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Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems

Solar Energy Program
Office of Housing and Building Technology
Center for Building Technology, IAT
National Bureau of Standards
Washington, D.C. 20234

March 1977

Final Report

Prepared for
Department of Housing and Urban Development
Office of Policy Development and Research
Division of Energy, Building Technology and Standards
Washington, D.C. 20410

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PREFACE

The "Minimum Property Standards for One and Two Family Dwellings" 4900 and the "Minimum Property Standards for Multifamily Housing" 4910 were developed to provide a sound technical basis for the planning and design of housing under numerous programs of the Department of Housing and Urban Development (HUD). These "Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems" are intended to provide a companion technical basis for the planning and design of solar heating and domestic hot water systems.

These standards have been prepared as a supplement to the MPS and consider only aspects of planning and design that are different from conventional housing by reason of the solar systems under consideration. To the greatest extent possible, they are based on current state-of-the-art practice and on nationally recognized standards including the MPS and the HUD "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings."

This document considers requirements and standards applicable to both one and two family dwellings and multifamily housing and references made in the text to the MPS refer to the same section in both the "Minimum Property Standards for One and Two Family Dwellings" 4900.1 and the "Minimum Property Standards for Multifamily Housing" 4910.1 unless otherwise noted.

In general, the Chapters and Divisions in this document are organized to parallel the Chapters and Divisions contained in the MPS. Within Divisions, however, these standards do not follow the numbering of the MPS, but rather list the solar topics sequentially. It has been found that this method allows the presentation of these new topics in a manner that is clearly related to the MPS and yet is not made cumbersome. Not all Chapters or Divisions in the MPS have topics of solar concern; for example, there are no such topics in Chapter 2, General Acceptability Criteria, nor in Division 512, Furnishings.

An example will help to illustrate the organization of this document:

> Consider hail loads to be applied to solar collectors. Hail loads are not a subject in the MPS, but would be covered in Chapters 6, Division 1, General Structural Requirements if they were. In these standards they are located in Chapter 6, Division 1, Section S-601-7. For comparison, plumbing construction is covered in Chapters 6, Division 15, Section 615-5 of the MPS. In these standards it is also located in Chapter 6, Division 15, but in Section S-615-12.

	MPS	MPS Solar Supplement
Hail loads	none	S-601-7
Plumbing	615-5	S-615-12

It has frequently been found useful to include a commentary on a particular standard. The commentaries are not mandatory, but are intended to give further explanation and guidance to users of the standards on topics which may have special consequences in solar installations. Several appendices are included which give additional information for assistance in use of the standards. Appendix A presents the calculation procedures for determining the thermal performance of solar heating and domestic hot water systems and Appendix C presents graphic illustrations of terms used in the standard.

The format developed for these standards has been structured to convey information in a number of categories as follows:

S - the prefix used on all sections (for solar) to distinguish them from existent MPS section

BOLD FACE TYPE - TO PRESENT STANDARDS AND COMMENTARIES APPLICABLE TO MULTIFAMILY HOUSING ONLY

Conventional type - to present standards applicable to one and two family dwellings and multifamily housing

Italics - to present commentaries applicable to one and two family dwellings and multifamily housing

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 document. In recognition of the position of the United States as a signatory to the General Conference of Weights and Measures, which gave official status to the metric SI system of units in 1960, assistance is given to the reader interested in making use of the coherent system of SI units by giving conversion factors applicable to U.S. units used in this document.

Length
1 in = 0.0254 meter (exactly)
1 ft = 0.3048 meter (exactly)

Area
1 $in^2 = 6.45 \times 10^{-4}$ $meter^2$
1 $ft^2 = 0.09290$ $meter^2$

Volume
1 $in^3 = 1.639 \times 10^{-5}$ $meter^3$
1 gal (U.S. liquid) = 3.785×10^{-3} $meter^3$

Mass
1 ounce-mass (avoirdupois) = 2.834×10^{-2} kilogram
1 pound-mass (avoirdupois) = 0.4536 kilogram

Pressure or Stress (Force/Area)
1 inch of mercury (60°F) = 3.377×10^3 pascal
1 pound-force/$inch^2$ (psi) = 6.895×10^3 pascal

Energy
1 foot-pound-force (ft-lbf) = 1.356 joule
1 Btu (International Table) = 1.055×10^3 joule

Power
1 watt = 1×10^7 erg/second
1 Btu/hr = 0.2929 watt

Temperature
$t_{°C} = 5/9\ (t_{°F} - 32)$

Heat
1 Btu-in/h-ft^2-°F = 1.442×10^{-1} W/m-K (thermal conductivity)
1 Btu/lbm-°F = 4.184×10^3 J/kg-K (specific heat)
1 langley = 4.184×10^4 J/m^2 = 1 cal/cm^2 = 3.69 Btu/ft^2

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CHAPTER 1

General Use

S-100 APPLICATION

These "Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems" are a supplement to MPS 4900.1, "Minimum Property Standards for One and Two Family Dwellings," and MPS 4910.1, "Minimum Property Standards for Multifamily Housing," and shall be used in conjunction with MPS 4900.1 and MPS 4910.1. Furthermore, the solar components must provide for the collection of solar energy, conversion of the solar energy to thermal energy, and distribution, storage and control of the thermal energy so obtained. Insofar as applicable, these standards apply to active and passive solar energy systems that utilize building elements, mechanical subsystems or combinations thereof.

Commentary: MPS 4900.1, and MPS 4910.1 are available from HUD Regional Offices.

S-101 VARIATIONS TO STANDARDS

S-101-1 NEW MATERIALS AND TECHNOLOGIES

These standards are intended to encourage the use of new or innovative designs, technologies, methods or materials in solar applications. These features include designs, methods of construction, systems, subsystems, components, materials and processes which do not comply with the MPS and this document, and whose acceptance cannot be determined by other provisions of these standards. Alternatives, nonconventional or innovative designs, methods, and materials shall demonstrate, however, equivalent quality to these standards in operating effectiveness, structural soundness, durability, economy of maintenance or operation, and usability. Variations shall be made in accordance with Section 101-4 of MPS.

Commentary: One basis for design, fabrication, construction, and acceptance of new and innovative solar systems, subsystems, components, materials, and processes is the "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings," January, 1975, available from GPO.

S-102 PRODUCT AND DESIGN MODIFICATIONS

Variations from approved designs shall be submitted to HUD for review.

Commentary: It is recognized that product or design changes may occur. These changes may affect the performance of the system or its components.

CHAPTER 2

GENERAL ACCEPTABILITY CRITERIA

(not used)

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CHAPTER 3

SITE DESIGN

S-300 GENERAL

The provisions of this chapter are applicable to solar energy systems including heating (H) and domestic hot water (DHW) systems. This chapter is a supplement to the Minimum Property Standards (MPS) Chapter 3.

S-301 PROPOSED SITE

S-301-1 SITE SURROUNDINGS

Solar buildings and solar system components shall be located and designed in such a manner as to harmonize with the surrounding community.

Commentary: Solar system components may include elements which are large and visually dominant when viewed from off-site. If not carefully designed and located, such elements can produce a detrimental effect on the overall quality of a residential area.

S-303 LAND USE

S-303-1 SOLAR EQUIPMENT LOCATION AND ARRANGEMENT

Solar buildings and site located solar equipment shall be arranged and located to relate well to:
a. The natural topography.

Commentary: The location of the solar collector should be planned to avoid pockets where frost can collect or unprotected ridges where winds can be more extreme in order to avoid heat losses due to low temperatures and high winds.

b. The climate.

Commentary: The location of the solar collector should be planned to take into account prevailing winds in order to avoid excessive heat losses due to wind and to drifting snow which impair the collection of solar energy. For specific requirements on tilt and orientation see S-615-2.1.2 and C-8, C-9 in Appendix.

c. Attractive on-site and off-site views.

Commentary: Components of the solar system may be large and could block attractive views from the building.

d. Existing and proposed site elements such as vegetation, fences, landforms and buildings.

Commentary: Proper relationship of a solar collector to site elements can minimize the shading of the collector and reduce air flow over the collector. Location of the solar building in the northern portion of the site can help to minimize the possibility of shading solar collector surfaces by future off-site development.

e. Existing and proposed pedestrian and vehicular circulation systems.

Commentary: Proper location of solar equipment in relation to pedestrian circulation may reduce tampering and vandalism.

f. Existing and proposed surrounding buildings and facilities.

Commentary: The location and orientation of the solar collector should consider physical and chemical air borne waste from nearby facilities such as incinerators and factories which might have an impact on the efficiency of the solar collector. (See S-515-1.5)

S-303-2 SITE HAZARDS

Special considerations must be given to assure that elements of the solar system do not create unnecessary safety hazards to users.

Commentary: Hazards which require special attention include the reflection of sunlight which creates visual distraction, the projection of sharp edges which influence the movement of people near free-standing collectors, and the proximity of solar components to recognized architectural hazards such as exterior overhangs, stairs, ramps, landings, doors, etc.

S-304 LOTS, YARDS AND BUILDING SETBACK DISTANCE

S-304-1 PROJECTION INTO YARD AREA

The projection of solar collectors into yards shall conform to those restrictions placed on open balconies, bay windows and uncovered porches in Section 304-2 of MPS.

S-304-2 USABLE OUTDOOR AREA

Components of the solar system shall not unnecessarily impinge on the requirements of Section 304-3 of MPS.

Commentary: Reasonable outdoor open space must be maintained for livability service, emergency access, isolation of fire and protection of adjacent property.

S-304-3 SNOW AND ICE

In areas which have a snow load of 20 pounds per square foot or greater required by local codes, provisions should be made over entrances and locations of pedestrian and vehicular ways to restrain or deflect sliding snow and ice masses which may slide off elevated solar system components.

Commentary: Solar system components may often include smooth slippery surfaces located in elevated positions at steep angles. These elements may heat up rapidly and loosen masses of snow or ice which may slide-off. Means should be provided to prevent a hazard to people or property. Methods such as deflectors, restraints, low friction materials, or design of "safe fall" areas (pedestrian or vehicular ways spaced away from the building) should be considered.

S-309 SERVICES

S-309-1 MAINTENANCE

Solar energy components located on the site should be accessible for cleaning, adjusting, servicing, examination, replacement or repair without trespassing on adjoining property.

Commentary: Components should not be located unnecessarily under buildings or roads or in other places which are difficult to reach. Storage tanks in particular are large and may need periodic replacement or inspection.

SOLAR COLLECTORS ON ROOFS OVER 3 STORIES MUST HAVE ACCESS PROVIDED FOR CLEANING AND MAINTENANCE.

COMMENTARY: THE USE OF PORTABLE LADDERS IS NOT CONSIDERED TO BE ADEQUATE UNDER THESE CIRCUMSTANCES.

S-311 DRAINAGE

S-311-5 DRAINAGE SWALES AND GUTTERS

Gutters or other means of controlling runoff shall be provided on solar collectors when the soil is of such a nature that excessive erosion or expansion may occur as a result of increased runoff.

S-311-7 DOWNSPOUTS

S-311-7.1 In addition to method of disposal of 311-7.1 of the MPS, downspouts may be discharged into an acceptable non-potable water storage tank if it is part of the solar system.

Commentary: Current MPS requires that the water from a downspout empty into available storm sewer or on a splash block. When downspouts are used as part of a solar system, it is acceptable for it to empty into a storage tank provided consideration has been given the quality of the water and its effect on the solar system. (See S-515-2.3)

S-312 PLANTING DESIGN

S-312-3 NEW PLANT MATERIAL

S-312-3.9 Plant material should be selected and located to prevent the unwanted reduction of thermal output of a solar collector from shading, sap or other by-products of plants.

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CHAPTER 4

BUILDING DESIGN

S-400 GENERAL

The provisions of this chapter are applicable to solar energy systems including heating (H) and domestic hot water (DHW) systems. This chapter is a supplement to the Minimum Property Standards (MPS) Chapter 4.

S-401 SPACE PLANNING

S-401-1 PASSIVE SOLAR SYSTEMS

Where normal building spaces are designed to also be part of passive solar energy collection, storage, distribution or control, provisions shall be made so that this use does not interfere with the intended use of these spaces.

S-402 ACCESS AND CIRCULATION

S-402-1 GENERAL

S-402-1.1 The design and installation of the solar heating and domestic hot water systems shall not impair the normal movement of occupants of the building or emergency personnel.

COMMENTARY: SPECIAL CONSIDERATION SHOULD BE GIVEN TO THE EFFECT OF THE CONFIGURATION OF ROOF-MOUNTED COLLECTORS ON FIRE EXITING, FIRE FIGHTING OR EMERGENCY RESCUE.

S-402-10 SOLAR ENERGY EQUIPMENT

Solar energy equipment shall be accessible for routine maintenance without disassembling any major structural or mechanical element. Sufficient space or clearance shall be provided based upon solar equipment sizes and potential maintenance equipment sizes to permit examination, replacement, adjusting, servicing and/or maintenance. See Section S-600-5.

Commentary: Accessibility for repair and maintenance should reflect the expected life of the equipment and the frequency of routine maintenance required. An element with a shorter maintenance cycle or life expectancy should be more accessible than one with a long maintenance cycle or life expectancy.

S-403 LIGHT AND VENTILATION

S-403-3 VENTILATION

When attics or structural spaces are used as part of a passive solar system, attic or structural space ventilation may be omitted if other means are provided to control condensation. See Section 403-3 of MPS.

S-405 FIRE PROTECTION

S-405-1 GENERAL

S-405-1.1 The incorporation of solar systems into the living unit shall not increase the fire hazard or interfere with the means of safe egress in the event of a fire.

S-405-4 FIRE RESISTANCE REQUIREMENTS

S-405-4.1 Integrated Construction

The incorporation of solar subsystems shall not reduce the fire resistance ratings required by 405-4 of the MPS.

Commentary: Roof-mounted collectors which are an integral part of the roof construction shall not reduce the required fire resistance rating of the roof assembly.

S-405-4.2 Penetrations

Penetrations through fire-rated assemblies shall not reduce the fire resistance ratings required by 405-4 of the MPS.

S-405-6 EXITS

Components of the solar system shall not be located in such a way as to interfere with the primary or secondary means of occupant egress.

Commentary: The location of solar equipment on a roof shall not reduce the usability of that roof for access or egress. Solar system components located remote from the building but near a means of egress shall not block the means of egress if a fire occurs in the solar system component.

S-405-7 FIRESTOPPING

Major solar system components that are integral parts of assemblies which normally require firestopping shall be firestopped on all sides. Firestopping shall be wood blocking of minimum 2 inch nominal thickness or of noncombustible materials providing equivalent protection. Firestopping may be included as an integral part of the component where the component as installed provides equivalent protection.

Commentary: It is the intent of the section to prevent solar system components from reducing the effectiveness of firestopping. For example, in the case where a solar collector is an integral part of a wood framed wall which would normally be firestopped between studs, firestopping shall be required in the wall above and below the solar collector.

S-405-12 ROOF COVERINGS

Installation of solar collectors or system components on or as an integral part of the roof shall not reduce the fire retardant characteristics of the roof covering below the level specified in 405-12 of the MPS.

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CHAPTER 5

MATERIALS

S-500 <u>GENERAL</u>

The provisions in this chapter are applicable to solar energy systems including heating (H), and domestic hot water (DHW) systems. This chapter is a supplement to the Minimum Property Standards (MPS). Materials provisions (Chapter 5) of the MPS are applicable in addition to the items explicitly discussed in this document.

Commentary: Conditions of potentially deleterious exposure of materials used in solar systems and particularly in solar collectors vary widely with the design and operating characteristics of the system and collectors. The performance of materials in the context of the overall normal and no-flow characteristics of system and collectors should be considered as primary factors in material selection.

S-500-1 APPLICABLE STANDARDS

Except as modified herein, materials, equipment and installation shall be in accordance with the standards and nationally recognized model codes cited within the body of this document; the current applicable editions and titles of referenced standards and codes are contained in Appendix E. State and local codes which deviate from nationally recognized codes or standards in order to satisfy local conditions may be accepted by HUD if such deviations are identified and substantiated with satisfactory engineering data.

S-500-2 EXCEPTIONS AND RE-STATEMENTS

S-500-2.1 <u>Exceptions</u>

Exceptions to the cited standards are included in this document where deemed appropriate by HUD.

S-500-2.2 <u>Re-statements</u>

Certain requirements that are already covered in the referenced standards are re-stated in this document to emphasize the need for implementing these requirements in HUD construction.

S-500-3 SUITABILITY OF ALTERNATE OR SPECIAL MATERIALS

Alternate or special materials or products, other than those contained herein may be used when found acceptable by established HUD procedures and Division 513 of MPS and Section S-101 of this document.

Commentary: Documentation of satisfactory long-term performance under in-use conditions may be used to demonstrate compliance with many of the requirements in this chapter.

S-501 GENERAL REQUIREMENTS

S-501-1 GENERAL

Materials installed shall be of such kind and quality as to assure that the solar energy system will provide a) adequate structural strength, b) adequate resistance to weather, moisture, corrosion and fire, c) acceptable durability and economy of maintenance and market acceptance.

S-501-2 LABELING

Mandatory labeling requirements, where applicable, are contained herein for specific materials and products.

Commentary: Installation, operation and maintenance information requirements are specified in S-600-3.

S-501-3 SAFETY

S-501-3.1 Protection of potable water and circulated air

No material, form of construction, fixture, appurtenance or item of equipment shall be employed that will introduce toxic substances, impurities, bacteria or toxic chemicals into potable water and air circulation systems in quantities sufficient to cause disease or harmful physiological effects.

Commentary: This situation is of concern not only as it pertains to ducts, piping, filters and joints but also to storage areas, such as rock beds. In addition, the growth of fungus, mold and mildew is possible when collectors are applied to a roof surface over the water tight membrane. If the collectors are in contact with the membrane or held away from the membrane to allow for drainage, the shaded membrane area can support the growth of mildew and other fungus in some warm, moist climates. Special design considerations should be included to avoid this problem in climates where it can occur.

S-501-4 DOCUMENTATION OF PERFORMANCE

Documentation of satisfactory long term performance of systems, components, or materials may be used to demonstrate compliance with the standards listed in this chapter.

S-508 DOORS, WINDOWS, GLAZING PANELS

S-508-7 HARDWARE

S-508-7.3 Screening

Solar control insect screening for windows and doors shall provide insect protection equivalent to 16 by 18 mesh insect screen.

Commentary: There are louvered solar control insect screens which have elongated openings. These vary from the traditional square openings of screens and are effective in limiting incident solar radiation as well as keeping out insects.

S-515 MECHANICAL - SOLAR POWERED EQUIPMENT

S-515-1 GENERAL PROVISIONS

S-515-1.1 Fire Safety

Assemblies and materials used in the solar systems shall comply with the nationally recognized codes for fire safety under all anticipated operating and no flow conditions.

S-515-1.2 Effects of external environment

The systems for heating (H) and for domestic hot water (DHW) and their various subassemblies shall not be affected by external environmental factors prevalent at the site to an extent that will significantly impair their function during their intended design life.

S-515-1.3 Temperature and Pressure Resistance

Components shall be capable of performing their functions for their intended design life when exposed to the maximum and minimum temperatures and pressures that can be developed in the system.

S-515-1.4 Materials Compatibility

All materials which are joined directly to or in contact with other materials shall have sufficient chemical compatibility with those materials to prevent deterioration that will significantly impair their function during their intended design life. Provisions shall be made to allow for differences in the expansion and contraction of joined materials due to expected temperature fluctuations.

S-515-1.5 Airborne Pollutants

Materials exposed to airborne pollutants while in service, such as ozone, salt spray, sulfur dioxide, oxides of nitrogen and/or hydrogen chloride, shall not be affected by those pollutants to an extent that will significantly impair their function during their intended design life.

S-515-1.6 Chemical Decomposition Products

Materials shall not be affected by chemical decomposition products expelled from components under in-use conditions to an extent that will significantly impair their function during their intended design life.

S-515-1.7 Abrasive Wear

Exterior materials shall not be affected by abrasive wear caused either by cleaning or by natural factors such as wind blown sand to an extent that will significantly impair their function during their intended design life.

S-515-1.8 Soil Corrosion

Materials installed in corrosive soil shall be either of a material unaffected by such soil or shall be isolated from it by a protective coating. The coating and its application shall conform to AWWA C-203.

S-515-1.9 Corrosion by Leachable Substances

Substances that can be leached by moisture from any of the materials within the system which may be exposed to mositure shall not cause corrosive deterioration of any other materials to an extent that will significantly impair their function during their intended design life.

S-515-1.10 Leakage

Leakage from assemblies or subassemblies which contain heat transfer fluids shall not significantly impair the function of other components which may come in contact with the leaking heat transfer fluid or create a safety hazard.

S-515-2 COLLECTORS

S-515-2.1 General

Collectors shall perform their function for their intended design life.

Commentary: In addition to their primary function of collecting solar energy, collector panels can be used as the roofing membrane. They can also be mounted over a roofing membrane or mounted remotely. The primary function of a roofing membrane is to prevent the entrance of water into the structure. When collector panels are designed to fulfill this function, leakage at joints must be considered in the design.

When collectors are mounted over a roofing membrane, consideration should be given to the growth of fungus, mold, and mildew between the roofing membrane and the collector and to potential problems in reroofing under collectors. Also, it is possible, due to extreme temperature differentials, to cause the formation of ice dams which could in turn back water under shingles or other roofing materials, causing rapid deterioration. Consideration should be given to the methods of applying non-integral collectors to roof structures and to the choice of waterproofing membrane.

S-515-2.1.1 Labeling and Technical Data Sheets

Collectors shall be labeled to show the manufacturer's name and address, model number, serial number, and collector weight (dry). Technical data sheets shall also be provided which include collector efficiency as measured according to S-615-2.2, maximum allowable operating and no-flow temperatures and pressures, minimum allowable temperatures, and the types of fluids which can and cannot be used.

Commentary: Other data related to the installation and operating conditions or characteristics is desirable such as the pressure drop across the collector.

S-515-2.1.2 Thermal Stability

Collectors shall not exhibit a change in the product of $F_R\ \tau\alpha$ (intercept) or $F_R\ U_L$ (slope) that would result in a 10% or greater decrease in thermal efficiency for the proposed system design operating conditions when evaluated in accordance with the following testing procedure.

Testing Procedure:

The parameters $F_R\ \tau\alpha$ and $F_R\ U_L$ shall be determined in accordance with the test procedure described in ASHRAE Standard 93 both before and after exposing the collector panel assembly to the Exposure Test described below. Both the before and after collector thermal performance tests (ASHRAE Standard 93) shall be performed utilizing the same test facility under similar climatic conditions.

Exposure Test:

A. Test specimen shall consist of a complete air or liquid collector panel assembly.

B. Pre-exposure preparation:

(1) Air collectors shall be sealed and capped with a pressure relief device set to a value within 10% of the collector manufacturer's maximum recommended operating pressure. The inlet shall be equipped with a check valve and desiccant to allow the admission of dry air if internal pressures of less than one (1) atmosphere occur.

(2) Liquid collectors intended for use in all systems (with or without draindown) shall be completely filled with clean tap water, following which the inlet shall be sealed and the outlet provided with a pressure relief valve set to a value of within 10% of the manufacturer's recommended maximum operating pressure.

(3) Liquid collectors limited to use in systems that draindown when not operating shall be completely filled with clean tap water, following which the water shall be allowed to gravity drain for 15 minutes with the collector mounted at a 45° tilt angle. The collector inlet shall then be sealed and the outlet provided with a pressure relief valve set to a value of within 10% of the manufacturer's recommended operating pressure.

C. Exposure conditions

Exposure conditions shall consist of 30 days of cumulative exposure to a minimum daily incident solar radiation flux of 1500 Btu/ft^2·day as measured in the plane of the collector aperture. The exposure conditions shall include at least one consecutive four-hour period with a minimum flux of 300Btu/ft^2·hr. In water filled specimens, this must occur after water boilout has occurred. The average ambient temperature shall be 80°F or higher during the 300Btu/ft^2·hr exposure time. The collector shall be mounted to a rack at a tilt angle such that the incident solar radiation during solar noon is within $\pm$ 10° of the normal to the plane of the aperture.

D. Data records

(1) The exposure conditions including insolation, ambient temperature, wind velocity, and precipitation shall be recorded to enable determination of the average daily values. Values shall be recorded every 30 minutes during the 300 Btu/ft^2·hr exposure.

(2) A regularly scheduled weekly visual inspection shall be made and a record of changes in the physical construction or appearance of the collector kept.

(3) The results of the pre-test and post-test thermal performance shall be plotted on the same graph for comparison purposes.

Commentary: The purpose of the "no-flow" test is to identify, in a short period of time, potential problems with collector materials or construction. The 30 days do not necessarily have to be consecutive but the test should be performed on a continuous basis until the solar radiation levels have been achieved for 30 cumulative days. It is recognized that other heat transfer fluid materials exist which may be preferred by the manufacturer or designer. If the test is conducted in a manner other than that prescribed, the collector specification shall state the specific conditions used during the test and identify the pertinent limitations regarding collector array installation *and operation. The test procedure is based upon draft versions of a test method in preparation by ASTM and will be superceded by a consensus test method as soon as possible.*

S-515-2.1.3 Outgassing of Materials

Outgassing products or condensates on the cover plate surfaces shall not contribute to a decrease in thermal performance greater than that specified after exposure as described in S-515-2.1.2.

Commentary: Outgassing from components inside the collector could lead to condensation on the underside of the collector cover plate(s) which may reduce the transmittance of the cover plate(s).

S-515-2.1.4 Flashing

a. Flashing for collector panel supports that penetrate the primary roof membrane shall be designed to prevent the penetration of water or melting snow for the life of the roof system.

b. Flashing systems shall be designed to permit minor repairs without disturbing the roof membrane, collector supports, or collector panels.

c. In general, flashing for roof penetrations shall comply with applicable Sections of 507-5 and 507-8 of the MPS.

Commentary: Suggested practices for flashing used on no-slope or low slope roofs and roof penetrations are provided in the National Roofing Contractors Association's "A Manual of Roofing Practice," 1970.

S-515-2.2 <u>Cover Plates</u>

S-515-2.2.1 General

The materials used as glazing for cover plates must meet the following requirements based on materials properties as well as safety considerations. The safety requirements are made with respect to the physical location of the glazing and the exposure risk of persons nearby.

Commentary: Appendix table B-1 lists properties of a number of materials that have been used for cover plates.

S-515-2.2.1.1 Structural Requirements

All glazing materials shall be of adequate strength and durability to withstand the loads and forces required by Section S-601 of this document.

S-515-2.2.1.2 Types of Applications

Applications include windows which act as cover plates for solar collectors, both integral with dwelling construction and freestanding components.

a. Glazing materials other than those specified in b or c below, shall meet the intent of the requirements for glazing in MPS Section 508-8.3.

Commentary: Consumer Product Safety Act, Part 1201, was published in the <u>Federal Register</u> January 6, 1977 and will become effective on July 6, 1977 (except for fire retardant glazing required by ordinance for which the effective date is January 6, 1980). This standard contains mandatory safety standards for architectural glazing materials.

Film-type glazing materials for the outermost cover plate, if unsupported, may be unacceptable if they can be deflected under load, e.g., a person's hand pushing against the glazing, may present an opportunity for exposure of the film (and the person's hand) to hot surfaces such as the absorber plate. Also, there is a probability of exposure to impact which may result in tearing of the film.

b. Glazing materials with slopes less than 45° which extend below 6' 0" (from ground level) shall be safety glazed or otherwise protected against impact of falling bodies.

Commentary: This commonly refers to glazing on which children may climb or against which a passerby may fall.

c. Glazing panels which are an integral part of a roof or rack-mounted system on a roof, not routinely accessible by the occupant, shall meet the requirements of Section S-601.

Commentary: Annealed glass or films may be acceptable.

S-515-2.2.2 Codes and Standards

Materials used as glazing for cover plates shall comply with MPS Section 508, Section S-601 of this document and applicable sections of local building codes and national standards.

S-515-2.2.3 Materials Performance

S-515-2.2.3.1 Thermal Stability

After testing as described in S-515-2.1.2, there shall be no cracking, crazing, warping, sagging, or buckling of the cover plate(s) that will result in premature failure or degradation in collector performance greater than the design limits.

S-515-2.2.3.2 Ultraviolet Stability

Documentation shall be provided that the cover plate(s) is resistant to degradation by UV radiation that would significantly impair its function during its design life. In lieu of other documentation, the transmittance of the cover plate(s) as measured by ASTM E 424-71 shall not significantly change after exposure using any one of the three aging procedures described below. The computation of solar transmittance based on the spectrophotometric method in E 424 shall be standarized on air mass 2.

For collectors with multiple covers, the tests below shall be performed with the cover plates in their design configuration.

<u>Aging Procedure 1</u>

Expose components or materials to simulated solar radiation (such as xenon arc radiation) for a period of 2000 equivalent sun hours. The exterior surfaces of components which are exposed to rainfall in service shall be subjected to a water spray for a period of 5 minutes during each 60 minutes of the light exposure. For components not exposed to rainfall under normal operating conditions, the water spray shall not be included in the procedure.

Aging Procedure 2

Expose components or materials to concentrated natural solar radiation using machines such as those referenced in ANSI Z97.1-1975, paragraph 4.3.2 for a period of 2000 equivalent sun hours. The exterior surfaces of components which are exposed to rainfall in service shall be subjected to a water spray for a period of 8 minutes during each 60 minutes of sunlight exposure. For components not exposed to rainfall under normal operating conditions, the water spray shall not be included in the procedure.

Aging Procedure 3

Expose components and materials to solar radiation outdoors for twelve months. The average daily flux of the solar radiation, as obtained by averaging the daily fluxes over the twelve month period of outdoor exposure, shall be at least 1,500 Btu/ft^2.

S-515-2.2.3.3 Glass

Where tempered glass is used, it shall meet the requirements of ANSI-Z97.1-1975 and MPS, Section 508, as specified in S-515-2.2.1.2 of this document. Other glass cover plates shall meet the requirements for glass as specified in Federal Specification DD-G-451C (June 15, 1972).

Commentary: Appendix Table B-1 contains solar transmittance data and recommended maximum operating temperature for a number of types of cover plate materials.

S-515-2.2.3.4 Other Materials

Cover plate materials other than glass shall conform to the requirements of MPS, Section 513 and the intent of S-515-2.2.3.3. Appendix Table B-1 lists a number of materials that have been used for cover plates.

S-515-2.3 Absorber Plate

S-515-2.3.1 General

Materials used for absorber plates shall not degrade to an extent that collector performance would be reduced below allowable design limits.

S-515-2.3.2 Materials Performance

S-515-2.3.2.1 Thermal Stability

Any deformation that occurs in the test described in S-515-2.1.2 shall not result in premature failure or degradation in collector performance greater than the design limits.

Commentary: In addition to buckling, sagging, and warping that can be produced in the thermal stability test, consideration should be given to the possibility that repeated boilout cycles can lead to deformation or rupture of the absorber plate.

S-515-2.3.2.2 Erosion/Corrosion

Flow rates shall be maintained below the values listed in Tables S-515-2.3.2 and 2.3.3 to prevent erosive wear.

Commentary: The variables which have an important impact on the rate of erosion/corrosion are:

1) *the quantity and size distribution of solids in suspension*
2) *the flow rate*
3) *the pipe diameter*
4) *the oxygen content of the fluid*
5) *the angle of the change of flow direction*
6) *the internal surface condition of the pipe*
7) *the temperature*
8) *partial obstructions in flow passages which create localized areas of highly turbulent fluid flow*

S-515-2.3.2.3 Compatibility with Transfer Medium

a. The absorber plate or flow conduits shall not be pitted, corroded, or otherwise degraded by the heat transfer medium to an extent that will result in failure during its design life. In lieu of other documentation for metals, modifications of tests listed in Table S-515-2.3.1 shall be used to demonstrate compliance with this requirement. For materials other than metals, documentation shall be provided to demonstrate compliance with S-515-1.4 and this requirement.

