42	.63	----	----
	b. 70% efficiency	.15	.30	.44	.59	.89	----	----
3. Electric Resistance (3413 Btu/kWh)								
$/kWh	100% efficiency	.005	.01	.015	.02	.03	.04	.05
4. Electric Heat Pump (6826 Btu/kWh)								
$/kWh seasonal COP=2 (EER=6.826)		.01	.02	.03	.04	.06	.08	.10

B. Cooling

Cost per 100,000 Btu removed	$0.45	$0.45	$0.45	$0.45	$0.60	$0.75	$0.90
1. Air Conditioner (6826 Btu/kWh)							
$/kWh COP=2 (EER=6.826)	.03	.03	.03	.03	.04	.05	.06

Table 5.2A

OPTIMAL ENERGY CONSERVATION COMBINATIONS

2000 Degree Days; 0 Cooling Hours. (– Avg. t_0); 20 Year Life

ELEMENT	ATTIC						WALL		FLOOR Over Unheated Area[1]		EXPOSED DUCTS Equipment Operational Time for Average Loading Conditions 20% 30% 40%			ENERGY PRICES Dollar Cost per 100,000 Btu's Delivered/Removed		ELEMENT	STORM WINDOWS[2] (Triple Track)	STORM DOORS[3]
Existing Insulation	None			R-11*			None		None	R-11*	None			Heating	Cooling			
Material Used	A	B	C	A	B	C	B	C	B		D	D	D					
Additional Inches	3"	4"	2"	0	0	0	3"	0	0	0	2"	2"	3"	$.15	$.45		0	0
Years to Pay Back	(19)	(15)	(18)	(0)	(0)	(0)	(11)	(0)	(0)	(0)	(3)	(2)	(2)			Years to Pay Back	(0)	(0)
Additional Inches	4"	4"	3"	0	0	0	3"	0	0	0	3"	4"	4"	$.30	$.45		4' x 5'	0
Years to Pay Back	(10)	(8)	(10)	(0)	(0)	(0)	(6)	(0)	(0)	(0)	(2)	(2)	(2)			Years to Pay Back	(23)	(0)
Additional Inches	6"	6"	4"	0	0	0	3.5"	3.5"	0	0	4"	4"	5"	$.45	$.45		3' x 4'	0
Years to Pay Back	(8)	(7)	(8)	(0)	(0)	(0)	(4)	(17)	(0)	(0)	(2)	(1)	(1)			Years to Pay Back	(15)	(0)
Additional Inches	7"	6"	4"	0	4"	0	3.5"	3.5"	0	0	4"	5"	6"	$.60	$.45		3' x 3'	0
Years to Pay Back	(7)	(5)	(6)	(0)	(17)	(0)	(3)	(13)	(0)	(0)	(2)	(1)	(1)			Years to Pay Back	(12)	(0)
Additional Inches	9"	10"	6"	4"	4"	3"	3.5"	3.5"	4"	0	5"	6"	7"	$.90	$.60		2' x 3'	0
Years to Pay Back	(5)	(5)	(5)	(16)	(10)	(15)	(2)	(9)	(16)	(0)	(1)	(1)	(1)			Years to Pay Back	(8)	0
Additional Inches	11"	10"	7"	6"	6"	4"	3.5"	3.5"	4"	0	6"	7"	9"	$1.20	$.75		2' x 3'	0
Years to Pay Back	(5)	(4)	(5)	(13)	(10)	(13)	(2)	(7)	(12)	(0)	(1)	(1)	(1)			Years to Pay Back	(6)	(0)
Additional Inches	12"	10"	8"	7"	6"	5"	3.5"	3.5"	6"	0	7"	8"	10"	$1.50	$.90		2' x 2'	0
Years to Pay Back	(4)	(3)	(4)	(11)	(8)	(11)	(2)	(5)	(11)	(0)	(1)	(1)	(1)			Years to Pay Back	(5)	(0)

*Equivalent to 3½" of Glass Fiber Batt/Blanket Insulation

A – Loose Fill Glass Fiber (R-2.2 per inch)

B – Glass Fiber Batt/Blanket (R-3.1 per inch) (not applicable to finished walls)

C – Loose Fill Cellulose Fiber (R-3.7 per inch in attic/R-3.3 per inch in walls)

D – Glass Fiber Duct Wrap (R-4 per inch)

1. Floor Over Unheated Basement, Crawlspace, or Garage
2. Minimum Economical Size; Payback for 3'x5' Storm Window
3. Refers to Minimum Glass Composition of Primary Door That Makes Storm Door Economical (10 year life)

Table 5.28

OPTIMAL ENERGY CONSERVATION COMBINATIONS

4000 Degree Days ; 0 Cooling Hours. t_i - Avg t_o|; 20 Year Life

ELEMENT	ATTIC						WALL		FLOOR Over Unheated Area[1]		EXPOSED DUCTS Equipment Operational Time for Average Loading Conditions 20% 30% 40%			ENERGY PRICES Dollar Cost per 100,000 Btu's Delivered/Removed		ELEMENT	STORM WINDOWS[2] (Triple Track)	STORM DOORS[3]
Existing Insulation	None			R-11*			None		None	R-11*	None			Heating	Cooling			
Material Used	A	B	C	A	B	C	B	C	B		D	D	D					
Additional Inches	5"	4"	3"	0	0	0	3"	0"	4"	0	2"	3"	3"	$.15	$.45	Years to Pay Back	4' x 5'	0
Years to Pay Back	(8)	(6)	(8)	(0)	(0)	(0)	(6)	(0)	(14)	(0)	(3)	(2)	(2)				(23)	(0)
Additional Inches	7"	6"	5"	0"	4"	0"	3.5"	3.5"	4"	0	3"	4"	5"	$.30	$.45	Years to Pay Back	3' x 3'	0
Years to Pay Back	(5)	(4)	(5)	(0)	(17)	(0)	(3)	(13)	(7)	(0)	(2)	(2)	(1)				(12)	(0)
Additional Inches	9"	10"	6"	4"	4"	3"	3.5"	3.5"	6"	4"	4"	5"	6"	$.45	$.45	Years to Pay Back	2' x 3'	0
Years to Pay Back	(4)	(4)	(4)	(13)	(10)	(13)	(2)	(9)	(6)	(20)	(2)	(1)	(1)				(8)	(0)
Additional Inches	11"	10"	7"	6"	6"	5"	3.5"	3.5"	6"	4"	5"	6"	7"	$.60	$.45	Years to Pay Back	2' x 3'	0
Years to Pay Back	(4)	(3)	(4)	(13)	(10)	(12)	(2)	(7)	(4)	(15)	(1)	(1)	(1)				(6)	(0)
Additional Inches	13"	12"	9"	9"	10"	6"	3.5"	3.5"	10"	6"	6"	7"	8"	$.90	$.60	Years to Pay Back	2' x 2'	0
Years to Pay Back	(3)	(2)	(3)	(10)	(8)	(10)	(1)	(5)	(4)	(11)	(1)	(1)	(1)				(4)	(0)
Additional Inches	16"	16"	10"	11"	12"	7"	3.5"	3.5"	10"	6"	7"	8"	10"	$1.20	$.75	Years to Pay Back	2' x 2'	x/40¢
Years to Pay Back	(3)	(2)	(2)	(9)	(7)	(8)	(1)	(4)	(3)	(8)	(1)	(1)	(1)				(3)	(10)
Additional Inches	18"	16"	11"	13"	12"	8"	3.5"	3.5"	10"	6"	8"	9"	10"	$1.50	$.90	Years to Pay Back	2' x 2'	x/20¢
Years to Pay Back	(2)	(2)	(2)	(8)	(6)	(7)	(1)	(3)	(3)	(7)	(1)	(1)	(1)				(3)	(10)

*Equivalent to 3½" of Glass Fiber Batt/Blanket Insulation

A – Loose Fill Glass Fiber (R-2.2 per inch)

B – Glass Fiber Batt/Blanket (R-3.1 per inch) (not applicable to finished walls)

C – Loose Fill Cellulose Fiber (R-3.7 per inch in attic/R-3.3 per inch in walls)

D – Glass Fiber Duct Wrap (R-4 per inch)

1. Floor Over Unheated Basement, Crawlspace, or Garage
2. Minimum Economical Size. Payback for 3'x5' Storm Window
3. Refers to Minimum Glass Composition of Primary Door That Makes Storm Door Economical (10 year life)

Table 5.2C

OPTIMAL ENERGY CONSERVATION COMBINATIONS

6000 Degree Days ; 0 Cooling Hours, (~ Avg t_0); 20 Year Life

ELEMENT	ATTIC						WALL		FLOOR Over Unheated Area[1]	EXPOSED DUCTS Equipment Operational Time for Average Loading Conditions 20% 30% 40%			ENERGY PRICES Dollar Cost per 100,000 Btu's Delivered/Removed		ELEMENT	STORM WINDOWS[2] (Triple Track)	STORM DOORS[3]
Existing Insulation	None			R-11*			None		None R-11*	None							
Material Used	A	B	C	A	B	C	B	C	B	D	D	D	Heating	Cooling			
Additional Inches	6"	6"	4"	0	0	0	3.5"	3.5"	4" 0	3"	3"	4"	$.15	$.45		3' x 4'	0
Years to Pay Back	(6)	(5)	(6)	(0)	(0)	(0)	(4)	(17)	(8) (0)	(3)	(2)	(2)			Years to Pay Back	(15)	(0)
Additional Inches	9"	10"	6"	4"	4"	3"	3.5"	3.5"	6" 4"	4"	5"	5"	$.30	$.45		2' x 3'	0
Years to Pay Back	(4)	(4)	(4)	(15)	(10)	(15)	(2)	(9)	(5) (10)	(2)	(2)	(1)			Years to Pay Back	(8)	(0)
Additional Inches	11"	10"	7"	7"	6"	4"	3.5"	3.5"	10" 4"	5"	6"	7"	$.45	$.45		2' x 2'	0
Years to Pay Back	(3)	(2)	(3)	(12)	(8)	(11)	(2)	(6)	(5) (12)	(2)	(1)	(1)			Years to Pay Back	(5)	(0)
Additional Inches	14"	12"	9"	9"	10"	6"	3.5"	3.5"	10" 6"	6"	7"	8"	$.60	$.45		2' x 2'	0
Years to Pay Back	(3)	(2)	(3)	(10)	(8)	(10)	(1)	(5)	(4) (10)	(1)	(1)	(1)			Years to Pay Back	(4)	(0)
Additional Inches	17"	16"	11"	12"	12"	8"	3.5"	3.5"	10" 6"	7"	8"	9"	$.90	$.60		2' x 2'	x/30%
Years to Pay Back	(2)	(2)	(2)	(8)	(6)	(8)	(1)	(3)	(3) (7)	(1)	(1)	(1)			Years to Pay Back	(3)	(10)
Additional Inches	20"	18"	12"	15"	16"	10"	3.5"	3.5"	10" 6"	8"	9"	10"	$1.20	$.75		2' x 2'	x/10%
Years to Pay Back	(2)	(2)	(2)	(7)	(6)	(7)	(1)	(2)	(2) (5)	(1)	(1)	(1)			Years to Pay Back	(2)	(10)
Additional Inches	22"	18"	14"	18"	18"	11"	3.5"	3.5"	10" 6"	8"	10"	10"	$1.50	$.90		2' x 2'	x/0%
Years to Pay Back	(2)	(2)	(2)	(6)	(5)	(6)	(1)	(2)	(2) (4)	(1)	(1)	(1)			Years to Pay Back	(2)	(10)

*Equivalent to 3½" of Glass Fiber Batt/Blanket Insulation

A – Loose Fill Glass Fiber (R-2.2 per inch)

B – Glass Fiber Batt/Blanket (R-3.1 per inch) (not applicable to finished walls)

C – Loose Fill Cellulose Fiber (R-3.7 per inch in attic/R-3.3 per inch in walls)

D – Glass Fiber Duct Wrap (R-4 per inch)

1. Floor Over Unheated Basement, Crawlspace, or Garage
2. Minimum Economical Size; Payback for 3'x5' Storm Window
3. Refers to Minimum Glass Composition of Primary Door That Makes Storm Door Economical (10 year life)

Table 5.2D

OPTIMAL ENERGY CONSERVATION COMBINATIONS

8000 Degree Days ; 0 Cooling Hours, t = Avg. t_0 ; 20 Year Life

ELEMENT	ATTIC						WALL		FLOOR Over Unheated Area[1]		EXPOSED DUCTS Equipment Operational Time for Average Loading Conditions 20% 30% 40%			ENERGY PRICES Dollar Cost per 100,000 Btu's Delivered/Removed		ELEMENT	STORM WINDOWS[2] (Triple Track)	STORM DOORS[3]
Existing Insulation	None			R-11*			None		None	R-11*	None			Heating	Cooling			
Material Used	A	B	C	A	B	C	B	C	B		D	D	D					
Additional Inches	7"	6"	5"	0"	4"	2"	3.5"	3.5"	6"	0"	3"	3"	4"	$.15	$.45		3' x 3'	0
Years to Pay Back	(5)	(3)	(5)	(0)	(16)	(20)	(3)	(13)	(7)	(0)	(2)	(2)	(2)			Years to Pay Back	(12)	(0)
Additional Inches	11"	10"	7"	6"	6"	4"	3.5"	3.5"	10"	4"	4"	5"	6"	$.30	$.45		2' x 3'	0
Years to Pay Back	(3)	(3)	(3)	(13)	(9)	(12)	(2)	(7)	(5)	(12)	(2)	(1)	(1)			Years to Pay Back	(6)	(0)
Additional Inches	14"	12"	9"	9"	10"	6"	3.5"	3.5"	10"	6"	5"	6"	7"	$.45	$.45		2' x 2'	0
Years to Pay Back	(3)	(2)	(3)	(10)	(8)	(10)	(1)	(5)	(3)	(10)	(1)	(1)	(1)			Years to Pay Back	(4)	(0)
Additional Inches	16"	16"	10"	11"	12"	7"	3.5"	3.5"	10"	6"	6"	7"	8"	$.60	$.45		2' x 2'	x/40%
Years to Pay Back	(2)	(2)	(2)	(9)	(7)	(8)	(1)	(4)	(3)	(7)	(1)	(1)	(1)			Years to Pay Back	(3)	(10)
Additional Inches	20"	18"	13"	15"	16"	10"	3.5"	3.5"	10"	6"	7"	9"	10"	$.90	$.60		2' x 2'	x/10%
Years to Pay Back	(2)	(2)	(2)	(7)	(6)	(7)	(1)	(2)	(2)	(5)	(1)	(1)	(1)			Years to Pay Back	(3)	(10)
Additional Inches	23"	22"	15"	18"	18"	12"	3.5"	3.5"	10"	6"	8"	10"	10"	$1.20	$.75		2' x 2'	x/0%
Years to Pay Back	(2)	(2)	(2)	(6)	(5)	(6)	(1)	(2)	(2)	(4)	(1)	(1)	(1)			Years to Pay Back	(2)	(9)
Additional Inches	26"	24"	16"	21"	18"	14"	3.5"	3.5"	10"	6"	9"	10"	10"	$1.50	$.90		2' x 2'	x/0%
Years to Pay Back	(2)	(1)	(1)	(5)	(4)	(5)	(1)	(2)	(1)	(3)	(1)	(1)	(1)			Years to Pay Back	(1)	(7)

*Equivalent to 3½" of Glass Fiber Batt/Blanket Insulation
A – Loose Fill Glass Fiber (R-2.2 per inch)
B – Glass Fiber Batt/Blanket (R-3.1 per inch) (not applicable to finished walls)
C – Loose Fill Cellulose Fiber (R-3.7 per inch in attic/R-3.3 per inch in walls)
D – Glass Fiber Duct Wrap (R-4 per inch)

1. Floor Over Unheated Basement, Crawlspace, or Garage
2. Minimum Economical Size. Payback for 3'x5' Storm Window
3. Refers to Minimum Glass Composition of Primary Door That Makes Storm Door Economical (10 year life)

Table 5.2E

OPTIMAL ENERGY CONSERVATION COMBINATIONS

10,000 Degree Days; 0 Cooling Hours (= Avg t_D); 20 Year Life

ELEMENT	ATTIC						WALL		FLOOR Over Unheated Area[1]		EXPOSED DUCTS Equipment Operational Time for Average Loading Conditions			ENERGY PRICES Dollar Cost per 100,000 Btu's Delivered/Removed		ELEMENT	STORM WINDOWS[2] (Triple Track)	STORM DOORS[3]
											20%	30%	40%					
Existing Insulation	None			R-11*			None		None	R-11*	None							
Material Used	A	B	C	A	B	C	B	C	B		D	D	D	Heating	Cooling			
Additional Inches	8"	6"	5"	3"	4"	2"	3.5"	3.5"	6"	4"	3"	4"	4"	$.15	$.45		2' x 3'	0
Years to Pay Back	(4)	(3)	(4)	(17)	(13)	(16)	(3)	(10)	(5)	(20)	(2)	(2)	(2)			Years to Pay Back	(10)	(0)
Additional Inches	12"	12"	8"	7"	6"	5"	3.5"	3.5"	10"	6"	4"	5"	6"	$.30	$.45		2' x 2'	0
Years to Pay Back	(3)	(2)	(3)	(11)	(8)	(10)	(2)	(5)	(4)	(11)	(2)	(1)	(1)			Years to Pay Back	(5)	(0)
Additional Inches	15"	12"	10"	11"	10"	7"	3.5"	3.5"	10"	6"	5"	7"	8"	$.45	$.45		2' x 2'	x/50%
Years to Pay Back	(2)	(2)	(2)	(9)	(6)	(8)	(1)	(4)	(3)	(7)	(1)	(1)	(1)			Years to Pay Back	(4)	(10)
Additional Inches	18"	16"	11"	13"	12"	9"	3.5"	3.5"	10"	6"	6"	8"	9"	$.60	$.45		2' x 2'	x/20%
Years to Pay Back	(2)	(2)	(2)	(7)	(6)	(7)	(1)	(3)	(2)	(6)	(1)	(1)	(1)			Years to Pay Back	(3)	(10)
Additional Inches	22"	18"	14"	18"	18"	11"	3.5"	3.5"	10"	6"	8"	9"	10"	$.90	$.60		2' x 2'	x/10%
Years to Pay Back	(2)	(1)	(2)	(6)	(5)	(6)	(1)	(2)	(2)	(4)	(1)	(1)	(1)			Years to Pay Back	(2)	(10)
Additional Inches	26"	24"	16"	21"	18"	14"	3.5"	3.5"	10"	6"	9"	10"	10"	$1.20	$.75		2' x 2'	x/0%
Years to Pay Back	(2)	(1)	(1)	(5)	(4)	(5)	(1)	(2)	(1)	(3)	(1)	(1)	(1)			Years to Pay Back	(2)	(7)
Additional Inches	29"	24"	18"	25"	25"	16"	3.5"	3.5"	10"	6"	10"	10"	10"	$1.50	$.90		2' x 2'	x/0%
Years to Pay Back	(2)	(1)	(1)	(5)	(4)	(5)	(1)	(2)	(1)	(2)	(1)	(1)	(1)			Years to Pay Back	(1)	(6)