   Commentary: Two types of heat transfer liquid, aqueous and anhydrous non-aqueous, may be used in the collector system. Generally, corrosion is associated with aqueous transfer media. However, corrosion could also occur in non-aqueous media under one or more of the following conditions:
   1) *if the liquid is initially agressive to the containment material*
   2) *if liquid decomposition generates corrosive products*
   3) *if water is initially present in the liquid or contaminates the liquid once in use.*

b. Metallic absorber plates or flow conduits in direct contact with heat transfer liquids in open systems should generally be used in accordance with the acceptable conditions listed in Table S-515-2.3.2 where applicable. Generally unacceptable conditions listed in this table should be avoided. Documentation shall be provided to demonstrate that materials applications not explicitly covered in Table S-515-2.3.3 meet the intent of S-515-1.4 and S-515-2.3.2.3a.

   Metallic absorber plates or flow conduits in direct contact with heat transfer liquids in closed systems should generally be used in accordance with the acceptable conditions listed in Table S-515-2.3.3 where applicable. Generally unacceptable conditions listed in this table should be avoided. Documentation shall be provided to demonstrate that materials applications not explicitly covered in Table S-515-2.3.3 meet the intent of S-515-1.4 and S-515-2.3.2.3a.

   Commentary: Tables S-515-2.3.2 and S-515-2.3.3 are intended to provide general guidelines for the selection of metals or alloys for use in solar collectors. Various alloys of the same base metal may be expected to show significant variability in resistance to corrosion. Small concentration changes in a number of chemical species may significantly change the corrosion behavior of a given material at a given temperature. A complete description of this behavior is not possible in this context. Therefore, generally unacceptable use conditions as stated should be avoided unless it has been demonstrated that the metal or alloy performs suitably in the anticipated use condition. Adequate performance is anticipated for normal operation in generally acceptable use conditions.

   The stated generally acceptable use conditions are directed toward normal operation. Under the conditions of stagnation, where high temperatures may be encountered, different behavior may occur. It is recommended that specific tests be carried out to ensure adequate materials performance in these conditions.

SAE Report J447a (1964), Prevention of Corrosion of Metals, provides guidance in preventing corrosion in aqueous media, but its application should be tempered by consideration of the special operating characteristics of solar collectors, e.g., no-flow temperature effects.

Table S-515-2.3.1: Corrosion Test Methods*

Number	Title	Comment
NACE TM-01-71	Autoclave Corrosion Testing of Metals in High Temperature Water	Modify to reflect conditions present in solar system
NACE TM-02-74	Dynamic Corrosion Testing of Metals in High Temperature Water	Modify to reflect conditions present in solar system
NACE TM-02-70	Conducting Controlled Velocity Laboratory Corrosion Tests	Modify to reflect conditions present in solar system
NACE TM-01-69 (1972)	Laboratory Corrosion Testing of Metals for the Process Industries	Describes factors to consider in corrosion testing
ASTM D1384-70 (1975)	Corrosion Test for Engine Antifreeze in Glassware	Modify to reflect conditions present in solar system
ASTM D2570-73	Simulated Corrosion Testing of Engine Coolants	Modify to reflect conditions present in solar system
ASTM D2776-72	Corrosivity of Water in the Absence of Heat Transfer	----------------------------

* Modification of test procedures developed for purposes other than collector material testing should adequately reflect all expected collector conditions including no-flow conditions.

Commentary: Open and Closed Systems

Open systems are those in which air, in addition to that initially in the transfer liquid, can be absorbed into the liquid by contact with the atmosphere or air entrapped in the system.

Closed systems are those in which the air initially absorbed in the transfer liquid is not replaced to a significant extent. In a closed system, there is no exposure of the liquid to the atmosphere except above the expansion tank (in some cases a nitrogen blanket above the liquid in the expansion tank may be used); there is no entrapped air in the piping or storage systems and the expansion tank is isolated from the flow path between the collector and storage. In addition, liquid leakage requiring frequent make up is avoided.

TABLE S-515-2.3.2 Generally Acceptable and Unacceptable Use Conditions for Metals in Direct Contact with Heat Transfer Liquids in Open Systems

Generally Unacceptable Use Conditions	Generally Acceptable Use Conditions 1/
Aluminum	
1. When in direct contact with untreated tap water with pH <5 or >9.	1. When in direct contact with distilled or deionized water which contains appropriate inhibitors and does not contact copper or iron.
2. When in direct contact with aqueous liquid containing less electro positive metal ions, such as copper or iron or halide ions.	2. When in direct contact with distilled or deionized water which contains appropriate inhibitors and a means of removing heavy metal ions obtained from contact with copper or iron.
3. When specific data regarding the behavior of a particular alloy are not available, the velocity of aqueous liquid shall not exceed 4 ft/sec.	3. When in direct contact with stable anhydrous organic liquids.
4. When in direct contact with a liquid which is in contact with corrosive fluxes.	
Copper	
1. When in direct contact with aqueous liquid containing high concentrations of chlorides, sulfates or liquid which contains hydrogen sulfide.	1. When in direct contact with distilled, deionized or low chloride, low sulfate and low sulfide tap water.
2. When in direct contact with chemicals that can form copper complexes such as ammonium compounds.	2. When in direct contact with stable anhydrous organic liquids.
3. When in direct contact with an aqueous liquid having a velocity greater than 4 ft/sec. 2/	
4. When in direct contact with a liquid which is in contact with corrosive fluxes.	
5. When in contact with an aqueous liquid with a pH lower than 5.	
6. When the copper surface is initially locally covered with a copper oxide film or a carbonasceous film.	
7. When operating under conditions conducive to water line corrosion.	
Steel	
1. When in direct contact with untreated tap, distilled or deionized water with pH <5 or >12.	1. When in direct contact with distilled, deionized or low salt content water which contains appropriate corrosion inhibitors.

TABLE S-515-2.3.2 (Contd.)

Generally Unacceptable Use Conditions	Generally Acceptable Use Conditions [1/]
2. When in direct contact with a liquid which is in contact with corrosive fluxes.	2. When in direct contact with stable anhydrous organic liquids.
3. When in direct contact with an aqueous liquid having a velocity greater than 6 ft/sec. [2/]	3. When adequate cathodic protection of the steel is used (practical only for storage tanks).
4. When operating under conditions conducive to water line corrosion.	
Stainless Steel	
1. When the grade of stainless steel selected is not corrosion resistant in the anticipated heat transfer liquid.	1. When the grade of stainless steel selected is resistant to pitting, crevice corrosion, intergranular attack and stress corrosion cracking in the anticipated use conditions.
2. When in direct contact with a liquid which is in contact with corrosive fluxes.	2. When in direct contact with stable anhydrous organic liquids.
Galvanized Steel	
1. When in direct contact with aqueous liquid containing copper ions.	1. When adequate cathodic protection of the galvanized parts is used (practical only for storage tanks).
2. When in direct contact with aqueous liquid with pH <7 or >12.	2. When in contact with stable anhydrous organic liquids.
3. When in direct contact with aqueous liquid with a temperature >55°C.	

Brass and Other Copper Alloys

Binary copper-zinc brass alloys (CDA 2XXX series) exhibit generally the same behavior as copper when exposed to the same conditions. However, the brass selected should resist dezincification in the operating conditions anticipated. At zinc contents of 15% and greater, these alloys become increasingly susceptible to stress corrosion. Selection of brass with a zinc content below 15% is advised. There are a variety of other copper alloys available, notably copper-nickel alloys, which have been developed to provide improved corrosion performance in aqueous environments.

[1/] The use of suitable antifreeze agents and buffers is acceptable provided they do not promote corrosion of the metallic liquid containment system. The use of suitable corrosion inhibitors for specific metals is acceptable provided they do not promote corrosion of other metals present in the system. If thermal or chemical degradation of these compounds occurs, the degradation products should not promote corrosion.

[2/] The flow rates at which erosion/corrosion becomes significant will vary with the conditions of operation. Accordingly, the value listed is approximate.

TABLE S-515-2.3.3 Generally Acceptable and Unacceptable Use Conditions for Metals in Direct Contact with Heat Transfer Liquids in Closed Systems

Generally Unacceptable Use Conditions	Generally Acceptable Use Conditions 1/
Aluminum	
1. When in direct contact with untreated tap water with pH <5 or >9.	1. When in direct contact with distilled or deionized water which contains appropriate corrosion inhibitors.
2. When in direct contact with liquid containing copper, iron or halide ions.	2. When in direct contact with stable anhydrous organic liquids.
3. When specified data regarding the behavior of a particular alloy are not available, the velocity of aqueous liguids shall not exceed 4 ft/sec.	
Copper	
1. When in direct contact with an aqueous liquid having a velocity greater than 4 ft/sec. 2/	1. When in direct contact with untreated tap, distilled or deionized water.
2. When in contact with chemicals that can form copper complexes such as ammonium compounds.	2. When in direct contact with stable anhydrous organic liquids.
	3. When in direct contact with aqueous liquids which do not form complexes with copper.
Steel	
1. When in direct contact with liquid having a velocity greater than 6 ft/sec. 2/	1. When in direct contact with untreated tap, distilled or deionized water.
2. When in direct contact with untreated tap, distilled or deionized water with pH <5 or >12.	2. When in direct contact with stable anhydrous organic liquids.
	3. When in direct contact with aqueous liquids of 5< pH <12.
Stainless Steel	
1. When the grade of stainless steel selected is not corrosion resistant in the anticipated heat transfer liquid.	1. When the grade of stainless steel selected is resistant to pitting, crevice corrosion, intergranular attack and stress corrosion cracking in the anticipated use conditions.
2. When in direct contact with a liquid which is in contact with corrosive fluxes.	2. When in direct contact with stable anhydrous organic liquids.

TABLE S-515-2.3.3 (Contd.)

Generally Unacceptable Use Conditions	Generally Acceptable Use Conditions [1/]
Galvanized Steel	
1. When in direct contact with water with pH <7 or >12.	1. When in contact with water of pH >7 but <12.
2. When in direct contact with an aqueous liquid with a temperature >55°C.	

Brass and Other Copper Alloys

Binary copper-zinc brass alloys (CDA 2XXX series) exhibit generally the same behavior as copper when exposed to the same conditions. However, the brass selected should resist dezincification in the operating conditions anticipated. At zinc contents of 15% and greater, these alloys become increasingly susceptible to stress corrosion. Selection of brass with a zinc content below 15% is advised. There are a variety of other copper alloys available, notably copper-nickel alloys, which have been developed to provide improved corrosion performance in aqueous environments.

1/ The use of suitable antifreeze agents and buffers is acceptable provided they do not promote corrosion of the metallic liquid containment system. The use of suitable corrosion inhibitors for specific metals is acceptable provided they do not promote corrosion of other metals present in the system. If thermal or chemical degradation of these compounds occurs, the degradation products should not promote corrosion.

2/ The flow rates at which erosion/corrosion becomes significant will vary with the conditions of operation. Accordingly, the value listed is approximate.

Commentary: Corrosion

Corrosion is a very complex phenomenon in which many parameters are of importance. In the case of the corrosion of metals likely to be used in the liquid containment system, parameters of importance are:
- *the composition of the metals or alloys*
- *the composition of the water, i.e. the concentrations of salts and dissolved gases and heavy metal ions*
- *the temperature*
- *the flow rate and the possibility of erosion-corrosion*
- *system design factors, particularly the presence of galvanic cells or differential aeration cells*
- *the presence of additives or their decomposition products*

Galvanic cells result from contact between dissimilar metals while differential aeration cells are areas where a metal is in contact with the liquid which has a variable dissolved oxygen content.

1. Water Composition

Water composition has an important effect on corrosion. The composition of tap water varies substantially from one geographic area to another. Even within a given area, water composition will vary depending on its source (surface vs. well water) and the time of year. The major variables include: pH, gas content (O_2, CO_2), chloride content, sulfate content, solids content (organic matter), and conductivity. Because of variation in water, similar variations in the type and severity of corrosion may be expected.

1a. pH

The pH of the transfer liquid will have an important impact on corrosion rates. However, the optimum pH range to achieve minimum corrosion of a given material will change with temperature [1]. Because varying temperatures occur within a solar heating system and the temperature at a given point will change with time, care must be taken to optimize the pH range. It should be noted that the pH of a system immediately after filling is not necessarily the equilibrium pH.

1b. O_2 Content of Aqueous Media

Generally, corrosion of metals such as Cu and carbon steel will decrease with a decreasing amount of O_2 in aqueous media. In the absence of O_2, measurable corrosion of Cu and steel does not occur. In a closed system, where O_2 will be depleted, the corrosion rate will become negligible. Corrosion inhibitors should not be necessary in a completely closed containment system composed of Cu or steel, if the proper pH is maintained. However, the probability of a closed system remaining closed is uncertain since the eventual intrusion of oxygen cannot be discounted. Therefore, the use of corrosion inhibitors or oxygen scavengers should be considered.

Oxidizing species such as dissolved oxygen act to stabilize the passivity of the protective film on stainless steel. When stainless steel is used in the absence of such species, it may be necessary to specify a grade which will provide adequate resistance to corrosion attack under these conditions.

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[1] *R. M. Diamant, "The Prevention of Corrosion," Business Books Ltd., London, 1971.*

The corrosion of Al may continue even in the absence of oxygen since an alternative corrosion process can occur. In this process, anodic dissolution of Al is accompanied by the evolution of molecular hydrogen. However, this reaction is expected to be negligible if the pH is maintained between 5 and 7 in the absence of aggressive ions.

1c. Chlorides

Chloride concentration should be kept to a minimum since the presence of chlorides in water accelerates corrosion of most metals. Therefore, the metallic collector components selected should be compatible with the chloride level anticipated in the heat transfer liquid. Aside from its initial presence in water, there are several potential sources of chloride in a solar unit:

- *Residual chloride from pickling treatment of metallic components. This may also be a source of sulfate; while this is a rather unlikely source of these ions, care should be taken that the components of the system are thoroughly cleaned before assembly.*

- *Chloride from the decomposition of non-metallic components in the system.*

- *Chloride from flux used in soldering or brazing components during installation.*

2. Temperature

The temperature is an important consideration with regard to selection of containment materials. Corrosion in aqueous media generally increases rapidly with temperature until the boiling point is approached. In systems open to the atmosphere, the corrosion rate will tend to decrease due to a sharp decrease in the solubility of oxygen in water at these temperatures. However, in a pressurized system, from which the dissolved oxygen cannot escape, corrosion may continue at an accelerated rate.

3. Copper in a Recirculating System

In "once through" systems, copper pipe is usually only connected downstream from iron pipe. Residential plumbing is an example of this. This practice is carried out because small amounts of copper tend to go into solution. When these copper ions contact more active metals such as Zn or Al, and to a lesser extent, Fe, they are reduced to copper metal which subsequently deposits on the metal surface. No such effect is anticipated for systems utilizing copper and stainless steel. When this occurs, a galvanic cell is set up and rapid corrosion initiates. The presence of a dielectric pipe joint between Cu and Al or Fe will not alleviate this problem. Similar action may be expected if Fe deposits on Al.

4. Galvanizing

Galvanizing has long been used to protect iron or steel from corrosion. Zinc is more active than iron and, when the two are in electrical contact, will corrode preferentially. Thus, the iron is cathodically protected. The rate of corrosion of zinc is generally lower than that of iron, so a relatively thin coating may last for quite a long time. However, there are data indicating that at elevated temperatures approaching 158°F (70°C), this effect is reversed and the iron corrodes rather than the zinc. [2]

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[2] *G. Butler and H. C. K. Ison, "Corrosion and its Prevention in Waters," Reinhold Publishing, N.Y., 1966.*

In addition, the corrosion rate of zinc itself increases rapidly in the temperature range between 131 and 194°F (55 and 90°C). Accordingly, the use of galvanized steel above 131°F (55°C) should be considered with care.

5. Stainless Steel

While stainless steel is generally regarded as corrosion resistant, it may be susceptible to intergranular attack, pitting, crevice corrosion or stress corrosion cracking. The corrosion resistance of stainless steel varies greatly with the grade used and the thermal treatment. Therefore, the grade of stainless steel selected should be resistant to corrosion when exposed to the anticipated heat transfer liquid.

6. Galvanic Coupling

Contact between dissimilar metals in the liquid containment system should be avoided when aqueous heat transfer media are to be used. However, physical separation of dissimilar metals may not always ensure against galvanic corrosion (see commentary on copper in a recirculation system).

7. Stress Corrosion

Collector components may be subject to substantial residual stresses resulting from their fabrication. In addition, thermal cycling during operation may introduce applied stresses. Typical collector designs and operating conditions may be such that it is virtually impossible to avoid residual or applied stresses.

Some metals and alloys are susceptible to stress corrosion when stressed in the presence of contaminants commonly present in water, aqueous fluids, or in the atmosphere. Therefore, the metals used in collectors should be limited to those which are not susceptible to stress corrosion when in contact with the anticipated heat transfer liquid.

8. Expression of the Results of Corrosion Measurements

Corrosion may be localized in the form of pitting, crevice corrosion, intergranular attack, stress corrosion, or erosion corrosion or it may be uniform. Localized corrosion is generally more destructive since it results in perforation in far shorter periods. Therefore, the type of attack observed should be reported. The measurement technique used in evaluating the severity of attack should also be consistent with the type of attack observed. For example, weight loss measurement would not be completely adequate to assess the degree of damage caused by localized corrosion. Weight loss measurement may be meaningful when the degree of localization of attack is described. However, results should also include pit density, maximum depth of penetration or rate of penetration measurement where appropriate.

ASTM standards G 1-72, G 16-71, and G 46-76 provide recommended practices relating to corrosion test evaluation.

S-515-2.3.2.4 Ultraviolet Stability

Organic absorber plates shall not degrade to an extent that will significantly impair their function during their design life when exposed to UV radiation.

Commentary: Organic absorber plates can crack, embrittle, soften, fade, or undergo other changes that could result in premature failure.

S-515-2.4 Absorptive Coatings

S-515-2.4.1 General

Materials used for absorptive coatings shall not degrade to an extent that collector performance will be reduced below allowable design limits.

Commentary: Appendix Table B-2 lists some characteristics of absorptive coatings currently in use. Absorptive coatings are generally of two types, selective or nonselective. A nonselective coating has an absorptance to emittance ratio near unity whereas in a selective coating, the ratio is higher. A selective coating has a high absorptance (α) over the solar spectrum (.3 to 2.0 μm) with low emittance (ε) to reduce thermal radiative heat losses.

For coatings applied by an electroplating process, as are many selective coatings, the substrate finish, plating geometry, bath composition, and current density may influence the properties necessary for optimum solar applications.

S-515-2.4.2 Materials Performance

S-515-2.4.2.1 Thermal Stability

After testing as described in S-515-2.1.2, there shall be no evidence of checking, cracking, blistering or flaking of the absorptive coating that will significantly impair its function. ASTM methods D660-44 (1970), D661-44 (1975), D714-56 (1974) and D772-47 (1975) shall be used to evaluate the above properties.

S-515-2.4.2.2 Ultraviolet Stability

Documentation shall be provided that the absorptive coating is not adversely affected by UV radiation to an extent that will significantly impair its function during its intended design life. In lieu of other documentation, the absorptive coating shall not exhibit checking, cracking, blistering or flaking after testing using any one of the three aging procedures described in S-515-2.2.3.2 in its design configuration.

Commentary: The above tests shall be performed with a cover plate between the absorptive coating and the light source (if so designed) to simulate in-service conditions. The cover plate shall be of the same type and configuration as used in an actual collector.

S-515-2.4.2.3 Moisture Stability

Documentation shall be provided that the absorptive coating is not adversely affected by moisture with which it comes in contact to an extent that will significantly impair its function during its intended design life. In lieu of other documentation, the absorptive coating shall not exhibit checking, cracking, blistering or flaking after testing for 30 days according to ASTM D 2247-68 (1973).

Commentary: Moisture is not expected to come in contact with absorptive coating in collectors which have a desiccant or in evacuated tube collectors.

S-515-2.4.2.4 Compatibility With Heat Transfer Medium

When absorptive coatings are in direct contact with the heat transfer medium documentation shall be provided to show that they are not affected by the medium to an extent that would significantly impair their function during their design lives. In lieu of other documentation, the absorptive coating shall exhibit no checking, cracking, blistering or flaking or signs of erosion after immersion in the fluid transfer medium for 100 hours at the maximum service temperature according to ASTM D1308-57 (1973).

S-515-2.5 Collector Enclosure

S-515-2.5.1 General

Collector enclosure materials shall be in accordance with applicable sections of Division 5 and 6 of the MPS.

Protective coatings, where used, shall be in accordance with Section 509-7 of the MPS.

S-515-2.5.2 Materials Performance

S-515-2.5.2.1 Thermal Stability

After testing as described in S-515-2.1.2, there shall be no cracking or warping of the collector enclosure materials to an extent that would result in premature failure or degradation in collector performance greater than the design limits.

S-515-2.6 Reflective and Antireflective Surfaces

S-515-2.6.1 General

Changes in reflective and antireflective surfaces due to in-use exposure shall not result in a decrease in collector performance below the design limits.

S-515-2.6.2 Materials Performance

S-515-2.6.2.1 Thermal Stability

After testing as in S-515-2.1.2, there shall be no cracking, crazing, delamination or change in reflectance properties of the surfaces to an extent that would result in premature failure or degradation in collector performance greater than the design limits.

S-515-2.6.2.2 Ultraviolet Stability

Documentation shall be provided that the reflectance properties of the surfaces will not be adversely affected by UV radiation to an extent that will significantly impair their function during their design life.

In lieu of other documentation, the reflectance, as measured for air mass 2 by ASTM E 424-71, method A, shall not decrease by more than 10% after exposure using any one of the three aging procedures described in S-515-2.2.3.2.

S-515-3 ENERGY TRANSPORT SYSTEM

This section includes materials used to transport the heat transfer medium to a heat exchanger or storage facility and also those necessary components used to return the heat transfer medium from the heat exchnager or storage facility to the collector subsystem.

S-515-3.1 Applicable Standards for Liquid Systems

S-515-3.1.1 Compliance with MPS

Materials used in the transport system shall be in accordance with Sections 515-3.2, 515-5.1, 515-5.2 and 515-6.4 of the MPS where applicable.

S-515-3.1.2 Other Standards

Materials used for transporting liquids shall be shown to be in compliance with applicable standards. Examples of some standards that may be useful are given in Appendix Table B-4. The standards and specifications for each component of the piping system shall also be given on plans or specifications.

Commentary: Most of the standards for piping shown in Appendix Table B-4 are the standards normally considered by the model plumbing codes. Designers may use other ANSI, ASTM, or Federal Standards or Specifications that may be more appropriate to their particular design.

S-515-3.2 Materials Performance for Liquid Systems

S-515-3.2.1 Thermal Stability

Components comprising the transport system shall not be damaged by normal thermal expansion and contraction of piping materials under in-use conditions. Proper pipe hangers and supports and fittings shall be used to allow normal movement of piping. See Appendix Table B-4.

S-515-3.2.2 Chemical and Physical Compatibility

a. Materials comprising the transport system shall have sufficient chemical and physical compatibility with organic materials in the system, such as sealants and gaskets, to which they are joined or in contact to prevent significant deterioration.

b. Materials comprising the piping or transport system shall have sufficient chemical and physical compatibility with the heat transfer liquid to prevent significant corrosive wear and deterioration. (For metals, see S-515-3.2.5)

S-515-3.2.3 Erosion/Corrosion

Materials comprising the transport system shall be in conformance with S-515-2.3.2.2.

S-515-3.2.4 Joints Between Dissimilar Metals

Dissimilar materials joined to form the transport system shall be electrically isolated from each other unless documentation is provided to demonstrate that the joints are sufficiently compatible to prevent corrosive wear and deterioration during their design lives.

Commentary: Care must be taken to avoid short circuiting of dielectric couplings. For example - dielectric couplings used to isolate dissimilar metals which are buried in soil may be ineffective because of contact of the metals with ground water, or dielectric couplings may be short circuited through pipe supports connected to metal structures.

S-515-3.2.5 Metals

Metals used in the transport system which are in direct contact with heat transfer liquids shall be used in accordance with the generally acceptable conditions listed in Tables S-515-2.3.2 or S-515-2.3.3 where applicable. Generally unacceptable conditions listed in these tables shall not be used. Documentation shall be provided to demonstrate that material usages not covered in the tables meet the intent of S-515-1.4 and S-515-3.2.3.

S-515-3.3 Applicable Standards for Air Systems

Design of all warm air heating systems shall be in accordance with the recommendations of the ASHRAE Guide or applicable manuals of NESCA, SMACNA, and ARI. Installation shall comply with NFPA Standards 31 and 54 and either NFPA 90A or 90B, as applicable and 515-3.1 of MPS.

S-515-3.3.1 Size

Air distribution equipment shall be adequately sized to fulfill the heating requirements of the system.

S-515-3.3.2 Air filters shall conform to the requirements of UL 900 (ANSI B124.1-1971).

S-515-3.3.3 Heating supply and return air ducts in unconditioned spaces shall be insulated with materials or have thermal characteristics as specified in 515-3.1 of MPS.

S-515-4 MECHANICAL SUPPORTING DEVICES

S-515-4.1 General

Mechanical supporting devices including support devices for roof, wall, or remote mounted collectors shall be designed and constructed of materials in accordance with Section 500 of MPS.

S-515-4.2 Applicable Standards

Materials used in mechanical supporting devices shall be in accordance with the following sections of MPS.

Wood	Section 506
Wood subject to termite damage	Section 502
Concrete	Section 503
Masonry	Section 504
Metals	Section 505
Coatings	Section 509-7

S-515-4-3 Pipe and Duct Hangers

Pipe and duct hangers, used to support insulated pipes or ducts, shall be designed to avoid damaging the insulation material.

Commentary: If pipe or duct hangers are installed over the insulation material, metal surface plates should be used to avoid damaging the insulation.

S-515-5 VALVES

S-515-5.1 Applicable Standards

Valves shall be shown to be in compliance with applicable standards. Examples of standards that may be useful are given in Appendix Table B-4. Valves manufactured to other standards not listed but fulfilling the requirements of a particular solar heating system design may be acceptable.

Commentary: Standards for valves usually present pressure-temperature ratings. Appendix Table B-5 presents these ratings as an example for ball valves, Federal Specification WW-V-35a-1975. National standards do not cover all valves useful to solar heating system design. Valves not covered by standards may be acceptable to HUD if a history of successful usage can be demonstrated by the valve manufacturer or solar heating system designer.

S-515-5.2 Material Performance

Valve materials shall be compatible with the heat transfer liquid as required in S-515-1.4 and S-515-3.2.

S-515-6 PUMPS AND FANS

S-515-6.1 Applicable Standards

a. Centrifugal, rotary and reciprocating pumps shall be in compliance with the requirements of the Hydraulic Institute [1].

Commentary: A Hydraulic Institute Standard defines the product, material, process or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerance, safety, operating characteristics, performance, quality, rating, testing and service for which designed [1].

b. Fans shall comply with the applicable standards of the AMCA or HVI and shall be tested, rated and labeled accordingly.

S-515-6.2 Material Performance

Pump materials shall be compatible with the heat transfer liquid as required in S-515-1.4 and S-515-3.2.

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[1] Hydraulic Institute, 1230 Keith Building, Cleveland, Ohio 44115

HYDRAULIC INSTITUTE STANDARDS FOR CENTRIFUGAL, ROTARY & RECIPROCATING PUMPS, thirteenth edition, 1975. Library of Congress Card No. A56-4036

S-515-7 THERMAL STORAGE UNITS

Thermal storage units are defined as any container, space or device which has the capacity to store thermal energy or transfer media (liquid or solid) containing thermal energy for later use.

S-515-7.1 General

Thermal storage units shall be of sufficiently durable material to fulfill the heating storage requirements of the system for the intended design life of the storage unit.

S-515-7.2 Applicable Standards

Applicable standards for thermal storage materials are presented in Appendix Table B-6. The thermal performance of storage units can be evaluated using ASHRAE 94.

S-515-7.3 Labeling

Pressurized thermal storage containers shall be labeled in accordance with 515-1.2 of the MPS. In addition, labels shall list the maximum operating pressure and temperature and minimum operating temperature.

S-515-7.4 Materials Performance

S-515-7.4.1 Contamination

Thermal storage tank materials, including any interior protective coatings and the heat storage medium used, shall not impart toxicity, undesirable tastes, or odors to either air or water intended for human consumption. For liquid system, the requirements of the U. S. Public Health Service Drinking Water Standards shall apply.

S-515-7.4.2 Materials Compatibility

a. Materials comprising the thermal storage system shall not cause corrosive wear and deterioration which results in premature failure or degradation in storage performance greater than the design limits.
b. Metals used in the thermal storage system which are in direct contact with heat transfer liquid shall be in accordance with the generally acceptable conditions listed in Tables S-515-2.3.2 or S-515-2.3.3, where applicable. Generally unacceptable conditions listed in these tables shall not be used. Documentation shall be provided to demonstrate that material usages not covered in the tables meet the intent of S-515-1.4 and S-515-7.4.2a.

S-515-8 HEAT TRANSFER FLUIDS

S-515-8.1 General

The heat transfer fluid shall be of sufficient stability to perform its intended heat transfer functions for the intended life of the fluid. The heat transfer fluid shall not cause premature failure or degradation in a system performance exceeding the design limit for those parts of the solar energy system with which it comes into contact.

Commentary: Appendix Table B-7 presents a partial listing of properties of several types of heat transfer liquids.

S-515-8.1.1 Labeling

The provisions of the Federal Hazardous Substances Act (1971) shall apply to heat transfer fluids. In addition, heat transfer media classified as combustible shall be labeled as such.

Emergency first aid instructions shall be included on the label of toxic heat transfer fluid containers. A technical data sheet shall be provided with all heat transfer fluids which contains the following information.

Service temperature range
Viscosity over service temperature range
Freezing point
Boiling point
Flash point
Auto ignition temperature
Specific heat
Vapor pressure over service temperature range
Instructions for inspection, treatment and disposal of fluid
Emergency first aid instructions.

For toxic fluids, a list of the chemical components of the fluid shall be available expressed in mg./liter. This list shall include any substances which comprise more than 0.10% of the medium.

S-515-8.2 Toxic and Combustible Fluids

S-515-8.2.1 General

Heat transfer fluids which require special handling (e.g., toxic, combustible, corrosive, explosive, etc.) shall not be used unless the systems in which they are used are designed to avoid unnecessary or unreasonable hazards; see Section S-615-10.1.

S-515-8.2.2 Flash point

Temperatures attained by fluids in solar systems under operating and no flow conditions shall not exceed a temperature which is 100°F below the flash point of the fluid. In no case shall a liquid with a flash point below 100°F or a flammable gas be used. Flash point shall be determined by the methods described in NFPA No. 321, Basic Classification of Flammable and Combustible Liquids.

Commentary: NFPA No. 321 (1973) defines <u>Flammable Liquids</u> as those with flash points below 100°F and <u>Combustible Liquids</u> as those with flash points at or above 100°F. This section prohibits the use of flammable liquids (flash point below 100°F) and permits the use of combustible liquids (flash point at or above 100°F) under prescribed conditions. In common, non-technical usage, the term flammable liquid frequently refers to any liquid with a flash point, including liquids classified as combustible.

S-515-8.2.3 Atmospheric Concentration of Toxic Materials

The concentration of the vapor of the heat transfer medium in the building's interior atmospheric environment shall not exceed 1/10th the threshold limit value (TLV) for that particular medium in an 8-hour period.

Commentary: The TLV is primarily concerned with industrial exposures. Because routine household exposure could be for much longer time periods, the 1/10th value of the TLV is recommended. TLV's are under continuous review; a list of currently adpoted values is published by the American Conference of Government Industrial Hygienists.

S-515-8.3 <u>Materials Performance</u>

S-515-8.3.1 Changes in the Heat Transfer Fluid

Except when such changes are allowed by the design of the system, the heat transfer fluid shall not freeze, give rise to excessive precipitation, give rise to sludge, asphaltic or resinous deposits or coatings, otherwise lose its homogeneity, boil, change pH or undergo changes in viscosity outside the design range when exposed to its intended service temperature and pressure range and other intended operating conditions.

Commentary: Some organic fluids may degrade by oxidation in open systems and thereby be unacceptable for use in such systems while providing satisfactory service in closed systems.

S-515-8.3.2 Chemical Compatibility

Heat transfer fluids designed to be used in contact with component materials shall not cause deterioration which results in premature failure or degradation in system performance greater than the design limits. Inhibitors in the concentration used shall be compatible with all components in the system with which they come in contact.

S-515-8.3.3 Thermal Stability

The heat transfer fluid shall not degrade at temperatures up to the maximum service temperature or cause deterioration of the system components which results in premature failure or degradation in system performance greater than the design limits.

Commentary: This maximum temperature will generally be reached under "no-flow" conditions. Appendix Table B-7 includes data for a number of typical transfer liquids. Some fluids may decompose somewhat at elevated temperatures. For example, ethylene glycol can degrade to form organic acids. Buffers are usually included with such liquids to control the pH. It may be desirable, if fluids decompose with time, to change the fluids periodically.

S-515-9 HEAT EXCHANGERS

S-515-9.1 <u>General</u>

When nonpotable liquid is used in a solar energy system to transfer heat to domestic (potable) hot water, the design of the heat exchanger shall be such that either a minimum of two walls or interfaces are maintained between the non-potable liquid and the potable water supply or protection is provided in such a manner that equivalent safety is provided.

Commentary: Double wall heat exchanger designs are one way of meeting the intent of this criterion. When double wall heat exchanger designs consisting of two single wall heat exchangers in combination with an intermediary potable heat transfer liquid are used, leakage through one of the walls would result in a single wall configuration. Although this design is considered to meet the intent of this criterion, there are several other designs that avoid this problem.

The use of single wall configurations which solely rely upon potable water pressure to prevent contamination is not considered to be an acceptable solution. Similarly, extra thick single walls are not considered to meet the intent of this criterion.

For approval of other than double wall designs, the procedures described in S-101 should be utilized.

S-515-9.2 <u>Applicable Standards</u>

Heat exchangers shall be in compliance with the applicable standards given in S-515-9.2.1 and S-515-9.2.2. Exchangers manufactured to other standards not listed but fulfilling the requirements of a particular solar heating system design may be acceptable.

S-515-9.2.1 Tubular Heat Exchangers

Tubular heat exchangers shall be in compliance with the appropriate requirements of TEMA.

S-515-9.2.2 Heating Coils

Forced circulation air-heating coils shall be in compliance with the requirements of ARI Standard 410.

S-515-9.3 <u>Material Performance</u>

Heat exchanger material shall be compatible with the heat transfer fluid as required in S-515-1.4 and S-515-3.2.

S-515-10 GASKETS AND SEALANTS

S-515-10.1 Applicable Standards

Caulking and sealants shall be in accordance with 507-6 of the MPS, where applicable. Gaskets which seal pressurized systems shall withstand the maximum service pressure when tested in accordance with ASTM D 1081-60 (1974).

Commentary: Since gaskets and sealants used in solar systems may not be adequately covered by existing specifications, Appendix Table B-8 is included to serve as a guide in selecting specific sealing materials.

S-515-10.2 Materials Performance

S-515-10.2.1 Thermal Stability

Gaskets and sealants included in the test described in S-515-2.1.2 shall not exhibit cracking, loss of elasticity, outgassing, or loss of adhesion sufficient to impair their function at the completion of the test.

Commentary: A potential problem with sealants and gaskets used in collectors is that during no-flow conditions outgassing may occur with the outgassing products being deposited on the interior surface of the cover plate. Such deposits can reduce the transmittance of the cover plate.

S-515-10.2.2 Chemical and Physical Compatibility

a. Gaskets and sealants shall be chemically and physically compatible with the substrates to which they are joined.

   Commentary: Compatibility of gaskets and sealants with substrates may be evaluated in the process of testing materials for compliance with the Federal Specifications listed in Appendix Table B-8.

b. Documentation shall be provided to show that gaskets and sealants in direct contact with the heat transfer fluid are not degraded by the fluid. In lieu of other documentation, gaskets and sealants which are in direct contact with heat transfer fluid shall not exhibit significant expansion, cracking, loss of elasticity or loss of adhesion when immersed for 100 hours in the heat transfer fluid at the maximum service terperature. ASTM D 471-75 or F 146-72 shall be used as a guide in performing these tests.

S-515-10.2.3 Ultraviolet Stability

Gaskets and sealants that are normally exposed to UV radiation in service shall not be adversely affected by such radiation. Documentation shall be provided demonstrating that such materials are capable of withstanding exposure to sunlight for their design lives without functional impairment.

Commentary: Data obtained under ambient environmental exposure conditions will be accepted if data obtained under in service conditions is unavailable.

Gaskets of ethylene propylene diene manomer (EPDM) rubber or silicone rubber are examples of materials that may be appropriate for these applications.

S-515-11 INSULATION/THERMAL AND MOISTURE PROTECTION

S-515-11.1 General

These requirements apply to both fixed and movable insulation installed in conjunction with or as an integral part of the solar system. Materials used for insulation shall be of sufficient proven effectiveness and durability under the expected operating conditions to assure that required design conditions concerning heat losses, sound control and fire rating are attained. Insulation in contact with the ground shall not be adversely affected by soil, vermin or water. Insulating materials shall be in accordance with 507-3 of the MPS and S-607-3. Insulating materials for air ducts shall be in accordance with S-515-3.1. Materials used for waterproofing shall be in accordance with Section 507-1 of the MPS. Materials used for vapor barriers shall be in accordance with Section 507-2 of the MPS.

Commentary: When movable insulation is used in passive systems, design considerations should be given to ensure protection of the insulation from structural damage, degradation due to weather or other degrading factors.

S-515-11.1.1 Flame Spread Classification

The flame spread classification index for all insulation materials shall not exceed the following values:

Plastic Foam	25
Loose Fill Insulation	50
Other Insulation Material	150

The ASTM E84 flame spread test method shall be the basis for evaluating the surface burning characteristics of the insulation materials. Where fibrous blankets with facings are to be used, the surface burning characteristics of the complete faced insulation blanket shall be measured.

Commentary: No single test is sufficient to provide a full estimate of performance of a product in a fire. Plastic foams and loose fill insulation are difficult to evaluate in ASTM E-84. The requirement of Flame spread classification of 25 maximum for plastic foams and 50 for loose fill insulation will provide as much safety assurance as is possible with current test methods. Such a classification shall not be construed as the equivalent of "noncombustible." Many insulation materials, including those consisting of cellulose, plastic foam and fibrous glass (containing organic binder) are combustible materials which will burn and release heat, especially when exposed to continuous large fire sources.

S-515-11.1.2 Flame Resistance Permanency

Chemical retardant insulations shall retain their flame resistance throughout their service lifetime. The procedures and equipment specified in ASTM C739-73, Section 10.4, "Flame Resistance Permanency" shall be used in judging the effect of aging on the permanence of any flame retardants used during manufacture.

S-515-11.2 Materials Performance

S-515-11.2.1 Collector Insulation

S-515-11.2.1.1 Thermal Stability

Collector insulation shall not degrade at the maximum service temperature to an extent which results in premature failure or degradation in collector performance greater than the design limits.

After testing as described in S-515-2.1.2, there shall be no swelling or other dimensional changes in the collector insulation, outgassing or physical changes resulting in the decrease in thermal performance in excess of that permitted in the test.

Commentary: Organic materials found in insulation have been known to evolve from collector insulation during system operation, leaving a coating on the cover plates which impairs collector performance. Normally, the insulation nearest the absorber plate is exposed to temperatures higher than insulation near other parts of the collector. It may be possible to use one type of insulation adjacent to the absorber plate and another type in areas of the collector which will not be exposed to extreme temperatures. Fiberglass insulation with binders can be preheated to expel volatiles prior to use in collectors. If such pretreatment is used, the upper temperature limit becomes somewhat higher.

S-515-11.2.2 Pipe or Duct Insulation

Pipe or duct insulation shall be sufficiently stable at the maximum temperature to which it will be exposed in service.

Commentary: General practice for the use and protection of pipe insulation is described in the ASHRAE Handbook of Fundamentals.

S-515-11.2.3 Storage Subsystem Insulation

If insulation whose thermal properties are affected by water is used, the insulation shall be protected in accordance with S-515-11.1.

S-515-12 CATCH BASINS

S-515-12.1 General

Catch basins shall be of adequate size and construction to fulfill their intended functions and be constructed of materials in accordance with Section 515-5 of MPS.

S-515-12.2 Materials Performance

S-515-12.2.1 Materials Compatibility

Catch basin materials which are jointed to or in contact with other materials shall have sufficient chemical and physical compatibility with those materials to prevent deterioration.

S-515-12.2.2 Coating

The catch basin coating, when used, shall not be significantly deteriorated during its design life by weathering or by the transfer medium with which it comes in contact.

S-515-13 ORGANIC COUPLING HOSES

S-515-13.1 Materials Performance

S-515-13.1.1 Thermal Stability

Organic coupling hoses included in the test described in S-515-2.1.2 shall not exhibit cracking, loss of elasticity, or embrittlement at the completion of the test that will significantly impair their function.

Commentary: The selection of coupling hoses and clamps is quite critical. Many failures have been noted due to the clamping of hoses with screw or spring-type clamps, exposing the hose to high temperatures which tend to vulcanize the area beneath the clamp, causing it to lose resiliency and begin to leak. Further tightening of the clamps will temporarily stop leakage but further vulcanizing will occur with the end result being a hard non-resilient ring under the clamp which can no longer be tightened to prevent leakage. Silicone rubber hose is one of the few materials which have been tested and tend to maintain their resiliency with no tendency to take a thermal set. The silicone rubber hoses, however, tend to be so pliable that screw-type clamps with perforated bands should not be used as it is possible to extrude the material through the perforations in the band. If this material is used, smooth band clamps should be utilized.

S-515-13.1.2 Ultraviolet Stability

Organic coupling hoses which are exposed in service to UV radiation shall not be adversely affected by the radiation. In lieu of other documentation, organic coupling hoses shall not exhibit significant cracking, loss of elasticity or embrittlement after 500 hours exposure as described in ASTM D750-68 (1974).

S-515-13.1.3 Compatibility with Heat Transfer Fluid

Documentation shall be provided to demonstrate that organic coupling hoses which are in direct contact with heat transfer fluids are not significantly degraded by the fluids. In lieu of other documentation, the hoses shall not exhibit cracking, loss of elasticity or embrittlement that will significantly impair their function when tested for 100 hours at the maximum service temperature according to ASTM D471-75 or F146-72.

Commentary: SAE Standard J20e (1974) covers coolant system hoses for automobiles. For solar systems using glycol liquids, this SAE Standard may be applicable for demonstrating compliance with S-515-13.1.3. It is expected, however, that hoses in solar systems will be exposed to more strenuous conditions than automobile hoses.

S-515-13.1.4 Compatibility with Piping Materials

Organic coupling hoses which are used to join piping shall be compatible with the piping.

S-515-13.1.5 Ozone Degradation

Documentation shall be provided to demonstrate that organic coupling hoses which are exposed in service to the environment are not significantly degraded by ozone in the air. In lieu of other documentation, the hoses shall exhibit no cracking or loss of elasticity that will significantly impair their function when tested for 100 hours to an ozone atmosphere of 50 ± 5 pphm/volume at 23° according to ASTM D1149-64 (1970).

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CHAPTER 6

CONSTRUCTION

S-600 GENERAL

The provisions of this chapter are applicable to solar energy systems including heating (H) and domestic hot water (DHW) systems. This chapter is a supplement to the Minimum Property Standards (MPS). Building construction provisions (Chapter 6) of the MPS are applicable in addition to the items explicitly discussed in this document.

S-600-1 LABELING

Solar heating (H) and/or domestic hot water (DHW) systems, subsystems, and components shall be labeled or given clear indication of their operating temperatures, pressures, flow direction and filled weight as appropriate in accordance with 515-1.2 of the MPS.

Commentary: Labeling requirements for specific material and products are given in Chapter 5 of this document.

S-600-2 ALTERNATE CONSTRUCTION

Alternate or special methods of construction other than those contained herein, may be used when found acceptable by established HUD procedures and Division 613 of MPS and Section S-101 of this ducument.

S-600-3 INSTALLATION, OPERATION AND MAINTENANCE MANUAL

Manuals shall be provided to describe the installation, operation and maintenance of the H and/or DHW systems.

A complete manual as described in S-600-3.1, 3.2, and 3.3 shall be provided to the installer or maintenance contractor. A simplified owners manual shall be provided to the building occupant which shall include as a minimum: system description including a schematic diagram; owner maintenance procedures; and a tabulation of appropriate pressure, temperature and flow information that is indicative of system performance. The owners manual shall also include the names and addresses of manufacturers of all the primary components of the system.

Commentary: It is suggested that each manufacturer of a subsystem should provide installation, operating and maintenance manuals for each subsystem he provides, and that he show typical systems using his and other subsystems to complete the whole. The installer, who is responsible for the complete installation and therefore for the complete system should assemble all the manuals from the subsystem manufacturers into a complete manual pertinent to the system. He should add any other information needed for an understanding of the complete system and its functioning. Control sequences are determined almost entirely in the field and should be described for the specific installation.

S-600-3.1 Installation Instructions

The manual shall include physical, functional and procedural instructions describing how the subassemblies of the H and/or DHW systems are to be installed.

These instructions shall include descriptions of both system interconnections and connections with the dwelling and site.

S-600-3.2 Maintenance and Operation Instructions

The manual shall completely describe the H and/or DHW systems, their breakdown into subsystems, their relationship to external systems and elements, their performance characteristics and their required parts and procedures for meeting specified capabilities.

The manual shall list all parts of the systems, by subsystem, describing as necessary for clear understanding of operation, maintenance, repair and replacement, such characteristics as shapes, dimensions, materials, weights, functions, and performance characteristics. The manual shall include a tabulation of those specific performance requirements which are dependent upon specific maintenance procedures. The maintenance procedures including ordinary, preventive and minor repairs, shall be cross-referenced for all subsystems and organized into a maintenance cycle. The manual shall fully describe operating procedures for all parts of the system including those required for implementation of specified planned changes in mode of operation. The instructions shall provide warning against hazards that could arise in the maintenance of the system and shall fully describe precautions that shall be taken to avoid these hazards.

S-600-3.3 Maintenance Plan

The manual shall include a comprehensive plan for maintaining the specified performance of the H and/or DHW systems for their design service lives.

The plan shall include all the necessary ordinary maintenance, preventive maintenance and minor repair work, and projections for equipment replacement, and should include important pressure, temperature and flow information as checkpoints throughout the system to assist in troubleshooting.

S-600-4 REPLACEMENT PARTS

Parts, components, special tools and test equipment required for service, repair or replacement shall be commercially available or available from the system or subsystem manufacturer or supplier.

Commentary: This provision is intended to preclude long periods of system down-time due to the need for the repair or replacement of parts.

S-600-5 MAINTAINABILITY OF SYSTEMS AND SUBSYSTEMS

S-600-5.1 Service Complexity

The H and DHW systems and subsystems shall be capable of being serviced with a minimum amount of special equipment by a trained service technician using a maintenance manual and common tools.

COMMENTARY: ON LARGER COLLECTOR INSTALLATIONS IT MAY BE DESIRABLE TO MAKE PROVISIONS FOR SUPPLYING ELECTRICAL POWER AND WATER FOR MAINTENANCE PURPOSES.

S-600-5.2 Access for System Maintenance

All individual items of equipment and components of the DHW systems which may require periodic examination, adjusting, servicing and/or maintenance shall be accessible for inspection, service, repair, removal or replacement without dismantling of any adjoining major piece of equipment or subsystem.

Commentary: It is recommended that individual collectors in an array be replaceable or repairable without disturbing non-adjacent collectors in the array.

Accessibility as a function of component life is an important consideration. Some manufactured collector systems and many individually designed systems are done in such a way that sequential installation is necessary. This can make it very difficult to replace an individual collector without disturbing the entire array.

S-600-6 SAFETY AND HEALTH REQUIREMENTS

S-600-6.1 General

The incorporation of solar systems into the living unit shall not create an environment which is more hazardous to the occupants than that of a conventional living unit. Materials and the construction used in installation of solar systems shall be in accordance with the fire protection provisions of S-405.

S-600-6.2 Combustible Liquids

The storage, piping and handling of combustible liquids shall be in accordance with the Flammable and Combustible liquids code NFPA No. 30.

S-600-6.3 Protection From Heated Components

Components of solar systems which are accessible, located in areas normally subjected to occupant traffic and which are maintained at elevated temperatures shall either be insulated to maintain their surface temperatures at or below 140°F at all times during their operation or suitably isolated. Any other exposed accessible components that are maintained at temperatures above 140° shall be identified with appropriate warnings.

S-600-6.4 System Component Clearances

Combustible solids adjacent to solar equipment or an integral part of a solar component shall not be exposed to elevated temperatures which may cause ignition.

Commentary: Heating of cellulosic materials as well as other combustible materials over an extended period of time may result in the material reaching and surpassing its autoignition temperature. The most commonly accepted ignition temperature of wood is 392°F. However, studies have indicated that wood may ingite when exposed to a temperature of 212°F for prolonged periods of time. The ignition temperature of plastics may be above or below those of cellulosic materials. Clearances for HVAC equipment, ducting and piping are discussed in NFPA No. 89M. Where applicable, clearances specified by a nationally recognized testing laboratory may be used.

S-600-6.5 Protection Against Over-Pressure and Over-Temperature

The total system shall be protected against excessive pressures and temperatures. Pressures shall be limited as specified in S-615-14.

S-600-6.6 Personal Safety

Where access for service of cleaning of solar subsystems requires a person to balance on a narrow or (steeply) sloping surface, provisions shall be made for securing a life-line, guard-rail or other personal protective device.

S-600-6.7 Growth of Fungi, Mold or Mildew

Compoments and materials used in the H and DHW systems shall not promote the growth of fungi, mold or mildew in accordance with applicable codes, the test specification of Section 10, UL 181-74 and MPS, Appendix D, Section E.

Commentary: Special consideration should be given to the presence of fungi in air handling systems since such micro-organisms are frequently allergenic.

S-600-6.8 Protection Against Vermin or Rodents

Solar energy systems (including piping, fixtures, appliances and other equipment) should not contribute to the entry or growth of vermin of rodents. Maintenance of physical barriers, minimization of concealed spaces conducive to harboring vermin or rodents, provisions of access for cleaning shall be in accordance with applicable codes such as Section 2.13 of the National Standard Plumbing Code.

S-600-6.9 Protection of Potable Water Supply

The design and installation of the solar system its subsystems and components shall be accomplished in such a manner as to provide complete protection of the potable water supply. Such installations shall be in accordance with Chapter 10 of the National Standard Plumbing Code and other applicable codes (see Section S-615-10).

DIVISION 1

S-601 <u>GENERAL STRUCTURAL REQUIREMENTS</u>

S-601-1 GENERAL

This section contains those supplemental requirements to Chapter 6 of the MPS needed to cover solar systems which utilize conventional structural materials (materials covered by the current MPS edition). Unless specifically modified herein, the requirements of MPS Chapter 6, apply in addition to the supplemental requirements in this section.

All structural design for solar systems and their mounting structures shall be based on generally accepted engineering practice. All loading shall be in accordance with ANSI A58.1 except as shown otherwise in this document or MPS.

S-601-2 DESIGN DEAD LOADS

In calculating the dead loads for solar systems, the weights of the transfer liquid in the collector, liquid in storage tank, and liquid in other subsystems and components shall be included, except when using dead load to resist uplift or overturning.

Commentary: Liquids are normally present in systems in which they are the heat transfer medium and thus are a long term sustained load where creep is a consideration. They also effect seismic forces in a fashion similar to any other dead load. However, it is possible to remove liquid, thus they should no be counted on to resist uplift.

S-601-3 DESIGN LIVE LOADS

S-601-3.1 <u>Roof Mounted Solar Systems</u>

Resistance to design live roof loads prescribed in Table 6-1.2 of MPS 4900.1 <u>shall not</u> be required for collector panels that are mounted on roofs but not form an integral part of the roof if adequate access is provided for service and maintenance personnel. For collectors which form an integral part of the roof, resistance to the design live roof loads listed in Table 6-1.2 <u>shall</u> be required.

Commentary: The design live loads contained in Table 6-1.2 of MPS 4900.1 constitute minimum loading requirements needed primarily for human safety. The roof will need to be repaired from time to time; therefore, it must support the workman making the repairs, regardless of the wind and snow loading requirements. This is not the case for accessible roof-mounted collectors; they do not need to support workmen when being repaired. Hence, they need only to sustain the required environmental loading (wind, snow and hail).

S-601-3.2 <u>Maintenance Loads</u>

All components of the solar energy systems which must support maintenance personnel shall resist a single concentrated load of 250 lbs. distributed over a 4 sq. in. area, acting on the installed component in the most critical locations. Special allowance shall also be made for heavy maintenance equipment, if used.

S-601-4 WIND LOADS

S-601-4.1 Flat Plate Collectors Mounted on Roofs and Walls

Wind loads on flat plate solar collectors shall be those specified for roofs and walls in Section 601-6 of the MPS or as modified in paragraphs S-601-4.1.1, .2, .3, and .4 below.

S-601.4.1.1 Flat plate collectors that are mounted with their cover plates and back surfaces flush with the surface of the roof shall resist the wind loads that would have been imposed on those areas of the roof covered by the collectors.

S-601-4.1.2 Flat plate collectors mounted at an angle or parallel to the surface of the roof on open racks shall resist any uplift load caused by the impingement of wind on the underside of the collector. This wind load is in addition to the equivalent roof area wind pressure and suction loads, and shall be determined by utilizing accepted engineering procedures which may include wind tunnel testing. Equivalent roof area wind loads are those wind loads that would have been applied to the areas of the roof occupied by the collectors. Equivalent roof area wind loads shall be applied to the outer cover plate of the collectors.

S-601-4.1.3 In calculating design wind loads for flat plate collectors mounted on roofs, the internal pressure coefficients, C_{pi}, listed in Table 11, ANSI A58.1 shall be taken as zero for the wind pressure within a collector. Collectors that form an integral part of the roof structure shall resist the internal pressures from the inside of the building just as any other roof member.

S-601-4.1.4 Wind loads on flat plate collectors mounted at an angle to a vertical wall shall be the same as those required for equivalent roof eave area as stipulated in section 6.5.3.2.4 of ANSI A58.1. Wind loads on flat plate collectors mounted parallel to, or integral with vertical walls shall be the same as those required for exterior walls.

S-601-4.2 Other Types of Solar Collectors Mounted on Roofs and Walls

Wind loading on other types of solar collectors shall be determined using the results of accepted engineering procedures including the MPS and ANSI A58.1 or physical simulation which may include wind tunnel testing.

S-601-4.3 Roof Wind Loads

Roof loading due to wind effects on flat plate collector and concentrating collector support structures and/or enclosures must be included not only in the design of the roof support framing, but also in the design of all structural elements influenced by these loads.

S-601-4.4 Ground Mounted Collectors

Wind loading on ground-mounted flat plate collectors and their support structures shall be determined in the same manner as that for roof-mounted flat plate collectors. Where flat plate collectors are mounted on open racks, equivalent roof area wind loads shall be those given for non-enclosed structures as given in section 6.6, ANSI A58.1, taking into account local terrain characteristics.

S-601-4.5 Exposed Storage Tanks

Wind loads on exposed storage tanks shall be determined in accordance with ANSI A58.1.

S-601-5 SNOW LOADS

S-601-5.1 Flat Plate Solar Collectors Mounted on Roofs and Walls

Snow loads acting on flat plate solar collectors or caused by their installation shall be those required for roofs as specified in Section 601-5 of MPS or as modified in paragraphs S-601-5.1.1, .2, and .3 below.

S-601-5.1.1 Flat plate collectors that are mounted with their cover plates and back surfaces parallel to the surface of a roof, and those that are mounted at an angle to the surface of a roof, on open or closed racks in a saw-tooth arrangement shall support the snow loads that would otherwise have been imposed on areas of the roof covered by the collectors. Where collectors are mounted with their cover plates forming steep slopes, shedding of snow from the collector may cause snow to accumulate at the base of the collector or other hazardous conditions which shall be considered in the design of the roof.

S-601-5.1.2 Flat plate collectors mounted at an angle to the surface of a wall, and supported by the wall, shall be designed to support the same snow loads as an equivalent roof eave area.

S-601-5.1.3 Consideration shall be given to the potential local accumulation of snow under flat plate collectors.

S-601-5.2 Roof Loading

A single or multiple saw-tooth array of collectors may cause severe drifting between each mounted collectors (and under open racks) in addition to the snow load on the cover plates. These unusual snow loads must be determined on the basis of local snow conditions.

S-601-5.3 Other Types of Solar Collectors

Snow loads on other types of solar collectors shall be determined as specified in the applicable portions of ANSI A58.1 and by accepted engineering procedures.

S-601-6 SEISMIC LOADS

S-601-6.1 General

Seismic design requirements for the mechanical and electrical components of solar energy systems are covered in this section. Architectural and structural components shall be designed in accord with MPS Sec. 601-9. The requirements of this section shall apply to the erection, installation, relocation, or replacement of, or addition to, any mechanical or electrical component of, a solar system. If elements of the solar energy system are attached to any existing structural element, or if parts of any existing structural element are modified or replaced with parts different in size and weight, the element, as well as its connections to the building shall be re-designed to comply with the seismic design requirements of Section 601-9 of MPS.

S-601-6.2 Mechanical and Electrical Components

For those buildings required to be designed for earthquake by section 601-9 of the MPS, mechanical and electrical components of solar energy systems shall resist seismic forces as specified for parts and portions of buildings in the latest edition of the Uniform Building Code (UBC) [1]. The value of C_p used in the UBC to establish the seismic force shall be taken from table S-601-6.

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[1] The Uniform Building Code is published by the International Conference of Building Officials, Whittier, California.

The design of all connections between the mechanical or electrical components and the structural frame shall allow for anticipated movements of the structure. The details of the connections shall be made a part of the contract documents.

Commentary: Mechanical or electrical components of a solar system are subjected to seismic forces generated by their mass and may also be influenced by interaction with elements of the structural system.

TABLE S-601-6

Part of System	Direction of Force	Value of C_p 1/ 2/
Storage tanks, pressure vessels boilers, furnaces, absorption air conditioners, other equipment using combustible or high temperature energy sources, electrical motors and motor control devides, storage tanks, heat exchangers, pressure vessels	any direction	0.12 when resting on ground 0.20 when connected to, or housed, elsewhere in the building.
Flat plate and concentrating solar collectors	any direction	0.20
Tranfer liquid pipes larger than 2 1/2 in. in diameter	any horizontal direction	0.12

1/ For flexible and flexibly mounted equipment and machinery, appropriate values of C_p shall be determined by a properly documented dynamic analysis, or by dynamic testing, using appropriate excitation spectra approved by HUD. Consideration shall be given to both the dynamic properties of the equipment and machinery and to the building or structure in which it is placed.

2/ WHEN LOCATED IN THE UPPER PORTION OF ANY BUILDING WHERE THE H_N/D RATIO IS 5:1 OR GREATER THE CP VALUE SHALL BE INCREASED BY 50%

WHERE H_N = HEIGHT IN FT. OF THE PART OF THE SYSTEM ABOVE THE BASE LEVEL OF THE BUILDING

D = THE DIMENSION OF THE STRUCTURE IN FEET IN A DIRECTION PARALLEL TO THE APPLIED FORCE

S-601-7 HAIL LOADS

The cover plates, lenses, and reflector surfaces of solar collectors shall be protected against or resist the perpendicular impact of a single hailstone of the magnitude stipulated below falling at its terminal velocity.

Hail size: D= 0.3d

in which D = hail stone diameter, inches

d = means annual number of days with hail taken from Figure S-601-7 [1].

Terminal velocities for various hail sizes are given in Table S-601-7. [2]. Compliance with this provision shall be based on documented past hail loading performance or testing using the procedures described in NBS Building Science Series BSS 23 [3] or analytical procedures acceptable to HUD.

Commentary: The correlation of hail size with mean annual number of days with hail was determined using data relating the probability of occurrence of hail particle size to the number of days with hail (tabulated in Ref. [4]*, and limited statistical information relating the local area covered by a hailstorm, and the regional area for which statistical data is compiled. The hail size indicated has a 5% probability of being exceeded in any one year (estimated 20 year recurrence interval). The hail requirements in this section are based on available information which does not contain physical test data. Therefore, local hailstone loading performance should be considered in implementing the requirements of this section.*

The impact from the vertical terminal velocity is used as a measure of the effect of hail falling with or without horizontal wind. It is possible that a larger impact could occur on surfaces sloped from 30° to 60° if the maximum particle diameter occurred simultaneously with a high horizontal wind velocity perpendicular to the surface. It may be overly conservative for particles over 1.5" impacting on near vertical surfaces. However, due to the lack of information on this phenomenon and the low probability of its occurrence, it is assumed that the terminal velocity gives the best measure of impact force consistent with the present state of the art.

The loadings specified in this section to determine collector performance closely parallel those that conventional asphalt shingles and built up roofing are expected to withstand for all but the mid-continent hail belt.

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[1] Baldwin, J. L., Climates of the United States, U.S. Dept. of Commerce, Washington, D.C. (1973).

[2] Mathey, R. C., Hail Resistance Tests of Aluminum Skin Honeycomb Panels for the Relocatable Lewis Building, Phase II, NBS Report 10193, National Bureau of Standards, Washington, D.C. (1970).

[3] Greenfield, H., Hail Resistance of Roofing Products, Building Science Series 23, National Bureau of Standards, Washington, D.C. (August 1969).

[4] Storm Data, U.S. Dept. of Commerce, National Oceanic and Atmosphere Administration, Environmental Data Service (monthly periodical).