*Equivalent to 3½" of Glass Fiber Batt/Blanket Insulation

A – Loose Fill Glass Fiber (R-2.2 per inch)

B – Glass Fiber Batt/Blanket (R-3.1 per inch) (not applicable to finished walls)

C – Loose Fill Cellulose Fiber (R-3.7 per inch in attic/R-3.3 per inch in walls)

D – Glass Fiber Duct Wrap (R-4 per inch)

1. Floor Over Unheated Basement, Crawlspace, or Garage
2. Minimum Economical Size. Payback for 3'x5' Storm Window
3. Refers to Minimum Glass Composition of Primary Door That Makes Storm Door Economical (10 year life)

Table 5.2F

OPTIMAL ENERGY CONSERVATION COMBINATIONS

2000 Degree Days ; 1500 Cooling Hours. (95° Avg. t_0); 20 Year Life

ELEMENT	ATTIC						WALL		FLOOR Over Unheated Area[1]		EXPOSED DUCTS Equipment Operational Time for Average Loading Conditions 20% 30% 40%			ENERGY PRICES Dollar Cost per 100,000 Btu's Delivered/Removed		ELEMENT	STORM WINDOWS[2] (Triple Track)	STORM DOORS[3]
Existing Insulation	None			R-11*			None		None	R-11*	None							
Material Used	A	B	C	A	B	C	B	C	B		D	D	D	Heating	Cooling			
Additional Inches	8"	6"	5"	3"	4"	2"	3.5"	3.5"	0	0	3"	3"	4"	$.15	$.45		3' x 5'	0
Years to Pay Back	(5)	(3)	(5)	(20)	(15)	(18)	(4)	(16)	(0)	(0)	(3)	(2)	(2)			Years to Pay Back	(15)	(0)
Additional Inches	9"	10"	5"	4"	4"	3"	3.5"	3.5"	0	0	3"	4"	5"	$.30	$.45		3' x 3'	0
Years to Pay Back	(5)	(4)	(4)	(17)	(11)	(16)	(3)	(12)	(0)	(0)	(2)	(2)	(1)			Years to Pay Back	(11)	(0)
Additional Inches	9"	10"	6"	5"	6"	3"	3.5"	3.5"	0	0	4"	5"	6"	$.45	$.45		3' x 3'	0
Years to Pay Back	(4)	(4)	(4)	(15)	(12)	(14)	(3)	(10)	(0)	(0)	(2)	(1)	(1)			Years to Pay Back	(5)	(0)
Additional Inches	10"	10"	7"	5"	6"	4"	3.5"	3.5"	0	0	5"	6"	7"	$.60	$.45		2' x 3'	0
Years to Pay Back	(4)	(3)	(4)	(13)	(10)	(13)	(2)	(8)	(0)	(0)	(2)	(1)	(1)			Years to Pay Back	(7)	(0)
Additional Inches	13"	12"	8"	8"	10"	5"	3.5"	3.5"	4"	0"	6"	7"	8"	$.90	$.60		2' x 2'	0
Years to Pay Back	(3)	(3)	(3)	(11)	(10)	(10)	(2)	(6)	(16)	(0)	(1)	(1)	(1)			Years to Pay Back	(5)	(0)
Additional Inches	15"	12"	9"	10"	10"	6"	3.5"	3.5"	4"	0"	6"	8"	9"	$1.20	$.75		2' x 2'	0
Years to Pay Back	(3)	(2)	(3)	(9)	(7)	(9)	(1)	(5)	(12)	(0)	(1)	(1)	(1)			Years to Pay Back	(4)	(0)
Additional Inches	16"	16"	10"	12"	12"	8"	3.5"	3.5"	6"	0"	7"	9"	10"	$1.50	$.90		2' x 2'	0
Years to Pay Back	(3)	(2)	(3)	(9)	(7)	(8)	(1)	(4)	(11)	(0)	(1)	(1)	(1)			Years to Pay Back	(3)	(0)

*Equivalent to 3½" of Glass Fiber Batt/Blanket Insulation

A – Loose Fill Glass Fiber (R-2.2 per inch)

B – Glass Fiber Batt/Blanket (R-3.1 per inch) (not applicable to finished walls)

C – Loose Fill Cellulose Fiber (R-3.7 per inch in attic/R-3.3 per inch in walls)

D – Glass Fiber Duct Wrap (R-4 per inch)

1. Floor Over Unheated Basement, Crawlspace, or Garage
2. Minimum Economical Size. Payback for 3'x5' Storm Window
3. Refers to Minimum Glass Composition of Primary Door That Makes Storm Door Economical (10 year life)

Table 5.2G

OPTIMAL ENERGY CONSERVATION COMBINATIONS

4000 Degree Days ; 1000 Cooling Hours. (90° Avg. t_0); 20 Year Life

ELEMENT	ATTIC						WALL		FLOOR Over Unheated Area[1]		EXPOSED DUCTS Equipment Operational Time for Average Loading Conditions 20% 30% 40%			ENERGY PRICES Dollar Cost per 100,000 Btu's Delivered/Removed		ELEMENT	STORM WINDOWS[2] (Triple Track)	STORM DOORS[3]
Existing Insulation	None			R-11*			None		None	R-11*	None							
Material Used	A	B	C	A	B	C	B	C	B		D	D	D	Heating	Cooling			
Additional Inches	7"	6"	5"	0"	4"	2"	3.5"	3.5"	4"	0"	3"	3"	4"	$.15	$.45		3' x 4'	0
Years to Pay Back	(5)	(4)	(5)	(0)	(16)	(20)	(4)	(16)	(14)	(0)	(3)	(2)	(2)			Years to Pay Back	(16)	(0)
Additional Inches	9"	10"	6"	4"	4"	3"	3.5"	3.5"	4"	0"	4"	4"	5"	$.30	$.45		3' x 3'	0
Years to Pay Back	(4)	(4)	(4)	(15)	(10)	(15)	(3)	(10)	(7)	(0)	(2)	(1)	(1)			Years to Pay Back	(10)	(0)
Additional Inches	11"	10"	7"	6"	6"	4"	3.5"	3.5"	6"	4"	4"	5"	6"	$.45	$.45		2' x 3'	0
Years to Pay Back	(4)	(3)	(3)	(13)	(9)	(12)	(2)	(7)	(6)	(20)	(1)	(1)	(1)			Years to Pay Back	(7)	(0)
Additional Inches	12"	12"	8"	7"	6"	5"	3.5"	3.5"	6"	4"	5"	6"	7"	$.60	$.45		2' x 2'	0
Years to Pay Back	(3)	(3)	(3)	(11)	(8)	(11)	(2)	(6)	(4)	(15)	(1)	(1)	(1)			Years to Pay Back	(5)	(0)
Additional Inches	15"	12"	10"	10"	10"	7"	3.5"	3.5"	10"	6"	6"	8"	9"	$.90	$.60		2' x 2'	0
Years to Pay Back	(3)	(2)	(3)	(9)	(6)	(9)	(1)	(4)	(4)	(11)	(1)	(1)	(1)			Years to Pay Back	(3)	(0)
Additional Inches	18"	16"	11"	13"	12"	8"	3.5"	3.5"	10"	6"	7"	9"	10"	$1.20	$.75		2' x 2'	x/40%
Years to Pay Back	(2)	(2)	(2)	(8)	(6)	(7)	(1)	(3)	(3)	(8)	(1)	(1)	(1)			Years to Pay Back	(3)	(10)
Additional Inches	20"	18"	12"	15"	16"	10"	3.5"	3.5"	10"	6"	8"	10"	10"	$1.50	$.90		2' x 2'	x/20%
Years to Pay Back	(2)	(2)	(2)	(7)	(6)	(7)	(1)	(3)	(3)	(7)	(1)	(1)	(1)			Years to Pay Back	(2)	(10)

*Equivalent to 3½" of Glass Fiber Batt/Blanket Insulation

A – Loose Fill Glass Fiber (R-2.2 per inch)

B – Glass Fiber Batt/Blanket (R-3.1 per inch) (not applicable to finished walls)

C – Loose Fill Cellulose Fiber (R-3.7 per inch in attic/R-3.3 per inch in walls)

D – Glass Fiber Duct Wrap (R-4 per inch)

1. Floor Over Unheated Basement, Crawlspace, or Garage
2. Minimum Economical Size, Payback for 3'x5' Storm Window
3. Refers to Minimum Glass Composition of Primary Door That Makes Storm Door Economical (10 year life)

Table 5.2H

OPTIMAL ENERGY CONSERVATION COMBINATIONS

6000 Degree Days ; 500 Cooling Hours. (90° Avg. t_0); 20 Year Life

ELEMENT	ATTIC						WALL		FLOOR Over Unheated Area[1]		EXPOSED DUCTS Equipment Operational Time for Average Loading Conditions 20% 30% 40%			ENERGY PRICES Dollar Cost per 100,000 Btu's Delivered/Removed		ELEMENT	STORM WINDOWS[2] (Triple Track)	STORM DOORS[3]
Existing Insulation	None			R-11*			None		None	R-11*	None			Heating	Cooling			
Material Used	A	B	C	A	B	C	B	C	B		D	D	D					
Additional Inches	7"	6"	5"	0"	4"	2"	3.5"	3.5"	4"	0"	3"	3"	4"	$.15	$.45	Years to Pay Back	3' x 4'	0
Years to Pay Back	(5)	(4)	(5)	(0)	(16)	(20)	(4)	(15)	(8)	(0)	(3)	(2)	(2)				(13)	(0)
Additional Inches	10"	10"	6"	5"	6"	3"	3.5"	3.5"	6"	4"	4"	5"	5"	$.30	$.45	Years to Pay Back	2' x 3'	0
Years to Pay Back	(4)	(3)	(3)	(14)	(11)	(13)	(2)	(8)	(5)	(18)	(2)	(2)	(1)				(7)	(0)
Additional Inches	12"	12"	8"	7"	6"	5"	3.5"	3.5"	10"	4"	5"	6"	7"	$.45	$.45	Years to Pay Back	2' x 2'	0
Years to Pay Back	(3)	(3)	(3)	(11)	(8)	(11)	(2)	(6)	(5)	(12)	(2)	(1)	(1)				(5)	(0)
Additional Inches	14"	12"	9"	9"	10"	6"	3.5"	3.5"	10"	6"	6"	7"	8"	$.60	$.45	Years to Pay Back	2' x 2'	0
Years to Pay Back	(3)	(2)	(3)	(9)	(8)	(9)	(1)	(5)	(4)	(10)	(1)	(1)	(1)				(4)	(0)
Additional Inches	18"	16"	11"	13"	12"	8"	3.5"	3.5"	10"	6"	7"	8"	9"	$.90	$.60	Years to Pay Back	2' x 2'	x/30%
Years to Pay Back	(2)	(2)	(2)	(8)	(6)	(7)	(1)	(3)	(3)	(7)	(1)	(1)	(1)				(3)	(10)
Additional Inches	20"	18"	13"	16"	16"	10"	3.5"	3.5"	10"	6"	8"	9"	10"	$1.20	$.75	Years to Pay Back	2' x 2'	x/10%
Years to Pay Back	(2)	(2)	(2)	(7)	(5)	(6)	(1)	(2)	(2)	(5)	(1)	(1)	(1)				(2)	(10)
Additional Inches	23"	22"	15"	18"	18"	12"	3.5"	3.5"	10"	6"	9"	10"	10"	$1.50	$.90	Years to Pay Back	2' x 2'	x/0%
Years to Pay Back	(2)	(2)	(2)	(6)	(5)	(6)	(1)	(2)	(2)	(4)	(1)	(1)	(1)				(2)	(10)

*Equivalent to 3½" of Glass Fiber Batt/Blanket Insulation

A – Loose Fill Glass Fiber (R-2.2 per inch)

B – Glass Fiber Batt/Blanket (R-3.1 per inch) (not applicable to finished walls)

C – Loose Fill Cellulose Fiber (R-3.7 per inch in attic/R-3.3 per inch in walls)

D – Glass Fiber Duct Wrap (R-4 per inch)

1. Floor Over Unheated Basement, Crawlspace, or Garage
2. Minimum Economical Size. Payback for 3'x5' Storm Window
3. Refers to Minimum Glass Composition of Primary Door That Makes Storm Door Economical (10 year life)

A close look at the tables will reveal a rather consistent increase in the optimal levels of variable techniques as fuel prices per Btu increase and as weather conditions become more severe. This will allow the reader to interpolate rather easily when using different energy rates, different climates (above 2,000 degree days) and different marginal costs for the techniques analyzed.

An example from the tables will be instructive in their use. Let us examine an optimal combination of energy conservation techniques for an existing wood-frame house with 3 1/2 inches of glass fiber batting (R-11) in the attic, but no wall insulation, no insulation over a vented crawlspace, and no storm windows or doors. This house is located in the Washington, D.C. area, which has approximately 4,200 degree days and 1,000 cooling hours. We will assume that it is oil heated and electrically cooled, and that current rates (including taxes, etc.) are approximately 32¢ per gallon for #2 fuel oil (50% efficiency) and 3¢ per kWh for air conditioning (COP = 2). What is the indicated optimal combination of energy conservation techniques?

Table 5.2G with 4000 degree days and 1,000 cooling hours best represents the Washington climate. We refer to the 3rd row of this table which is based on heating at $.45 per 100,000 Btu delivered and air conditioning at $.45 per 100,000 Btu removed, equivalent to our example. (See Table 5.1)

Depending on the availability of materials, the accessability of the attic, and the homeowners preference for one material over another, the optimal amount of insulation to add to the attic is either 6 inches of blown-in glass fiber, a 6 inch glass fiber batt, or 4 inches of cellulose. The payback period for each of these options is included in parenthesis. If the homeowner is able and willing to install one of these alternatives himself, the payback period may be considerably shortened.

Adding blown-in insulation to open wall spaces appears to be economically attractive as well. At 50¢ per square ft., loose-fill cellulose will pay off in about 7 years, at the same time returning an annual dividend equal to the rate of fuel price increases during this period. After checking with several reputable commercial insulation firms to get estimates on both price and the suitability of the walls for blown-in insulation, the homeowner may decide that the exterior walls should be insulated.

Six inches of insulation are indicated as optimal for installation under the floor in the crawlspace. This same amount would be appropriate in floors between heated areas and an unheated basement or garage as well.

All windows and doors should be weather stripped by the owner. Storm windows are indicated for all windows equal to or larger than 2' x 3'. A storm door is not considered economical as there is an existing screen door in place, making its replacement with a storm door difficult to justify.

After calculating the Btu's per hour needed to keep the indoor temperature at approximately 70°F when the outdoor temperature is at its winter average (45°F for Washington), the homeowner determines that the furnace must run 20% of the time to maintain that indoor temperature level after these other retrofitting techniques have been installed. (Alternatively, he can actually time this on a 45° day.) Four inches of insulation are then indicated for wrapping exposed heating ducts in the attic and in an unheated basement, crawlspace, or garage.

5.3 Further Interpretation of Results

The tabular data presented in this section provide additional information of interest to homeowners and others concerned with energy conservation in buildings. The following information on the economic aspects of energy conservation in buildings has been derived from tables 5.2A-H and from the thermodynamic and economic considerations that went into their making.

(1) Closer examination of the tables show that, as expected, optimal investment levels increase as energy prices rise and climate factors grow more severe. (The actual investment level, of course, is dependent on the size of the specific areas to be insulated, the number of windows and doors to be covered with storm sash, etc.) As one moves from price level to price level within a given climate zone, more of each variable ECT is indicated as profitable. Because these combinations are economically balanced (Condition II) at each price level, the marginal increments of each ECT (those newly-profitable increments) are all approximately equivalent in value in that they return approximately the same savings per dollar invested. Each is somewhat less profitable than the marginal investments immediately preceeding and somewhat more profitable than those immediately following. Thus one can quite easily determine, for example, whether the fifth or sixth inch (over no existing insulation) of attic insulation is more profitable than a 4' x 5' storm window in a 4000 degree day climate zone. Examination of Table 5.2B with 4000 degree days and 0 cooling hours shows that at $.15 per therm only 4" of insulation is optimal, while at $.30 per therm. 6" is optimal. However, at $.15 per therm. 4' x 5' storm windows are indicated as optimal so that these must return more savings per dollar than the fifth and sixth inches of insulation. (Adjustment of these tables for different ECT costs, or different initial levels of insulation could change these relationships.) Moving further down to $.45 per therm we see that the seventh through tenth inches of attic insulation return approximately the same savings per dollar as the fifth and sixth inches of floor insulation, the fourth inch of duct insulation (at 20% operational time), and the storm windows between 2' x 3' and 3' x 3'.

With a limited retrofit budget the homeowner should use the highest cost combination of ECT's that is consistent with his budget in the appropriate climatic zone. This will assure an economically balanced allocation of his retrofit budget (Condition II) and consequently generate the greatest dollar savings to the homeowner for his limited budget.