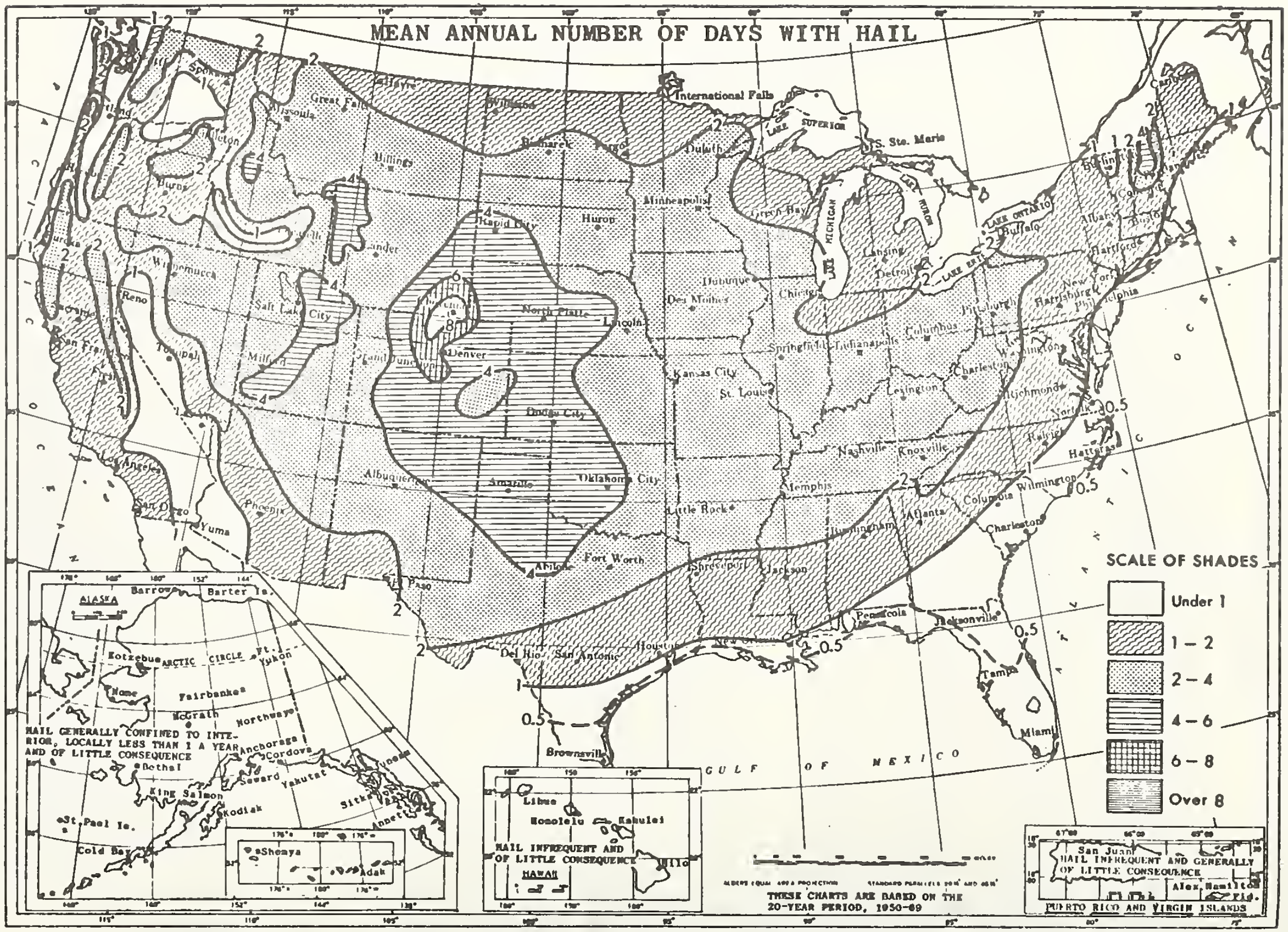

FIGURE S-601-7

from: Baldwin, J. L., Climates of the United States, U.S. Department of Commerce, Washington, D.C., 1973.

TABLE S-601-7

Values of weight and terminal velocity in free fall computed for smooth ice spheres.

Diameter in	Weight gm	Weight lb	Terminal Velocity ft/sec
1/2	0.98	0.002	51
3/4	3.30	0.007	62
1	7.85	0.017	73
1 1/4	15.33	0.034	82
1 1/2	26.50	0.058	90
1 3/4	42.08	0.093	97
2	62.81	0.138	105
2 1/4	89.43	0.197	111
2 1/2	122.67	0.270	117
2 3/4	163.28	0.360	124
3	211.98	0.467	130

from: Mathey, R. C., Hail Resistance Tests of Aluminum Skin Honeycomb Panels for the Relocatable Lewis Building, Phase II, NBS Report 10193, National Bureau of Standards, Washington, D.C., 1970.

S-601-8 DYNAMIC LOADS

Dynamic Loads resulting from sun tracking solar collectors or other moving equipment shall be taken into account in the design of the dwelling frame.

S-601-9 THERMAL DISTORTION

Thermal distortion of the mechanical or structural components of the solar system shall not cause premature failure or degradation in system performance greater than the design limits.

Thermal distortion of the solar system, including that occurring during periods of stagnation, shall not cause damage to the system or the supporting dwelling structure.

Commentary: Expansion coefficient data for cover and absorber plate materials is listed in Appendix Tables B-1 and B-3.

S-601-10 COLLECTOR COVER PLATES

Deflection or local distress of cover plates resulting from the maximum design loading shall not allow the cover plate to become separated from the unit nor result in degradation in collector performance greater than the design limits. This shall be demonstrated by analysis or physical simulation.

Commentary: Since wind can come from any direction, there will be maximum pressure (inward) loading for units mounted on the windward side of an installation and maximum suction (outward) loading for those mounted on the leeward side (unless shielding is provided). Depending on the installation, suction loading can, and often does, exceed pressure loading; hence, cover plate retainers must be adequately designed to prevent them from being separated from the collector frame or induce failure of the cover plate by suction loading.

S-601-11 CONNECTIONS OF COLLECTOR FRAMES AND/OR OTHER SUPPORT STRUCTURES

When collector frames and/or other support structures are mounted on walls, roofs, or other weather resistant surfaces, distortion of the frame from imposed loading shall not cause penetrations or separations of these surfaces such that moisture leaks occur through the weather resistant surfaces.

S-601-12 STORAGE TANKS

S-601-12.1 <u>Design and Fabrication</u>

Storage tanks shall be designed and fabricated to standards embodying principles recognized as good engineering design and fabrication practice for the materials used. These standards shall include those listed in appendices C and E of the MPS and others as approved by HUD.

Tanks containing soil or rock like materials shall be designed for lateral pressures in accordance with accepted principles of soil mechanics.

S-601-12.2 <u>Testing</u>

Each liquid storage tank shall be tested in accordance with section S-615-10.10 to prove that leakage does not occur. Storage tanks designed to contain only dry heat storage material need not be leak tested unless a safety hazard can result from a storage tank failure.

S-601-12.3 <u>Environmental and Vehicular Loading</u>

In addition to meeting the design, fabrication and test requirements, stipulated in the preceeding paragraphs of this section, storage tanks shall meet the following loading requirements.

S-601-12.3.1 Above Ground

Unsheltered storage tanks shall resist loads resulting from snow, wind, hail, thermal, and seismic loading. Sheltered (completely enclosed) tanks need only resist seismic loading.

S-601-12.3.2 Underground

Underground tanks shall resist soil and hydrostatic loads and foundation loads transmitted to them; and they shall be anchored to prevent flotation resulting from flooding or high ground water level when the tanks are empty. For sites subject to commercial traffic or heavy truck traffic, storage tanks shall resist the wheel loads transmitted to them as specified in AASHTO H20-44, with no impact. For areas subject to other vehicular or human traffic, the pertinent loads stipulated in the MPS, section 601-4.3 shall be resisted.

Commentary: The criterion specifies the level of vehicular traffic for which buried components should be designed in cases where heavy vehicular traffic is anticipated to occur in service for purposes of access. The H20-44 truck is considered to be representative of load levels associated with heavy vehicles such as trucks for repair, maintenance, moving, and delivery of fuel.

S-604 MASONRY

S-604-1 GENERAL

S-604-1.1 Termination Height of Masonry Chimneys

Termination height of masonry chimneys shall be in accordance with NFPA 211.

Commentary: The presence of solar equipment may introduce building components that are elevated above the roof surface more than is usually required, thus producing wind disturbance at a higher level. The standard of NFPA 211 provides for proper clearance and separation.

S-607 THERMAL AND MOISTURE PROTECTION

S-607-2 WATERPROOFING, DAMPPROOFING AND VAPOR BARRIERS

S-607-2.1 Waterproofing of Storage Tanks and Reservoirs

Underground thermal storage tanks and unsheltered above ground thermal storage tanks shall be waterproofed to stop water seepage into the tanks and tank insulation. See Section 607-2 of MPS.

S-607-3 BUILDING INSULATION

S-607-3.1 Areas of Application

Materials used for thermal insulation shall be in accordance with S-515-11 and may be applied to the following areas: walls, roofs, ceilings, floors, pipes, ducts, vessels and equipment exposed to the external environment.

Exposed plastic foam (untreated or fire-retardant treated), Kraft-asphaltic vapor barrier on mineral and organic fiber insulations, and non-fire-retardant treated loose fill insulation shall not be permitted in habitable areas unless fully protected from the interior of the building by a thermal barrier of 1/2 inch gypsum wallboard having a finish rating of not less than 15 minutes or other approved material having an equivalent finish rating as determined at ASTM E-119. Thermal barriers shall be installed in a manner such that they will remain in place for a minimum of 15 minutes under the same test conditions.

Installed insulation and vapor barriers shall not make contact with recessed light fixtures, motors, fans, blowers, heaters, flues, and chimneys. Thermal insulation shall not be installed within 24 inches of the top or within 3 inches of the side of a recessed electrical fixture enclosure, wiring compartment or ballast unless labeled for the purpose. To retain loose fill insulation from making contact with other energy-dissipating objects, a minimum of 2 inches of air space should be provided and assured by the use of blocking.

Commentary: Although a degree of material combustibility is allowed, the intent is to allow insulating materials which are not more combustible (or flammable) than existing construction and insulation materials, and to preclude any increased fire hazard due to the retention of heat from energy dissipating objects. In areas where occupants are likely to be engaged in normal activities, the insulation should perform its intended function without the increased risk of ignition, rapid flame spread, and heat and smoke generation. Insulation in concealed spaces may be a particular fire problem due to its susceptibility to smoldering and its inaccessibility for fire fighting.

S-607-3.2 Insulation Values

Insulation values may vary where they can be shown to improve the overall energy balance of the building.

Commentary: Section 607-3 of MPS was originally written to conserve energy or minimize the U-value of the exterior enclosure. For some solar systems it may be desirable to vary the U-value in order to collect useful energy and prevent it from escaping or, at least, to provide a compromise U-value between the collection and loss of useful energy. An example might be a *shuttered window which has single glazing. When the shutters are open the window collects energy and its U-value can be lower than those stated in 607-3. When the shutters are closed the window conserves energy and the U-value would fall at or higher than those stated in 607-3.*

DIVISION 15

S-615 **MECHANICAL**

S-615-1 THERMAL DESIGN

S-615-1.1 General

The solar energy system shall be capable of collecting and converting solar energy into thermal energy. Solar thermal energy shall be used, in combina-ation with a conventional auxiliary energy source and other components such as thermal storage or heat pumps to augment the system effectiveness to meet the standards and requirements for space heating and domestic hot water set forth in Section 615 of MPS. The system shall be capable of dissipating thermal energy where this function is included in the design.

Commentary: The prediction of system performance should reflect the cumulative degradation in components resulting from environmental or system wear and deterioration. Solar energy systems for residential applications generally are capable of storing and providing thermal energy to meet at least the average 24 hour heating load for the peak heating month. The residential domestic hot water load is generally considered constant throughout the year for purposes of system design.

S-615-1.2 Back-up

The thermal energy contribution provided by solar energy shall be backed up 100 percent with an auxiliary thermal energy subsystem which will provide the same degree of reliability and performance as a conventional system.

Commentary: The uncertainty in the availability of solar energy during inclement weather requires complete back-up of the solar energy contribution to meet comfort and hot water standards.

S-615-1.3 System Capacity - Space Heating

S-615-1.3.1 Auxiliary Energy Subsystem

Heat load requirements used to determine the size of the auxiliary energy subsystems shall be calculated in accordance with the procedures and 97 1/2% design temperatures described in Section 615-3.1 of MPS.

Commentary: Uncertainties of ±10 percent or more in the calculated heating load are tolerated in sizing the auxiliary energy subsystem. Thermal load programs should reflect the energy conserving features of the building construction and operation such as insulation, thermal windows, actual indoor temperature and night-time set-back. There are benefits if the back-up method is designed to minimize the use of a utility supplied, on-line, auxiliary energy during peak load conditions.

S-615-1.3.2 Solar Energy System

a. The solar energy system size shall be based upon monthly average heat loads determined by a degree-day method using average monthly design temperature and conditions as the maximum analytical time interval. Hourly or daily simulation times may be used if detailed local solar radiation is available. Calculations of building heat loss for use in sizing the solar energy subsystem shall be performed for the full heating season using a method at least as sophisticated as described in Appendix A.

Commentary: Since the methods of calculating heat losses and heat gain specified in 615-3.1 and 615-4.2 of MPS may not be detailed enough to predict the performance of the heating and cooling systems for buildings using passive solar systems other approved methods may be used for making calculations for passive solar buildings. An example of the considerations and level of detailed analysis are presented in ASHRAE Standard 90-75 Energy Conservation in New Building Design.

b. The solar energy contribution shall be determined as a percentage of the dwelling average annual space heating energy requirements. Analytical simulations or correlations based upon simulations combining the building heating load, solar system performance and climatic conditions shall be utilized to predict the average monthly and annual energy contribution to be provided by solar energy, auxiliary energy and electrical operating energy as illustrated in Appendix A.

Commentary: Parametric studies have shown that a solar energy contribution of between 30 to 70% for an active system is generally optimum when cost benefits have been considered. Passive systems may contribute from 5 to 100% depending upon the relationship between the demand/building/climate.

S-615-1.4 System Capacity - Domestic Hot Water Heating

S-615-1.4.1 Auxiliary Energy Subsystem

The auxiliary energy domestic hot water heating subsystem shall meet the minimum requirements for storage, draw and recovery shown in Tables 6-15.2 or 6-15.3 of MPS.

Commentary: There are benefits if the back-up method is designed to minimize the use of a utility supplied, on-line, auxiliary energy service during peak load conditions. The minimum acceptable hot water storage is listed in the MPS but generally solar energy DHW systems have a larger storage capacity than the MPS requirements.

S-615-1.4.2 Solar Energy System

a. Determination of the average annual energy requirements for solar hot water heating applications shall be based on average monthly conditions as the maximum analytical simulation time interval to compare solar energy system performance with the load.

b. Minimum daily usage shall be as indicated in Table S-615-1.

Commentary: The design shall allow for the higher requirement where the potential increase in use exists.

c. An average hot water temperature of 140°F and an average source water temperature of 55°F shall be used for design purposes, if local temperatures are unknown.

Commentary: A residential DHW design temperature of 140°F is required by the MPS and is necessary to meet some appliance operating temperatures. Local source water temperature can vary from 45 to 75°F with climate region and season.

Table S-615-1 Daily Hot Water Usage (140°F) for Solar System Design

Category	One and Two Family Units 1/ and Apartments up to 20 Units					Apts. of 2/ 20-200 Units	Apts. of 2/ over 200 Units
No. of People	2	3	4	5	6	---	---
No. of Bedrooms	1	2	3	4	5	---	---
Hot Water/Unit (gal/day)	40	55	70	85	100	40	35

1/ Assumes 20 gal. per person for first 2 people and 15 gal. per person for additional family members.

2/ From: R. G. Werden and L. G. Spielvogel: "Part II Sizing of Servic Water Heating Equipment in Commercial and Institutional Buildings," ASHRAE Transactions, Vol. 75, PII, 1969 p. iv.1.1.

d. The solar energy contribution shall be determined as a percentage of the dwelling average annual DHW energy requirements. Analytical simulation or correlations based upon simulations including the load, solar system performance and climatic conditions shall be utilized to predict the average monthly and annual energy contribution to be provided by solar energy and auxiliary energy as illustrated in Appendix A.

Commentary: Parametric studies have shown that a solar energy contribution of between 50 and 80% of the DHW load is generally optimum when cost benefits have been considered.

S-615-1.5 <u>System Capacity Combined Space and Domestic Hot Water Heating Systems</u>

a. The solar energy contribution shall be determined as a percentage of the combined dwelling average annual space heating and average annual DHW energy requirements. Analytical simulations or correlations based upon simulations combining the space and DHW loads, solar system performance and climatic conditions shall be utilized to predict the average monthly and annual energy contributions to be provided by solar energy, electrical operation energy and auxiliary energy as illustrated in Appendix A.

S-615-1.6 <u>Environmental Conditions - Passive Systems</u>

Where normal building spaces are designed to be part of a solar energy collection, storage, distribution or control system, indoor design conditions can vary as long as they do not interfere with the normal use of a space.

S-615-1.6.1 Design Air Temperature for Passive System

The air temperature in areas that can be thermally isolated such as halls and storage, can be designed for fluctuations from 57°F to 83°F [1]. Other areas can be designed for fluctuation from 62°F to 78°F [1] provided there are provisions for bringing the air temperature up to design conditions required in section 615-3.1 of MPS when the space is in use.

Commentary: The operation of a passive system is dependent upon temperature gradiants to get energy into and out of storage and to transport energy from one location to another. To accomplish this temperature differences of at least 4°F to 6°F should be allowed in a completely passive system. Temperature fluctuations are permitted during non-use periods such as night hours.

S-615-1.6.2 Radiant Temperatures

The temperatures of various surfaces in a living space, used as part of a passive solar system, shall not exceed the following values:

Floor	78° [1]
Walls up to 6'- 8"	84° [1]
Ceiling and walls up to 6'- 8"	115° [2]

Commentary: When a living space is used as a solar collector, occupants of that space may experience discomfort from direct solar radiation, from the longwave radiation emitted by the solar heated glass or from the floor or walls of the space. To achieve the required conditions, means of control may be necessary such as shutters, draperies or louvered screens.

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[1] Grandjean, Etienne, 1973 <u>Ergonomics of the Home</u>, New York, Halstead Press.

[2] Flynn, John E. and Segil, Arthur W., 1970. <u>Architectural Interior Systems</u>, New York: Van Nostrand Reinhold Co.

S-615-1.6.3 Draft

The movement of air through a living space used to transport solar heated air in a passive system shall not exceed 70 FPM measured in the occupant zone.

Commentary: See ASHRAE Standard 55-74.

S-615-1.7 Protection Against Blockage of Fluid Flow

The entire heat transport system shall be protected to prevent contamination by foreign substances that could impair the flow and quality of the heat transfer fluid beyond acceptable limits.

Commentary: The heat transfer fluid passages in solar collectors and some heat exchangers may have small cross sections in which blockage by dirt, scale, pieces of gasket material, pieces of packing or other foreign matter in the heat transfer fluid could occur.

S-615-1.8 SYSTEM SHUTDOWN

THE SHUTDOWN OF THE SOLAR HEATING OR DOMESTIC HOT WATER SYSTEM IN ONE UNIT OF A MULTI-FAMILY DWELLING SHALL NOT INTERFERE WITH THE FUNCTION OF THESE SYSTEMS IN ANY OTHER UNIT.

COMMENTARY: THIS IS TO PERMIT THE SHUTDOWN OF EQUIPMENT IN AN INDIVIDUAL DWELLING UNIT FOR REPAIRS WITHOUT IMPAIRING THE OPERATION OF THE EQUIPMENT IN OTHER DWELLING UNITS THAT ARE CONNECTED TO THE SAME CENTRAL SYSTEM.

S-615-1.9 Excess Collected Energy

Provisions for dumping excess thermal energy shall be provided during the off-peak heating season when required for safe operation of the system.

Commentary: For systems in which it is not practical to shut the collection system down, the excess energy can be transfered to the external environment using a heat exchanger or alternate methods.

S-615-2 COLLECTORS

S-615-2.1 General Provisions

S-615-2.1.1 Design Flow Rates

When an array of solar collectors is connected by manifolds, the design shall assure, or provision shall be incorporated in the manifolds and/or collectors to balance the flow rate through each collector. The variation shall not exceed ± 20% of the design flow range.

Commentary: An available method of balancing air and liquid HVAC equipment is described in the National Standards for Field Measurement and Instrumentation: Total System Balance, Vol. 2, No.12173 (Associated Air Balance Council 2146 Sunset Blvd., Los Angeles, California 90026). The method describes procedures and measurements, but does not establish standard balance values.

S-615-2.1.2 Tilt and Orientation

The collector shall be installed in a mount capable of maintaining tilt and orientation to within ± 10 degrees of design conditions.

Commentary: A collector tilt angle equal to the latitude plus 10 to 15 degrees from the horizontal is generally used to provide maximum collection during the winter season for space heating applications. However, deviations of ± 10 degrees from this value, when using conventional flat plate collectors, will have little effect as illustrated in Figure S-615-2.1 which shows, for a particular example, the effect on annual performance of variations of tilt angles for a collector facing south.

A fixed collector tilt angle equal to the latitude or latitude +15 degrees for domestic hot water applications is typically used to favor winter heating requirements. This angle will tend to maximize the year-round performance of domestic hot water heaters.

Conventional flat plate collector orientation should be such that the effective aperature generally faces south. However, deviations to the east or west by up to 20° may not result in a significant decrease in incident radiation as indicated by the example of the influence of air collector orientation on the solar fraction of total load shown in Figure S-615-2.2. Other weather conditions such as morning or evening fog may influence the deviation from south.

If the optimum tilt angle will seriously interfere with building design requirements, or will impose extensive additional structural provisions, tradeoffs for less optimum tilt angles or relocation of the collector where the optimum tilt angle can be utilized should be considered.

The orientation of concentrating type collectors is a function of the collector acceptance angle design and may require tracking within specific limits.

S-615-2.1.3 Shading

Shading of collectors shall be considered during the design so that shading by trees, adjacent collectors or other obstructions is accounted for.

Commentary: On east and west exposures during the entire year, and on south exposures during the winter, the solar altitude may be low enough to cause direct shading and a resultant loss in collection capability. A practical design goal is to limit the reduction in collected useful thermal energy during the month of peak load to less than 5%.

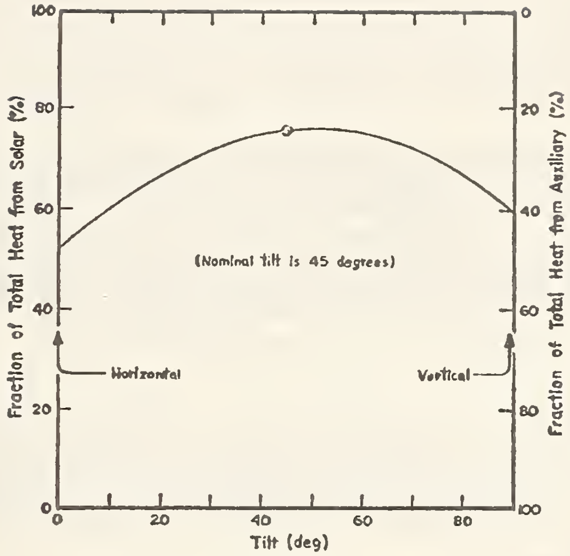

Figure S-615-2.1 An example of the effect of Collector Tilt for a particular System/Climate Combination. 1/

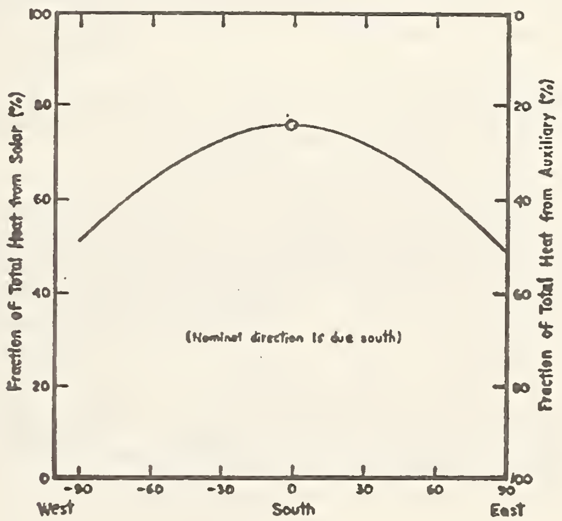

Figure S-615-2.2 An example of the effect of Collector Orientation (45° Tilt) for a particular Collector/Climate Combination. 1/

1/ Balcomb, J.D., J.C. Hedstrom, B.T. Rogers, "Design Considerations of Air Cooled/ Collector Rock-Bin Storage Solar Heating Systems," presented at the 1975 ISES Congress, Los Angeles, California, 1 Aug. 1975.

S-615-2.1.4 Dirt Retention

The cover plate(s) shall not collect or retain dirt to an extent that would significantly reduce its ability to transmit sunlight.

Commentary: The possible collection and retention of dirt by the cover plate and the effect of retained dirt on collector performance may be significant. The retention of dirt may depend on the surface characteristics and tilt angle of the collector. Rainfall and snow melt are generally sufficient to keep the collector cover plates clean. If periodic scrubbing is necessary for cleaning, the cover plates should be resistant to damage by abrasion resulting from the scrubbing. If the collector is ventilated, provisions should be made for exclusion of dust by appropriate filters.

S-615-2.1.5 Cleaning

In designs where the interior surfaces of collector glazing and cover plates or absorber surfaces are not protected against accumulation of dust or dirt, provisions shall be made to allow cleaning of these surfaces as frequently as necessary to prevent a significant deterioration of collector performance.

Commentary: On active collectors that are not hermetically sealed or provided with air filters and in passive installations which may have large air plenums behind glazed surfaces or combine solar collection with view provisions, accessability for periodic cleaning is essential to continued high solar transmittance. Selective absorber surfaces must be kept clean as dust accumulations can change their emittance characteristics.

S-615-2.1.6 Ice Dams and Snow Build Up

The design of solar buildings and systems shall provide for the possibility of formation of ice dams and snow build up.

Commentary: In very cold climates, water flowing off a warm collector may freeze on cold surfaces immediately below it (such as exposed eaves), thereby forming an ice dam which can cause water to back up under roofing or into the collector itself. This may be moderated by methods such as elimination of the cold surface or provision of an impervious surface such as continuous flashing. Snow sliding off a collector may pile up at the bottom and cover part of the collector. This would have a tendency to reduce the efficiency of the collector and increase the possibility of thermal breakage of glass in the collector. This may be moderated by methods such as the provision of space below the collector for snow pile up or by the installation of heating cables.

S-615-2.1.7 Mud Splash

The design of solar buildings and systems shall minimize the possibility of mud splash on collector surfaces.

Commentary: Water running off collectors located close to the ground can cause mud splashing to coat portions of the collector and reduce its efficiency. Remedies to this include: easy access for cleaning, position of collectors elevated sufficiently to avoid splashing, or provisions of gutters or splash free material at the base of the collector.

S-615-2.1.8 Protection Against Thermal Shock and Pressure

Collectors shall not be damaged or adversely affected by extreme temperature and pressure that could occur by thermal shock resulting from sudden environmental or fluid flow changes.

Commentary: Thermal shock could result from the passage of hot fluid through a cold collector or cold fluid through a hot collector during start-up. The designer should either assure that the materials used in the collector can withstand the extreme temperatures and pressures or provide temperature and pressure relief from thermal cycling or shock. See S-615-14.

S-615-2.1.9 Moisture Build-up Control

Means shall be provided to prevent moisture build-up in collectors to an extent that would reduce collector performance below allowable design limits.

Commentary: Moisture build-up in the collector can soak insulation and reduce its effectiveness, leach alkalies out of fiberglass insulation and hasten its degradation, lead to chemical attack on absorber plates and cause condensation on cover plates.

Depending on the design, the likelihood of condensate forming on the interior surface(s) of the cover plate(s) may be high. Desiccants in breather tubes or breather plugs can be used to maintain a dry environment. The desiccants should be located in such a way that they are not in contact with the collector plate and it is desirable that they be capable of regeneration by solar energy as the collector builds temperature.

One additional potential problem with collectors is that, in industrial atmospheres, the introduction of pollutants in condensate solution may cause permanent etching of the underside of the cover plate(s)or chemical attack of the absorber over a period of time. Such etching can permanently reduce the transmittance. When this possible condition exists, design considerations must be given to avoid the problem.

S-615-2.1.10 Access to Components

If routine maintenance or repair of collector components is anticipated, the collector shall be designed to permit easy access to those components.

Commentary: Some materials such as rubber hoses, joint sealants, exterior coatings, etc. may have to be replaced periodically. Also, in some geographic locations, the cover plates may have to be cleaned occasionally. If materials in the collector are likely to be replaced, repaired or maintained within the design life of the collector, it is important to provide easy access to those materials.

S-615-2.1.11 Openings

All openings in the collector enclosure shall be protected to prevent the entry of insects and vermin.

S-615-2.2 Collector Thermal Performance

S-615-2.2.1 General

This section is intended to cover component and integral collectors which can be flat plate, concentrating, reflector aided, fixed or tracking types.

S-615-2.2.2 Collector: Component

This type collector can be characterized as a component for an active solar system requiring the use of powered mechanical equipment to move the heat transfer fluid (liquid or gas) through the collector. The collector thermal performance shall be based upon the slope-intercept method of expressing efficiency for the range of operating conditions including solar power density, heat transfer fluid temperature, ambient temperature, wind, solar radiation incident angle, and flow rates, to be used in the design.

Commentary: The collector performance characteristics can be measured using the ASHRAE test method 93-77 for rating solar collectors or any other method demonstrated to have an overall limit-of-error of less than ±5%. This method provides sufficient efficiency versus operating condition data to construct a curve normalized for insolation and temperature difference between ambient and heat transfer fluid temperature. Curves for typical flat black and selective coated absorber panels with one and two covers are shown in Appendix A for air and water collectors. Collectors with other geometric, optical or thermal characteristics may require additional tests to fully describe their thermal performance for all environmental and operating conditions. The operating electrical power is recorded and reported during all tests.*

S-615-2.2.3 Collector: Combined With Storage

This type of combined component system can be characterized as an active system with integral construction and operation of the components such that the solar radiation collection and storage phenomena cannot be measured separately in terms of flow rate and temperature changes. The system thermal performance is determined by the short term (1 to 3 days) collection and storage of thermal energy obtained from solar radiation and the amount of useful energy delivered to the load from storage for part and full load conditions. Experimental performance data, in terms of heat collected and stored or delivered to load, shall be provided for the design conditions including solar power density, heat transfer fluid temperature, ambient temperature, wind, solar radiation incident angle, and flow rates. The daily and average test period electrical operating requirements are reported with system performance.

Commentary: Although a consensus test method to rate and evaluate these systems does not exist, the efficiency in terms of converting incident solar energy into useful thermal energy can be measured and reported as a function of the specified operating conditions.

S-615-2.2.4 Passive: Integral Collector, Storage and Building System

A passive integral collector system can be characterized as one in which the collector and storage components are an integral part of the building. Auxiliary energy may be used for control purposes but heating is generally achieved by natural heat transfer phenomena. The thermal performance of a passive, integral collector system can be obtained from a detailed simulation analysis of the climate, building thermal properties and occupancy thermal influence.

Commentary: Roof ponds, modified walls, roof sections with sky lights, or similar applications where solar energy is used to supply a significant fraction of the building heating requirements, are examples of passive integral collectors.

A more detailed simulation of solar heating, building thermal capacitance and thermal energy control must be included in the traditional building load determination programs for the design and evaluation of a passive, integral solar system. Experimental evaluation of the system performance includes measurement of the climatic conditions, auxiliary energy use and comfort level for sufficient periods to account for building thermal capacitance effects (minimum of 7 days and, preferably, monthly or seasonal).

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*ASHRAE Standard 93-77, "Methods of Testing Solar Collectors Based on Thermal Performance," American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc., 345 East 47th Street, New York, N.Y. 10017

S-615-2.2.5 Passive: Component (Thermosyphon) Systems

This type collector can be characterized as one in which the collector is a separate component to collect, convert and transfer the thermal energy. The thermal performance of individual collector panels can be obtained from procedures described in Section S-615-2.2.2 for active collectors. System performance is obtained from measurements of incident solar energy and hot water delivered to the load for extended periods to determine monthly averages.

Commentary: A thermosyphon water heating system is an example of the application of a passive component type collector where the hot water circulation results from the change in density of the fluid with temperature.

The movement of a heat transfer fluid by natural convection is achieved by relatively low pressure differentials. Therefore, it is necessary that pipe or duct size, shape, distance and elevations are considered in predicting the performance based upon individual collector panel test data.

S-615-3 MECHANICAL SUPPORTING DEVICES

S-615-3.1 <u>Pipe Hangers and Supports</u>

Pipe hangers and supports shall be installed in accordance with the prevailing model plumbing code having jurisdiction in the area.

S-615-4 VALVES

Gate valves or similar valves that open to nearly full pipe bore shall be used for shut off valves. Globe ball or similar valves shall be used for flow control.

S-615-5 PUMPS & FANS

S-615-5.1 Applicable Standards

a. Pumps shall be installed in accordance with the requirements of the Hydraulic Institute.[1]
b. Fans shall be installed in accordance with the recommendations of the ASHRAE Guide or applicable manuals of NESCA and SMACNA.

c. All moving machinery shall be protected and guarded to comply with the current safety standards of ANSI B15.1 if such machinery is exposed to other than maintenance personnel.

S-615-6 MECHANICAL VIBRATION ISOLATION

S-615-6.1 General Requirements

All operating mechanical equipment shall be isolated by suitable piping or duct connections and where necessary by isolation pads or foundations to prevent transmission of noise or vibration. The dwelling shall be free of objectionable sound as required in HUD circular 1390.2, Noise Abatement and Control.

Equipment conforming to other sound level criteria referenced in these standards shall also be acceptable.

S-615-7 THERMAL STORAGE

S-615-7.1 General

This section applies to sensible and latent heat type thermal energy storage devices using gas or liquid as the heat transfer fluid and liquid or solid as the heat storage medium. The storage medium can be contained in a separate enclosure, stored at more than one temperature, or can be a part of the building structure. Some typical storage subsystem arrangements are shown in Appendix C.

Commentary: The interaction between storage temperature and collector operating efficiency must be considered in the location and operation of the auxiliary energy source. Auxiliary energy supplied to the storage medium directly can result in decreased system efficiency. Designs which enhance normal storage temperature gradients and control the heat transfer fluid mixing, which use utility supplied, on-line, energy during peak load conditions or which use solar assisted heat pumps may influence storage temperature or operation.

S-615-7.2 Applicable Standards

Thermal storage shall comply with the design standards of MPS Section 615 and the applicable recognized standards given in MPS Appendicies C and E.

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[1] Hydraulic Institute Standards for Centrifugal, Rotary and Reciprocating Pumps, Thirteenth Edition, 1975. The Hydraulic Institute, 1230 Keith Building, Cleveland, Ohio 44115.

S-615-7.3 Thermal Storage Requirements

S-615-7.3.1 Space Heating

The thermal energy storage capacity for space heating shall not be less than 500 Btu per square foot of solar collector area for an active system. The thermal energy storage capacity for space heating shall be not less than 1000 Btu per square foot of collector area for a passive system. (The capacity shall be based upon a temperature difference determined from the lowest temperature that useful heat can be extracted from storage and the highest practical storage temperature.)

Commentary: A relationship between the load fraction supplied by solar energy to the storage capacity for liquid and air applications is presented in Appendix A. Since system efficiency is affected by storage temperature and capacity, storage capacity requirements less than those stated may be justified in terms of the effect on system efficiency. The storage heat capacity for integral (passive) systems is a function of the thermal coupling between storage and the load but, because of usual lower storage temperatures, a larger heat capacity is desired.

S-615-7.3.2 Domestic Hot Water Heating

The solar thermal energy storage for preheating domestic hot water shall have a volume capacity not less than the number of gallons shown in Tables 6-15.2 or 6-15.3 of MPS.

Commentary: Although it is possible to design a hot water storage container with large temperature gradients permitting the auxiliary energy source to be incorporated in the same container, it is preferred to add the auxiliary energy after the water has been removed from the solar heated container.

S-615-7.3.3 Combined Space and Domestic Hot Water Heating

The thermal energy storage capacity for a solar energy system providing thermal energy for both space and domestic hot water shall not be less than 500 Btu per square foot of solar collector area.

Commentary: Since system efficiency is affected by storage temperature and capacity, storage capacity requirements less than those stated may be justified in terms of the effect on system efficiency.

S-615-7.3.4 Thermal Energy Loss

The thermal energy loss from storage containers located outside the heated dwelling shall not exceed 10 percent of the maximum operating thermal energy capacity over an average 24 hour winter design day.

Commentary: Thermal energy losses within the heated dwelling will contribute to the heating requirements. However, losses during the summer operation could add to cooling requirements and should be accounted for in the design. Calculations of the thermal loss from tanks, piping, and valves can be performed using average fluid and ambient temperatures and thermal insulation conductivity values with procedures described in the ASHRAE Handbook of Fundamentals.

S-615-7.4 Tank Drainage

Each tank shall be provided with means of emptying the liquid. Each tank located above grade or floor level shall be provided with a valved pipe at its lowest point to permit emptying the tank. Each buried tank, including tanks with a solid storage medium, shall have provisions for utilizing a pump or siphon or other means to allow emptying.

Commentary: Buried storage tanks containing solid storage media may be subject to leakage or flooding; means should be provided to remove this water.

S-615-7.5 Tank Filling

Tanks of large capacity should have an indicator or other means for determining that the tank is full. Tanks should have overflows with outlets located so that spillage will not run into the building structure or damage the premises. Tanks that do not contain potable water but require make up water from the potable water system shall be filled by way of an air gap or other means acceptable to the administrative authority having jurisdiction.

S-615-7.6 Inlet and Outlet Location

The inlet and outlet piping or ducts for thermal storage shall be located in the container to prevent thermal "short circuiting" of the fluid flow.

Commentary: The collector performance is a function of the fluid temperature, therefore, the storage-to-collector fluid outlet should be located in the coldest portion of the container such as the lower 5% of a vertical liquid tank. The inlet should be located in the warmest storage volume such as the upper 5% of the tank. Inlets and outlets of liquid containers should be installed to provide flow parallel to the top and bottom of the tank, respectively, to minimize mixing.

S-615-7.7 Auxiliary Energy Location

Auxiliary energy heating elements or the inlet of heat transferred from auxiliary energy sources to the inside of storage devices shall be located in the warmest practical area of the container.

Commentary: In designs where it is possible to add auxiliary energy to storage, the configuration should be designed to maintain the collector inlet temperature as low as possible.

S-615-7.8 Pebble Bed Storage Design

The size, shape and cleanliness of pebbles, when used for storage, shall be considered in designing the thermal performance and pressure drop.

*Commentary: The effectiveness of pebble bed storage is related to the specific heat and thermal conductivity of the pebbles and the configuration of the container to achieve a temperature gradient through the bed. Clean, smooth pebbles are desired to facilitate the passage of air and minimize maintenance. Additional design considerations and typical performance data has been reported.**

S-615-7.9 Protection Against Maximum Temperature, Pressure and Vacuum

Thermal storage shall be protected against maximum temperature, pressure and vacuum in accordance with the provisions of S-615-14.1.

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*ASHRAE Publication, "Applications of Solar Energy for Heating and Cooling of Buildings," GRP 170.

S-615-8 HEAT TRANSFER FLUIDS

S-615-8.1 Toxic and/or Combustible Fluids

S-615-8.1.1 General

Requirements for handling non-potable heat transfer fluids are discussed in Sections S-615-9, Waste Disposal; S-615-10, Plumbing; and S-615-12, Heat Exchangers, of this document.

S-615-8.1.2 Detection of Toxic and/or Combustible Fluids

If toxic or combustible heat transfer fluids are used, means shall be provided for the recognition of leaks and thus the warning of occupants when leaks occur.

Commentary: These substances may be treated in a manner similar to antifreeze and gases when providing for tell-tale indicators. For instance, antifreeze agents, such as ethylene glycol, may be treated with non-toxic dyes which distinguish them clearly. Furthermore, if any such materials are to be stored on the premises, they should be stored in containers which are labeled in accordance with the Federal Hazardous Substances Act and be protected from easy opening by children e.g., childproof lids. Safe storage locations should be provided.

S-615-8.1.3 Identification

Drains and other designated fluid discharge or fill points in solar systems at which toxic, combustible, high temperature or high pressure fluids may be discharged shall be labeled with a warning describing the identification and hazardous properties of the fluid, instructions concerning the safe handling of the fluid, and emergency first aid procedures.

Commentary: The original fluid containers will frequently be discarded after the system is charged which could result in no record of the fluid's properties being retained. The system drain is the point at which the owner or service personnel are most likely to contact the heat transfer fluid and permanent labeling should be retained at that point. Identification may be provided by attaching a tag containing the required information such as may be supplied by the heat transfer fluid manufacturer.

S-615-9 WASTE DISPOSAL

S-615-9.1 Catchment

Systems utilizing other than air or potable water as a heat transfer fluid shall provide for the catchment and/or harmless removal of these fluids from vents, drains or re-charge points as approved by local administrative code authority. Potable water shall be discharged to suitable drainage systems connected to the building or site drains. See MPS Section 615-9.

S-615-9.2 Provision of Containment for Discharge Treatment of Toxic and/or Combustible Fluids

Adequately sized and protected receptacles shall be provided when toxic and/or combustible fluids are used in order to collect and store the overflow from: pressure relief valves, liquids drained from the system when it is being serviced, and identifiable leakage. Provisions of MPS Section 615-4.4 shall be applied.

Commentary: When a toxic heat transfer fluid is used (see Section S-515-8.2), a catch basin must be provided. It must be sufficiently large to accept dilution as required by MPS Section 515-9 before disposal.

If the diluted medium is biodegradable through conventional sewage treatment, the diluted medium is to be flushed into the sanitary sewer system (not the storm sewer system). Consideration should be given to the effect of flushing solar systems on the "Basic Design Loading" for sewage treatment, Section CS 603, HUD Handbook 4940.3, Minimum Design Standards for Community Sewage Systems.

S-615-10 PLUMBING

S-615-10.1 Handling of Nonpotable Substances

Potable water supply shall be protected against contamination in accordance with the prevailing model plumbing code having jurisdiction in the area.

S-615-10.1.1 Separation of Circulation Loops

Circulation loops of subsystems utilizing non-potable heat transfer fluids shall either be separated from the potable water system in such a manner that a minimum of two walls or interfaces is maintained between the non-potable liquid and the potable water supply or otherwise protected in such a manner that equivalent safety is provided.

Commentary: Double wall heat exchanger designs are one way of meeting the intent of this criterion. When double wall heat exchanger designs consisting of two single wall heat exchangers in combination with an intermediary potable heat transfer liquid are used, leakage through one of the walls would result in a single wall configuration. Although this design is considered to meet the intent of this criterion, there are several other designs that avoid this problem.

The use of single wall configurations which solely rely upon potable water pressure to prevent contamination is not considered to be an acceptable solution. Similarly, extra thick single walls are not considered to meet the intent of this criterion

For approval of other than double wall designs, the procedures described in S-101 should be utilized.

S-615-10.1.2 Identification of Nonpotable and Potable Water

In buildings where dual fluid systems, one potable water and the other non-potable fluid, are installed each system may be identified either by color marking or metal tags as required in ANSI A13.1-1956 [1] or other appropriate method as may be approved by the local administrative code authority. Such identification may not be required in all cases.

S-615-10.1.3 Backflow Prevention

Backflow of nonpotable heat transfer fluids into the potable water system shall be prevented in a manner approved by the local administrative code authority.

Commentary: The use of air gaps and/or mechanical backflow preventers are two possible solutions to this problem. The following are some recognized standards that may be acceptable to the local administrative code authority: Complete titles are given in Appendix E.

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[1] Scheme for the Identification of Piping Systems, ANSI A13.1 - 1956.

Air gaps	*- ANSI-A112.1.2*
Backflow preventers	*- FCCCHR Chapter 10*
	IAPMO PS 31-74
	AWWA C506-69
	A.S.S.E. 1011
	A.S.S.E. 1012
	A.S.S.E. 1013
	A.S.S.E. 1015
	A.S.S.E. 1020
	ANSI-A112.1.1

S-615-10.2 Pipe Sizing

Pipe sizing shall be in accordance with recognized methods.

S-615-10.3 Expansion and Contraction

Provisions for expansion and contraction without undue strain or distortion shall be made as required by means of offset branches, expansion compensators, or flexible pipes. Piping shall be adequately supported to prevent undue strain on the flexible pipes and branches.

S-615-10.4 Protection Against Maximum Temperature, Pressure and Vacuum

Systems shall be protected against maximum temperature, pressure and vacuum in accordance with the provisions of S-615-14.1.

S-615-10.5 System Drainage

Liquid systems shall be designed so that complete isolation and drainage of all system components, piping, or storage tanks can take place in a reasonable length of time for maintenance purposes. See S-615-7.4, Tank Drainage.

S-615-10.6 Protection from Scalding

All domestic hot water systems shall be equipped with means for limiting temperature of the hot water for personal use at fixtures to 140° F.

S-615-10.7 Provision of Valves and Fittings

S-615-10.7.1 Shutoffs

All domestic water heaters and water heating systems shall be valved to provide shutoff from the cold water supply systems.

S-615-10.7.2 Water Hammer Arresters

When a liquid is used as the transfer fluid in a solar energy system and quick-closing valves are employed in the design, the piping system shall be able to control or withstand potential "water hammer". Water hammer arresters shall be in compliance with local codes.

S-615-10.7.3 Air Bleeds

When liquid heat transfer fluids are used in solar heating systems, the systems shall be provided with suitable means for air removal.

S-615-10.8 System Cleaning

After completion of piping tests and after all equipment has been installed, the entire liquid systems shall be thoroughly flushed to remove sediment, dirt and loose scale, etc. Strainers shall be cleaned or replaced. During the flushing of the system, the collectors must be disconnected or bypassed to preclude passage of debris through the collectors.

S-615-10.9 Expansion Tanks

Adequate provisions for the thermal expansion of solar heat transfer and storage liquids that would occur over the service temperature range shall be incorporated into the solar heating system design.

Expansion tanks shall be sized in accordance with the recommendations of ASHRAE Guide and Data Book.

S-615-10.10 Leak Testing

S-615-10.10.1 Pressurized Tanks and Systems

Those portions of heating systems which contain liquid heat transfer fluids and are not directly connected to the potable water supply shall not leak when pressures of not less than 1-1/2 times their design pressure are imposed for a minimum of 15 minutes [1]. The pressure shall be gradually applied and sustained for a sufficient length of time to permit examination of all pipe joints for leakage. Those portions of the system using domestic hot water shall not leak when tested in accordance with the code having jurisdiction in the area where the system is used. In areas having no building code, a nationally recognized model code shall be used [1].

S-615-10.10.2 Non-Pressurized Tanks

Non-pressurized tanks shall be tested visually for leaks by filling tanks with water.

Commentary: A hydrostatic test pressure of 1-1/2 times design pressure is considered a standard test pressure for pressurized system [2]. *For most applications, clear water is used. The temperature of the water should be no lower than that of the ambient atmosphere. Otherwise, sweating will result and proper examination will be difficult. In environments where freezing may occur, antifreeze or hydrocarbons may be added to keep the water from freezing. Bleeder valves or petcocks should be provided at the highest point or points in the system to permit venting of all air in the piping during the filling operation* [2]. *Automatic vents must be protected from freezing.*

S-615-10.11 Discharge of Liquids

Relief valves shall be piped to discharge to locations acceptable to the local administrative code authority having jurisdiction.

S-615-10.12 Location of Exposed Piping

Piping and equipment shall be located so as not to interfere with normal operation of windows, doors, or other exit openings and so as to prevent damage to piping, equipment, or injury to persons.

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[1] The BOCA Basic Plumbing Code, Southern Standard Plumbing Code, The Uniform Plumbing Code, and The National Plumbing Code.

[2] Piping Handbook, Remo C. King and Sabin Crocker, McGraw-Hill Book Company, 5th Edition.

S-615-10.13 Underground Piping

Underground water service piping shall be installed in accordance with the provisions of Section 615-5.3 of MPS. Underground heat distribution piping shall be installed in accordance with Section 615-3.5 (k) of MPS.

S-615-10.14 Treatment of Water

When make-up water is of such a quality that excessive corrosion or scaling is known to exist, a suitable water treatment system as recommended by the Water Quality Foundation shall be provided.

Commentary: The use of small water passages in collectors and heat exchangers makes them susceptible to plugging and any size water passage may be subject to reduction in heat transfer from the precipitation of salts or corrosion products.

S-615-10.15 Freeze Protection

For systems subject to freezing of the heat transfer fluid, freeze protection by draining, circulation of an anti-freeze agent or other means shall be provided.

S-615-10.15.1 Draindown Freeze Protection

In draindown systems, if drainage of heat transfer fluid to the thermal storage tank is intended, the storage tank shall be sized adequately to accommodate it. See S-615-7.3.1 and S-615-10.2. System designs incorporating automatic drainage of heat transfer fluid to storage to prevent freezing of the fluid in solar collectors shall not be constructed of materials which corrode in the presence of air or shall be suitably protected.

Commentary: One means of preventing corrosion during system drainage would be by introducing an inert gas such as nitrogen.

S-615-10.15.2 Draindown Venting

In draindown systems, provisions for venting of collector panels and manifold lines shall be provided as required to allow refill of the collector system without air entrapment.

Commentary: Operation and maintenance of draindown venting must be compatible with venting for normal operations. Draindown venting may employ either venting to the atmosphere or pressurized methods with valves and holding tanks which automatically accomplish the refilling and venting.

S-615-11 AUXILIARY ENERGY SYSTEMS

Commentary: The auxiliary energy subsystem may be integrated directly into the solar energy system, or it may be completely separate from it, and contain its own means for delivery of heat and/or hot water to the building.

S-615-11.1 Applicable Standards

S-615-11.1.1 Heating and domestic hot water systems shall comply with the design standards of MPS Section 615 and the applicable recognized standards given in MPS Appendices C and E.

S-615-11.1.2 Heat pumps shall be installed in compliance with the requirements of ANSI B 9.1-1971, "Safety Code for Mechanical Refrigeration" (ASHRAE); ANSI B 191.1-1976, "Standard for Heat Pumps" (UL 559); ARI Standard 240, "Standard for Unitary Heat Pump Equipment" (1975); ARI Standard 260, "Standard for Application, Installation, and Servicing of Unitary Systems" (1967); and tested in accordance with the procedure outlined, in ASHRAE Standard 37-69, "Method of Testing for Unitary Air Conditioning and Heat Pump Equipment".

S-615-11.2 System Interconnection

The interconnections of the auxiliary energy system to the solar energy system shall be made in a manner which will not result in excessive temperature or pressure in the auxiliary system or in bypassing of safety devices of the auxiliary system.

S-615-12 HEAT EXCHANGERS

S-615-12.1 Sizing

a. A heat exchanger when used in conjunction with the solar collector and storage shall be evaluated for its effectiveness in transferring heat from the collector to storage. The heat exchanger effectiveness is expressed by:

$$\varepsilon_c = (\dot{m}c_p)_c\ (t_o - t_i)/(\dot{m}c_p)_{min}\ (t_o - t)$$

where

$C_{min} = (\dot{m}c_p)_{min}$ = the minimum fluid capacitance rate of collector (C_c) or storage (C_s)
$C_s = (\dot{m}c_p)_s$ = fluid capacitance rate in the flow circuit between storage and the collector heat exchanger
$C_c = (\dot{m}c_p)_c$ = fluid capacitance rate in the flow circuit between collector and the collector heat exchanger
t = storage temperature (°F)
t_o = collector outlet temperature (°F)
t_i = collector inlet temperature (°F)
ε_c = effectiveness of the collector - storage heat exchanger
$\dot{m}$ = flow rate of the working fluid (lb/h)
c_p = fluid specific heat (Btu/lb·°F)

Commentary: Diagrams of typical locations and a discussion of heat exchangers are presented in Appendix A and C. Calculation methods for heat exchanger performance are described in the ASHRAE Handbook of Fundamentals. A minimum effectiveness value of 0.7 is a typical value that is used. This value was used in the correlation studies which provide the basis for the Appendix A calculation method.

b. The load heat exchanger heat transfer rate shall be selected such that the ratio of the heat exchanger effectiveness times the minimum capacitance rate to the total heating load is between a value of 1 and 3. This dimensionless parameter and relationship is expressed by:

$$1 \geq \frac{\varepsilon_L(\dot{m}\ c_p)_{min}}{UA} \leq 3$$

where

ε_L = Effectiveness of load heat exchanger

UA = Building heat loss factor (Btu/h °F)

Commentary: The load heat exchanger effectiveness can degrade the system performance if the heat transfer rate is not sufficiently large. Oversizing the heat exchanger results in unused capacity.

S-615-12.2 Protection Against Maximum Temperature, Pressure and Vacuum

Heat exchanger shall be protected against maximum temperature, pressure and vacuum in accordance with the provisions of S-615-14.1.

S-615-13 AIR DISTRIBUTION

S-615-13.1 Applicable Standards

Design of all warm air heating systems shall be in accordance with applicable recommendations of the ASHRAE Guide, and manuals of NESCA and ARI. Installation shall comply with NFPA Standards 90B, 31 and 54.

Commentary: Duct work should be designed for the shortest practical run and elbows should be kept to a minimum. Constrictions should be avoided.

S-615-13.2 Dust and Dirt Prevention

Duct and fan systems shall be protected against accumulation of deposits of dust or dirt that could reduce flow and efficiency in addition to creating a potential health hazard when admitted into occupied spaces. Air filters are required on the outlet side of rockbed storage in active systems.

Commentary: The gravel used for rockbed storage with air systems is selected for size and freedom from dirt and dust. Therefore, smooth and washed material combined with the use of filtered air is desirable to provide a maintenance free, clean distribution system. Fan grilles should be removable or hinged to permit access to the fan and motor for cleaning, servicing, replacement, or repair.

S-615-14 CONTROLS AND INSTRUMENTATION

S-615-14.1 Fail-Safe Controls

The control subsystem shall be designed so that in the event of a power failure, or a failure of any of the components in the subsystem, the temperatures and/or pressures developed in the H and DHW systems will not be damaging to any of the components of the systems and the building or present a danger to the occupants. The safety devices shall meet the requirements of Section 515-6.4 of MPS and be demonstrated to be adequately safe and protected for the intended application.

S-615-14.1.1 Automatic Pressure Relief Devices

Adequately sized and responsive pressure relief devices shall be provided in those parts of the energy transport subsystem containing pressurized fluids. A pressure release device shall be provided in each portion of the system where excessive pressures can develop. Each section of the system shall have a pressure relief device so that no section can be valved off or otherwise isolated from a relief device. Automatic pressure relief devices shall be set to open at not more than the maximum pressure for which the subsystem is designed.

Relief devices shall drain to locations in accordance with Section S-615-9.1.

Commentary: Care should be taken in the design and layout of the fluid transport system to prevent conditions in which locally excessive pressures are developed as a result of flow restrictions. Precautions must be taken to assure that heat transfer liquids do not discharge on asphalt base roofing materials or other types of roofing or locations which may be hazardous, cause structural damage, building finish discoloration, or damage to plant materials.

S-615-14.1.2 Vacuum Relief

The solar energy system, including collectors, pipes, tanks, and heat exchangers shall be protected against possible collapse by design or by provision of vacuum relief valves.

Commentary: System components may be subjected to collapse if heating system leakage were to occur or if the system were drained without venting.

S-615-14.1.3 Collector Thermal Shock

Automatic flow control valves shall be provided for collectors unable to withstand temperature shock.

S-615-14.2 Identification and Location of Controls

Main shutoff valves and switches shall be conspicuously marked and placed in a readily accessible location, in the same manner as electrical service panels, in accordance with Section 240.24 of NFPA 70, and MPS, Section 616.

S-615-14.3 Indirect Water Heaters

Indirect domestic water heater installations shall include operating controls for the heat source, of the type recommended by the boiler manufacturer. The installation shall be made in accordance with the boiler manufacturer's instructions.

S-615-14.4 Efficient Operation (Active Systems)

Automatic control of the heat transfer fluid circulation between the collector and storage or load shall be used to limit operations to conditions when useful energy can be collected. Designs utilizing collector flow as a fail-safe method shall employ override controls as required.

Commentary: The collector circulation in liquid systems is normally limited to conditions when the absorber plate temperature is greater than the storage or load temperature by a Δt of 10°F for start-up and a Δt of 3°F for shut-down. A larger Δt may be used for air systems depending upon the circulating fan electrical power requirements.

S-615-15 CHIMNEYS AND VENTS

S-615-15.1 Termination Height of Chimneys and Vents

Termination height of chimneys and vents shall be in accordance with NFPA 211.

Commentary: The presence of solar equipment may introduce building components that are elevated above the roof surface, thus producing wind disturbance at a higher level. The standards of NFPA 211 will provide for proper clearance and separation.

S-615-16 MECHANICAL VENTILATION

S-615-16.1 Air Discharge Openings

Air discharge openings through roofs or exterior walls shall not be located such that their exhaust will cause the deposition of grease, lint, condensation or other deleterious materials on solar optical components.

APPENDIX A

CALCULATION PROCEDURES FOR DETERMINING THE THERMAL PERFORMANCE OF ACTIVE, SOLAR SPACE HEATING AND DOMESTIC HOT WATER SYSTEMS

PREFACE

The system performance calculation procedure for determining the thermal performance of active solar space heating and domestic hot water systems is presented in five sections for clarity and ease of use.

The Introduction provides background information on the applicability of the method and the systems modeling research from which it has been derived.

Section two, Basis of the Calculation Method, gives a concise description of the procedure's steps, lists the assumptions on which it is based, provides schematic drawings of the systems for which it is applicable and indicates the scope of data which is required in order to perform the calculation.

Section three presents the Procedure arranged in six steps each including a description of the calculations required and worksheets on which to carry out and tabulate the calculations. Also included in this section is a procedure for determining heat exchanger effectiveness, and important ancillary calculation that may be required if information on heat exchangers is not provided in the required form.

Section four, Typical Examples, carries out a set of calculations for each of three typical solar energy systems; a liquid heating and domestic hot water system, an air heating and domestic hot water system, and a liquid domestic hot water only system. Typical data is provided for these and worksheets have been completed for each.

Section five, Reference Materials, provides a table of nomenclature, lists references, includes reference tables required to carry out the calculations and provides a set of blank worksheets which may be reproduced for individual calculation.

TABLE OF CONTENTS

1.. INTRODUCTION

The performance of any solar energy system is directly related to the amount of solar radiation available, the outdoor conditions, the heat load thermal characteristics, and the solar energy system characteristics. The energy flow diagram for one type of a simplified active solar energy system (using a flat plate collector) is shown in the figure below. Specific systems for providing heat and/or hot water using air and liquid collectors are illustrated in Figure A-4.

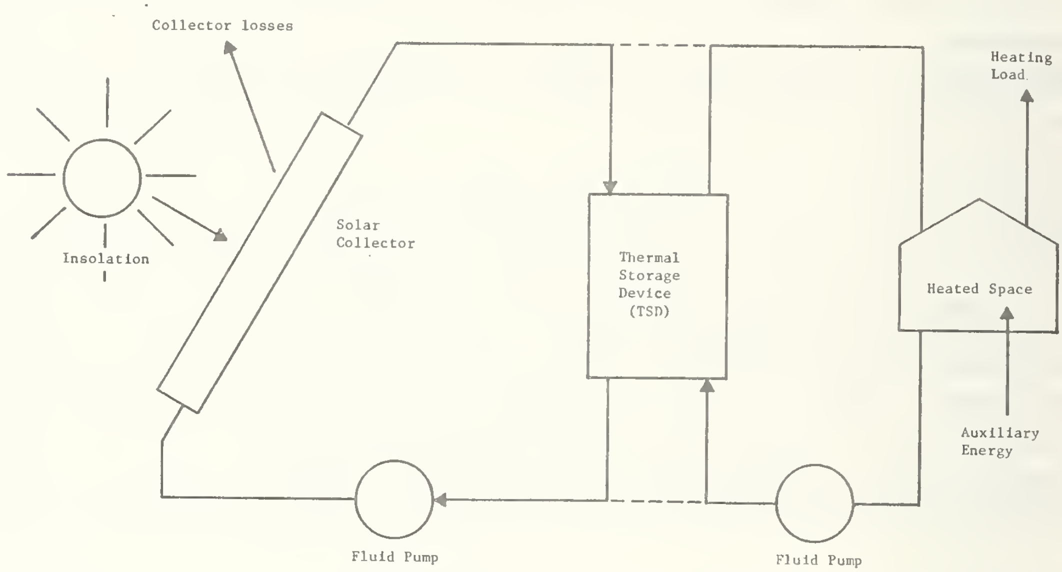


Figure A-1 Energy Flow Diagram for a Typical Active Solar Energy System

Starting on the left side of the figure, solar energy is incident on the solar collector. Some energy is lost from the collector due to reflection from the collector and heat transfer to the ambient surroundings. The amount of energy actually collected by a solar collector is termed useful energy and is directly proportional to the collector area.

Useful energy is transferred directly to the heated space, hot water load or thermal storage device (TSD) by a working fluid. The TSD is necessary due to the intermittent nature of solar energy and is characterized by the TSD heat capacity.

Energy from the TSD to the heated space or hot water load is transferred as needed to meet the load. If the TSD cannot meet the load, auxiliary energy from other sources is necessary. Heat exchangers and pumping systems must be properly sized to meet energy flow requirements.

Precise prediction of performance of solar heating systems is difficult because of the random variation in climatic conditions and the mathematically complex relationships between the system components.

The procedure for estimating performance of a solar energy system used in this document is called the "f-chart" method and was developed by Klein, Beckman, and Duffie of the University of Wisconsin. [1, 17, 18] Their approach was to use a detailed hour by hour computer simulation for several typical solar energy systems covering a wide range of system parameters at several geographic locations in order to develop a generalized correlation ("f-chart") which is useful in evaluating long term system performance.

Of the methods presently in use, this method is widely accepted and offers flexibility in the range of design parameters that can be evaluated.

Although differences were found between the simulated and estimated performance using the generalized chart for specific monthly periods, the correlation, determined by a least squares fit, was found to be quite satisfactory in most cases for predicting year-long performance, as shown in Figure A-2. It should be emphasized, however, that the "f-chart" procedure is not intended to provide an accurate estimate of system performance for any particular month, but rather for the long-term. The difference between the simulated and estimated yearly performance of systems in different locations were also found to be small. The standard deviation in the fraction of load to be met by solar predicted for four different cities was 0.018, an error judged to be substantially lower than the errors inherent in the simulation model and the recorded data.

The "f-chart" procedure has been checked using the data obtained from existing solar heating systems and the difference between estimated and actual performance is small. For example, for M.I.T Solar House IV [2], the difference between actual performance and estimated performance using the "f-chart" procedure over two complete heating seasons was about eight percent.

The procedure can accommodate various non-tracking flat plate collector designs when the thermal performance is available in terms of the effective collection and conversion of solar radiation into useful thermal energy for a range of operating conditions. Simulations used to derive the "f-chart" correlation include typical ranges for heat transfer fluid flow rates, heat exchangers, thermal storage capacity and configuration, auxiliary energy integration and control modes. Methods of estimating the performance of systems having characteristics other than those used to generate the "f-chart" are included in some instances. The procedure does not apply to passive systems and is generally limited to geographic regions below sixty degrees latitude. Preliminary design considerations for passive systems have been studied [3] but no procedure is currently available. The method does not apply to systems using heat pumps.