An example of such a procedure is shown in Table 5.3. An energy conservation budget of $731 would be needed to invest in the optimal level of ECT's. The homeowner does not wish to invest more than $500, however. In this case he will add those levels of ECT's shown as optimal for the $.15 heating, $.45 cooling energy costs (cost = $461) plus as much as possible of the levels shown for $.30 heating, $.45 cooling energy costs. Here he will add one additional storm window on a 3' x 3' window (the optimal insulation levels have not changed for these higher energy prices). Of the $500 budget the homeowner will spend $486 ($461 + $25). Since these investment levels are economically balanced, the savings generated by this limited investment will be maximized.

(2) Optimal levels of energy conservation investments are as sensitive to fuel prices as they are to climate factors, i.e., doubling of fuel prices is similar in effect to a doubling of climatic factors.[44] As an example, the doubling of #2 fuel oil prices in the winter of 1973-74 had an effect on homeowner pocketbooks similar to that of physically moving their homes from Washington, D.C., to northern Minnesota.

(3) While the optimal level of investment in ECT's varies as a function of climate factors, fuel prices, and ECT costs, note that small variations (i.e., less than 20%) in any one of these have little effect on optimal investment levels. The optimal levels listed in tables 5.2A-H are meant to be guidelines and not to be followed to the exact inch where this is not practical. However, any costly modifications needed to incorporate these ECT's require further analysis.

(4) When determining optimal levels of ECT's, winter heating and summer cooling energy loads should be summed in dollar terms (heating and cooling energy costs are likely to be substantially different). Design criteria which specify insulation levels (or coefficients of conductance) for new buildings or existing buildings should reflect these combined loads rather than the greater of the two, as is common procedure.

(5) When shopping for insulation, the homeowner should consider the cost per resistance unit (R) rather than cost per inch. Loose-fill glass fiber insulation has an R value of approximately 2.2 per inch while glass fiber batts have an R value of approximately 3.1 per inch. Thus even at a 40% greater price per inch, batts would be a better investment than loose fill. Where batts are impractical, loose fill may still be a good buy, however.

(6) Storm windows can be shown to be economical even over existing double-glazed windows in some cases. The additional window will reduce conductive heat loss and heat gain by 33%, as well as reducing air infiltration. Where 3' x 5' storm windows are shown in tables 5.2A through H to pay off (including interest) in less than 7 years, storm windows added to existing double-pane windows of that size or larger will be economical (20 year life, $25.00 cost assumed).

(7) Insulation blown into existing walls with no previous insulation appears to be economical in many climates and for the higher fuel prices. Benefits such as reduced infiltration through walls, a higher mean radiant temperature, and increased occupant comfort make this even more attractive than shown. However, this technique must be considered carefully because of possible moisture problems. More information on this technique can be found in Appendix A.

(8) Much of this study is applicable to new housing design as well. In some cases it may be shown that increasing exterior wall thickness in new homes to accommodate further insulation is economically desirable. The marginal analysis model may not be practical for use in making design decisions about siting, exposure, window size versus wall size, and other design decisions because of the many interdependencies involved. However, once these design decisions are made, the model may be very useful in decision making regarding further energy conservation investments.

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[44] A doubling of degree days will have a slightly greater effect than a doubling of energy prices on the optimal level of insulation for attics and floors over unheated areas because the average temperature in these areas does not vary in constant propotion to the average outside temperature.

Table 5.3

Optimal Allocation of a Limited Energy
Conservation Budget -- Example

Assume $500 Budget

- Wood frame house in Washington, D.C. -- approximately 4000 degree days and 1000 cooling hours (Use Table 5.2G)
- 1200 square feet (single-story)
- Existing R-11 insulation in walls and attic
- Existing weather stripping
- No insulation in floor over crawlspace
- No ductwork in unheated areas
- No storm windows or storm doors
- 11 windows (5 -- 3' x 5', 3 -- 3' x 3', 3 -- 3' x 2')
- No storm doors
- Oil heated ($.45 per 100,000 Btu delivered)
- Electrically cooled ($.45 per 100,000 Btu removed)

Heating/ Cooling Costs		Attic	Floor	Windows	Total
$.15/$.45	Add Cost[1]	4" (1200 x $.135) $162	4" (1200 x $.145) $174	3' x 5' (5 x 25) $125	$461
$.30/.45	Add Cost	4" (1200 x $.135) $162	4" (1200 x $.145) $174	3' x 5', 3' x 3' (8 x 25) $200	$536
$.45/.45	Add Cost	6" (1200 x $.185) $222	6" (1200 x $.195) $234	3' x 5', 3' x 3', 3' x 2' (11 x $25) $275	$731

[1] Costs from Appendix B.

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6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

An economic optimization model has been applied to a selected group of energy conservation techniques in order to determine the optimal combination of such techniques in terms of maximizing net dollar savings in space heating and cooling operations for existing residential buildings. Results of this analysis have shown that optimal investment levels in the various techniques are quite sensitive both to climate factors and to energy prices, and that in many cases these levels are considerably higher than those currently recommended by government and industry. These lower recommendations may be due in large part to the failure of these institutions and the general public to adequately consider the impact of recent fuel price increases on the economically optimal levels of energy conservation investments for various climates and fuel types.

It should be noted that these combinations of ECT's are economically optimal for the energy consumer in that they reflect his own expectations of energy and ECT costs. To the extent that such costs may diverge from competitive (free market) prices due to regulation, price controls, or rationing, or to the extent that actual costs may not include externalities, e.g. air pollution from electric power generation, these consumer optimal combinations may not be socially optimal levels. Artificially low fuel prices due to price controls have not only stimulated increased demand for these controlled fuels in comparison to other fuels but have encouraged their socially inefficient use (i.e., waste) by inducing lower levels of consumer-optimal energy conservation investments than those that would be determined by higher free-market prices.

Still, it is essential that an economic analysis of energy conservation requirements be included in strategies for retrofitting existing buildings and in the design of new buildings if there is to be an efficient allocation of resources between energy use and energy conservation. This is especially true in the wake of energy conservation building codes and standards being developed today for adoption by state and local building code authorities. Many of these codes specify (explicitly or implicitly) levels of energy conservation techniques which show little regard for economic optimality, either in terms of maximizing net savings or in terms of an economically balanced combination of energy conservation investments. While it is recognized that these are minimum specifications, the very fact that they are included as an integral part of an "energy conservation" standard may endorse their use as maximums by builders and homeowners. While they may increase energy conservation levels over past efforts, they should in no way be considered as optimal. If treated as such they may be responsible for inefficient energy use and eventually lead to considerable cost burdens on homeowners.

It is hoped that the relatively high levels of insulation determined as optimal in this study will encourage further research, both economic and thermal, into energy conservation techniques for all building types, new and old. Verification data for fuel savings is needed for a wide range of climatic and structural conditions. Current energy conservation research at the National Bureau of Standards includes precise measurements of heat loss and heat gain in new and existing buildings. Fuel usage is being measured in an existing residence on the NBS site before and after retrofitting the ECT's examined in this study. Preliminary results of this testing will be available in 1975.

In addition, more research and development into wall insulation for retrofitting applications are needed. Current techniques are not acceptable to many homeowners because of uncertain results. In general, blown-in insulation has been shown in this study to be cost effective in many climatic regions. More data is needed on the long term durability and effect of such insulation, however.

This research could be further expanded to include new residential buildings and new and existing commercial buildings. Because of difficulties in handling interdependent ECT's simultaneously, the economic model outlined in this study will need to be expanded if it is to handle more complex design decisions in new buildings. The results of such research should be well worth the effort, however.

Further stimulation of homeowner investments in energy conservation might be achieved by increasing the visibility of low cost FHA Title I home improvement loans. It has been shown in this study that it will often pay the homeowner to borrow at Title I loan rates (near 10%) if he invests this in the energy conservation projects outlined. Tax credits for investment in energy conservation would also increase the economic incentives to invest in these projects.

Most importantly, however, this information must be placed in the hands of homeowners and homebuyers if it is to contribute toward any substantial measure of energy conservation. Homeowners must be aware of the economic implications of higher levels of energy conservation investments before they can be expected to respond in an efficient manner to supply and demand conditions in the energy market. Even today, in a period of rapidly rising energy prices, most homeowners have little feeling for the potential economic return from the energy conservation techniques examined in this paper. And yet, in the end, it is up to the homeowners and potential homeowners to demand more energy conservative housing if it is to appear in the housing market.

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SI Conversion Units

In view of the present accepted practice in this country for building technology, common U.S. units of measurement have been used throughout this publication. In recognition of the position of the United States as a signatory to the General Conference on Weights and Measures, which gave official status to the metric SI system of units in 1960, appropriate conversion factors have been provided in the table below. The reader interested in making further use of the coherent system of SI units is referred to:

NBS SP330, 1972 Edition, "The International System of Units"

E380-72 ASTM Metric Practice Guide (American National Standard Z210.1)

Table of Conversion Factors to Metric (S.I.) Units

Physical Quantity (and symbol used in paper)		To convert from	to	multiply by
Length	x	inch	meter	$2.54^* \times 10^{-2}$
		foot	m	$3.048^* \times 10^{-1}$
Area		inch^2	m^2	$6.4516^* \times 10^{-4}$
		foot^2	m^2	9.290×10^{-2}
Volume		inch^3	m^3	1.639×10^{-5}
		foot^3	m^3	2.832×10^{-2}
Temperature		Fahrenheit	Celsius	$t_C = (t_F-32)/1.8$
Temperature difference		Fahrenheit	Kelvin	$K = (\Delta t_F)/1.8$
Pressure		inch Hg (60F)	newton/m^2	3.377×10^3
Mass		lbm	kg	4.536×10^{-1}
Mass/unit area	M	lbm/ft^2	kg/m^2	4.882
Moisture content rate		lbm/ft^2 week	kg/m^{2}s	8.073×10^{-3}
Density	ρ	lbm/ft^3	kg/m^3	1.602×10^1
Thermal conductivity	k	Btu/hr ft^2 (F/inch)	$\frac{W}{mK}$	1.442×10^{-1}
U-value	U	Btu/hr ft^2 F	$\frac{W}{m^2 K}$	5.678
Thermal resistance	R	F/(Btu/hr ft^2)	K/(W/m^2)	1.761×10^{-1}
Heat flow		Btu/hr ft^2	W/m^2	3.155
Water vapor:				
permeability	μ	$\frac{\text{grain}}{\text{hr ft}^2\text{(in.Hg/in.)}}$	kgm/Ns	1.457×10^{-11}
permeance	p,P	$\frac{\text{grain}}{\text{hr ft}^2\text{(in.Hg)}}$ (perm)	kg/Ns	5.738×10^{-11}

*Exact value; others are rounded to fourth place.

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Appendix A

ENERGY CONSERVATION TECHNIQUES - SOME OPTIONS

The purpose of this appendix is to explore briefly some of the options available to homeowners who may wish to retrofit their residence with the energy conservation techniques outlined above. There is often considerable flexibility in choosing materials and procedures for accomplishing a given conservation goal. What is best in one situation may not be best in another, however, so that some judgment must be made as to which options are economically or structurally more attractive in any given application.

Whichever materials are used, it is of utmost importance that they be properly installed so that the full potential savings, on which the estimates in the study are based, will be realized. This is especially true for the "do-it-yourself" homeowner, but it should not be overlooked by those who may contract for such work, in order to assure that the installation has been properly accomplished.

In general the manufacturers of energy conservation materials will supply complete installation instructions at no charge. Further information may be useful, however, especially for insulation applications. One such source is the Insulation Manual - Homes/Apartments. 44/ Other sources may often be found at the local library under household repair.

a. Insulation in Attic Spaces

Insulation of heated rooms from unheated attic spaces directly above is usually accomplished by the placing of insulating materials between the ceiling joists in the attic area. This is the most likely location in an existing house to have some existing level of insulation; it may be desirable to upgrade this, however.

There are two basic forms of attic insulation available, both of which are acceptable if properly installed. The first of these is preformed glass or mineral fiber blankets or batts; the second is loose fill materials, generally made of cellulose (recycled waste paper) or glass fiber. The following R values 45/ are approximately correct for proper installation;

Glass fiber batts: R = 3.1 per inch 46/

Cellulose loose fill (2 1/2 lbs. per cubic foot): R = 3.7 per inch

Glass fiber loose fill (0.7 lbs. per cubic foot): R = 2.2 per inch 47/

Preformed insulation blankets or batts may be more economically attractive than loose fill materials in an unobstructed attic area with no flooring, especially for the do-it-yourself homeowner. These blankets or batts can be rolled out quickly and minimize the raising of fibers into the air which create an uncomfortable working environment.

If no previous insulation exists, foil-faced vapor barrier batts should be used, with the foil facing downward. This is to retard moisture, rising from the room below, from penetrating into the insulation. When adding batts over existing insulation, it is preferable to install unfaced batts. These are generally cheaper, and prevent moisture from condensing in the existing insulation. If unfaced batts are not available or cannot be purchased for less than faced batts, faced batts can be used if the facing is stripped off or slashed at frequent intervals to allow free passage to moisture.

44/ National Association of Home Builders Research Foundation, Inc., 627 Southlawn Lane, P.O. Box 1627, Rockville, Md. 20850.

45/ The R value, or coefficient of resistance, is the reciprocal of U, the coefficient of conductance, which in turn is defined as the time-rate of heat flow through a thermal barrier (Btu per hour per square foot per degree Fahrenheit temperature difference between the air on either side).

46/ ASHRAE Handbook of Fundamentals, 1972, p. 361.

47/ Based on recent manufacturers report (downgraded from ASHRAE value).

Loose fill insulation may be preferred when the attic is difficult to access or flooring is present. If flooring is present some strips may be pulled up or holes can be drilled in the floor at intervals between the joists. This insulation is usually pneumatically pumped or blown into the attic through flexible tubing by a small machine which puffs up the insulation as it pushes it through. This may cause some settling after the insulation is in place so that some margin of safety should be allowed in measuring depth. For this reason the densities recommended by the manufacturer for different desired R values should be carefully adhered to.

There is no reason to restrict the depth of attic insulation to the height of the ceiling joists, in areas not needed for storage, if more insulation is warranted. However, insulation should not come in contact with the roof above at any point. When installing blankets or batts above the joists it may be useful to run the batts perpendicular to the joists in order to cover the attic more thoroughly.

It is essential that a well insulated attic be well ventilated. This will minimize the chance of condensation during the heating months which can cause temporary or permanent damage to the insulation and increase the heat flow. More on this can be found in the Insulation Manual - Homes/Apartments mentioned above or from manufacturers of ventilating equipment.

b. Insulation in Exterior Walls

The potential energy savings from insulating exterior walls of wood frame and brick veneer residences is certainly significant, both in terms of BTU savings per square foot and in sheer wall area. On the other hand the problems that arise in assessing the benefits and costs of retrofitting exterior walls with insulation make this the most difficult of all the energy conservation techniques considered in this study. Where the addition of insulation appears to be economically advantageous to the homeowner, he should undertake such a project only after securing the best technical advice available. Equally important is the careful selection of a firm to do the work. Only a reliable firm with considerable experience should be chosen, for it is nearly impossible to check on the quality of work done inside the wall, and doing the job right takes a good deal of skill and time.

The basic feature of an exterior wall which lends itself to thermal insulation is the airspace, usually 3 1/2" to 4" deep, between the exterior and the interior wall. Three and one-half inches of insulation properly placed in the airspace can reduce the heat loss and heat gain through the walls by as much as two-thirds. The proper time to install insulation in the airspace is during construction, just before the inside wall is attached. Many older houses and even some new houses outside of extremely cold climates were not insulated at this time, however, for reasons discussed elsewhere in this study. As a result, retrofitting insulation into exterior walls requires that access to the airspace be gained through the outside or inside wall. This immediately presents several problems.

1. It is relatively costly.

2. It is difficult to monitor the quality of work done, both at the time of installation and at periodic intervals later in time.

3. A vapor barrier cannot be placed between the interior wall and the insulation so that possible water damage from condensation can result. This cannot be detected until it begins to show through the wall.

4. It may be difficult to restore the wall through which access was made to its original condition.

Despite these problems, there has been a growing demand for insulation added to existing walls. The most commonly used materials are cellulose and urea-formaldehyde foam. These are generally adaptable to pneumatic "blowing" or "pumping" through small holes drilled between the studs into the airspace.

Loose-fill glass or mineral fiber is not considered to be adequate for such applications because of its low density and its tendency to hang up in the wall, making its even dispersion in the wallspace difficult. Cellular plastics, such as polyurethane and polystyrene, are no longer being used in residential applications because of potential fire and gas hazards. Polyurethane also expands with greater pressure than other foams which can cause some problems with bursting walls.

Cellulose in walls has a resistance value (R) per inch of approximately 3.3. [48/] The urea-formaldehyde resistance value is closer to 4.2 per inch.[49/] The most common procedure for insulating existing

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48/ Based on report of Cellulose Insulation Manufacturers Association (CIMA) at density of 3.5 lbs/ft^3 in walls.

49/ Samples averaging .6lbs/ft^3 tested in NBS guarded hot plate apparatus conforming with standard method of test ASTM C177.

walls is to remove a strip of exterior siding from around the top of the house, drill a hole 1 inch in diameter through the sheathing, and pump the insulation from a mixing machine through a flexible hose into the airspace until it is filled. The siding is then replaced over the sheathing. If there is a firestop between the studs halfway up the wall, this whole procedure must be repeated below the firestop. Alternatively, holes may be drilled right through the exterior wall and later plugged up. This procedure is occasionally applied from the inside of the exterior walls as well. In brick veneer homes, bricks may be removed in order to reach the sheathing and replaced when finished.

While there are substantial benefits available in retrofitting existing walls, there are also considerable problems that may arise, and these should be carefully considered.

The most important of these is the moisture accumulation problem. It is extremely important that water vapor generated from within the home be either stopped at the interior wall surface or allowed to pass entirely through the wall to the outside. Several coats of a good grade, low permeability paint should be used on the interior walls while the outside wall covering should have a permeable surface. Water vapor that is allowed to pass through the interior wall on a cold day will condense and turn to moisture or ice if it comes into contact with a cold surface that it cannot permeate. Unfortunately, it is difficult to monitor the build-up of moisture in a wall and it may not be noticed until the paint begins to peel away from the wall. Generally the problem can be avoided if the proper precautions are taken. Trouble spots that may require extra care are bathrooms and kitchens, both of which produce a significant amount of water vapor. High humidifier settings should also be avoided. In fact, in a well insulated home with storm windows and weather stripping, a humidifier may not be needed.