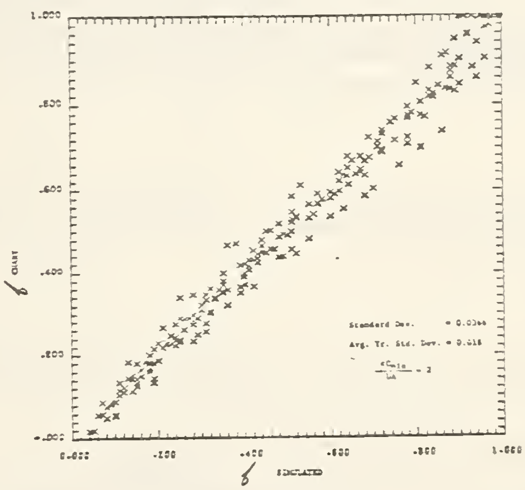


Figure A-2 Comparison of System Performance

Between f-chart and Detailed Simulation

The procedure is intended for use in the evaluation of the capability of a solar energy system to provide a portion of the heating and hot water requirements for a residential dwelling. The method is not intended to perform the thermal design of a unique system or to optimize the solar energy system performance for a unique thermal load profile. The calculation can be performed using a slide rule, hand calculator or simplified computerized program. Another method is available to size collectors for a specific type system using hand calculations [4] and a somewhat more detailed method has been described using a computer [5]. Each of these methods can be used to estimate the cost and fuel savings for local environments and conditions.

2 BASIS OF THE CALCULATION METHOD

2.1 DESCRIPTION

The procedure for calculating the performance of solar heating and/or hot water system allows the estimation of long-term solar heating system performance applicable for space heating and domestic hot water systems, either individually or combined. The method is applicable to those air and liquid heat transfer systems in which solar energy and auxiliary energy are added directly to the heating and/or hot water loads. Solar energy systems using heat pumps are not covered. Examples of each application are presented in section 4 of this appendix. The system evaluation procedure is not intended to provide an accurate prediction of system performance for any particular month, but rather for the long-term average.

The procedure is based on a computer simulated systems analysis. Solar energy system performance is characterized by the term f, which denotes the monthly fraction of the total heating load supplied by the solar energy system and is determined from a single parametric chart, the "f-chart," Figure A-5 and A-6. The systems analysis has shown the performance of the system to be well correlated to two systems performance parameters D_1 and D_2, the coordinates used on the "f-chart." D_1 is a function of solar insolation and system heat load and D_2 is a function of solar collector heat losses and system heat load. Several other design parameters were found to have only a small effect on system performance and thus, the method can be used for a wide range of these design parameters by means of correction factors, K_1, K_2, K_3, and K_4.

The calculation method is applicable to systems schematically identical to Figure A-4 or similar simplified models. The basis of the calculation procedure is the "f-chart" and the two equations which define D_1 and D_2. The equations, given below, have been labeled with the section numbers that describe the indicated elements. These sections are further listed in the order in which they appear in the text.

$$\overbrace{D_1}^{3.2} = \frac{\text{energy absorbed by collector plate}}{\text{total heating load}} = \left[\frac{\overbrace{A_c}^{3.2}\ \overbrace{F_R'(\overline{\tau\alpha})}^{3.5}\ \overbrace{S}^{3.4}}{\underbrace{L}_{3.3}}\right] \times \overbrace{K_4}^{3.6.4}$$

$$\overbrace{D_2}^{3.2} = \frac{\text{reference collector plate energy losses}}{\text{total heating load}} = \left[\frac{\overbrace{A_c}^{3.2}\ \overbrace{F_R'U_L}^{3.5}\ \overbrace{(t_{ref} - t_o)\Delta time}^{3.2}}{\underbrace{L}_{3.3}}\right] \times \overbrace{K_1}^{3.6.1} \times \underbrace{K_2}_{3.6.2} \times \overbrace{K_3}^{3.6.3}$$

3.1 Determination of the portion of the total heating load supplied by solar energy (f_1 and F_{Annual})

3.2 Determination of the System Performance Parameters (D_1, D_2)

3.3 Determination of the total building heating and/or domestic hot water load (L)

3.4 Determination of solar energy available to satisfy the heating requirements (S)

3.5 Determination of the collector combined performance characteristics [F_R' $(\overline{\tau\alpha})$, $F_R'U_L$]

3.6 Determination of the correction factors (K_1, K_2, K_3, K_4)

3.7 Heat Exchanger Effectiveness (ε_{HX})

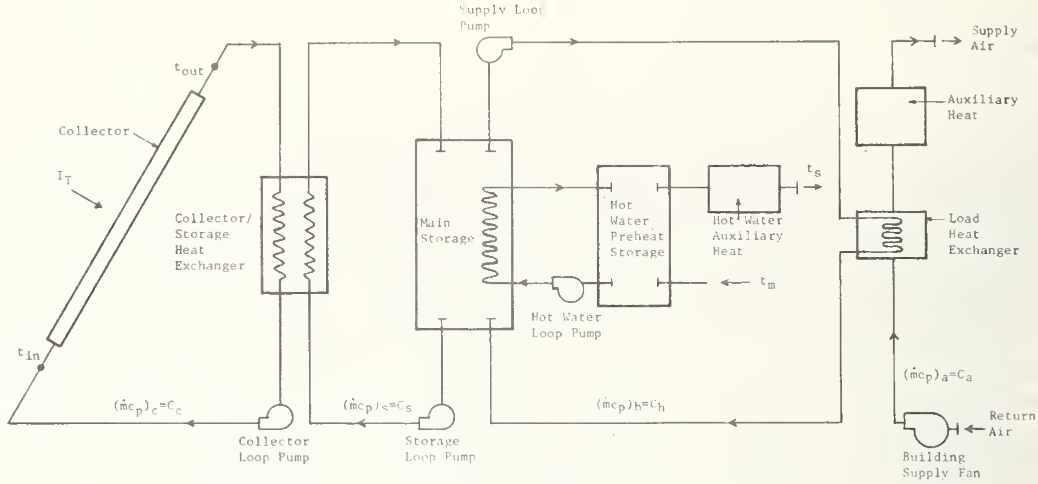
Project Data Worksheet A, is provided at the end of this section to record the basic information necessary to carry out the calculation procedure.

2.2 ASSUMPTIONS

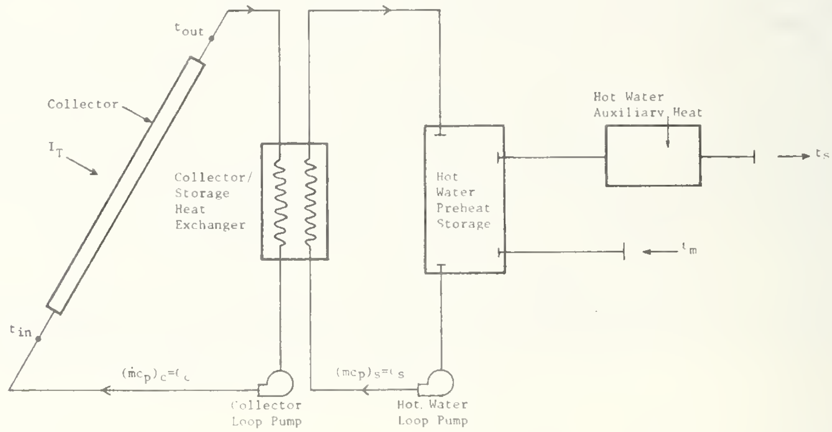
The following assumptions were made in developing the procedure:

1) Thermal storage is contained within the heated structure and all storage heat losses are considered to supplement the space heating load.
2) Auxiliary heat sources are provided to supply energy for both the space and water heating when the energy in storage is depleted, or the rate at which solar energy can be supplied in less than the total heating load.
3) For heating systems utilizing a liquid heat transfer fluid, a heat exchanger can be used between the collector and the storage tank. When an anti-freeze solution is circulated through the collector to avoid the problems of freezing and corrosion, the use of a heat exchanger in conjunction with water storage may be more economical than using the anti-freeze solution as the energy storage medium.
4) The heat transfer fluid is circulated through the collector whenever a positive energy gain can be achieved. During periods of low radiation (when the energy gain becomes zero or negative), the collector pump or blower is turned off.
5) For the space heating load determination, the energy per degree day method is adequate. Load calculations are provided using the "Manual J" method but any procedure that reasonably predicts the building thermal load is acceptable.
6) The average domestic hot water demand as a function of the time of day and family size was established in the development of the procedure. In general, hot water consumption is highly dependent upon the habits of the occupants, however, it has been determined that the actual time distribution of the water heating load will have only a small effect upon the long-term performance for solar heating systems combining domestic hot water and space heating.
7) For those solar energy systems used only for hot water heating, the procedure has been developed using an assumed hourly hot water consumption pattern that is repeated every day, Figure A-3. It is not known how deviations from this consumption pattern effect the performance of the hot water system.
8) Since in most instances flat plate collectors are utilized for heating buildings, the collector component parameters are only valid for modeling flat plate collectors. Concentrating collectors or tracking collectors cannot be incorporated into the solar heating system evaluation as it is presently written in this Appendix.

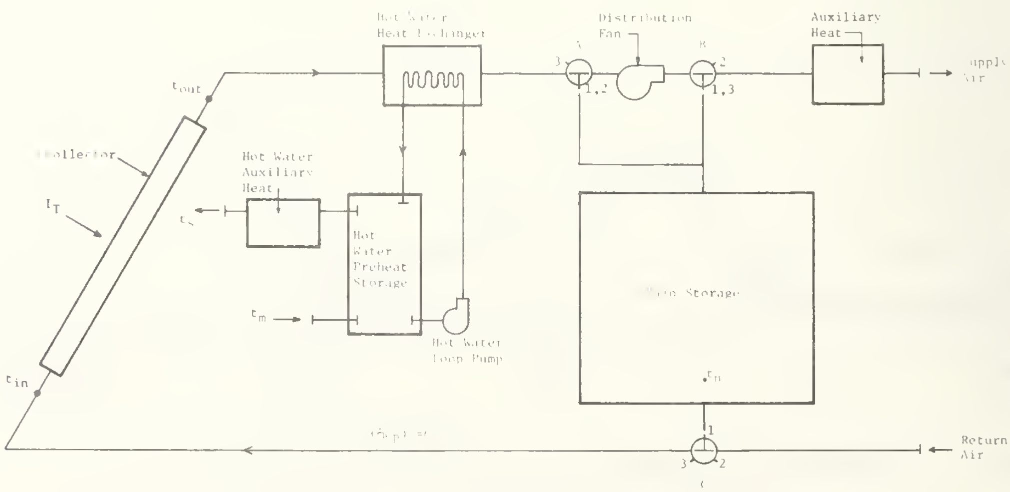
Figure A-3 Assumed Hourly Hot Water Consumption



a) Liquid System: Space Heating and Domestic Hot Water



b) Liquid System: Domestic Hot Water Only



c) Air System: Space Heating and Domestic Hot Water

Figure A-4

2.4 PROJECT DATA SHEET

WORKSHEET A PROJECT DATA

PROJECT ______________________________

Location Latitude	=	
Building Heating and/or Hot Water Load		
Design Heat Loss Rate, q_d	=	Btu/h
Winter Design Temperature (97 1/2%), t_w	=	°F
Average Hot Water Consumption (may vary on a monthly basis)	=	gal/day
Average Cold Water Supply (main) Temp., t_m (may vary on a monthly basis)	=	°F
Hot Water Supply Temp., t_s	=	°F
Collector Subsystem Data		
Collector Type: ______________________,		
Selective or non-selective, no. cov r plates _____		
Collector Area, A_c	=	ft^2
Tilt Angle	=	°
Azimuth Angle	=	°
Collector Shading (av. % month of Dec.)	=	%
Collector Efficiency Data (from manufacture): $F_R(\tau\alpha)_n$	=	
F_RU_L	=	$Btu/h \cdot ft^2 \cdot °F$
Reference Temp. Basis: t_{in}, $\frac{t_{in} + t_{out}}{2}$, t_{out}		
Fluid:		
Composition: ______________________		
Specific Heat, c_p	=	Btu/lb·°F
Specific Gravity (if applicable)	=	lb/lb
Volumetric Flow Rate	=	gal/min or ft^3/min
Storage Subsystem Data		
Volume	=	gal or ft^3
Storage Medium ______________________		
Specific Heat, c_p	=	Btu/lb·°F
Specific Gravity/or Density	=	lb/lb or lb/ft^3
Circulation Loop Volumetric Flow Rate	=	gal/min or ft^3/min
Collector/Storage Heat Exchange Effectiveness, ε_{cs}	=	
Hot Water Preheat Storage Volume	=	gal
Load Subsystem Data		
Load Heat Exchanger Effectiveness, ε_L	=	
Supply Loop Volumetric Flow Rate	=	gal/min
Building Air Supply Volumetric Flow Rate	=	ft^3/min

3. PROCEDURE

3.1 FRACTION OF TOTAL HEATING LOAD SUPPLIED BY SOLAR ENERGY, F_{Annual}

The fraction of the heating load supplied by solar energy is the measure of system performance that is calculated. The solar contribution is calculated first on a monthly basis and then summed to provide the yearly total.

3.1.1 Monthly Fraction (f)

The monthly fraction of the heating load supplied by solar energy is determined from the "f-charts", figure A-5 for air systems and figure A-6 for liquid systems. Worksheet B has been provided for tabulating monthly values of (f) and calculating F_{Annual}. On figure A-5 or A-6 locate the two system parameters D_1 and D_2 for each month and read off the corresponding value of f. D_1 and D_2 are determined by the procedure described in section 3.2.

3.1.2 Annual Fraction (F_{Annual})

As previously mentioned, the procedure is not intended to provide an accurate estimate of system performance for a particular month but will provide a relatively good estimate for long-term performance such as a year. f is calculated on a yearly basis in the following steps:

3.1.2.1 The actual solar energy supplied for each month is calculated as follows:

$$E_{Jan} = f_{Jan} L_{Jan}$$

$$E_{Feb} = f_{Feb} L_{Feb}$$

$$\begin{matrix} \cdot \\ \cdot \\ \cdot \end{matrix} \qquad (1)$$

$$E_{Dec} = f_{Dec} L_{Dec}$$

The total solar energy supplied for the year is calculated by summing the contributions from each month.

$$E_{Total} = E_{Jan} + E_{Feb} \cdot \cdot + E_{Dec} \qquad (2)$$

3.1.2.2 The total heating load for the year is calculated by summing the contributions for each month.

$$L_{Total} = L_{Jan} + L_{Feb} \cdot \cdot \cdot + L_{Dec} \qquad (3)$$

3.1.2.3 Knowing the total annual solar energy supplied by the heating system (E_{Total}) and the total annual heating load (L_{Total}), determine F_{Annual} for the entire year as follows:

$$F_{Annual} = \frac{E_{Total}}{L_{Total}} \qquad (4)$$

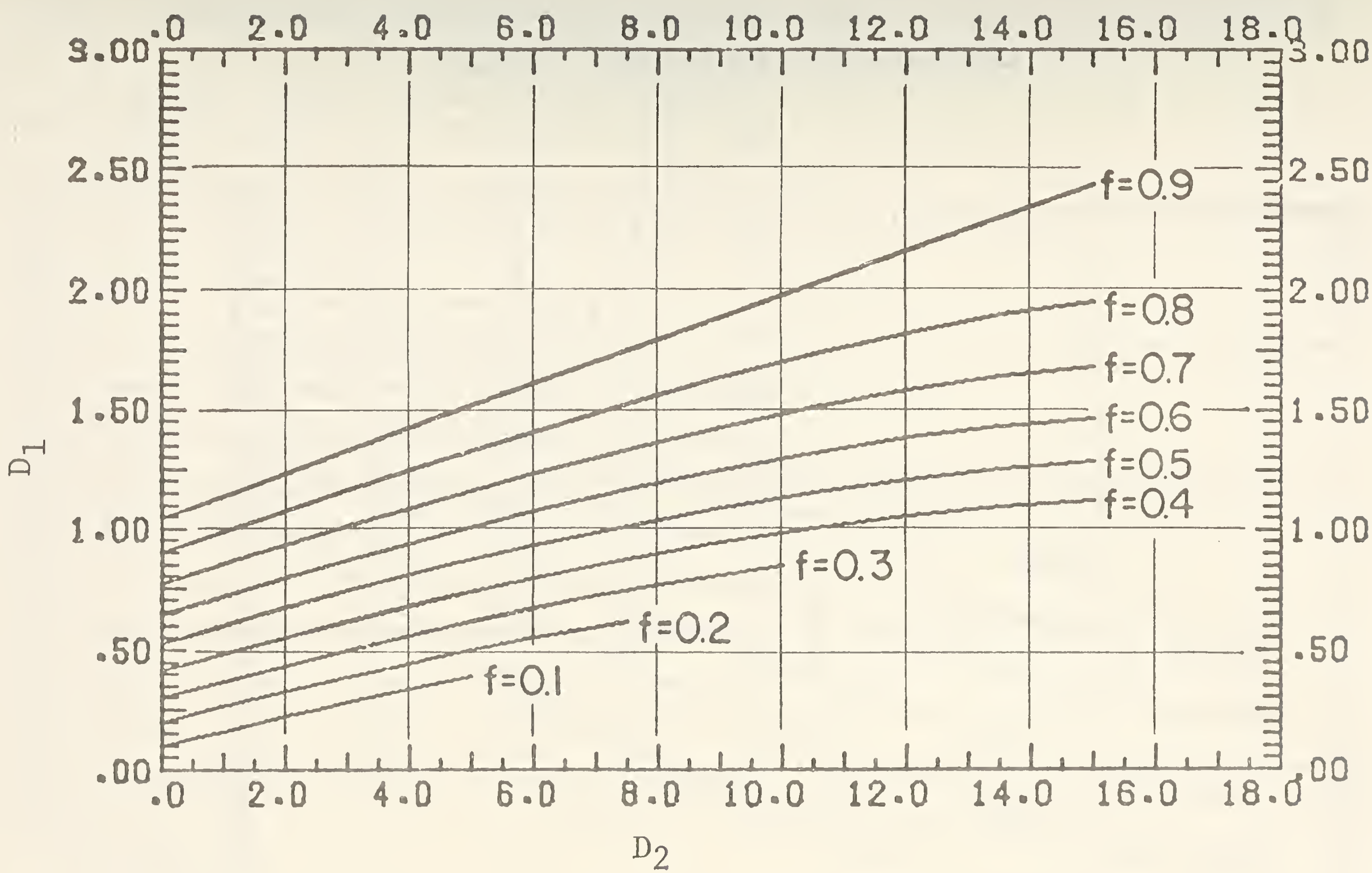


Figure A-5 f - Chart for Solar Air Heating Systems

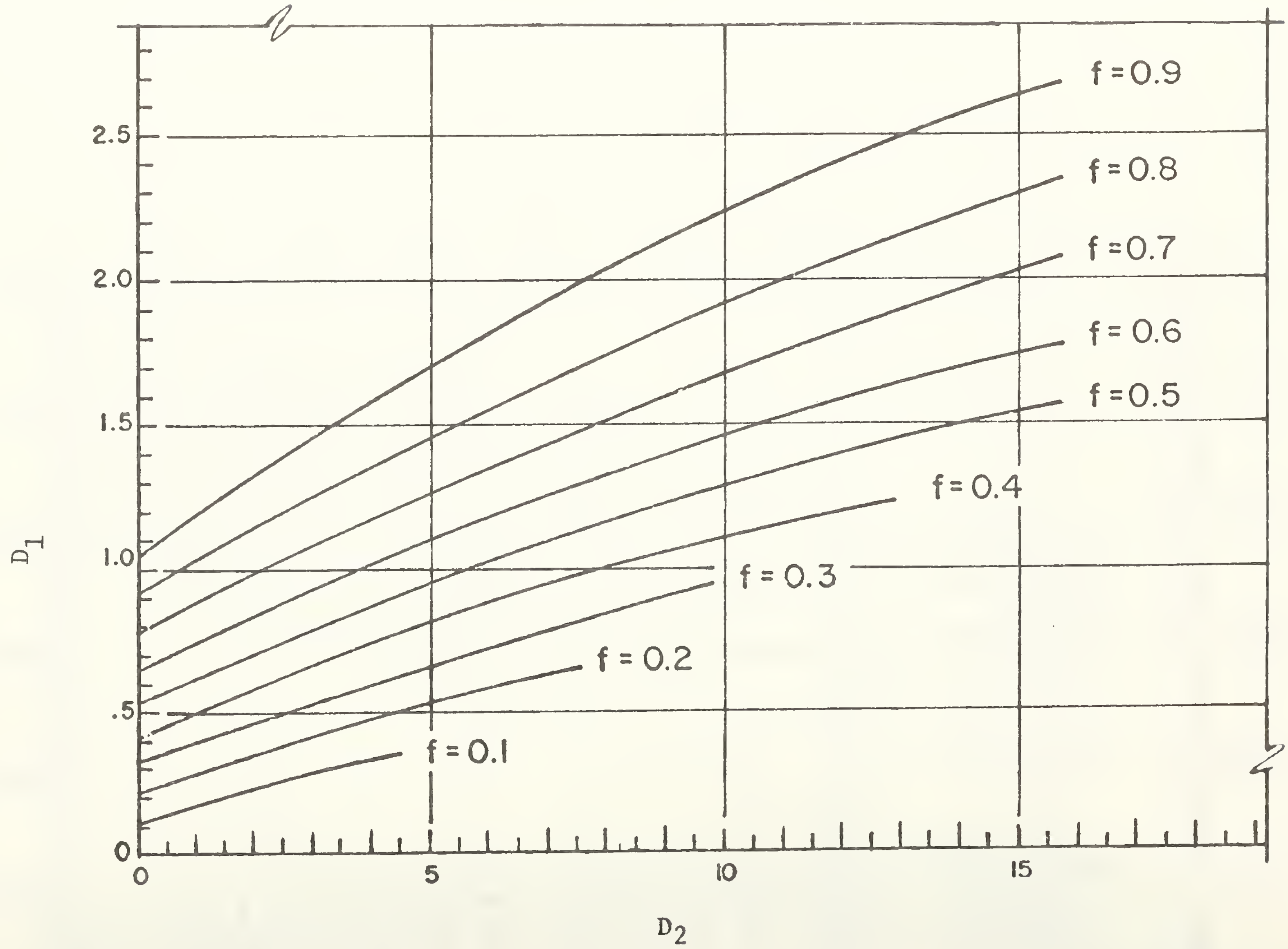


Figure A-6 f - Chart for Solar Liquid Heating Systems

WORKSHEET B FRACTION OF TOTAL HEATING LOAD SUPPLIED BY SOLAR ENERGY, F_{Annual} PROJECT ____________

	1	2	3	4	5
Month	Tot. Mo. Htg. Load L Btu/mo.	System Parameters D_1	System Parameters D_2	Solar Fraction/ mo. f	Actual Solar en/mo E Btu/mo.
Jan.					
Feb.					
March					
April					
May					
June					
July					
Aug.					
Sept.					
Oct.					
Nov.					
Dec.					

L_{tot} =

E_{tot} =

$F_{Annual} = \frac{E_{tot}}{L_{tot}}$ = ________ = ________

1. From Worksheet D
2. From Worksheet C
3. From Worksheet C
4. From "f chart"
5. E = f x L

3.2 SYSTEM PERFORMANCE PARAMETERS, D_1, D_2

The system performance parameters D_1 and D_2 characterize the entire solar energy system thermal performance. Worksheet C is included for tabulating the system performance parameters. The two parameters are calculated for each month using the following equations:

$$D_1 = \frac{\text{energy absorbed by collector plate}}{\text{total heating load}}$$

$$= \frac{A_c F_R' \, (\overline{\tau\alpha}) S}{L} \times K_4 \qquad (5)$$

$$D_2 = \frac{\text{ref. collector plate energy losses}}{\text{total heating load}}$$

$$= \frac{A_c F_R' U_L (t_{ref} - t_o) \Delta time}{L} \times K_1 \times K_2 \times K_3 \qquad (6)$$

where:

A_c = collector aperture area (ft^2). This must be consistent with the collector manufacturers performance data and in most instances equals A_a used in the collector thermal performance test, ASHRAE 93-P.

S = total incident solar radiation normal to the surface of the collector for an average month (Btu/month · ft^2), (a detailed calculation procedure and data are provided in section 3.4, sample calculations are in section 4 and worksheets are in section 5).

L = total heating and hot water load for the particular month (Btu/month). In hot water only systems this term equals Q_w (a detailed calculation procedure is provided in section 3.3, sample calculations are in section 4 and worksheets are in section 5).

$F_R' \, (\overline{\tau\alpha})$ and $F_R' \, U_L$ = collector combined performance characteristics that are obtained from the experimentally determined efficiency plot for the collector combined with heat exchanger performance data. The $F_R' \, (\overline{\tau\alpha})$ product is dimensionless and the $F_R' \, U_L$ product has units (Btu/h·°F·ft^2), (a detailed calculation procedure and data are provided in section 3.5, sample calculations are in section 4 and worksheets are in section 5).

t_{ref} = 212°F, reference temperature (arbitrarily chosen).

t_o = monthly average day-time temperature (°F), (table A-4 in section 5 provides tables of these temperatures for many locations).

Δtime = total number of hours for the particular month.

K_1 = air collector flow capacitance rate factor.

K_2 = storage mass capacitance factor, for liquid and air heating and hot water systems (dimensionless).

K_3 = hot water factor, for liquid hot water only systems (dimensionless).

K_4 = load heat exchanger factor, for liquid heating systems (dimensionless).

(A detailed calculation procedure for K_1, K_2, K_3, and K_4 is provided in section 3.6, sample calculations are in section 4 and worksheets are in section 5).

WORKSHEET C SYSTEM PERFORMANCE PARAMETERS D_1, D_2 PROJECT ________

	1	2		3	4			5	6
Month	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo·ft^2)	Total Heating Load L Btu/Mo.	S/L	D_1	Mo. Av. Day Time Temp. t_o °F	$212-t_o$ °F	Tot. Hrs in Mo. Δ time hr.	K_3	D_2
Jan.							744		
Feb.							672		
March							744		
April							720		
May							744		
June							720		
July							744		
Aug.							744		
Sept.							720		
Oct.							744		
Nov.							720		
Dec.							744		

A_c = Given data

$F'_R(\overline{\tau\alpha})$ = Worksheet F

$F'_R U_L$ = worksheet F

K_1 = Worksheet G

K_2 = Worksheet G

K_4 = Worksheet G

1. From Worksheet E
2. From Worksheet D
3. $D_1 = \left[\dfrac{A_c\ F'_R\ (\overline{\tau\alpha})\ S}{L}\right] \times K_4 = (D_1 \text{ prod.}) \dfrac{S}{L} =$

   Where: D_1 prod. $= \left[A_c\ F'_R\ (\overline{\tau\alpha})\right] \times K_4 =$
4. From Sec. 5 Table A-4
5. From Table A-14 and Worksheet G
6. $D_2 = \left[\dfrac{A_c\ F'_R\ U_L\ (t_{ref} - t_o)\ \Delta time}{L}\right] \times K_1 \times K_2 \times K_3 = (D_2 \text{ prod.}) \left[\dfrac{(212 - t_o)\ \Delta time}{L}\right] \times K_3 =$

   Where: D_2 prod. $= (A_c\ F'_R\ U_L) \times K_1 \times K_2 =$

3.3 TOTAL BUILDING HEATING AND DOMESTIC HOT WATER LOAD, L

The total heating load is determined on a monthly basis for both space and domestic hot water heating.

The space heating and domestic hot water heating loads are calculated separately and for combined systems the monthly individual loads are added to get a monthly total load.

Worksheet D is included for tabulating the heating load calculation.

3.3.1 Space Heating Load

It is recommended that the space heating load for each month be calculated using the degree-day method. It is based on the assumption that over the long-term, solar and internal heat gains will offset the residential heat loss when the mean daily outdoor air temperature is 65°F and that the long-term heating load will be proportional to the difference between the mean daily temperature and 65°F. Tables of degree-days with a base of 65°F have been constructed and are published for a large number of cities in Chapter 43 of the 1976 ASHRAE Systems Handbook [9]. However, in many current buildings larger internal heat gains coupled with the increased insulation levels are sufficient to offset a home's heat loss to a mean daily temperature as low as 56°F (reported in Reference [9]). Therefore, a modified degree day procedure is suggested. It consists of the use of proportionality factor (PF). This factor can range in value from 0.60 to 0.80 depending on the insulation level, weather patterns, internal gains, etc. However, it is recommended that a value of 0.75 be used unless practical experience in the particular locality would dictate the use of a different value.

The ASHRAE Handbook of Fundamentals [8] describes the basic method for calculating heat losses in a chapter entitled Heating Load. In addition, NESCA Manual J, [14] IBR Guide H-21, [15] and ARI Standard 230 present slightly different methods, including examples, tables, and pre-printed calculation forms which simplify the calculating process. For multi-family installations NESCA Manual M may be used instead of Manual J. Although the various methods differ somewhat in format and details, the principles and the overall approach are essentially the same.

3.3.1.1 Calculate the Building Design Heat Loss Rate (q_d).

The following outline of the main steps in calculation are adopted from ASHRAE's Fundamentals [8] and a typical calculation form. Figure A-7 is shown from NESCA Manual J. Note that the Manual J form also contains spaces for use only in cooling load calculation notably the columns labeled C19 and lines 7 and 16-21.

Select the design outdoor weather conditions. The data on winter climatic conditions are given in the ASHRAE Handbook of Fundamentals (select from the 97 1/2 column) or Table A-3 in section 5.

Select 70 F for family and 75 F for care-type and elderly housing as the indoor air temperature to be maintained in living spaces during winter.

Estimate temperatures in adjacent unheated spaces. Consult ASHRAE's Fundamentals for formulae, examples, and tables.

Select or compute the heat transmission coefficients for outside walls and glass, and for inside walls, nonbasement floors, and ceilings, if these are next to unheated spaces; include roof if next to heated space. On the Manual J form, a HTM (heat transfer multiplier) is used which equals the heat transmission coefficient multiplied by the temperature difference.

Determine net area of outside wall, glass, and roof next to heated spaces, as well as any cold walls, floors, or ceilings next to unheated space. Such measurements are made from building plans, using inside dimensions.

Compute the heat transmission losses for each kind of wall, glass, floor, ceiling, and roof in the building by multiplying the heat transmission coefficient in each case by the area of the surface in square feet and the temperature difference between the indoor and the unheated space or outdoor air. Note: In the Manual J form heat transmission coefficient x temperature difference is replaced by the HTM.

Compute heat losses from floors over crawl space or basement floors or grade-level slab floors.

Estimate infiltration rate (number of air changes per hour) and compute the heat equivalent of the infiltration of cold air taking place around outside doors and windows. The infiltration rate depends on the type of or width of cracks, wind speed, and the temperature difference between the indoor and outdoor air; the result expresses the heat required to warm the cold air infiltrating into the building. Refer to ASHRAE's Fundamentals.

The sum of the transmission losses or heat transmitted through the confining walls, floor, ceiling, glass, and other surfaces, plus the heat equivalent of the cold air entering by infiltration represents the total heating load. Since these are for the design heat loss conditions and are expressed as an hourly rate, this value represents q_d the building design heat loss rate.

3.3.1.2 Obtain the monthly total Degree Days from the ASHRAE Systems Handbook [9], Climatic Atlas of the U.S. [13], or Table A-3 in section 5 for the particular location for each month.

3.3.1.3 Calculate the monthly space heating load using the equation:

$$Q_s = (PF)\ (24)\ (UA)\ (\text{Degree Days}) \qquad (7)$$

where:

PF = 0.75 (or more appropriate value)

$$UA = \frac{q_d}{\Delta t_d} = \frac{\text{Design Heat Loss Rate (Btu/h)}}{\text{Temperature difference between inside and outside for design conditions (°F)}} = \frac{q_d}{70-t_w} \qquad (8)$$

Select the 97 1/2% winter design temperature (t_w) from Table A-3, section 5 or from ASHRAE Handbook of Fundamentals [8] or from available weather data.