Another problem which may occur within the wall is settling or shrinkage of the insulation materials over time; and like the moisture problem, it is difficult to detect. While many insulation installers will guarantee that there will be no settling, in general there will be some, and its effect may be significant. As the settling occurs no insulation is protecting the top of the wall, and heat transfer through this area resumes its pre-insulation rate. A 10 percent allowance for settling and unfilled cavities was made in calculating the conductive heat savings due to wall insulation. Over a period of many years the settling of some types of insulating materials may amount to more than this, however. With urea-formaldehyde foam some shrinkage occurs rather than settling -- this is claimed by the manufacturer to be about 2 percent. However, improper installation and curing can cause shrinkage to be considerably higher.

A potential means of monitoring settling at the time of installation and at periodic intervals is through thermographic imagery. An infra-red "picture" of the wall taken from the outside on a cold day will show "hot spots" which are most likely uninsulated areas. Unfortunately, such systems are quite expensive and limited in use at present.

In addition to the conductive heat savings due to the addition of insulation, there may also be some savings in convective heat transfer, i.e., infiltration through the wall may be slowed. While infiltration through walls may be negligible for well-constructed homes, it may be significant in older homes or in walls which were not well sealed. One suggested way to detect the relative amount of infiltration entering through a wall is to remove a switch plate cover from the inside of an exterior wall on a windy day and hold a burning match close to the opening. If it flickers wildly or blows out, there may be significant air infiltration leaking into the house. Filling the wall with insulation will stop much of this air leakage, but it is difficult to assess the savings available under the wide variety of conditions that may exist.

Cost estimates for insulation blown into existing walls vary considerably from house to house and firm to firm. Much of the work involves removing and replacing siding or bricks to gain access to the walls. Where holes are drilled directly into the wall, costs are somewhat less, but the results are not as acceptable. In general the removal of bricks is somewhat more expensive than wood or aluminum siding or asbestos-cement shingles. At present the cost of such work ranges from about $.25 to $1 per square foot with the median value around $.40 per square foot for cellulose insulation and somewhat higher for urea-formaldehyde. Repainting the interior and other incidental charges would probably make $.50 per square foot a more reasonable estimate for cellulose insulation and this is the figure that is used in evaluating the benefit-cost ratio in the study.

c. Insulation Under Floors

Insulation of heated rooms from unheated areas directly below, usually a crawlspace, garage, or unheated basement, is generally accomplished by installing preformed glass fiber blankets or batts in the floor joists directly below the floor. Such insulation is often overlooked because many homeowners feel that heat flow downward is not a problem. This is not correct, of course, heat flows to cold in any direction. Where the basement is heated, no insulation in the floor is warranted. Where heat escaping from the furnace or hot water heater raises the temperature of an otherwise unheated basement, the optimal level of insulation may be somewhat less than that level indicated on Table 5.2A-H.

The insulation batts can be held in place by a number of methods. Where the depth of the insulation is less than the depth of the joists it may be secured by using wire bows which spring into place

between the joists. If the insulation is approximately the same depth as the joists, it can be secured by stringing wire in a criss-cross fashion over small nails in the joists. In basements and garages it is not recommended that the insulation extend below the joists where it may be exposed to damage. In crawlspaces, however, it is possible to extend the depth of the insulation several inches, where warranted, by the use of long nails with heads, around which a wire harness can be strung. Analysis of floor insulation was limited to ten inches in this study due to impracticality of extending the depth further. In extreme climates where fuel is expensive, this may be considered, however. When insulating floors over vented crawlspaces it may be necessary to insulate water pipes as well to keep them from freezing in the more severe climates.

As in the case of attic insulation, when adding preformed batts to existing insulation, it is preferable to use unfaced blankets or batts. If batts with facing are found to be less expensive or the only type available, the facing should be stripped off or slashed.

d. Insulation of Exposed Ducting

Heating and cooling ducts which run through unconditioned spaces (especially attics, garages and crawlspaces) can be a major source of heat loss (or gain) if not properly taped and insulated.[50/] Even where a sufficient amount of insulation exists it may be worthwhile removing this temporarily to check on the condition of the ducts: escaping air indicates the need for retaping the joints. This is especially important if the warm air in the duct is humid, as condensation inside the moisture barrier surrounding the insulation will result.

Most homes have no more than one or two inches of insulation wrapped around the exposed ducting. However, it will be seen that considerably more than this may be economically desirable in colder climates, especially for electrically heated homes.

Duct wrap insulation is available in a wide variety of widths; it is generally not available in thicknesses greater than two inches, however. Where more than two inches are indicated, several layers of duct wrap should be used. Unfaced wrap should be installed beneath the outer layer. A heavy foil face is usually used on the outer layer as a vapor barrier during space cooling operations. Alternatively, regular unfaced batts can be wrapped around the ducts and covered with a vinyl wrapping sealed to form an adequate vapor barrier. In either case it is important to avoid crushing the insulation or binding it too tightly in order to maximize its resistance to heat flow.

The R value of duct wrap may vary considerably according to its density. Estimates of optimal thickness are based on glass fiber with a resistance value of 4 per inch. A 50 percent materials allowance was made over the basic duct perimeter measurement to allow for the wider perimeter at the outside of the insulation pack and for some crushing of the insulation. Labor charges are not included in these estimates, unlike the analysis for other energy conservation techniques. Such charges are to a great extent dependent on total job size rather than on a per square foot basis. To the extent that installation charges are independent of the depth installed, this should have no effect on the optimal level of insulation when there is no existing base. The addition of insulation to an existing base will probably not be cost-effective, however, unless the homeowner undertakes this himself or the ductwork is obviously leaking and the insulation in bad shape.

Ducting insulation requirements are not directly proportional to exterior climatic conditions but rather are a function of the climate, the general insulation level of the building envelope, and heat/cooling system efficiency. In a well-insulated home, other things held equal, the heating/cooling system will be used less and the heat loss and gain through the duct work will be lower. For this reason, insulation requirements for exposed ducting are not independent of other insulation levels and thus must be estimated as a function of other energy conservation modifications. In this study the percent of time the heating/cooling system operates to maintain the desired indoor temperature when the outdoor temperature is at its average level[51/] is used as the basis for determining insulation requirements in any given climate. This should be estimated for the thermal load that is expected after all energy conservation modifications have been incorporated.

50/ Insulation is not generally needed on ducting within a heated basement or walls of a single-family house as the heat loss and gain is retained within the building.

51/ For winter this is defined as (65°-degree days/heating days); for summer this is the average temperature in the duct-occupied space during cooling hours.

e. Storm Windows and Doors

Storm windows and doors vary widely in basic design, durability, and cost. Storm windows range from single glass panels that must be put in place each fall and removed each spring to triple track assemblies which include sliding upper and lower windows and a screen. These latter windows are recommended for double-hung windows and sliding casement windows because they can be left in place permanently, thereby encouraging their use during winter heating and summer cooling, while allowing windows to be left open for natural ventilation during the mild weather seasons. This also minimizes wear and tear on the windows and the chance of breakage. Other types of storm windows, especially those for use on basement windows or hinged casement windows are often somewhat less expensive than triple track windows. Therefore the data in Tables 5.2A-H should be adjusted to reflect these lower costs.

Storm doors with interchangeable glass and screen inserts are recommended because such doors can be used for ventilation during the non-heating months when needed. Because such inserts are not conveniently and quickly interchangeable it is suggested that the screen be left in place during the non-heating months. For this reason no summer cooling savings are included. Storm doors over primary doors with substantial window area are more likely to be cost-effective than those over solid doors.

Both storm windows and storm doors can be effective in slowing infiltration as well as conductive heat transfer. In combination with weather stripping a great deal of infiltration may be eliminated. In this case, however, the marginal effect due to either one when the other is in place will be considerably smaller than when it is used singlely. In this study weather stripping will be assumed to be in place. Therefore infiltration through the cracks directly around windows and doors will be assumed to be reduced by 30 percent in loose fitting and 10 percent in average to tight-fitting windows and doors.[52/] Such savings are based on tight fitting storm windows. In order to assure a tight fit, these windows should be sealed to the outer window frame with caulking compound or other sealing solutions.

Storm windows from a particular manufacturer generally vary little in cost up to 100 united inches.[53/] After this a cost per united inch is usually included. A considerable savings on such windows can be realized if stock sizes, available at many department and hardware stores, are used. Custom made windows cost considerably more. A cost of $25 per window has been assumed for storm windows up to 100 united inches plus $.50 per inch over 100". This is for a basic triple track window without colored trim. While considerably more may be spent, much of this will be for convenience or aesthetic value and not directly for energy conservation purposes.

Storm doors costs vary widely as well. Again stock sizes may be less expensive than custom made doors. Costs here are based on $75 per door.

f. Weather Stripping

When properly installed, weather stripping can be quite effective in reducing the rate of infiltration through cracks around windows and doors, especially that of the loose fitting variety. (In conjunction with storm windows or doors, however, its effect is generally halved.) Weather stripping is available in a wide selection of materials and shapes, some of these being more durable than others and likely to be more effective at the same time. Good weather stripping will not only cut heat loss (or gain) but reduces uncomfortable drafts as well.

52/ This does not include infiltration around the outside of window and door frames, which should be sealed by caulking.

53/ United inches is the sum of the height and width of the storm window, in inches. One hundred united inches is approximately 3' x 5'.

APPENDIX B

Prices Used for Energy Conservation Techniques

1. Attic Insulation (dollars per square foot)

   a. R-2.2 blown-in glass fiber
      Materials and installation
      First inch = $.06
      Each additional inch = $.03

   b. R-3.1 glass fiber batting

      Materials:

Inch	1	2	3	4	5	6
Foil Faced	.035	.025	.02	.02	.025	.025
Kraft Faced/ Unfaced	.025	.025	.02	.02	.025	.025

      Installation: $.035 first batt.
      .025 each additional batt

   c. R-3.7 cellulose
      Materials and installation
      First inch = $.075
      Each additional inch = $.045

2. Wall Insulation (dollars per square foot)

   a. Blown-in cellulose:[54/]

      Materials and installation: 3 1/2 inches = $.50

   b. R-3.1 glass fiber batts (in open walls)
      Materials (see Attic insulation)
      Installation=$.025

3. Floors (dollars per square foot)

   a. R-3.1 glass fiber batt
      Materials (see attic insulation)
      Installation:
      (a) Floors over garage or basement:
          First batt = $.025
          Each additional batt = $.025
      (b) Floors over crawlspaces:
          First batt = $.045
          Each additional batt = $.025

54/ 10 percent assumed settling not included.

4. Duct Insulation (dollars per square foot of duct surface)
   R-4 glass fiber duct wrap[55/]
   Materials Only
   Foil faced: $.20 per two inches
   Unfaced: $.15 per two inches

5. Storm Windows
   Triple track plain aluminum (with screen) $25.00 up to 100 united inches
   + $.50 per additional united inch.

6. Storm Doors
   Plain Aluminum (with screen inserts) $75.00

7. Weather Stripping
   Materials Only: Maximum of $.15 per linear foot.
   (Installation prices run as high as $20.00 per window or door.)

55/ Does not include 50 percent allowance for greater perimeter at outside of insulation pack and compression of insulation.

APPENDIX C: CLIMATE FACTORS FOR SELECTED CITIES

Climate factors that may be used for quick reference are presented in this appendix. However, it is recommended that climatic data more specific to a given geographic area be obtained for use with this study when referenced for actual retrofitting purposes. Such data can often be obtained from the local weather bureau. More data is also available from the sources which were used as the basis of the following data.

The degree day chart (chart C-1) and the average winter temperature chart (chart C-2) are taken from the Handbook of Air Conditioning, Heating and Ventilating, Strock and Koral, The Industrial Press, 1965. Cooling hours over 80°F (rounded to the nearest 50 hours) are taken from Air Force publication AFM88-8, Chapter 6, "Engineering Weather Data." Similar data can also be found in the NAHB Insulation Manual - Homes/Apartments.

Alabama, Birmingham	1500	Missouri, St. Louis	1150
Alaska	n/a	Montana, Helena	250
Arizona, Flagstaff	200	Nebraska, Lincoln	1000
Phoenix	2750		
Arkansas, Little Rock	2000	Nevada, Las Vegas	2350
		Reno	650
California, Los Angeles	550	New Hampshire, Concord	400
Sacramento	1000		
San Francisco	< 50		
Colorado, Denver	650	New Jersey, Trenton	450
Connecticut, Hartford	500	New Mexico, Albuquerque	1150
Delaware, Wilmington	600	New York, New York City	650
District of Columbia, Washington	1000	North Carolina, Raleigh	1050
Florida, Miami	2400	North Dakota, Bismarck	450
Jacksonville	1800		
Georgia, Atlanta	1000	Ohio, Columbus	600
Hawaii, Honolulu	1350	Oklahoma, Oklahoma City	1450
Idaho, Boise	700	Oregon, Salem	300
Illinois, Chicago	750	Pennsylvania, Philadelphia	700
Indiana, Indianapolis	750	Rhode Island, Providence	700
Iowa, Des Moines	600	South Carolina, Columbia	1350
Kansas, Topeka	1150	South Dakota, Rapid City	550
Kentucky, Louisville	1050	Tennessee, Nashville	1300
Louisiana, New Orleans	1750	Texas, San Antonio	2000
Maine, Bangor	200	Utah, Salt Lake City	900
Maryland, Baltimore	850	Vermont, Montpelier	300
Massachusetts, Boston	400	Virginia, Richmond	1000
Michigan, Detroit	500	Washington, Seattle	100
Minnesota, Minneapolis	500	West Virginia, Charleston	800
Mississippi, Jackson	1600	Wisconsin, Madison	500
		Wyoming, Casper	550

Chart C-1. Normal number of degree-days per year for the continental U.S.

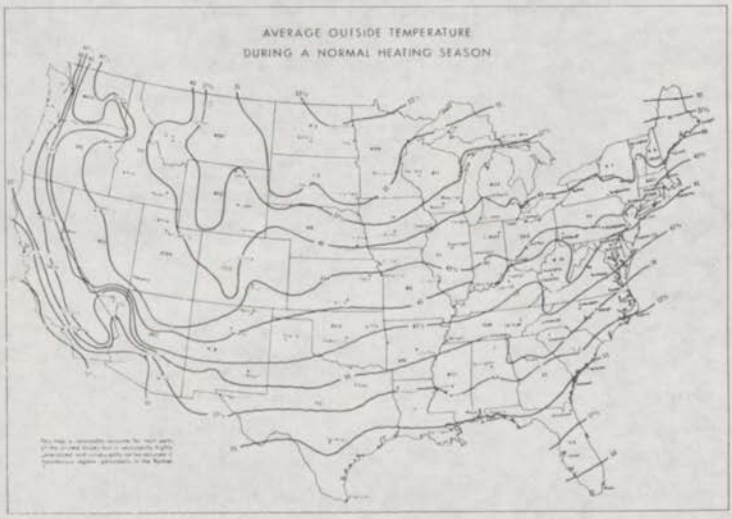

Chart C-2. Average outside temperature during a normal heating season in the continental U.S.

APPENDIX D

Methodology for Calculation of Marginal Heat Losses and Heat Gains

The following methodologies were used in calculating annual heat losses and heat gains for specific envelope sections of residential structures. These heat losses and heat gains are the basis of the marginal savings attributed to the various energy conservation techniques considered in this study.

Notation is meant to be consistent throughout. Basic notation is as follows:

U = thermal conductance

R = thermal resistance

A = area

V = ventilation rate

V_w = wind velocity (M.P.H.)

t = temperature

DD = degree days

HD = heating days

ATTIC INSULATION: WINTER (All calculations per square foot of attic floor area.)

(1) Compute ceiling U:

$$U_c = .875/(1/U_p + a \cdot R_t) + .125/(1/U_p + S)$$

where U_c = equivalent thermal conductance of ceiling

U_p = thermal conductance of ceiling without insulation or joist adjustment

a = insulation thickness, inches

R_t = thermal resistance per inch of insulation

S = thermal resistance of ceiling joists

.875 and .125 are weights for non-joist and joist areas of attic floor respectively.

(2) Compute attic temperature:

$$t_a = \frac{A_c U_c t_i + t_o (A_r U_r + A_w U_w + 1.08 A_c V)}{A_c U_c + A_r U_r + A_w U_w + 1.08 A_c V}$$

where t_a = attic temperature

t_i = inside air temperature (near ceiling)

t_o = outside air temperature

V = ventilation rate of attic in CFM/sq. ft. of ceiling

1.08 = specific heat of air x density of air x minutes per hour = .24 · .075 · 60

and subscripts

c = ceiling

r = roof

w = end walls of attic

t_a is computed at average t_o where average $t_o = 65° - \frac{DD}{HD}$

t_a is recomputed for each additional increment of insulation.

(3) Compute hourly heat loss into attic (H_L):

$$H_L = U_c (t_i - t_a)$$

(4) Compute annual heat loss (H_{AL}):

$$H_{AL} = H_L \cdot HD \cdot 24$$

(5) Compute annual heat loss reductions due to the i^{th} increment of insulation (ΔH_{AL_i})

$$\Delta H_{AL_i} = H_{AL_{(i-1)}} - H_{AL_{(i)}}$$

Parameters Used:

U_p = .60

U_w = .31

U_r = .44

A_c = 1000

A_w = 150

A_r = 1120

V = .1 CFM/sq. ft.

S = 6.88 (5.5 inches thick)

ATTIC INSULATION: SUMMER (All calculations per square foot of attic floor area.)

(1) Compute ceiling U:

(See Attic Insulation: Winter)

(2) Compute attic temperature

$$t_a = \frac{A_c U_c t_i + A_r U_r t_{ar} + A_w U_w t_{sw} + 1.08\, A_c V t_o}{A_c U_c + A_r U_r + A_w U_w + 1.08\, A_c V}$$

Where t_{ar} = sol air temperature equivalent of roof

t_{sw} = sol air temperature equivalent of walls

t_o = outside dry bulb temperature

t_a is computed for <u>average</u> outdoor dry bulb temperature during cooling hours above 80° using sol air temperature equivalent appropriate for such conditions[1] (design temperature is not used).

t_a is recomputed for each additional increment of insulation.