3.3.2 Domestic Hot Water Heating Load

3.3.2.1 Determine the volume of domestic hot water (Gal) required on a monthly basis from known consumption figures or sources such as the ASHRAE Guide or Table S-615-1 (in section 6 of this MPS)

3.3.2.2 Determine the water main temperature (t_m) or assume t_m = 55°F (see S-615-1.4 in this MPS). Figure A-8 gives typical values for a number of major cities and shows the monthly variations, particularly pronounced in those cities which rely on surface water sources.

3.3.2.3 Determine the domestic hot water supply temperature (t_s) or assume t_s = 140°F (see S-615-1.4 in this MPS).

3.3.2.4 Calculate the monthly domestic hot water heating load using the following equation:

$$Q_w = \left(\frac{\overset{\text{(gal)}}{\text{DHW Consumed}}}{\text{Month}} \right) x \left(\frac{8.33 \text{ lb}}{\text{gal}} \right) x \left(\begin{matrix}\text{Specific}\\ \text{Heat of}\\ \text{Water}\end{matrix} \right) x \left(\begin{matrix}\text{Temp.}\\ \text{Supply}\end{matrix} - \begin{matrix}\text{Temp.}\\ \text{Water}\\ \text{Main}\end{matrix} \right)$$

$$Q_w = mc_p \quad (t_s - t_m) \tag{9}$$

where: m (mass of water) = volume of water (gal) x 8.33 lb/gal
c_p (water) = 1 Btu/(lb·°F)

3.3.3 Total Heating Load

The monthly total heating and hot water load is the sum of the space heating and domestic hot water load for each month. Where only domestic hot water or space heating is provided, the appropriate single load is used.

Monthly Total Heating and Hot Water Load, $L = Q_s + Q_w$ (10)

1	Name of Room					Entire House			1			2			3			4			5		
2	Running Ft Exposed Wall																						
3	Room Dimensions, Ft																						
4	Ceiling Ht, Ft	Directions Room Faces																					
TYPE OF EXPOSURE			Const. No.	HTM Htg	HTM Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg
5	Gross Exposed Walls and Partitions	a																					
		b																					
		c																					
		d																					
6	Windows and Glass Doors (Htg)	a																					
		b																					
		c																					
7	Windows and Glass Doors (Clg)		North																				
			E & W or NE & NW																				
			South or SE & SW																				
8	Other Doors																						
9	Net Exposed Walls and Partitions	a																					
		b																					
		c																					
		d																					
10	Ceilings	a																					
		b																					
11	Floors	a																					
		b																					
12	Ventilation																						
13	Sub Total Btuh Loss																						
14	Duct Btuh Loss																						
15	Total Btuh Loss																						
16	People @ 300 and Appliances 1200																						
17	Sensible Btuh Gain (Structure)																						
18	Duct Btuh Gain																						
19	Sum of Lines 17 and 18 (Clg)																						
20	Total Btuh Gain (Line 19 x 1.3)				1.3																		
21	Btuh for Air Quantities																						

Figure A-7 Building Design Heat Loss Calculations Form
from: Load Calculations for Residential Winter and Summer Air Conditioning, Manual J, NESCA [14]

City	Source[1]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1. Phoenix	Ri, Re, W	48	48	50	52	57	59	63	75	79	69	59	54
2. Miami	W	70	70	70	70	70	70	70	70	70	70	70	70
3. Los Angeles	Ri, W	50	50	54	63	68	73	74	76	75	69	61	55
4. Albuquerque	W	72	72	72	72	72	72	72	72	72	72	72	72
5. Las Vegas	W	73	73	73	73	73	73	73	73	73	73	73	73
6. Denver	Ri	39	40	43	49	55	60	63	64	63	56	45	37
7. Ft. Worth	L	56	49	57	70	75	81	79	83	81	72	56	46
8. Nashville	Ri	46	46	53	66	63	69	71	75	75	71	58	53
9. Washington, DC	Ri	42	42	52	56	63	67	67	78	79	68	55	46
10. Salt Lake City	W, C	35	37	38	41	43	47	53	52	48	43	38	37
11. Seattle	Ri	39	37	43	45	48	57	60	68	66	57	48	43
12. Boston	Re	32	36	39	52	58	71	74	67	60	56	48	45
13. Chicago	L	32	32	34	42	51	57	65	67	62	57	45	35
14. New York City	Re	36	35	36	39	47	54	58	60	61	57	48	45

1. Data from Handbook of Air Conditioning System Design, p. 5-41 through 5-46 McGraw Hill Book Company, New York (1965). Abbreviations: C-creek, L-lake, Re-reservoir, Ri-river, W-well.

Figure A-8 Monthly Temperature (t_1) in °F at Source for City Water in 14 Selected Cities

WORKSHEET D HEATING AND/OR DOMESTIC HOT WATER LOAD, L

PROJECT ______________________

	1	2		3		4	5	6
Month	Monthly Degree Days DD °F·days	Monthly Space Htg Load Q_s Btu/Mo.	No. of Days/ Mo. N	Vol. of DHW Used/Mo. Gal./Mo.	Temp. Water Main Sup. t_m °F	DHW Temp. Rise $t_s - t_m$ °F	Monthly DHW Load Q_w Btu/Mo.	Total Heating Load L Btu/Mo.
Jan.			31					
Feb.			28					
March			31					
April			30					
May			31					
June			30					
July			31					
Aug.			31					
Sept.			30					
Oct.			31					
Nov.			30					
Dec.			31					

q_d = ______________ Btu/h

(Given data or calculate from Manual J or equivalent.)

$\Delta t_d = 70 - t_w$

$= 70 -$ ______ =

Where: t_w = 97 1/2% winter design temperature

(From ASHRAE Fundamentals, Table A-3, section 5 or known weather data.)

70° = indoor design temperature

$UA = \frac{q_d}{\Delta t_d} =$

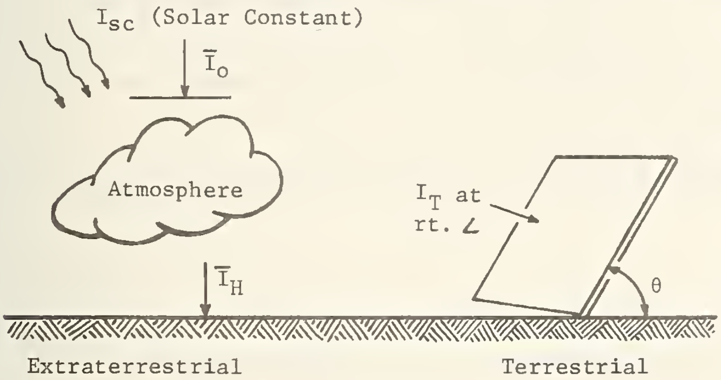
t_s = __________

1. From ASHRAE Systems, Climatic Atlas or Table A-3, section 5.
2. Q_s = (PF)(24)(UA)(Degree Day) = ______________ x (Degree Day) =
   Where: PF = 0.75 or more appropriate value.
3. (Vol/day) (no. days/mo.) = __________(gal./day) (no. days/mo.)
4. May be constant or may vary.
5. Q_w = (vol. of water) x 8.33 x 1 x $(t_s - t_m)$.
6. $L = Q_s + Q_w$

3.4 SOLAR ENERGY AVAILABLE (INCIDENT SOLAR RADIATION), S

The solar radiation incident on the collector is determined for a particular collector tilt and orientation, on a monthly basis, by modifying known insolation values for a given geographic location with factors which relate this to the specific collector geometry.

The relationship between the various solar radiation variables is presented in figure A-9. Terminology and methods developed by Liu and Jordan [10] are used.



$$\bar{K}_t = \frac{\text{Terrestrial}}{\text{Extraterrestrial}} = \frac{\bar{I}_H}{\bar{I}_o}$$

$$\bar{R} = \frac{\text{Tilted}}{\text{Horizontal}} = \frac{\bar{I}_T}{\bar{I}_H}$$

Figure A-9 Relationship Between Insolation Variables

Worksheet E is included for tabulating the incident solar radiation calculation.

3.4.1 Monthly Average of the Daily Radiation Incident on a Horizontal Surface, ($\bar{I}_H$).

For cases where local detailed horizontal insolation is available, this data should be used to calculate $\bar{I}_H$. Where detailed horizontal radiation is not available, an estimate of $\bar{I}_H$ can be made using the values listed for 80 cities in section 5, Table A-4 or the mean daily insolation maps shown in section 5, figure A-29. [11]

3.4.2 Ratio of the Monthly Averages of the Daily Radiation on a Horizontal Surface to the Extraterrestrial Radiation, ($\bar{K}_t$).

Values of $\bar{K}_t$ for each month are listed in section 5, Table A-4. Intermediate values can be calculated by interpolation between cities. Alternatively using the extraterrestrial insolation, $\bar{I}_o$, for the given location (listed in section 5, Table A-5 for various latitudes), $\bar{K}_t$ can be obtained from the relationship:

$$\bar{K}_t = \frac{\bar{I}_H}{\bar{I}_o} \tag{11}$$

3.4.3 Ratio of the Monthly Average Daily Radiation on a Tilted Surface to that on a Horizontal Surface for Collectors Facing Due South, ($\bar{R}$).

The factor $\bar{R}$ accounts for the three components of radiation included on the collector surface, beam, sky diffuse, and ground reflected. In accounting for ground reflected radiation, a diffuse reflectance of 0.2 has been used for ground surface conditions. If it is desired to use other values a computer procedure such as reference [19] should be used.

$\bar{R}$ is determined from Table A-6 in section 5 by entering with the known latitude of the installation (ϕ), tilt of the collector (θ) (expressed in relation to the latitude), and ratio of extraterrestrial to terrestrial radiation ($\bar{K}_t$) (calculated in the preceeding step). For tilt angles other than those listed values may be interpolated. These tables assume the collector is oriented due south (γ = 180°).

For exact evaluation of the effects of collector azimuth angle (γ) on incident radiation, a computer procedure such as reference [19] should be used. However, for collector tilt angles approximately equal to the lattitude and for lattitudes of 45° or less, reference [16] states that the total annual beam radiation will not vary by more than 2% for collectors oriented up to 22 1/2 degrees east or west of due south.

For graphic illustration of collector tilt and orientation angles, see page C-11.

3.4.4 Monthly Average Daily Radiation on a Tilted Surface, ($\bar{I}_T$).

$\bar{I}_T$ is calculated by multiplying $\bar{I}_H$ (for a horizontal surface) by $\bar{R}$ (ratio of the horizontal to tilted).

$$\bar{I}_T = (\bar{I}_H)\ (\bar{R}) \tag{12}$$

3.4.5 Total Monthly Radiation on a Tilted Surface, (S)

$\bar{I}_T$, the monthly average daily radiation on a tilted surface, must be multiplied by the total days in each month, (N) to obtain total insolation for each month.

$$S = (\bar{I}_T)\ (N) \tag{13}$$

3.4.6 Shading

Shading should not be neglected in calculating the incident solar radiation on a particular collector array. The amount of shading is strongly dependent on the collector site and orientation; thus, each case must be analyzed separately. Calculation of the collector array shaded for the month of largest energy requirement and lowest solar altitude (i.e., December) will provide a useful correction factor, reducing the amount of available solar radiation. For graphic illustration of collector shading, see page C8-12.

WORKSHEET E TOTAL MONTHLY SOLAR RADIATION AVAILABLE, S PROJECT ____________

	1	2	3	4	5		6
Month	Horizontal Insolation $\bar{I}_H$ Btu/(Day·ft^2)	Extra-terrestrial Insolation $\bar{I}_o$ Btu/(Day·ft^2)	Ratio Horizontal to Extra-terrestrial $\bar{K}_t$	Ratio Horizontal to Tilt $\bar{R}$	Monthly Avg. Daily Rad. on Tilt Surf. $\bar{I}_T$ Btu/(Day·ft^2)	No. of Days in Month N	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo · ft^2)
Jan.						31	
Feb.						28	
March						31	
April						30	
May						31	
June						30	
July						31	
Aug.						31	
Sept.						30	
Oct.						31	
Nov.						30	
Dec.						31	

1. From Table A-4 or Fig. A-29 section 5, or known data.
2. From Table A-5 section 5, used only for eq. 11.
3. From Table A-4 section 5, or eq. 11.
4. From Table A-6 section 5, latitude (Ø) = ________°, with collector tilt (θ) = ______°, and latitude - tilt = ______°.
5. From eq. 12, $\bar{I}_T + (\bar{I}_H)(\bar{R})$.
6. From eq. 13, $S = (\bar{I}_T)(N)$.

3.5 COLLECTOR COMBINED PERFORMANCE CHARACTERISTICS, $F_R'(\overline{\tau\alpha})$, $F_R'U_L$

In this section, the procedure for calculating the collector combined performance characteristics $F_R'(\overline{\tau\alpha})$ and $F_R' U_L$ used in equations 5 and 6 is developed. The procedure is developed for a liquid system containing a collector/storage heat exchanger which is the most complex case. The simplified steps for air of liquid systems which do not contain a collector/storage heat exchanger are also explained.

To calculate the combined performance characteristics, it is necessary to first establish the performance characteristics for the collector alone, $F_R(\tau\alpha)_n$ and F_RU_L. $(\tau\alpha)_n$ is corrected by the incident angle modifier which modifies test data taken with the sun normal to the collector to the performance that can be expected from the average (varying angle) radiation. This gives $F_R(\overline{\tau\alpha})$. Both of the characteristics are then corrected for the effects of the collector/storage heat exchanger by the heat exchanger modifier factor, $\frac{F_R'}{F_R}$ which includes corrections for both the heat exchanger effectiveness and capacitance rates. This step gives $F_R'(\overline{\tau\alpha})$ and $F_R' U_L$.

Worksheet F is provided for these calculations.

3.5.1 Collector Performance Characteristics, $F_R(\tau\alpha)_n$, F_RU_L

The performance characteristics for the collector alone are determined from manufacturers data (which may be presented in any of several forms) or if this is not available from typical characteristics curves such as those included. 1/

3.5.1.1 Collector Efficiency Data Available From Test

Determine the $F_R(\tau\alpha)_n$ and F_RU_L factors from the thermal performance efficiency curves provided by the manufacturer covering the appropriate range of operational temperature, insolation, tilt angle and fluid flow rates. The collector performance efficiency curve must be plotted such that the y axis is the thermal efficiency(η) and the x axis is the temperature difference between a reference fluid temperature (t*) and the ambient temperature divided by the incident solar radiation $[(t^*-t_a)/I_t]$ as shown in figure A-10.

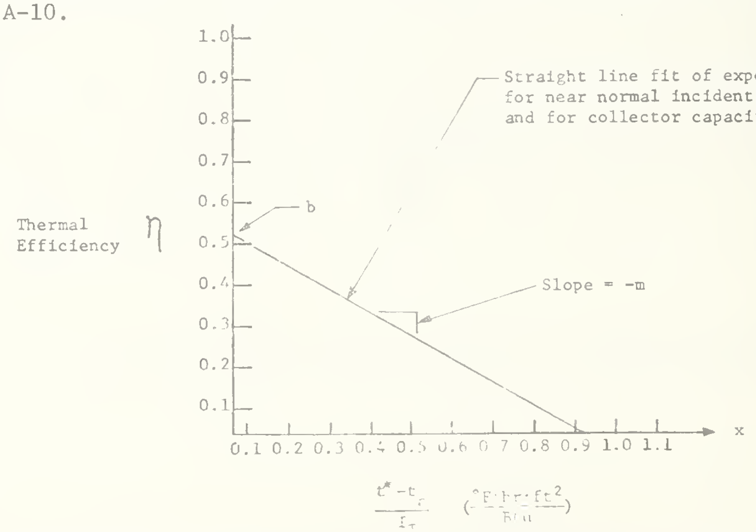


Figure A-10 Example Collector Thermal Performance Efficiency Chart

1/ ASHRAE 93-77 defines the collector efficiency using the gross collector area whereas previous data was generally reported using aperture area. Figure A-27a and A-27b present data for several liquid collector types with the efficiency based upon gross area and aperture area, respectively. Calculations for this procedure can be performed with either definition, however, the efficiency and area must be consistent in all portions of the calculation.

The equation of the straight line fit of the experimental data is given by:

$$y = -mx + b \tag{14}$$

where:

$-m$ = the slope of the straight line

b = the y axis intercept (value of y when x=o)

Usually, the reference temperature t* in the plot of experimental data is the fluid inlet temperature, in which cases the collector characteristics $F_R(\tau\alpha)_n$ and F_RU_L are obtained directly from the efficiency graph. However, in some cases the data is based on other reference temperatures. The following procedure describes the determination of $F_R(\tau\alpha)_n$ and F_RU_L for three different values of reference temperature.

<u>case 1</u> $t^* = t_{in}$ (fluid inlet temperature)

then $F_R(\tau\alpha)_n = b$ (the y axis intercept of the data line)

$F_RU_L = m$ (the magnitude of the data line slope)

<u>case 2</u> $t^* = \frac{t_{in} + t_{out}}{2}$ (average of inlet and exit temperature)

then
$$F_R(\tau\alpha)_n = b \times \left[\frac{1}{1 + \frac{mA_c}{2C_c}}\right] \tag{15}$$

and
$$F_RU_L = m \times \left[\frac{1}{1 + \frac{mA_c}{2C_c}}\right] \tag{16}$$

where C_c = collector fluid capacitance rate ($\dot{m}c_p$) Btu/h·°F

<u>case 3</u> $t^* = t_{out}$ (fluid exit temperature)

then
$$F_R(\tau\alpha)_n = b \times \left[\frac{1}{1 + \frac{mA_c}{C_c}}\right] \tag{17}$$

$$F_RU_L = m \times \left[\frac{1}{1 + \frac{mA_c}{C_c}}\right] \tag{18}$$

It should be noted that the fluid mass flow rate of air collectors can significantly influence the performance of the collector. Therefore, the efficiency data used for air collectors in this procedure must have been obtained for the specific range of flow rates anticipated for collector operation.

3.5.1.2 No Measured Efficiency Data For Collector

When collector efficiency data are not available for the specific collector, performance characteristics may be estimated from the data provided in figures A-27 and A-28 in section 5 for liquid and air systems respectively. Note that in figure A-27 for liquid collectors, the primary parameters affecting performance are the number of cover glass sheets and the radiative properties of the absorber coating (whether selective or non-selective). Figure A-28 shows that air collectors with flat black absorbers have performance characteristics that are sensitive to air flow rate, number of cover glass sheets and to the specific configuration of the absorber.

Alternatively, for flat plate collectors constructed with relatively simple flow path geometry, the analytical equations described in reference [16] can be used to estimate performance. For this purpose, the optical properties of several glazing materials and absorber coatings are provided in tables A-1 and A-2 in section 5.

3.5.2 Incident Angle Modifier $\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}$

Angular variations in transmittance and absorptance due to changing sun angle during the day or changing diffuse component affect τ and α. Determine the transmittance - absorptance ($\tau\alpha$) product angle modifier that relates normal incident radiation to average incident radiation either from manufacturers data obtained during collector testing or by the following approximate relation:

$$\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n} = \begin{cases} .91, & \text{for two cover plates} \\ .93, & \text{for one cover plate} \end{cases} \tag{19}$$

3.5.3 Collector Loop Heat Exchange Modifiers, $\frac{F_R'}{F_R}$

3.5.3.1 Capacitance Rates

Calculate the collector loop and storage loop capacitance rates and determine the minimum capacitance rate. The loop capacitance rate is the product of the mass flow rate, $\dot{m}$ (lb/h) and fluid specific heat, c_p (Btu/lb·°F).

$$C_c = (\dot{m}c_p)_c \quad \text{collector loop} \tag{20}$$

$$C_s = (\dot{m}c_p)_s \quad \text{storage loop} \tag{21}$$

The minimum capacitance rate C_{min} is the lesser of C_c or C_s.

3.5.3.2 Heat Exchanger Effectiveness

The effectiveness of the collector/storage heat exchanger, ε_{cs} is a function of the particular heat exchanger design and size and capacitance rate of each loop. If a numerical value of ε_{cs} is not known, section 3.7 describes procedures whereby values can be calculated or estimated depending on information available from the heat exchanger manufacturer.

3.5.3.3 Heat Exchange Modifier Factor. $\frac{F_R'}{F_R}$

The heat exchanger modifier is determined by first calculating the following dimensionless parameters:

$$x = \frac{C_c}{\varepsilon_{cs}\ C_{min}} \tag{22}$$

$$y = \frac{A_c(F_R U_L)}{C_c} \tag{23}$$

The heat exchanger modifier is then determined either from the following equation or from figure A-11.

$$\frac{F_R'}{F_R} = \frac{1}{1 + y(x-1)} \tag{24}$$

For air systems and liquid systems without a collector/storage heat exchanger $\frac{F_R'}{F_R} = 1.$

3.5.4 Collector Combined Performance Characteristics, $F_R'(\overline{\tau\alpha})$, $F_R' U_L$

The values for the combined collector performance characteristics are calculated as follows:

$$F_R'(\overline{\tau\alpha}) = F_R(\tau\alpha)_n \times \left[\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}\right] \times \left[\frac{F_R'}{F_R}\right] \tag{25}$$

$$F_R' U_L = F_R U_L \times \left[\frac{F_R'}{F_R}\right] \tag{26}$$

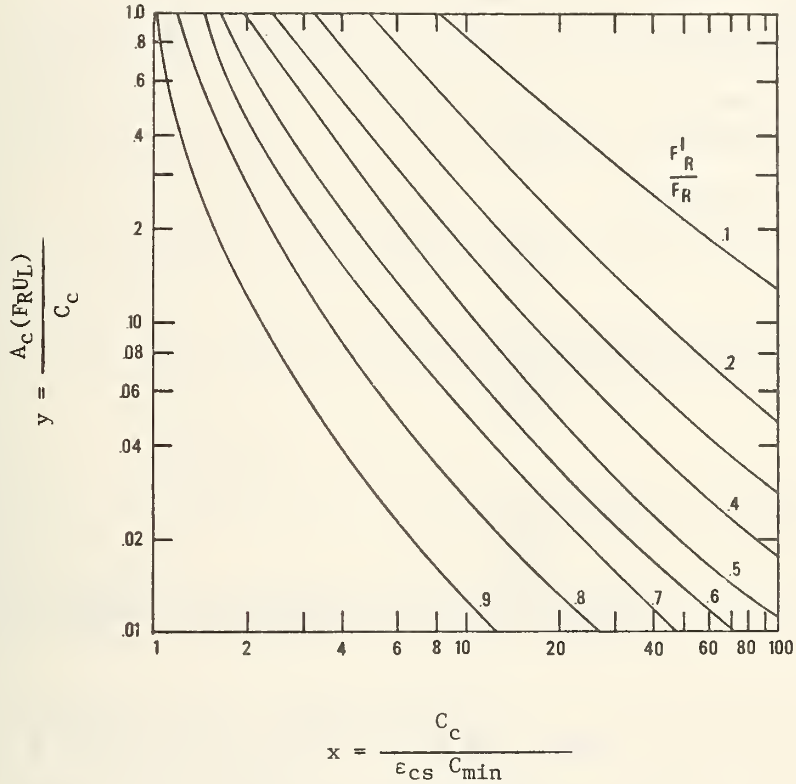


Figure A-11 Relationship Used to Determine the Ratio of $\frac{F'_R}{F_R}$

PROJECT: ____________________

(3.5.1) Collector Efficiency Data From Test

intercept, $b = F_R(\tau\alpha)_n$ =

slope, $m = F_R U_L$ =

Reference Temperature Basis: 1. t_{in}, 2. $\dfrac{t_{in} + t_{out}}{2}$, 3. t_{out}

Collector area, A_c =

Collector volumetric flow rate =

Correction to t_{in} basis:

Case 1: (no correction) $F_R(\tau\alpha)_n$ =

$F_R U_L$ =

Case 2: $$F_R(\tau\alpha)_n = b \times \left[\frac{1}{1 + \frac{mA_c}{2C_c}}\right] =$$

$$F_R U_L = m \times \left[\frac{1}{1 + \frac{mA_c}{2C_c}}\right] =$$

$$C_c = \dot{m}c_p = \begin{pmatrix}\text{volumetric} \\ \text{flow rate}\end{pmatrix} \begin{pmatrix}\text{density}\end{pmatrix} \begin{pmatrix}\text{time} \\ \text{conversion}\end{pmatrix} \begin{pmatrix}\text{specific} \\ \text{heat}\end{pmatrix}$$

=

where: for liquids, density $= \left(8.33 \text{ lb/gal}\right) \times \begin{pmatrix}\text{specific} \\ \text{gravity}\end{pmatrix}$

for air, density = 0.75 lb/ft^3, at 70° and 1 atm.

specific heat = 0.24 Btu/lb·°F

Case 3: $$F_R(\tau\alpha)_n = b \times \left[\frac{1}{1 + \frac{mA_c}{C_c}}\right] =$$

$$F_R U_L = m \times \left[\frac{1}{1 + \frac{mA_c}{C_c}}\right] =$$

(3.5.2) Incident Angle Modifier, $\dfrac{(\overline{\tau\alpha})}{(\tau\alpha)_n} = \begin{cases} .91, \text{ for two cover plates} \\ .93, \text{ for one cover plate} \end{cases}$

WORKSHEET F (Continued)

(3.5.3) Collector Loop Heat Exchanger Modifier, $\frac{F_R'}{F_R}$

for air systems and liquid systems without a collector/storage heat exchanger,

$$\frac{F_R'}{F_R} = 1$$

Capacitance Rate

C_c = (from above) =

C_s = (calc. as for C_c above) =

C_{min} = (lesser of C_c of C_s) =

Collector Storage Heat Exchanger Effectiveness, ε_{cs} =

$$x = \frac{C_c}{\varepsilon_{cs}\, C_{min}} =$$

$$y = \frac{A_c(F_R U_L)}{C_c} =$$

$$\frac{F_R'}{F_R} = \text{from figure A-11 or} = \frac{1}{1 + y(x-1)} =$$

(3.5.4) $F_R'\,(\overline{\tau\alpha}) = F_R(\overline{\tau\alpha})_n \times \left[\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}\right] \times \left[\frac{F_R'}{F_R}\right] =$

$F_R'U_L = F_R U_L \times \left[\frac{F_R'}{F_R}\right]$ =

3.6 CORRECTION FACTORS, K_1, K_2, K_3, K_4

This section develops the correction factors to be applied to D_1 and D_2 in equation 5 and 6 to account for the effect of variation of several design parameters. The validity of the procedure for values outside of the ranges indicated on accompanying figures A-12 through A-15 is not known, therefore evaluation of systems outside this range is not recommended. Worksheet G is provided for these calculations.

3.6.1 Air Collector Flow Capacitance Rate Factor, K_1

K_1 modifies D_2 in equation 6 and accounts for the effect of flow capacitance rate on the performance of air collectors. For liquid collectors $K_1 = 1$. Figure A-12 presents a plot of K_1 as a function of the ratio of collector flow capacitance rate C_c to collector area for the range of values noted. C_c is calculated using equation 20.

3.6.2 Storage Mass Capacitance Factor, K_2

K_2 modifies D_2 in equation 6 and accounts for the effect of storage thermal capacitance on the performance of liquid and air systems. Figure A-13 presents a plot of K_2 as a function of the ratio of storage mass capacitance, $(Mc_p)_s$ to collector area, A_c for the range of values noted. Separate curves are used for air and liquid systems. The storage mass capacitance $(Mc_p)_s$ is the product of the storage mass M (lb) times the specific heat of the storage medium, c_p (Btu/lb·°F).

3.6.3 Hot Water Factor, K_3

K_3 modifies D_2 in equation 6 and permits the use of the correlations originally developed for combined heating and hot water systems to be used for systems that provide domestic hot water only. For liquid systems that provide heating only or combined heating and hot water and for all air systems $K_3 = 1$. Figure A-14 presents a plot of K_3 as a function of average day-time temperature t_o. t_o may be read from table A-4 in section 5. In this plot the cold water supply temperature, t_m and the hot water delivery temperature, t_s are parameters that must be supplied.

3.6.4 Load Heat Exchanger Factor, K_4

K_4 modifies D_1 in equation 5 and accounts for the effect of load heat exchanger sizing on the performance of liquid systems for heating or combined heating and hot water. In air systems or domestic hot water only systems where there is no load heat exchanger $K_4 = 1$. Figure A-15 presents a plot of K_4 as a function of $\varepsilon_L C_{min}/AU_{bldg}$.

where:

- ε_L = load heat exchanger effectiveness.
- C_{min} = capacitance rate of the fluid with the minimum mass flow rate - specific heat product ($\dot{m}c_p$) and is usually the air side fluid capacitance rate.
- AU_{bldg} = overall heat transfer coefficient for the building calculated in equation 8.

When information on the load heat exchanger effectiveness is not provided, section 3.7 describes several alternate methods for estimating a value.