(3) Compute hourly heat gain from attic (H_G):

$$H_G = U_c\ (t_i - t_a)$$

(4) Compute annual heat gain (H_{AG}):

$$H_{AG} = H_G \cdot CH$$

(5) Compute annual heat gain reduction due to the i^{th} increment of insulation (ΔH_{AG_i}):

$$\Delta H_{AG_i} = H_{AG_{(i-1)}} - H_{AG_{(i)}}$$

Factors used:

U_p = .43 (adjusted for heat flow downward: R increased by 2 x (.92 - .61))

U_w = .31

U_r = .44

A_c = 1000

A_w = 150

A_r = 1120

V = .1 CFM/sq. ft.

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[1] Sol air temperature equivalents for this study were based on "Design Equivalent Temperature Differences" (ASHRAE Handbook of Fundamentals, 1972, p. 441, Table 50) plus 75°, on which these estimates are based. Medium daily temperature ranges were used. Results compare favorably with available measured data.

WALL INSULATION (All calculations per square foot of wall area)

(1) Compute wall U:

$$U_w = .875/(R_p + R_a + a \cdot R_t) + .125/(R_p + S)$$

where .857 and .125 are weights for non-studded and studded areas of wall, respectively.

R_p = thermal resistance of basic wall (less air space and studding)

R_a = thermal resistance of air space

R_t = thermal resistance per inch of insulation

a = thickness of insulation in inches

S = thermal resistance of studding

Note: When a = 3.5, $R_a = 0$

(2) Compute hourly heat loss (gain) (H_L, H_G):

$$H_L = U_w \cdot (t_i - t_o)$$

$$H_G = U_w \cdot \Delta t$$

where Δt = temperature difference between outside sol air temperature equivalent[1] and inside air temperature.

(3) Compute annual heat loss (gain) (H_{AL}, H_{AG}):

$$H_{AL} = U_w \cdot DD \cdot 24$$

$$H_{AG} = U_w \cdot \Delta t \cdot CH$$

(4) Compute annual heat loss (gain) reduction due to the i^{th} increment of insulation (ΔH_{AL_i}, ΔH_{AG_i}):

$$\Delta H_{AL_i} = H_{AL_{(i-1)}} - H_{AL_{(i)}}$$

$$\Delta H_{AG_i} = H_{AG_{(i-1)}} - H_{AG_{(i)}}$$

Factors used:

R_p = 4.76 (Winter, wind speed = 10 mph.)

R_p = 4.80 (Summer, wind speed = 7.5 mph.)

R_a = 1 (Winter); R_a = .84 (Summer)

S = 4.35 (3.5 inches thick)

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[1] See footnote for Attic Insulation: Summer.

FLOOR OVER UNHEATED BASEMENT (WINTER ONLY) (All calculations per square foot of floor area)

(1) Compute floor U Value (U_f):

$$U = .875/(R_p + a \cdot R_t) + .125/(R_p + S)$$

where .875 and .125 are weighing factors for non-joist and joist areas of floor.

a = thickness of insulation in inches

R_p = thermal conductance of floor without insulation or joists

S = thermal resistance of studs

R_t = thermal resistance per inch of insulation

(2) Compute basement temperature (t_b):[1]

$$t_b = \frac{A_f U_f t_i + t_o(A_G U_G + A_{w1} U_{w1}) + t_g(A_b U_b + A_{w2} U_{w2})}{A_f U_f + A_g U_g + A_{w1} U_{w1} + A_b U_b + A_{w2} U_{w2}}$$

with subscripts:

f = floor over basement

G = window

w1 = wall above grade

w2 = wall below grade

b = basement floor

t_g = ground water temperature

Note: t_b is recomputed for each additional increment of insulation.

t_b is computed at average $t_o = 65° - \frac{DD}{HD}$

(3) Compute hourly heat loss through floor (H_L):

$$H_L = A_f \cdot U_f \cdot (t_i - t_b)$$

(4) Compute yearly heat loss (H_{AL}):

$$H_{AL} = H_L \cdot HD \cdot 24$$

(5) Compute annual heat loss reduction due to the i^{th} increment of insulation (ΔH_{AL_i}):

$$\Delta H_{AL_i} = H_{AL_{(i-1)}} - H_{AL_{(i)}}$$

Factors used:

A_f, A_b = 500 sq. ft.

A_{w1} = 180 sq. ft. (1/4 basement wall above grade)

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[1] Heat losses to basement from furnace and hot water heater are not accounted for. If these are substantial, little or no insulation may be needed.

A_{w2} = 540 sq. ft. (3/4 basement wall below grade)

A_G = 10 sq. ft.

U_f = .36

U_b = .1

U_{w1} = .5

U_{w2} = .2

U_G = 1.0

Ground water temperatures used:

2000 DD - 65°

4000 DD - 55°

6000 DD - 50°

8000 DD - 45°

10000 DD - 40°

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FLOOR OVER VENTED CRAWLSPACE (WINTER ONLY) (All calculations per square foot of floor area)

(1) Compute floor U value (U_f):

(See: Floor Over Unheated Basement)

(2) Compute crawlspace temperature (t_c):

$$t_c = \frac{A_f U_f t_i + t_o (A_w U_w + 1.08\ A_f V) + A_g U_g t_g}{A_f U_f + A_w U_w + 1.08\ A_f V + A_g U_g}$$

with subscripts:

f = floor

w = walls

g = ground

V = ventilation rate in CFM/ft.^{2} of floor

t_c is computed at average t_o, where average $t_o = 65 - \frac{DD}{HD}$.

t_c is recomputed for each additional increment of insulation.

(3) Compute hourly heat loss (H_L):

$$H_L = U_f \cdot (t_i - t_c)$$

(4) Compute yearly heat loss (H_{AL})

$$H_{AL} = U_f \cdot DD \cdot 24$$

(5) Compute annual heat loss reduction due to the i^{th} increment of insulation (ΔH_{AL_i}):

$$\Delta H_{AL_i} = H_{AL_{(i-1)}} - H_{AL_{(i)}}$$

Factors used:

$A_f = A_g = 1000$ ft.^{2}

$A_w = 380$ ft.^{2}

$U_f = .36$

$U_g = .33$ (1 foot of earth assumed as thermal barrier)

$U_w = .35$

V = .1 CFM/ft.^{2} of floor area

See: "Floors Over Unheated Basement" for t_g used.

EXPOSED DUCTING INSULATION (IN ATTIC) (All calculations per square foot of duct surface)

(1) Compute ductwork R and U (R_d, U_d):

$R_d = 1/U_p + a \cdot R_t$

where U_p = thermal conductance of duct wall (without insulation)

a = thickness of insulation around duct in inches

R_t = R value per inch of insulation

$U_d = 1/R_d$

Computation of U_p:

$$U_p = \frac{1}{.72 + .01 + .26} = 1.0$$

where $.72 = \frac{.61 + .68 + .68 + .92}{4}$ (Average R for 4 directions of heat loss from duct)

.01 = R for sheet metal

.26 = R value for inside air surface (air velocity = 600 FPM, ASHRAE recommended)

(2) Compute hourly heat loss (gain) (H_L, H_G) when in operation:

$H_L = U_d \cdot (t_i - t_a)$ $(t_i > t_a)$

$H_G = U_d \cdot (t_a - t_i)$ $(t_a > t_i)$

where t_i = average temperature inside duct

t_a = average temperature in attic.

(3) Compute yearly heat loss (gain) (H_{AL}, H_{AG})

$H_{AL} = U_d \cdot (t_i - t_a) \cdot HD \cdot 24 \cdot X_w$

$H_{AG} = U_d \cdot (t_a - t_i) \cdot CH \cdot X_s$

where X_w = % of time furnace system operates when outdoor temperature is at average winter temperature (decimal form).

X_s = % of time air conditioner operates when outdoor temperature is at average cooling hour temperature (decimal form)

[No heat loss (gain) assumed when HVAC system is not operating -- conservative estimate.]

Note: During winter attic temperature is assumed = t_o in well-insulated attic. During summer attic temperature is calculated as outlined in "Attic Insulation: Summer" (see values used below)

(4) Calculate annual heat loss (gain) reduction due to the i^{th} increment of insulation (ΔH_{AL_i}, ΔH_{AG_i}):

$\Delta H_{AL_1} = H_{AL_{(1-1)}} - H_{AL_{(1)}}$

$\Delta H_{AG_1} = H_{AG_{(1-1)}} - H_{AG_{(1)}}$

Factors used:

t_1 (winter) = 140°

t_1 (summer) = 55°

Average Cooling t_o	Corresponding t_a used
90°	105°
95°	110°

WINDOWS -- STORM WINDOWS OVER WOODEN DOUBLE-HUNG PRIMARY

(1) Conductive heat loss (gain)

(a) Compute U Value of Window:

(i) Compute outside surface air boundary (R_o):

$$R_o = \frac{1}{2 + .2667 \cdot W}$$

where W = wind velocity in mph.

(This is derived from Table I, section A, ASHRAE Handbook of Fundamentals, 1972, p. 357)

(ii) Inside air surface air resistance $R_I = .68$

(iii) Compute window R_w and U_w:

$$R_w = \frac{1}{2 + .2667 \cdot w} + .68$$ (thermal resistance of window pane negligible)

$$U_w = 1/R_w$$

(iv) Adjust U for wood sash-factor:.9 for 80% glass:

$$U_{w_a} = U_w \cdot .9$$

(v) Conductance reduction due to storm windows (ΔU_s):

Storm windows reduce conductive heat loss (gain) by 50%

$$\Delta U_s = .5U_{w_a}$$

(Based on ASHRAE handbook of Fundamentals, 1972, p. 370.)

(b) Compute hourly heat loss (gain) reduction (H_L, H_G):

$H_L = \Delta U_s \cdot A \cdot (t_i - t_o)$ where $t_i > t_o$

$H_G = \Delta U_s \cdot A \cdot (t_o - t_i)$ where $t_o > t_i$

(c) Compute yearly conductive heat loss (gain) (H^c_{AL}, H^c_{AG}):

$H^c_{AL} = U_s \cdot A \cdot DD \cdot 24$

$H^c_{AL} = U_s \cdot A \cdot CH \cdot (t_o - t_I)$

where t_o = average t_o during cooling hours

(2) Air infiltration heat loss (gains)

Crack method is used rather than air change method. Only wind pressure is used in estimating infiltration rates per area of crack. Stack pressure is ignored because of its difficulty to estimate in the abstract.

(a) Compute wind pressure difference:

(i) $P_v = .000482\ V_w^2$

where P_v = velocity head, inches water

V_w = wind velocity, mph.

(ii) Effective pressure difference requires a factor of .64 to account for build up of pressure inside a building.

$P = .64\ P_v$

(b) Compute air leakage per foot of crack around double-hung windows as a function of P:

Establish functions for different window types, derived from Table 2, p. 337, ASHRAE Handbook of Fundamentals, 1972.

Types:

(1) Loose fit w/o weather strip

(2.a) Average fit w/o weather strip

(2.b) Loose fit with weather strip

(3) Average fit with weather strip

Infiltration functions:

(1) $I = 40 + 370\ P$

(2) $I = 14 + 132.5\ P$

(3) $I = 7 + 70\ P$

where I = CFH per foot of crack

(c) Compute crack length:

$L = 2 \cdot H + 3 \cdot w$

where L = crack length in feet

H = window height

W = window width

(d) Compute effect of storm windows over primary windows in reducing infiltration:

Methodology:

ASHRAE Handbook of Fundamentals states that tight fitting storm windows reduce air infiltration by 50% for loose windows (type 1) and by 30% for equally tight primary windows (2a, 2b). This has been extrapolated to 10% reduction for type 3 windows.

(e) Compute CFH reduced by storm window (ΔQ):

$\Delta Q = L \cdot I \cdot F$

where F is the infiltration reduction factor for storm windows

(f) Reduce ΔQ by one half to account for exiting air:

$\Delta Q = .5\Delta Q$

(g) Compute hourly heat loss (gain) reduction due to decreased infiltration (H_L, H_G):

$$H_L = .240 \cdot \Delta Q \cdot \rho \cdot (t_i - t_o)$$

$$H_G = .240 \cdot \Delta Q \cdot \rho \cdot (t_o - t_i)$$

where .240 = specific heat of air

ρ = density of air = .075

(h) Compute annual air infiltration heat loss (gain) reduction (H^i_{AL}, H^i_{AG}):

$$H^i_{AL} = .240 \cdot \Delta Q \cdot \rho \cdot DD \cdot 24$$

$$H^i_{AG} = .240 \cdot \Delta Q \cdot \rho \cdot CH \cdot (t_o - t_i)$$

Factors used:

Winter wind velocity = 10 mph.

Summer wind velocity = 7.5 mph.

t_i (winter) = 65°F (degree day base)

t_i (summer) = 75°F

(3) Add annual conductive heat loss (gain) reduction to annual air infiltration heat loss (gain) reductions to find total annual heat loss (gain) reduction due to storm window (H_{AL}, H_{AG}):

$$H_{AL} = H^c_{AL} + H^i_{AL}$$

$$H_{AG} = H^c_{AG} + H^i_{AG}$$

STORM DOOR

(1) Conductive heat loss

(No summer cooling help attributed because it is better to remove glass and replace with screens for ventilation during non-cooling hours.)

(a) Compute U for primary door:

(i) Compute outside surface R (R_o):

$$R_o = \frac{1}{2 + .2667 \cdot V_w}$$ (see windows)

(ii) Calculate door R (R_d):

$$R_d = t \cdot R_t$$

where t = thickness (inches) of door, and

R_t = thermal resistance per inch.

(iii) Inside surface $R_i = .68$

$$U_d = \frac{1}{R_o + R_d + R_i}$$

(b) Compute U for glass in door (if any):

(i) Compute outside surface R, R_o (as above).

(ii) Inside surface R, $R_i = .68$

$$U_g = \frac{1}{R_o + R_i}$$ (thermal resistance of glass is negligible)

(c) Compute reduction in thermal conductance due to storm door (ΔU):

(i) Airspace $R_a = 1.0$

(ii) $$U_{d,s} = \frac{1}{R_o + R_d + R_i + R_a} \; ; \; U_{g,s} = \frac{1}{R_o + R_i + R_a}$$

(iii) Effective reduction in thermal conductance due to storm door (ΔU):

$$\Delta U = (U_d - U_{d,s}) \cdot \% \text{ wood} \cdot 10^{-2}$$
$$+ (U_g - U_{g,s}) \cdot \% \text{ glass} \cdot 10^{-2}$$

(d) Compute area of door (A):

$$A = H \cdot W$$

(e) Compute effective hourly heat loss reduction (H):

$$H = A \cdot \Delta U \cdot (t_i - t_o)$$

(f) Compute annual heat loss reduction (H_{AL}):

$$H_{AL} = A \cdot \Delta U \cdot DD \cdot 24$$

(2) Infiltrative heat loss (again only wind pressure is considered significant):

(a) Compute effective wind pressure differential (P):

$P = .64 \cdot .000482 \cdot V_w^2$

where V_w = wind velocity

(See windows for rationale)

(b) Compute air leakage per foot of crack around door (average):

ASHRAE recommends using two times the window crack rate

(i) Well-fitted door, $I = 2 \cdot (14 + 132.5P)$

(ii) Average/poor-fitted door, $I = 2 \cdot (40 + 370\ P)$

(Based on values for poorly fitted double hung window)

where I = CFH per foot of crack

(c) Compute crack length (L):

$L = 2 \cdot H + 2 \cdot W$

(d) Compute hourly CF of infiltration (Q):

$Q = L \cdot I$

(e) Compute effect of storm door on reducing air infiltration (ΔQ) --

Factors Derived from Data on Windows:

Type (i): Weather stripping reduces infiltration by 50%

Storm door reduces infiltration by 30%

Combination WS and SD reduces infiltration by 55%

Type (ii): Weather stripping reduces infiltration by 50%

Storm door reduces infiltration by 50%

Combination WS and SD reduces infiltration by 65%

(f) Reduce ΔQ by one-half to account for exiting air:

$\Delta Q = .5\ \Delta Q$

(g) Compute hourly heat loss reduction due to storm door (H):

$H = .24 \cdot \Delta Q \cdot \rho \cdot (t_i - t_o)$

(h) Compute yearly heat loss reduction due to storm door (H_{AL}):

$H_{AL} = .24 \cdot \Delta Q \cdot \rho \cdot DD \cdot 24$

Factors used in calculations:

$R_d = t\ R_t = 1\ 1/2" \cdot .91 = 1.36$

$V_w = 10$ mph.

Glass in door computed at 0%, 10%, 20%, 30%, 40%, 50%.

Door size = 3' x 6 2/3" = 20 $ft.^2$

Perimeter = 19 1/3'

APPENDIX E

A NOTE ON THE COMPUTER PROGRAMS USED IN THIS STUDY

The computer programs needed to solve for the economically optimal levels of investment in each ECT were written in BASIC (Beginners All-purpose Symbolic Instruction Code) language. One program was written for each ECT, using the methodology outlined in Appendix D. These programs compute annual marginal energy savings for both heating and cooling operations as a function of degree days, cooling hours, inside temperatures, existing coefficients of conductance, the resistance per unit of the ECT materials, and other relevant variables. Marginal savings are computed for each inch of insulation, for decreasing storm window sizes, and for storm doors over prime doors with decreasing glass content. Energy savings due to weather stripping are calculated for loose and average fitting doors and windows with or without existing storm sash.

The marginal energy savings generated by variable-usage techniques (insulation, storm windows and storm doors) are then read into a general purpose benefit-cost analysis program (BENCØ). This program calculates the present value marginal savings in dollars corresponding to annual marginal energy savings, calls out appropriate marginal costs from a supporting cost file, and then searches for the globally optimal investment level (satisfaction of condition I and II) for the specified energy prices, using a search procedure similar to that outlined in Figure E-1.

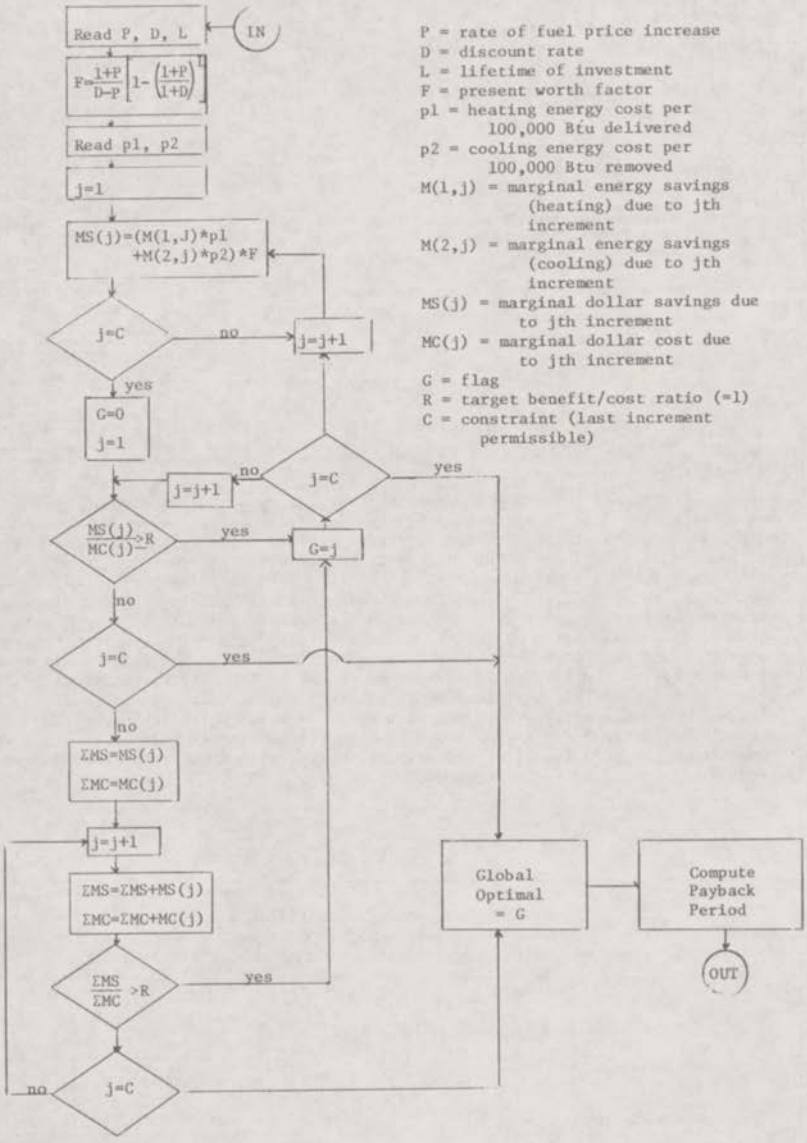
Satisfaction of Condition II only cannot be solved for directly because specific parametric information (building dimensions, number and size of windows and doors, etc.) for a given building is needed in order to calculate the optimal level of investment in each technique which meets the specific budget constraint for that building. However, the model can be used with MS/MC ratios other than 1 in order to find lower or higher levels of investment which are economically balanced in the sense of Condition II. Given a fixed-sized investment budget and specific parametric information, the allocation of a constrained budget among alternative techniques can then be estimated using an iterative approach. (See Section 5.3 for more details on this approach.)

It should be noted that BENCØ is structured to reflect the particular cost and savings functions typical of insulation, i.e., marginal costs (MC) may rise and fall while marginal savings (MS) decline monotonically. In addition, the use of the i^{th} increment assumes the use of the $(i - 1)^{th}$ increment. Because there may be more than one local optimal, this program searches for the global optimal, i.e., that level of investment which maximizes net savings for the entire range of application. Rather than directly identifying those investment levels where MS = MC (Condition I), the program instead examines each successive increment of insulation to insure that total cost does not exceed total savings at the global optimum. This may require more computer time and information on fixed costs than the direct approach but it is manageable in cases where there are a limited number of increments under consideration such as are encountered in this study.

In order that BENCØ finds the minimum economic configuration of storm windows and doors, these configurations must be entered in order of decreasing MS/MC ratios. In general the use of any given size window or door configuration is physically independent of the use of other windows or doors. In ordering such ECT's by decreasing MS/MC ratios, the search routine will select only those units which generate savings greater than or equal to cost.

Payback periods are computed for the total investment (average payback period) for the techniques involving insulation. For storm windows, payback is computed for a 3' x 5' (average size) window as actual average payback is a function of the number and size distribution of windows in an actual house. Payback periods for storm doors are evaluated for the least profitable configuration which has a benefit-cost ratio greater than or equal to one.

Figure E-1



P = rate of fuel price increase
D = discount rate
L = lifetime of investment
F = present worth factor
p1 = heating energy cost per 100,000 Btu delivered
p2 = cooling energy cost per 100,000 Btu removed
M(1,j) = marginal energy savings (heating) due to jth increment
M(2,j) = marginal energy savings (cooling) due to jth increment
MS(j) = marginal dollar savings due to jth increment
MC(j) = marginal dollar cost due to jth increment
G = flag
R = target benefit/cost ratio (=1)
C = constraint (last increment permissible)

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16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

This study examines the economic aspects of energy conservation techniques suitable for retrofitting into existing housing, including insulation, storm windows and doors, and weather stripping. The objective of this study is to determine that combination of techniques which will maximize net dollar savings in life-cycle operating costs for heating and cooling operations in existing homes, subject to specific climate conditions, fuel costs, and retrofitting costs. Using micro-economic marginal analysis we find that such a combination must be economically balanced (i.e., the ratio of savings to cost must be equal at the margin for each technique) and that each technique should be utilized up to the point where the present value of the life-cycle savings generated by the last increment will just cover the costs of that last increment. Thermal engineering data is combined with the economic analysis in a computer-assisted model which estimates such optimal combinations for a wide range of climatic conditions and fuel costs. These combinations include levels of application considerably higher than what has been previously recognized as "economical."

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*) Benefit-cost analysis; building economics; building envelope; economic analysis; economic efficiency; energy conservation; engineering economics; insulation; life-cycle costs; marginal analysis; thermal efficiency

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MAKING THE MOST OF YOUR ENERGY DOLLARS

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Energy Conservation Now

A WORD TO THE READER

During the height of the energy crisis many homeowners turned their thermostats down and wore heavy sweaters in an effort to save fuel. Today, with energy prices on the rise, saving energy also means saving money on monthly heating and cooling bills. As a result, many homeowners are thinking about more permanent ways to reduce their household energy consumption.

Energy can be conserved by making relatively simple improvements at home. Installing or adding insulation, fitting storm windows and doors and applying weather stripping and caulking are effective energy saving improvements. But many people are reluctant to invest in these improvements because of the cost. In general, homeowners have not been able to calculate the potential return on their investment.

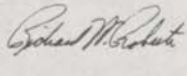
By using this booklet you can determine the best combination of energy conservation improvements for your house—improvements that will give you the largest long-run return on your investment. The booklet also provides information on affording or financing your investment and tips on making the improvements.

This publication is based on the findings and methods presented in a technical report, entitled *Retrofitting Existing Housing for Energy Conservation: An Economic Analysis,* published earlier this year. The report resulted from a joint study conducted by the National Bureau of Standards and the Federal Energy Administration. The report was undertaken to determine what level of investment in home energy improvements would produce the maximum long run savings in home heating and cooling expenses.

This booklet is not a comprehensive "how-to-do-it" book. For more detailed information we recommend a new publication from the Department of Housing and Urban Development, entitled *In the Bank . . . Or Up the Chimney?*

We think *Making the Most of Your Energy Dollars* will convince you that investing in energy conservation improvements can help you offset rising energy prices. And that's good news for you! You'll be saving money and you'll also be doing your part to help conserve our nation's precious energy supplies.

Frank G. Zarb
Administrator
Federal Energy Administration



Richard W. Roberts
Director
National Bureau of Standards

SAVING ENERGY IS SAVING MONEY

If you are a homeowner who wants to save energy and money without sacrificing comfort—this booklet is for you. It is not a "how-to" book, but a "how much" guide to energy conservation investments.

For your climate and the type of energy used to heat and cool your house, this booklet tells what combination of energy conservation improvements to invest in to get the largest, long run net savings in your heating and cooling bills.

Of course, there are many ways to save energy in your house. You can save energy by dialing down thermostats in winter and setting them higher in the summer, turning off lights, shutting drapes, closing off unused rooms, and tuning up your furnace every few years.

But there are other effective ways to save energy and money on your monthly fuel bills—and still keep your house at comfortable temperatures. By investing in the energy conservation improvements described in this booklet, you can *permanently* reduce the amount of energy used to heat and cool your house. These improvements include the installation of insulation in the attic and walls, under floors, and around ducts in unheated areas; storm windows and doors; and weather stripping and caulking.

These energy conservation improvements are wise investments if you can be sure they'll save you enough money on heating and cooling bills to pay for themselves. If you think that doing too much or too little can be a waste of your money, you're right!

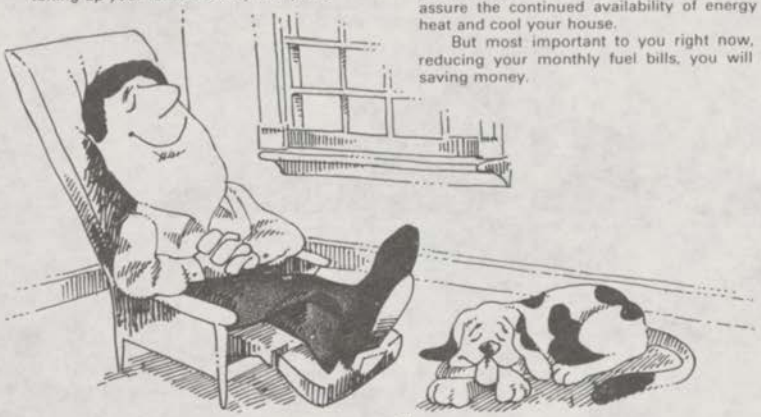
That's why the National Bureau of Standards, in cooperation with the Federal Energy Administration, has published this guide—to help you balance your energy budget and get the most for your money.

You may be surprised to learn how much insulation you should install. In some parts of the country, when higher priced fuels are used, R-38 insulation (about 12 inches of mineral fiber batts) in the attic is recommended to give the best results. Even in milder climates, R-30 insulation (about 10 inches) may be economically justified if you use oil or electric heating at current high prices.

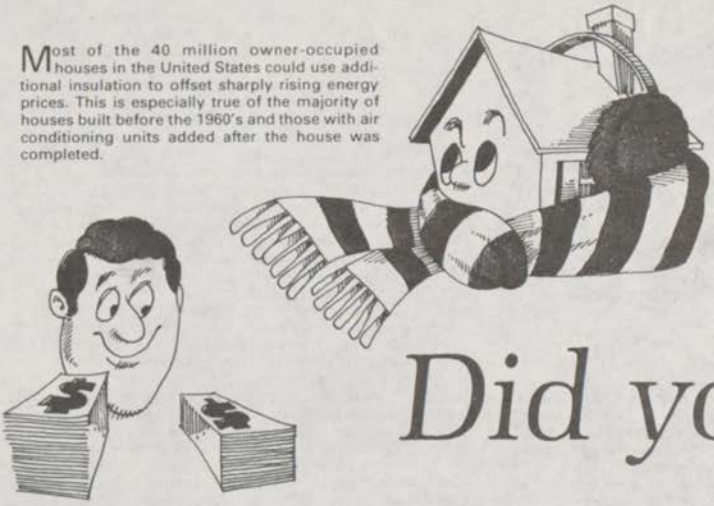
You may be just as surprised to learn that investing in energy conservation improvements now can earn you greater dividends than putting your money in the bank!

By using the guidelines in this booklet, you will be doing your part to help conserve our country's energy resources—which will help assure the continued availability of energy to heat and cool your house.

But most important to you right now, by reducing your monthly fuel bills, you will be saving money.



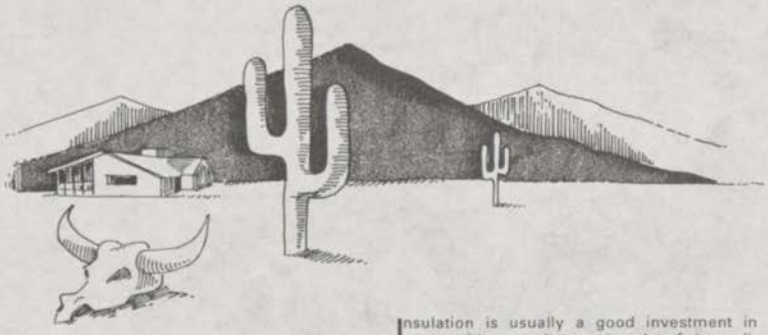
Most of the 40 million owner-occupied houses in the United States could use additional insulation to offset sharply rising energy prices. This is especially true of the majority of houses built before the 1960's and those with air conditioning units added after the house was completed.



Did you

The more you pay for energy, the more you will save from increased investments in energy conservation improvements. Currently, electricity is generally more costly than fuel oil, and fuel oil is more costly than natural gas. As a result, even in the same climate, houses heated and cooled by different energy sources require different levels of investment.

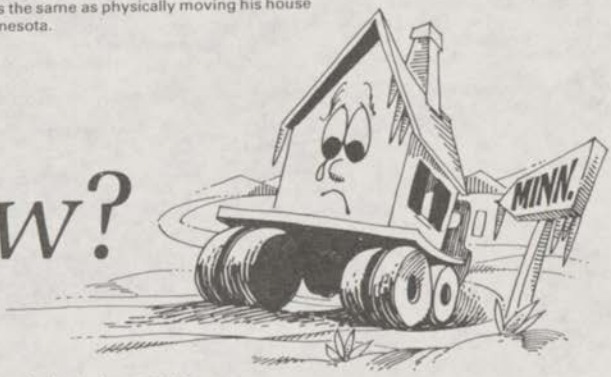
Balancing your energy budget means striking a happy medium between dollars spent on energy consumption and energy conservation improvements. A balanced budget gives you the greatest possible long run net savings on heating and cooling expenses. Your net savings are the total savings on fuel bills less the cost of improvements.



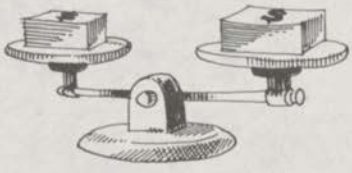
Insulation is usually a good investment in geographic areas that require a lot of air conditioning, even if heating requirements are low.

How much you should invest in energy conservation improvements depends equally on climate *and* energy prices. A doubling of energy prices has the same effect on a homeowner's energy budget as a doubling of heating and cooling requirements. For example, when prices for home heating oil doubled in Washington, D.C., the effect on a homeowner's heating bill was the same as physically moving his house to Minnesota.

Know?



Balancing your energy budget also means using a balanced combination of energy conservation techniques. You may not be making the best use of your money if you invest only in attic insulation and neglect the use of storm windows or insulation in floors over unheated areas where these are economical.



Energy conservation improvements not only increase your family's comfort, but also cut down on unwanted, outside noise.

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FIGURING YOUR ENERGY CONSERVATION BUDGET

To find the "best combination" of energy conservation measures for your climate and fuel prices, use the tables on the following pages. This best combination gives you the largest, long run net savings on your heating and cooling costs for your investment. By comparing this best combination with what already exists in your house, you can figure out how much more needs to be added to bring your house up to the recommended levels.

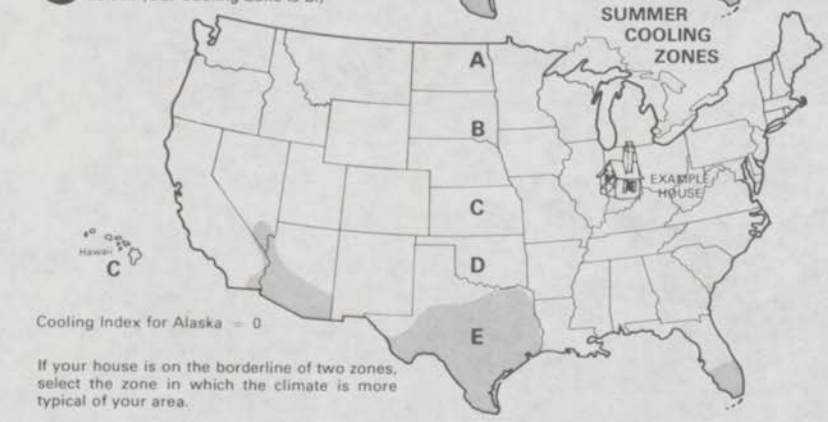
The recommended improvements apply to most houses to the extent they can be installed without structurally modifying the house. Recommended improvements are based on sample costs given in Table 7. If your costs are substantially different, see page 9.

Follow the steps outlined below and fill in the information for your house on Worksheet A. We have filled in the information for a typical house located in Indianapolis, Indiana.

1 Locate your city on the Heating Zone Map below. (Our house is located in Heating Zone III.)

Heating Index for Hawaii = 0

2 Locate your city on the Cooling Zone Map below. (Our Cooling Zone is B.)



Cooling Index for Alaska = 0

If your house is on the borderline of two zones, select the zone in which the climate is more typical of your area.

3 Our house currently uses fuel oil at a cost of 34¢ a gallon to heat. It uses electricity at 4¢ a kilowatt hour to cool. Obtain your unit heating and cooling costs from the utility companies as follows: Tell your company how many therms (for gas) or kilowatt hours (for electricity) you use in a typical winter month and summer month (if you have air conditioning). The number of therms or kilowatt hours is on your monthly fuel bill. Ask for the cost of the last therm or kilowatt hour used, including all taxes, surcharges, and fuel adjustments. For oil heating, the unit fuel cost is simply your average cost per gallon plus taxes, surcharges, and fuel adjustments.

4 Locate your Heating Index from Table 1 by finding the number at the intersection of your Heating Zone row and heating fuel cost column (to the nearest cost shown). (Our house has a Heating Index of 20.)

If your house is air conditioned, or you plan to add air conditioning, find your Cooling Indexes from steps 5 and 6. If your house is not air conditioned and it is not planned, your Cooling Indexes are zero.

TABLE 1 HEATING INDEX

Type of fuel:			Cost per unit*								
Gas (therm)			9¢	12¢	15¢	18¢	24¢	30¢	36¢	54¢	72¢	90¢
Oil (gallon)			13¢	17¢	21¢	25¢	34¢	42¢	50¢	75¢	$1.00	$1.25
Electric (kWh)						1¢	1.3¢	1.6¢	2¢	3¢	4¢	5¢
Heat pump (kWh)			1¢	1.3¢	1.7¢	2¢	2.6¢	3.3¢	4¢	6¢	8¢	10¢
HEATING	ZONE	I	2	2	3	3	4	5	6	9	12	15
		II	5	6	8	9	12	15	18	27	36	45
		III	8	10	13	15	20	25	30	45	60	75
		IV	11	14	18	21	28	35	42	63	84	105
		V	14	18	23	27	36	45	54	81	108	135
		VI	22	28	36	42	56	70	84	126	168	210

Note: In Tables 1-3, if your fuel costs fall midway between two fuel costs listed, you can interpolate. For example, if our fuel oil costs were 38¢ a gallon, our Heating Index would be 22.5.

5 Locate your Cooling Index for Attics from Table 2 by finding your Cooling Zone and cooling cost to the nearest cost shown. (Our house has a Cooling Index for Attics of 5.)

6 Locate your Cooling Index for Walls from Table 3 by finding your Cooling Zone and cooling cost to the nearest cost shown in the table. (Our house has a Cooling Index for Walls of 2.)

TABLE 2 COOLING INDEX FOR ATTICS

Type of air conditioner:			Cost per unit*						
Gas (therm)			9¢	12¢	15¢	18¢	24¢	30¢	36¢
Electric (kWh)			1.5¢	2¢	2.5¢	3¢	4¢	5¢	6¢
COOLING	ZONE	A	0	0	0	0	0	0	0
		B	2	2	3	4	5	6	7
		C	3	5	6	7	9	11	13
		D	5	6	8	9	12	15	18
		E	7	9	11	14	18	23	27

TABLE 3 COOLING INDEX FOR WALLS

Type of air conditioner:			Cost per unit*						
Gas (therm)			9¢	12¢	15¢	18¢	24¢	30¢	36¢
Electric (kWh)			1.5¢	2¢	2.5¢	3¢	4¢	5¢	6¢
COOLING	ZONE	A	0	0	0	0	0	0	0
		B	1	1	2	2	2	3	4
		C	2	2	3	4	5	6	7
		D	3	3	4	5	7	8	10
		E	4	5	6	8	10	13	15

*Cost of last unit used (for heating and cooling purposes) including all taxes, surcharges, and fuel adjustments.

7 Find the sum of your Heating Index and Cooling Index for Attics. (Our sum is 25.)

8 Find the sum of your Heating Index and Cooling Index for Walls. (Our sum is 22.)

Energy savings result from decreasing the heat flow through the exterior shell of the building. The resistance, or "R," value of insulation is the measure of its ability to decrease heat flow. Two different kinds of insulation may have the same thickness, but the one with the higher R value will perform better. For that reason, our recommendations are listed in terms of R values with the approximate corresponding thickness. R values for different thicknesses of insulation are generally made available by the manufacturers.

9 Find the resistance value of insulation recommended for your attic and around attic ducts from Table 4. (For our house the recommended resistance value is R-30 for attic floors and R-16 for ducts.)

TABLE 4 ATTIC FLOOR INSULATION AND ATTIC DUCT INSULATION

INDEX Heating Index Plus Cooling Index for Attics	ATTIC INSULATION Approximate Thickness				DUCT INSULATION*	
	R-Value	Mineral Fiber Batt/Blanket	Mineral Fiber Loose-Fill**	Cellulose Loose-Fill**	R-Value	Approximate Thickness
1-3	R-0	0"	0"	0"	R-8	2"
4-9	R-11	4"	4-6"	2-4"	R-8	2"
10-15	R-19	6"	6-10"	4-6"	R-8	2"
16-27	R-30***	10"	13-15"	7-9"	R-16	4"
28-35	R-33	11"	14-16"	8-10"	R-16	4"
36-45	R-38	12"	17-19"	9-11"	R-24	6"
46-60	R-44	14"	19-21"	11-13"	R-24	6"
61-85	R-49	16"	22-24"	12-14"	R-32	8"
86-105	R-57	18"	25-27"	14-16"	R-32	8"
106-130	R-60	19"	27-29"	15-17"	R-32	8"
131—	R-66	21"	29-31"	17-19"	R-40	10"

* Use Heating Index only if ducts are not used for air conditioning. ** High levels of loose-fill insulation may not be feasible in many attics. ***Assumes that joists are covered, otherwise use R-22.

10 Find the recommended level of insulation for floors over unheated areas from Table 5. (Our house should have R-19.) Using Table 5, check to see whether storm doors are economical for your home. Storm doors listed as optional may be economical if the doorway is heavily used during the heating season.

TABLE 5 INSULATION UNDER FLOORS AND STORM DOORS

INDEX Heating Index Only	INSULATION UNDER FLOORS*		STORM DOORS
	R-Value	Mineral Fiber Batt Thickness	
0-7	R**	0"**	None
8-15	R***	4"***	None
16-30	R9	6"	Optional
31-45	R2	7"	Optional
46—	R2	7"	On all doors

* If your furnace and hot water heater are located in an otherwise unheated basement, not your Heating Index in half to find the level of floor insulation.

**In Zone I and II R-11 insulation is usually economical under floors over open crawlspaces and over garages; in Zone I insulation is not usually economical if crawlspace is closed off.

11 Find the recommended level of insulation for your walls and ducts in unheated areas from Table 6. (Our house should have full-wall insulation if none existed previously and R-16 insulation around ducts.) Table 6 also shows the minimum economical storm window size in square feet for triple-track storm windows. (Our house should have storm windows on all windows 9 square feet in size or larger where storm windows can be used.)

TABLE 6 WALL INSULATION, DUCT INSULATION, AND STORM WINDOWS

INDEX Heating Index Plus Cooling Index for Walls	WALL INSULATION (blown-in)	INSULATION AROUND DUCTS IN CRAWLSPACES AND IN OTHER UNHEATED AREAS (EXCEPT ATTICS)* Resistance and Approximate Thickness	STORM WINDOWS (Triple-Track) Minimum Economical Window Size
0-10	None	R-8 (2")	none
11-12	Full Wall Insulation Approximately R-14	R-8 (2")	20 sq. ft.
13-15		R-16(4")	15 sq. ft.
16-19		R-16(4")	12 sq. ft.
20-28		R-16(4")	9 sq. ft.
29-35		R-16(4")	6 sq. ft.
36-45		R-24(6")	4 sq. ft.
46-65		R-24(6")	All windows**
66—		R-32(8")	All windows**

* Use Heating Index only if ducts are not used for air conditioning. **Windows too small for triple-track windows can be fitted with one-piece windows.

12 Weather stripping and caulking. Regardless of where you live or your cost of energy, it is almost always economical to install weather stripping on the inside around doors and windows where possible and to caulk on the outside around doors and window frames—if you do it yourself. This is especially true for windows and doors which have noticeable drafts.

YOU NOW KNOW your best combination of energy conservation improvements. Of course, the size of your investment depends on your existing insulation and the size of your house.

In addition, some of the recommended improvements in this booklet are not appropriate for all houses. For instance, insulation cannot be added under floors in houses built on concrete slabs. In such cases, the other recommended improvements should still be added to the extent indicated in this booklet. Similarly, R-30 insulation may be recommended for your attic although only R-19 may fit at the eaves or in areas where the attic is floored. In this case, you should still put R-30 insulation wherever it fits.

Use Worksheet B and Table 7 (or your own cost information) to calculate how much you need to add to reach your best combination and how much this will cost. We have provided this information on Worksheet B for our example house. Our house only has R-11 attic insulation, some wall insulation, and R-8 attic duct insulation to begin with. To reach our best combination, the improvements would cost about $1200.

REMOVE THIS SHEET FOR YOUR RECORDS

WORKSHEET A

EXAMPLE:		YOUR CALCULATIONS:	
Climate:		Climate:	
Heating Zone	III	Heating Zone	
Cooling Zone	13	Cooling Zone	
Fuel Costs:		Fuel Costs:	
Heating Energy	Oil	Heating Energy	
Cost per Unit	34¢/gal.	Cost per Unit	
Cooling Energy	Electric	Cooling Energy	
Cost per Unit	4¢/KWH	Cost per Unit	
Indexes:		Indexes:	
Heating	20	Heating	
Cooling (Attic)	5	Cooling (Attic)	
Cooling (Wall)	2	Cooling (Wall)	
Heating + Cooling (Attic)	25	Heating + Cooling (Attic)	
Heating + Cooling (Wall)	22	Heating + Cooling (Wall)	

BEST COMBINATION			BEST COMBINATION
Attic Insulation (Batt)	R-30 (10 inches)	FROM TABLE 4	Attic Insulation
Duct Insulation (in attics)	R-11 (4 inches)		Duct Insulation (in attics)
Insulation Under Floors	R-19 (6 inches)	FROM TABLE 5	Insulation Under Floors
Storm Doors	optional		Storm Doors
Wall Insulation (blown-in)	full-wall R-14 (3½ inches)	FROM TABLE 6	Wall Insulation (blown-in)
Duct Insulation (in unheated crawl spaces, etc.)	R-11 (4 inches)		Duct Insulation (in unheated crawlspaces, etc.)
Storm Windows (minimum size)	9 sq. ft.		Storm Windows (minimum size)
Weather strip and caulk windows and door frames	all		Weather strip and caulk windows and door frames

See page 12 for recommendations on combining insulation batts to make up greater thicknesses than 6 inches.

WORKSHEET B

OUR EXAMPLE:

ATTIC INSULATION

1. Attic area (sq. ft.)	1200	
2. Recommended level	R-30 (10")	
3. Existing level	R-11 (4")	
4. Add	R-19 (6")	
5. Cost sq. ft.	$.25	
6. Total cost (1 · 5)		$300

WALL INSULATION (BLOWN-IN)

1. Wall area (sq. ft.)	900	
2. Recommended level	fullwall	
3. Existing level	some	
4. Add	0	
5. Cost sq. ft.	$.60	
6. Total cost (1 · 5)		0

FLOOR INSULATION

1. Floor area (sq. ft.)	1200	
2. Recommended level	R-19 (6")	
3. Existing level	0"	
4. Add	R-19 (6")	
5. Cost sq. ft.	$.30	
6. Total cost (1 · 5)		$360

DUCT INSULATION (ATTIC)

1. Length (ft.)	30'	
2. Perimeter (ft.)	2'	
3. Area (1 · 2 · 1.5)*	90 sq. ft.	
4. Recommended level	R-16 (4")	
5. Existing level	R-8 (2")	
6. Add	R-8 (2")	
7. Cost sq. ft.	$.30	
8. Total cost (3 · 7)		$27

DUCT INSULATION (OTHER AREAS)

1. Length (ft.)	30'	
2. Perimeter (ft.)	2	
3. Area (1 · 2 · 1.5)*	90 sq. ft.	
4. Recommended level	R-16 (4")	
5. Existing level	0	
6. Add	R-16 (4")	
7. Cost sq. ft.	$.50	
8. Total cost (3 · 7)		$45

STORM WINDOWS (over 9 sq. ft.)

size (sq. ft.)	number	cost each	sub-total
20	2	$35	$ 70
15	4	30	120
12	3	30	90
9	2	30	60
Total cost			$340

STORM DOORS

1. Doors Needed	1 (optional)	
2. Cost per door	$75	
3. Total cost		$75

WEATHER STRIPPING (MATERIALS ONLY)

1. Linear feet	200	
2. Cost per foot	$.10	
3. Total cost		$20

CAULKING (MATERIALS ONLY)

1. Variable costs	$20-50	
2. Estimated cost		$33

Total cost of all improvements: $1200

YOUR ESTIMATES:

ATTIC INSULATION

1. Attic area (sq. ft.)		
2. Recommended level		
3. Existing level		
4. Add		
5. Cost/sq. ft.		
6. Total cost (1×5)		

WALL INSULATION (BLOWN-IN)

1. Wall area (sq. ft.)		
2. Recommended level		
3. Existing level		
4. Add		
5. Cost/sq. ft.		
6. Total cost (1×5)		

FLOOR INSULATION

1. Floor area (sq. ft.)		
2. Recommended level		
3. Existing level		
4. Add		
5. Cost/sq. ft.		
6. Total cost (1×5)		

DUCT INSULATION (ATTIC)

1. Length (ft.)		
2. Perimeter (ft.)		
3. Area (1×2×1.5)*		
4. Recommended level		
5. Existing level		
6. Add		
7. Cost/sq. ft.		
8. Total cost (3×7)		

DUCT INSULATION (OTHER AREAS)

1. Length (ft.)		
2. Perimeter (ft.)		
3. Area (1×2×1.5)*		
4. Recommended level		
5. Existing level		
6. Add		
7. Cost/sq. ft.		
8. Total cost (3×7)		

STORM WINDOWS

size (sq. ft.)	number	cost each	sub-total
Total cost			

STORM DOORS

1. Doors needed		
2. Cost per door		
3. Total cost		

WEATHER STRIPPING (MATERIALS ONLY)

1. Linear feet		
2. Cost per foot		
3. Total cost		

CAULKING (MATERIALS ONLY)

1. Variable costs		
2. Estimated cost		

Total cost of all improvements

REMOVE THIS SHEET FOR YOUR RECORDS

*1.5 is an adjustment factor for increased width of insulation needed to fit around duct.

TABLE 7 SAMPLE IMPROVEMENT COSTS

These sample costs were used in estimating the best combination of energy conservation improvements for the various climates and fuel prices covered in this booklet. They include an allowance for commercial installation, except in the case of weather stripping and caulking which is considered to be a do-it-yourself project. While these costs are typical of 1975 prices, there may be considerable variation among specific materials, geographic locations, and suppliers. It usually is worth your time to obtain several estimates for materials and installation before making any purchase. Many of these items can be purchased at substantial discounts if you watch the advertised sales. Considerable savings may be made by installing these yourself, where possible.

ATTIC INSULATION (ALL MATERIALS)

Installed cost per square foot of attic:

R-11 = 15¢	R-44 = 57¢
R-19 = 25¢	R-49 = 64¢
R-22 = 29¢	R-57 = 74¢
R-30 = 39¢	R-60 = 78¢
R-33 = 43¢	R-66 = 86¢

WALL INSULATION (ALL MATERIALS)

Installed cost = 60¢ per square foot of net wall area*

FLOOR INSULATION (MINERAL FIBER BATT)

Installed cost:

R-11 = 20¢
R-19 = 30¢
R-22 = 34¢

DUCT INSULATION (MINERAL FIBER BLANKET)

Installed cost per square foot of material:

R-8 = 30¢	R-32 = 90¢
R-16 = 50¢	R-40 = $1.10
R-24 = 70¢	

STORM WINDOWS (TRIPLE-TRACK, CUSTOM-MADE AND INSTALLED**)

Up to 100 united inches (height + width) = $30.00
Greater than 100 united inches = $30.00 + $.60 per united inch greater than 100"

STORM DOORS (CUSTOM-FITTED AND INSTALLED**)

All sizes = $75.00

WEATHER STRIPPING AND CAULKING

Prices vary according to material used. Use the most durable materials available.

* Price includes allowance for painting inside surface of exterior walls with water vapor-resistant paint.

**Prices may be considerably less for stock sizes, homeowner-installed.

If you find that the costs of any of the improvements to your house are substantially different from the sample costs in Table 7, you can easily compensate for the difference.

Take the Index Number appropriate for the improvement in question, multiply this by our sample cost, and divide the result by your cost. This will give you an Adjusted Index Number with which you can find the best level of investment for that particular improvement.

$$\frac{\text{Original Index} \times \text{Our Cost}}{\text{Your Cost}} = \text{Adjusted Index}$$

EXAMPLE

For our example house, we might find that we can get good quality storm windows for $20 apiece instead of our $30 estimate. Our Index Number for storm windows was 22. Our new Adjusted Index Number for storm windows would be: $\frac{22 \times \$30}{\$20} = 33$

Using our Adjusted Index Number of 33 we find that storm windows are economical on all windows 6 square feet in size or larger, instead of 9 square feet in size. In other words, if your costs are substantially less than ours, you will want to go beyond the recommended level.

Similarly, if R-30 insulation in the attic costs 65¢ per square foot instead of our 39¢ price, the Index Number of 25 for attic insulation would be adjusted to $\frac{25 \times 39¢}{65¢} = 15$

From Table 4 we find that R-19 insulation is now recommended instead of R-30. In other words, if your costs are substantially greater than ours, you may want to use a little less than the recommended level.

YOUR DIVIDENDS GROW

You may not have thought about energy conservation this way, but investing in these improvements is better than most alternative low-risk, long-term investments you can make. When you invest in energy conservation improvements, you immediately begin to earn dividends in the form of reduced utility bills. These dividends not only pay off your investment, but they pay "interest" as well. And unlike dividends from many other investments, these are not subject to income taxes.

At current fuel prices, the recommended improvements will pay for themselves many times over during the life of the house. The energy conservation improvements for a house similar to our example house in Zone III B will pay for themselves in seven to nine years—and even more quickly if the improvements are installed by the homeowner. If the index numbers were higher, the improvements also would pay off more quickly. For example, with a Heating Index of 50, instead of 20, the recommended improvements (R-44 attic insulation, full-wall insulation, R-22 floor insulation, R-24 duct insulation, and storm windows on all suitable windows) would take only three to four years to pay back for this same house. Similarly, the more poorly insulated the house is to begin with, the shorter the payback period.

On the other hand, if the Heating Index number were less than 20 or if the house were better insulated to begin with, the payback period would be a little longer.

More important than the payback period are net savings. In our example house, R-19 insulation in the attic would cost less and pay back faster than the recommended R-30. But the long run net savings are greater with R-30 because each additional resistance unit—up to the recommended level—pays back more than it costs. The best combinations shown in this booklet have varying payback periods, but they always yield the *greatest net savings* over the long run.

Even though utility bills rise as energy prices increase, the rise will be much less than it would have been without increased insulation. In fact, you might think of energy conservation improvements as a hedge against inflation. (Are you beating inflation with your after-tax dividends from other investments?)

Even if you don't plan to live in your house long enough to reap the full return on your investment in the form of lowered utility bills, it will probably still pay to invest in energy conservation improvements now. Because of higher energy prices, a well-insulated house is likely to sell more quickly and at a higher price than a poorly-insulated house that costs a lot to heat and cool. Show your low fuel bills to prospective buyers. They will find the small increase in monthly mortgage payments will be more than offset by monthly fuel bill savings, possibly bringing the cost of living in the house within their reach. The increased value of the house alone might cover the cost to you of making the investment in energy conservation improvements.

CAN YOU AFFORD YOUR INVESTMENTS?
(Can you afford not to invest?)

You may have found that the amount of money needed to finance the best combination of energy conservation improvements is more than you can pay for all at once. If this is the case, you might consider taking a low-cost, long-term home improvement loan.

Whether it is to your advantage to borrow money depends to some extent on the existing condition of your house. A house that is poorly insulated compared to the levels recommended in this booklet requires a greater investment in energy conservation than a house which is close to these recommended levels. However, the poorly-insulated house will yield much greater savings on fuel bills after the improvements are made. This means that your investment will generally pay back fast enough to cover the monthly payments on a long-term home improvement loan. Once the loan is paid off, the additional savings are free and clear!

If you feel you just can't afford to invest in the best combination of energy conservation improvements for your house, you can still make the most of a limited energy conservation budget. Keep in mind the idea of a "balanced" combination—not spending too much on one improvement in relation to the other improvements.

To find this less costly, but still balanced, combination of improvements, decrease each of the index numbers you used in Tables 4, 5, and 6 by the same percentage, say 20 percent. Use the new index numbers to find a new combination of improvements in these tables. Keep reducing your index numbers by the same percentage increments until you reach a balanced combination you can afford.

In the example house, we used index numbers of 25 in Table 4, 20 in Table 5, and 22 in Table 6. Reducing these by 40 percent, for instance, gives us new index numbers of 15, 12, and 13, respectively. Using these numbers gives us the following balanced combination:

	Less Costly Combination	Best Combination
Attic insulation (batts)	R-19	R-30
Duct insulation (attics)	R-8	R-16
Floor insulation	R-11	R-19
Storm doors	none	optional
Wall insulation (blown-in)	full-wall	full-wall
Duct insulation (other areas)	R-8	R-16
Storm windows (minimum size)	12 square feet	9 square feet

Based on our existing level of insulation, this new combination would cost about $750, compared to $1200 for the best combination. If this is still more than we can afford, we might reduce our index numbers by 50 percent or even 80 percent.

On the other hand, if you think that you will eventually add all of the recommended improvements in your best combination, but that it will take a year or two to get them all in, it is usually best to start with those which provide the first level of protection—such as insulation in places where none exists, storm windows, and weather stripping and caulking, where you have poorly fitting windows and doors. Add the others as you can afford them.

Things you should know before

THE RECOMMENDED levels of insulation and other energy conservation improvements in this booklet will only return the maximum energy and dollar savings if they are properly installed. If you're not a do-it-yourself homeowner, check with several reliable contractors before deciding on a contract. If you plan to make these improvements yourself, always follow the manufacturer's instructions. For a step-by-step description of proper installation procedures, we recommend *In the Bank . . . or Up the Chimney?*, published by the Department of Housing and Urban Development (see inside back cover). But whether you do it yourself or use a contractor, there is some basic information you should know before you invest in energy conservation improvements.

INSULATION RATINGS

It is always best to select insulation on the basis of cost per resistance unit—the so-called "R" value (usually made available by the manufacturer)—rather than on cost per inch. Durability and resistance to flame spread and vermin should also be considered.

Energy savings are provided by resistance to heat flow and not thickness *per se*. Two different kinds of insulation may have the same thickness, but the one with the higher R value will perform better. For example, loose-fill mineral fiber (glass fiber or rock wool) insulation may have an R value as low as 2.2 per inch, while mineral fiber batts have an R value of about 3 per inch. Even if batts cost 30 to 40 percent more than loose fill per inch, they might be a better investment.

Insulation batts are generally available in R-11 (about 4 inches thick), R-19 (about 6 inches), and R-22 (about 7 inches). If more than R-19 is recommended for your house, batts should be combined to make up the desired resistance. For example, R-30 may consist of an R-11 and an R-19 batt. Note that R values are additive.

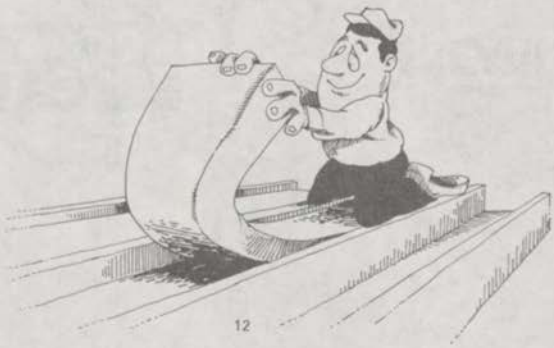
When adding insulation batts to existing insulation, you may not be able to get to our recommended levels exactly. In this case, try to get as close as you can—a little under or over won't make a large difference in your net savings.

MOISTURE CONTROL

Insulation batts can be purchased with or without a "vapor barrier." This is the paper or foil covering on one side of the batt. The barrier retards water vapor, normally present in the house, from passing through or condensing in the insulation. The vapor barrier should face the living quarters of the house, unless a competent air conditioning specialist advises otherwise.

When combining batts or adding batts to existing insulation, additional vapor barriers should not be used beyond the barrier immediately facing the living quarters. If batts without vapor barriers cannot be found or cost more than faced batts, strip off the vapor barrier or slash it to allow any water vapor to pass through freely.

Before you install insulation in closed cavities (such as wallspaces), consult an insulation specialist about possible moisture problems. If water vapor is allowed to condense in the insulated space, it will lower the performance of the insulation and could damage the structure. In general, moisture problems can be prevented with proper installation of vapor barriers and adequate ventilation, but high humidifier settings should be avoided.



you proceed

INSULATION IN ATTICS AND CRAWLSPACES

Two basic kinds of insulation are available for floors of unheated attics. Both will do the job if they are properly installed. One type is preformed mineral fiber (glass fiber or rock wool) batts or blankets. The other type is cellulose or mineral fiber in loose-fill form.

When installing insulation in attics, you don't have to stop at the ceiling joists if the attic has no flooring, but insulation should not touch the roof at the eaves.

If you have a finished attic, check with an insulation specialist or one of the recommended books on the inside back cover for the proper procedure for installing insulation. In this case there may not be room to use the amount of insulation we recommend.

Preformed insulation batts may be more economical than loose-fill materials in an unobstructed attic area without flooring, if they fit snugly between the joists and you do the work yourself. You can add insulation to your attic in one afternoon using batts—they can be laid out easily and there is no need to staple them down.

Once the area between the joists is fully insulated, the greatest source of heat loss in the attic is through the joists themselves, which may cover as much as 10 percent of the attic. For this reason, when adding insulation batts above the level of the ceiling joists, cover the joists completely if possible.

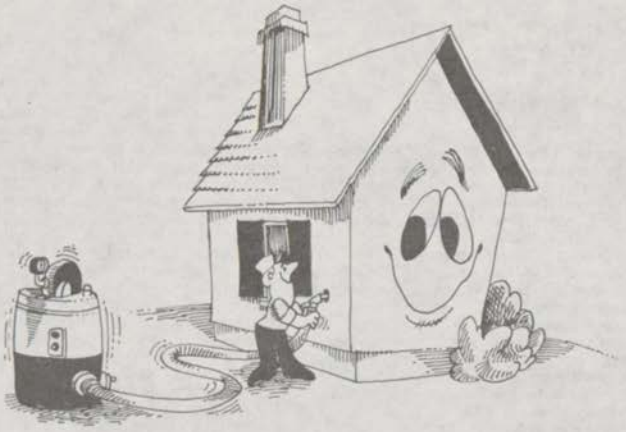
If you want to add R-19 or R-22 insulation to your existing insulation, it is usually best to add R-11 batts up to the level of the joists and cover the entire area with another layer of R-11 batts. Place the batts as close together as possible to prevent air from circulating between them.

Loose-fill insulation may be better if the access to your attic is difficult or if it has a floor. If flooring is present in an otherwise unfinished attic, you may have to remove some of it temporarily to allow insuation to be blown in. Loose insulation is usually blown into the attic through flexible tubing by a small machine which puffs up the insulation as it pushes it through the tube. This may cause some settling after the insulation is in place so you should take that into account when measuring the depth. Small holes should be drilled into tight fitting flooring at one-foot intervals to allow passage of any water vapor that may rise from the rooms below.

Density of loose-fill insulation is extremely important in assuring the proper resistance to heat flow. The manufacturer will generally specify the number of bags of loose-fill materials needed to achieve a given R value over a specific area. If a contractor is insulating your attic, you should verify that the proper number of bags has been used.

A well-insulated attic should also be well ventilated to prevent moisture accumulation problems. Never block ventilation ports and always provide at least two vent openings, located in such a way that air can flow in one and out the other. A good rule of thumb is to provide at least one square foot of opening for each 300 square feet of attic floor area.

During the inspection of your attic, you may notice interior wall spaces open to the attic, allowing cold air from the attic to fall down into the wall spaces or duct wells. These areas should be sealed off and covered with insulation.



INSULATION IN EXTERIOR WALLS

Three or 4 inches of insulation properly placed in the air space can reduce the heat transfer through the walls by as much as two thirds. The best time to install insulation in the air space is while the house is being built. When the wall is open, it is almost always economical to fill the wall space with batt insulation. For example, unfinished garage walls next to heated areas of the house should be insulated with R-11 batts, except in the mildest climates.

Once a wall is finished off, it is usually difficult to reach the air space and insulation has to be blown or injected into the wall through small holes drilled between the wall studs. (This can be done from the outside or the inside, depending on the ease of sealing the holes and refinishing the surface.) Loose-fill materials, usually mineral fiber or cellulose, are the insulation forms best suited for this job. While this process is much more costly than adding batt insulation during construction, it may still be a good investment in many cases if done properly. Only an experienced contractor should be employed, however, as the process can be quite complicated and poor workmanship will greatly lower the quality of the finished work.

Loose-fill wall insulation is recommended in this booklet only for exterior walls with an air space at least 3 to 4 inches wide and with no existing insulation.

In some older houses, access can be gained to the wall space from the attic. In this case, loose-fill insulation material can be dropped into the space from above at very low cost, making this economical in all but the mildest climates with low fuel prices. (Make sure the insulation doesn't fall all the way into the basement!)

A potential problem with insulation in closed cavities in some climates is the possibility of moisture accumulation. This may be difficult to detect until moisture begins to show through the wall. If moisture problems occur, they can be minimized, however. The interior surface of the wall can be made vapor resistant with a paint or covering that has low-moisture permeability. Cracks around windows and door frames, electrical outlets, and baseboards should be sealed at the surface facing the room. Outside surfaces should not be tightly sealed but allowed to "breathe."

Another potential problem which you may encounter with blown-in insulation is settling or shrinkage. Generally, this problem can be avoided if the insulation is properly installed. Calculating the number of bags of material needed per square foot of wall area and assuring that these have been installed is the best way to avoid this problem.

INSULATION UNDER FLOORS

Floors over unheated areas, such as crawlspaces, garages, or basements, can be a major source of heat loss in an otherwise well-insulated house. Everyone knows that hot *air* rises, but remember, heat flows to cold through solid surfaces in any direction— up, down, or sideways.

Water pipes in unheated areas should also be insulated if there is danger of freezing after the floor insulation has been installed. Crawlspaces can be closed off in winter, but must be well ventilated in summer to prevent the build-up of moisture from the ground and from the rooms above. In many areas it is a good idea to cover the ground under a crawlspace with plastic sheeting to reduce the moisture level in this area.

If your house is built on a concrete slab, it is sometimes possible to insulate around the edges of the slab. Consult an insulation specialist to find the best way to do this.

INSULATION OF HEATING AND COOLING DUCTS IN UNHEATED AREAS

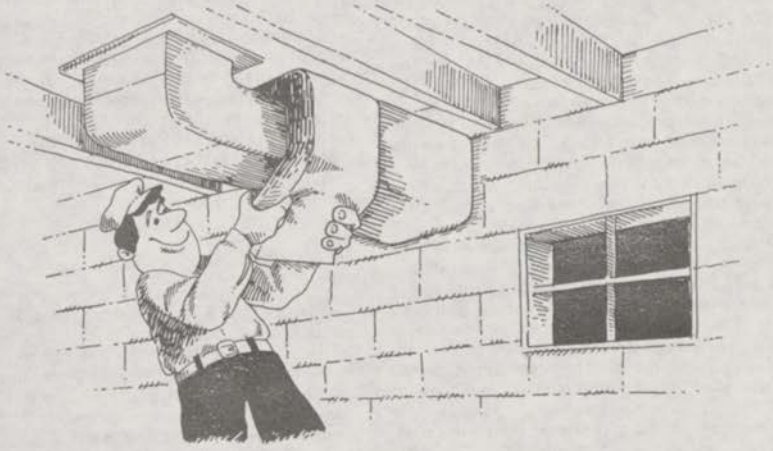
Heating and cooling ducts in attics, crawlspaces, and garages should be well insulated. Even if a sufficient amount of insulation exists, you might want to loosen it temporarily at the joints to check the condition of the ducts. Escaping air indicates the need for retaping of the duct joints.

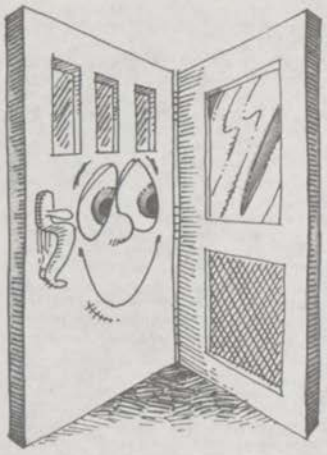
Most houses have no more than 1 or 2 inches of insulation wrapped around ducts in unheated areas. As Tables 4 and 6 show, more is often desirable. Duct wrap in layers of 2-inch thicknesses may be used to insulate ductwork. As an alternative, ordinary mineral fiber batts can be placed around the ducts. Avoid crushing the insulation because this lowers its resistance to heat flow.

Where ductwork is used for heating purposes only, a vapor barrier is not usually needed. However, if ducts are used for air conditioning as well as heating, a vapor barrier is required around the outside of the insulation to prevent condensation on the ducts. In either case, some protective covering should be used. Check with insulation manufacturers for the correct procedure for your climate.

STORM WINDOWS AND DOORS

Storm windows and doors vary widely in basic design, durability, and cost. Storm windows range from single glass panels, that must be put in place each fall and removed each spring, to permanent triple-track assemblies, which include sliding upper and lower windows and a





screen. Triple-track windows can be used both during heating and cooling periods and can be opened for natural ventilation at other times. Because they are left in place permanently, wear and tear and the chance of breakage is minimized.

You should be aware that it is not the storm window itself that keeps the warmth inside in winter and outside in summer. It is actually the dead air space—at least 3/4 inch—between the two windows that saves energy. For this reason a plastic sheet, placed over the window in such a way to create a dead air space, will work nearly as well as more permanent storm windows. If you want to put off buying storm windows for a year or so, you might consider this as a temporary solution.

The size of the storm window is determined by the size of the window frame and not by the glass area. Storm windows should be properly installed and fit tightly to do the most good. To assure a tight fit, permanent storm windows should be sealed to the outer window frame with caulking compound or other sealing material. Storm window frames should have a tiny opening at the bottom to allow water vapor to escape.

Storm windows are generally more economical than double pane windows in existing houses, because they usually cost less to install and they reduce infiltration of air around the window sash. Where double pane windows already exist, it may still pay you to use storm windows over the larger windows (15 to 20 square-foot range) when your Index Number in Table 6 is greater than 50.

Storm doors may not always be economical when considered for winter heating savings alone unless the doorways are frequently used. However, they may still be a good investment, since they can be used as a screen door in the summer months if they have interchangeable glass and screen inserts. If your house already has a screen door, it generally will not pay to replace it with a storm door unless it is shown to be economical for your Index Number in Table 5. Storm doors over doors with inset glass areas save more energy than those over solid doors.

Storm windows and doors vary greatly in price. In general, custom-made windows and doors are more expensive, but they may fit better and last longer.

WEATHER STRIPPING AND CAULKING

In a well-insulated house the largest source of heat loss is from air leaks, especially around windows and doors. Good weather stripping and caulking of exterior window and door frames will not only reduce the heat loss in winter and heat gain in summer, but they will reduce uncomfortable drafts as well.

Weather stripping and caulking are generally economical in all climates, if you install them yourself. This is especially true for drafty windows and doors.

Weather stripping is available in a wide selection of shapes and materials. Caulking materials vary greatly in quality as well. More durable varieties will not have to be replaced as often, which is an important consideration.

When weather stripping, don't overlook hatches to your attic. Even small cracks allow large amounts of warm air to be lost during a heating season.

VENTILATION

Some people think that a tightly sealed, well-insulated house does not allow sufficient air circulation to maintain a healthy environment. In most houses, 70 to 100 percent of inside air is exchanged with outside air every hour. Actually, only a 20 percent hourly air change is needed for normal ventilation purposes. It is most unlikely that an existing house could be sealed up that tightly by these energy conservation improvements alone.

In new houses with tight construction it may be necessary to provide a separate combustion air inlet to the furnace. In both existing and new houses it is more economical to remove moisture and odors from kitchens and baths by localized exhaust fans than to provide continuous, uncontrolled air infiltration.