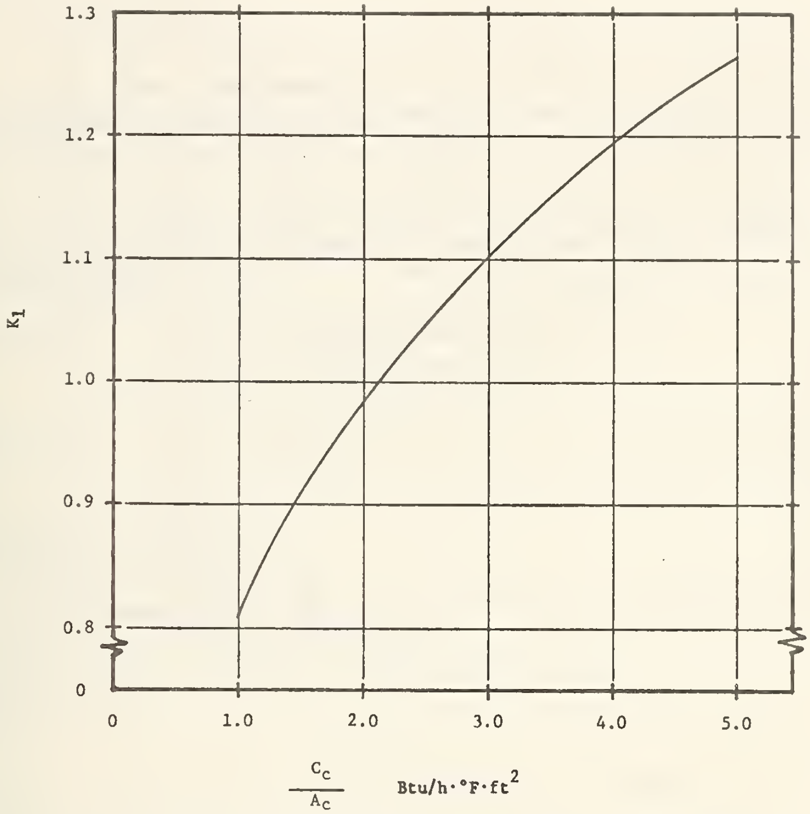


Figure A-12 Collector Capacitance Rate Factor (Air), K_1

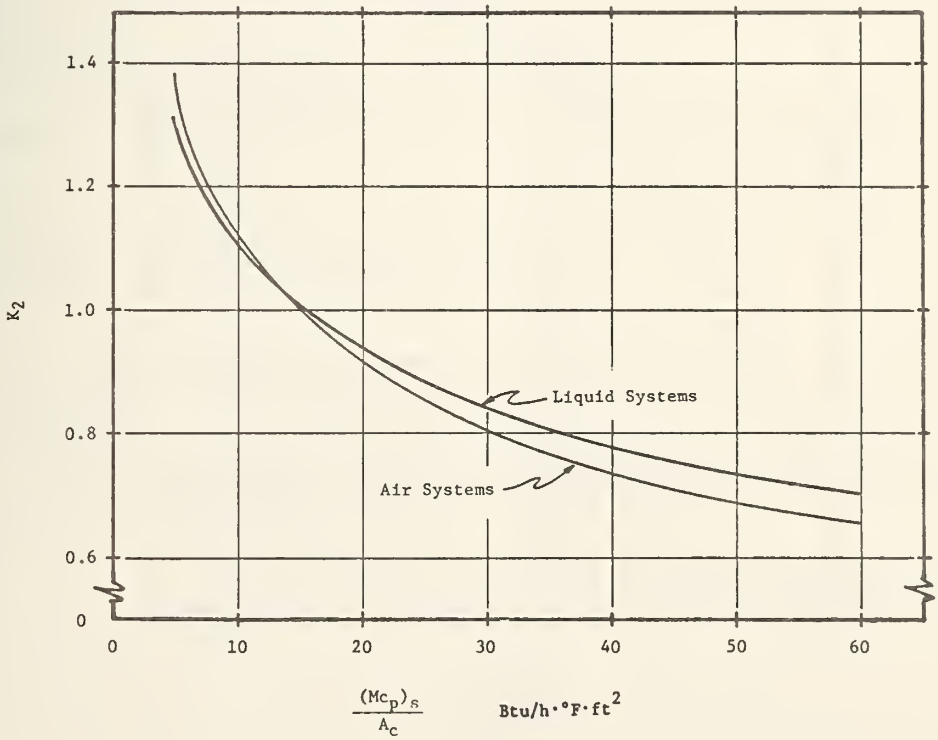


Figure A-13 Storage Capacitance Factor, K_2

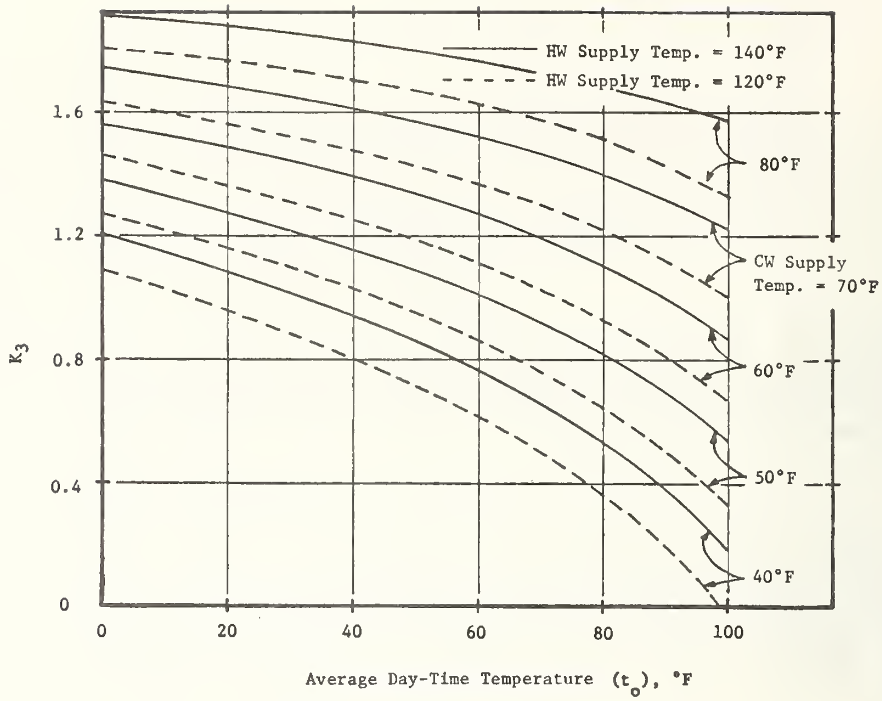


Figure A-14 Hot Water Factor, K_3

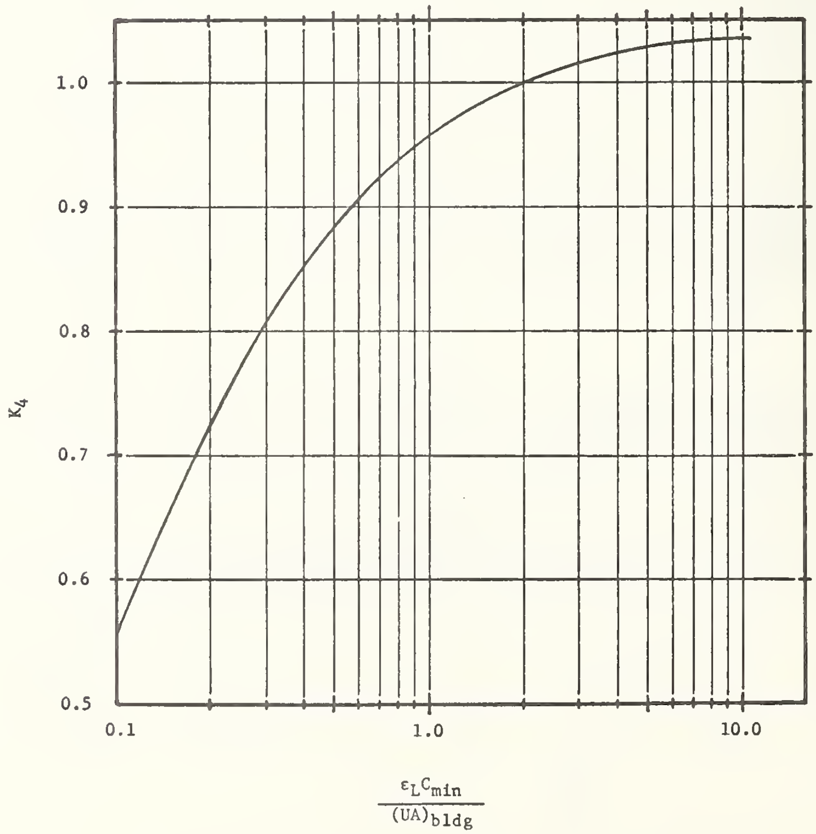


Figure A-15 Load Heat Exchanger Factor, K_4

WORKSHEET G CORRECTION FACTORS, K_1, K_2, K_3, K_4

PROJECT ______________________________________

Air Collector Flow Capacitance Rate Factor, K_1

for liquid collectors $K_1 = 1.0$

for air collectors: C_c = (from worksheet F) =

A_c = (from worksheet A) =

$\frac{C_c}{A_c}$ = K_1 = (from Figure A-12) =

Storage Mass Capacitance Factor, K_2

M = (vol. storage media) x (density) =

Note: M includes hot water storage volume where it is solar heated.

c_p = (from worksheet A) =

$\frac{(Mc_p)_s}{A_c}$ = K_2 = (from Figure A-13) =

Hot Water Factor, K_3

for liquid systems providing heating only or heating and hot water, and for all air systems $K_3 = 1.0$

for DHW only systems: t_s = (from worksheet A) = °F

t_m = (from worksheet A or if variable see worksheet D) = °F

t_o is taken from table A-4 section 5

K_3 is taken from figure A-14 and tabulated on a monthly basis on worksheet C

K_3 = (tabulated or const.) =

Load Heat Exchange Factor, K_4

for air systems and DHW only systems, $K_4 = 1.0$

ε_L = (from worksheet A) =

$C_{\text{hot water supply loop}} = \dot{m}c_p$ =

$C_{\text{air loop}} = \dot{m}c_p$ =

C_{min} = lesser of C_H or C_A =

UA bldg = (from worksheet D) =

$\frac{UA}{C_{min}\,\varepsilon_L}$ = K_4 = (from Figure A-15) =

3.7 HEAT EXCHANGER EFFECTIVENESS, ε_{HX}

In the evaluation of solar energy system performance using the "f-chart" method, there are two locations in the calculation procedure at which an explicit value for heat exchanger effectiveness, ε_{HX} must be known. This section describes two approaches to calculation of effectiveness, based on different ways design data may be provided by a heat exchanger manufacturer. In situations when no manufacturer design data is available, a method is described to estimate heat exchanger effectiveness.

Definitions

- Overall conductance $(AU)_{HX}$ for a heat exchanger is the product of the overall heat transfer coefficient U (which depends on the thermal properties of each fluid, the fluid mass flow rate and the heat exchanger geometry) and the associated heat transfer surface area.

- Effectiveness ε_{HX} is the ratio of the actual rate of heat transfer in the exchanger to the theoretical maximum rate of heat transfer that would occur only in a counter-flow exchanger with infinite surface area.

- Log-mean temperature difference Δt_{LM} is the effective temperature difference between the inlet and outlet fluids such that the product Δt_{LM} and $(AU)_{HX}$ equals the actual heat transfer rate.

The basic relationships are developed in the following paragraphs.

In the following schematic heat exchanger drawing, the hot stream with capacitance rate C_H and inlet temperature $t_{h,in}$ and the cold stream with capacitance rate C_c and inlet temperature $t_{c,\,in}$ both enter a heat exchanger that has an overall conductance $(AU)_{HX}$.

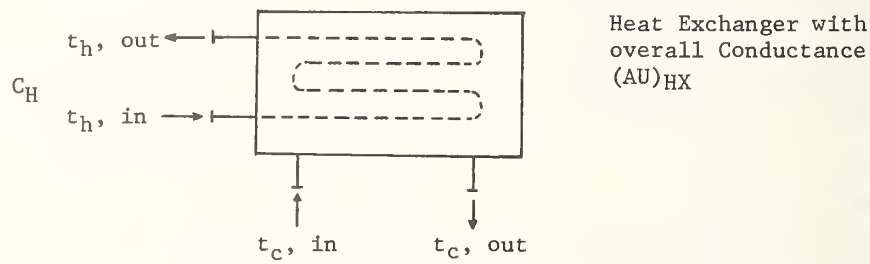


Figure A-16 Schematic Heat Exchanger

The actual heat transfer rate is given by

$$Q = C_c\,(t_{c,\,out} - t_{c,\,in}) \quad (27)$$

$$= C_H\,(t_{h,\,in} - t_{h,\,out}) \quad (28)$$

$$= (AU)_{HX}\,\Delta t_{LM} \quad (29)$$

The maximum theoretical heat transfer rate would occur if the fluid having the minimum capacitance rate were heated (or cooled) to the inlet temperature of the maximum capacitance rate fluid, i.e.

if $C_{min} = C_H$

Then $Q_{max} = C_H\ (t_{h,\ in} - t_{c,\ in})$ (30)

Or if $C_{min} = C_c$

Then $Q_{max} = C_c\ (t_{h,in} - t_{c,\ in})$ (31)

The effectiveness is given by

$$\varepsilon_{HX} = \frac{Q}{Q_{max}} = \frac{C_c(t_{c,\ out} - t_{c,\ in})}{C_{min}(t_{h,\ in} - t_{c,\ in})} = \frac{C_H(t_{h,\ in} - t_{H,\ out})}{C_{min}(t_{h,\ in} - t_{c,\ in})} \quad (32)$$

The log mean temperature difference is a complex function of the hot and cold fluid inlet and outlet temperatures and depends on the heat exchanger flow arrangement. The term Δt_{LM} is defined in terms of a reference log mean temperature difference for a counterflow heat exchanger $(\Delta t_{LM})_{cf}$ and a correction factor K as follows:

$$\Delta t_{LM} = (\Delta t_{LM})_{cf} \times K \quad (33)$$

where

$$(\Delta t_{LM})_{cf} = \frac{(t_{h,\ in} - t_{c,\ out}) - (t_{h,\ out} - t_{c,\ in})}{\log_e\left(\frac{t_{h,\ in} - t_{c,\ out}}{t_{h,\ out} - t_{c,\ in}}\right)} \quad (34)$$

and K depends on the particular heat exchanger flow geometry and two dimensionless temperature ratios R_1 and R_2 such that:

$$R_1 = \frac{t_{c,\ out} - t_{c,\ in}}{t_{h,\ in} - t_{c,\ in}} \quad (35)$$

$$R_2 = \frac{t_{h,\ in} - t_{h,\ out}}{t_{c,\ out} - t_{c,\ in}} \quad (36)$$

Tabular or graphical values of $(\Delta t_{LM})_{cf}$ and K are usually provided by heat exchanger manufacturers.

Example 1

Calculate the effectiveness of a counterflow heat exchanger located in the collector/storage circulation loop. Assume the collector circulation loop flow rate is 2 gpm and the storage loop flow rate is 6 gpm and that fluid leaves the collector at 120°F and fluid leaves the storage tank at 100°F. The heat exchanger manufacturers performance data for the specific heat exchanger and fluid properties is given in the following curves:

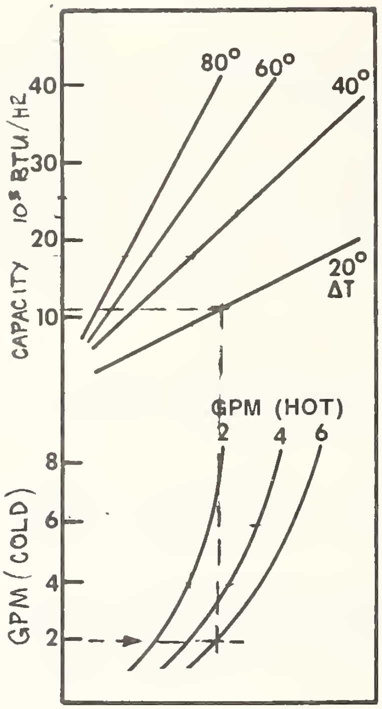


Figure A-17 Example Heat Exchanger Performance

Entering the above curve with 2.0 gpm (cold) and 6.0 gpm (hot), with a 120°F - 100° = 20°F Δt, the actual heat transfer rate is determined to be 11,000 Btu/h. The maximum rate of heat transfer is:

$$Q_{max} = C_{min}\ \Delta t =$$

$$= 2.0\ \frac{gal}{min} \times 8.33\ \frac{lb}{gal} \times 60\ \frac{min}{h} \times 1.0\ \frac{Btu}{lb°F} \times 20°F = 20{,}000\ Btu/h.$$

From the definition, the heat exchanger effectiveness is calculated as:

$$\varepsilon_{HX} = \frac{Q_{act}}{Q_{max}} = \frac{11{,}000}{20{,}000} = .55$$

Example 2

Calculate the effectiveness of a two pass shell and tube heat exchanger transferring heat between water and a heat transfer fluid. Water enters the heat exchanger at 110°F and 10 gpm and the heat transfer fluid enters the heat exchanger at 160°F and 15 gpm. The properties of the heat transfer fluid are c_p = .65 Btu/lb·°F and density = 55 lb/ft^3.

The manufacturers data consist of the following:

° overall heat transfer coefficient U = 150. (Btu/h·°F·ft^2)

° heat transfer surface area A = 30.0 ft^2

° a table of factors to convert the performance of a counterflow heat exchanger to the performance of the actual heat exchanger by the log mean temperature difference correction factor K is shown in Figure A-18.

R_1

R_2	.05	.1	.15	.2	.25	.3	.35	.4	.45	.5	.6	.7	.8	.9	1.0
.2								.999	.993	.984	.972	.942	.908	.845	.71
.4							.994	.983	.971	.959	.922	.855	.70		
.6						.992	.980	.965	.948	.923	.840				
.8					.995	.981	.965	.945	.916	.872					
1.0					.988	.970	.949	.918	.867	.770					
2.0			.997	.973	.940	.845	.740								
3.0			.977	.933	.835										
4.0		.993	.950	.850											
5.0		.982	.917												
6.0		.968	.855												
8.0		.930													
10.0	.996	.880													
12.0	.985	.720													
14.0	.972														
16.0	.958														
18.0	.940														
20.0	.915														

No correction required when K & R fall in this area.

Figure A-18 Example of Heat Exchanger Log-Mean Temperature Difference Correction Factor

Since neither of the fluid exit temperatures are known, it is necessary to use a trial and error procedure.

The capacitance rate for the heat transfer fluid (hot) is given by:

$$C_h = \left(15\ \frac{\text{gal}}{\text{min}}\right) \text{x} \left(8.33\ \frac{\text{lb } H_2O}{\text{gal}}\right) \text{x} \left(\frac{55}{62.4}\ \frac{\text{lb fluid}}{\text{lb } H_2O}\right) \text{x} \left(60\ \frac{\text{min}}{\text{h}}\right) \text{x} \left(.65\ \frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}\right) = 4295\ \frac{\text{Btu}}{\text{h}\cdot{}^\circ\text{F}}$$

The capacitance rate for the water (cold) is given by:

$$C_c = 10\ \frac{\text{gal}}{\text{min}} \text{ x } 8.33\ \frac{\text{lb } H_2O}{\text{gal}} \text{ x } 60\ \frac{\text{min}}{\text{h}} \text{ x } 1.0\ \frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}} = 4998\ \frac{\text{Btu}}{\text{h}\cdot{}^\circ\text{F}}$$

Assume the exit temperature of the water $t_{c,\ out}$ is 130°F.

The actual heat transfer rate is calculated from equation (27) as:

$$Q = C_c\ (t_{c,\ out} - t_{c,\ in}) = 4998\ (130-110) = 99960\ \frac{\text{Btu}}{\text{h}}$$

$$t_{h,\ out} = t_{h,\ in} - \frac{Q}{C_h} = 160 - \frac{99960}{4295} = 136.7^\circ\text{F}$$

The reference log mean temperature difference for a counter flow heat exchanger is calculated from equation (34):

$$(\Delta t_{LM})_{cf} = \frac{(160 - 130) - (136.7 - 110)}{\log_e \left(\frac{160 - 130}{136.7 - 110}\right)} = 28.3^\circ\text{F}$$

Since the heat exchanger is not of the counter flow arrangement, a correction factor K must be determined from the manufacturers supplied data, in this example Figure A-18 based on the computed values of R_1 and R_2 as follows:

From equation (35)

$$R_1 = \frac{130 - 110}{160 - 110} = .4$$

From equation (36)

$$R_2 = \frac{160 - 136.7}{130 - 110} = 1.16$$

K is then determined from the Figure A-18 (by extrapolation) as: K = .90

Then from equations (29) and (33)

$$Q = (AU)_{HX} \times (\Delta t_{LM})_{cf} \times K = (150)\ (30)\ (28.3)\ (.90) = 114615\ \frac{Btu}{h\cdot}$$

and $t_{c,\ out} = 110 + \frac{114615}{4998} = 132.9°F.$

Since the original exit temperature of the water was estimated to be 130°F, the procedure is repeated until the estimated water temperature and the calculated water temperature are the same.

For this problem, the exit water temperature is then calculated to be

$$t_{c,\ out} = 131.2°F$$

The actual heat transfer rate is then

$$Q = 4988\ (131.2 - 110) = 105{,}960\ Btu/h\cdot$$

The maximum possible heat transfer rate would occur if the minimum capacitance rate fluid (the hot fluid in this example) were cooled to the cold fluid inlet temperature.

$$Q_{max} = C_{min}\ (t_{h,\ in} - t_{c,\ in}) = 4295\ (160 - 110) = 214{,}750\ \frac{Btu}{h}$$

The heat exchanger effectiveness is given by equation (32) as:

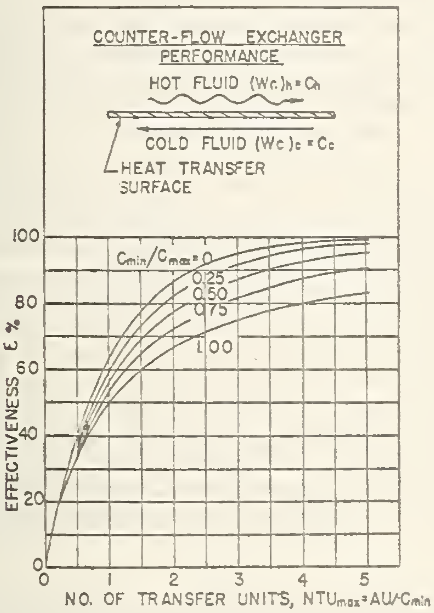
$$\varepsilon_{HX} = \frac{105{,}960}{214{,}750} = .49$$

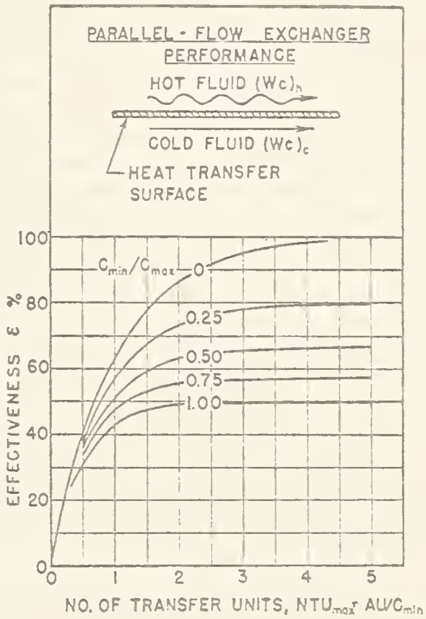
The heat exchanger effectiveness can be assumed to be a constant for a given heat exchanger and fluid mass flow provided the thermal properties of the fluids do not vary substantially and provided no change of phase occurs. Thus, the calculated value of effectiveness based on an assumed set of inlet temperatures would still be valid over a range of hot fluid and cold fluid inlet conditions usually found in most solar heating applications.

For the case where there are no performance data available for the particular heat exchanger, an estimate of effectiveness can be made from the data of reference [7] for a range of different heat exchanger designs, provided the overall conductance $(AU)_{HX}$ is known. Figure A-19 shows the effectiveness of counter flow, parallel flow, and cross flow heat exchangers as a function of the ratio $(AU)_{HX}/C_{min}$ with the ratio C_{min}/C_{max} as the parameter. For the cross flow arrangement usually found in the liquid to air load heat exchangers, C_{min} is usually the air side capacitance rate and the parameter $C_{mixed}/C_{unmixed}$ shown in Figure A-19 for this arrangement is equivalent to C_{min}/C_{max}.

If the particular flow arrangement of a heat exchanger is unknown, the effectiveness can be estimated by taking an average of the calculated effectiveness for the counter flow and parallel flow arrangements for the given $(AU)_{HX}/C_{min}$ and C_{min}/C_{max} design parameters.

For situations in which a heat exchanger consists of a coil of tubing submerged in a tank of water, C_{min} is the capacitance rate of the fluid circulating through the coil and C_{max} is essentially infinite. Thus, the ratio $C_{min}/C_{max} = 0$ is used to determine effectiveness from any of the three arrangements shown since for $C_{min}/C_{max} = 0$, the expressions for effectiveness as a function of $(AU)_{HX}/C_{min}$ for all flow arrangements reduce to the same expression.





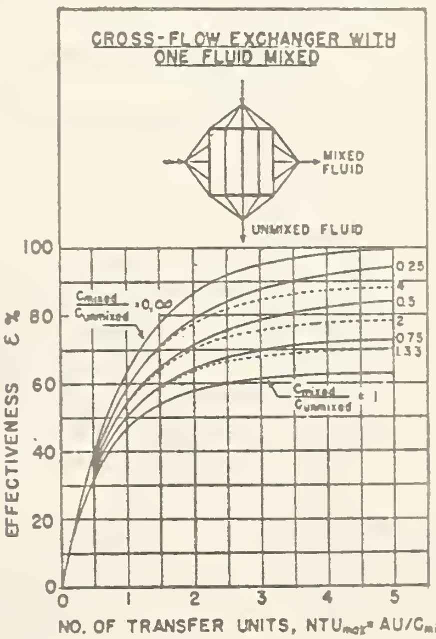


Figure A-19 General Heat Exchanger Performance [7]

4 TYPICAL EXAMPLES OF SYSTEM THERMAL PERFORMANCE CALCULATION

The following examples demonstrate the utilization of the calculation method for evaluation of solar heating and hot water systems. Examples using air and water as working fluids were chosen to represent existing typical solar heating systems.

4.1 SOLAR HEATING AND DOMESTIC HOT WATER SYSTEM - LIQUID WORKING FLUID

Our example is a typical liquid working fluid solar heating system shown in Figure A-20. The system is designed to provide space and domestic hot water heating. A flat plate collector is used to transform incident solar radiation into thermal energy. This energy is stored in the form of sensible energy and used as needed to supply the space and water heating loads. In this case, antifreeze solution is circulated through the collector to avoid the problems of freezing and corrosion. A heat exchanger is used between the collector and the tank as it is generally more economical than using the antifreeze solution as the energy storage medium. A second heat exchanger is used to transfer energy from the main storage tank to the smaller domestic hot water tank. Conventional auxiliary heaters are provided to supply energy for both the space and water heating loads when the energy in the storage tank is depleted. Controllers, relief valves, pumps and piping make up the remaining equipment. All heat losses from the solar energy system are assumed to contribute to the building heating load. The temperature of the fluid entering the collector is assumed equal to the temperature at the outlet of the collector - storage heat exchanger. The relief valves ensure that the fluid temperature leaving the collector or heat exchangers does not exceed the boiling point of water. At night, or during periods of low radiation, a differential temperature controller between the outlet at the bottom of the storage tank and the collector outlet manifold turns off the pump if this difference is less than about 9°F. Collected solar energy is stored in two tanks, a large main tank and a smaller domestic water tank. When the temperature of the domestic water tank is less than the main tank, energy is transferred to it. The model assumes that these two tanks are at the same temperature. No temperature gradients are assumed in the storage tanks.

Madison, Wisconsin has been selected as the location of the example problem as it represents a city with major winter heating requirements and reasonable amount of solar radiation to meet these requirements. Project data for the example are presented on worksheet A.

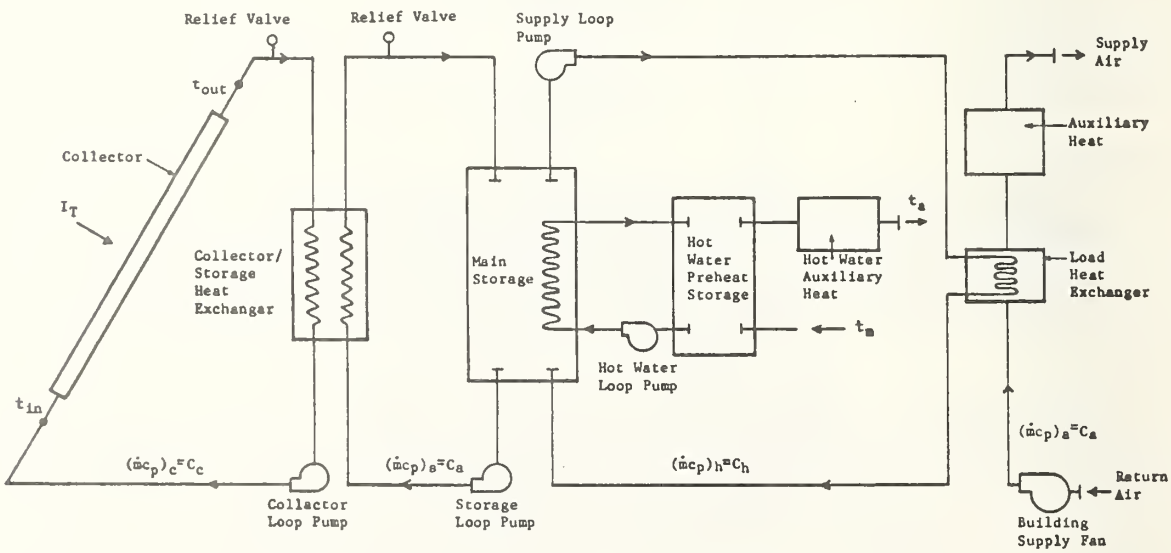


Figure A-20 Liquid System: Space Heating and Domestic Hot Water

WORKSHEET A PROJECT DATA

PROJECT LIQUID H & DHW EXAMPLE, MADISON, WIS.

Location MADISON, WIS. Latitude	=	43°
Building Heating and/or Hot Water Load		
Design Heat Loss Rate, q_d	=	71,700 Btu/h
Winter Design Temperature (97 1/2%), t_w	=	-5 °F
Average Hot Water Consumption (may vary on a monthly basis)	=	82.7 gal/day
Average Cold Water Supply (main) Temp., t_m (may vary on a monthly basis)	=	55 °F
Hot Water Supply Temp., t_s	=	140 °F
Collector Subsystem Data		
Collector Type: FLAT PLATE,		
Selective or non-selective, no. cover plates 2		
Collector Area, A_c	=	860 ft^2
Tilt Angle	=	43 °
Azimuth Angle	=	S=180 °
Collector Shading (av. % month of Dec.)	=	0 %
Collector Efficiency Data (from manufacture): $F_R(\tau\alpha)_n$	=	.79
$F_R U_L$	=	.85 Btu/h·ft^2·°F
Reference Temp. Basis: t_{in}, $\frac{t_{in} + t_{out}}{2}$, t_{out}		
Fluid:		
Composition: 50% ETHYLENE GLYCOL/WATER		
Specific Heat, c_p	=	0.82 Btu/lb·°F
Specific Gravity (if applicable)	=	1.05 lb/lb
Volumetric Flow Rate	=	20 gal/min or ft^3/min
Storage Subsystem Data		
Volume	=	1000 gal or ft^3
Storage Medium WATER		
Specific Heat, c_p	=	1.0 Btu/lb·°F
Specific Gravity ~~or Density~~	=	1.0 lb/lb or lb/ft^3
Circulation Loop Volumetric Flow Rate	=	16 gal/min or ft^3/min
Collector/Storage Heat Exchange Effectiveness, ε_{cs}	=	.70
Hot Water Preheat Storage Volume	=	80 gal
Load Subsystem Data		
Load Heat Exchanger Effectiveness, ε_L	=	.80
Supply Loop Volumetric Flow Rate	=	10 gal/min
Building Air Supply Volumetric Flow Rate	=	1200 ft^3/min

1. Fraction of Total Heating Load Supplied by Solar Energy, F_{Annual}

The values and calculations developed in this section are tabulated on Worksheet B.

1.1 Monthly Fraction (f)

By locating the system parameters D_1 and D_2 on figure A-6, (f) can be determined on a monthly basis. D_1 and D_2 are taken from Worksheet C, L is from Worksheet D and S from Worksheet E. For February, the value for (f) was 0.48 and is tabulated in Worksheet B.

1.2 Annual Fraction (F_{Annual})

1.2.1 The solar energy supplied for the example month of February is,

$$E_{Feb} = (f_{Feb})\ (L_{Feb})$$
$$= (.48)\quad (23.5 \times 10^6) = 11.28 \times 10^6 \text{Btu}$$

The total solar energy supplied for the entire year is calculated on Worksheet B

1.2.2 The total heating load for the entire year is calculated on Worksheet B

1.2.3 F_{Annual} for the entire year is equal to,

$$F_{Annual} = \frac{E_{Total}}{L_{Total}} = \frac{97.0 \times 10^6}{156.1 \times 10^6} = 0.62$$

2. System Performance Parameters, D_1, D_2

The values and calculations developed in this section are calculated on Worksheet C.

The parameters D_1 and D_2 are obtained from equations 5 and 6.

For the month of February this is done as follows:

$$D_1 = \left[\frac{A_c F_R' \ (\overline{\tau\alpha})\ S}{L}\right] \times K_4 = (D_{1\ prod})\ \frac{S}{L} = (860)\ (.69)\ (.95)\ \frac{S}{L}$$

$$= (563.7)\ \frac{S}{L} = 563.7\ \frac{35.8 \times 10^3}{23.5 \times 10^6} = .86$$

$$D_2 = \left[\frac{A_c F_R' U_L (t_{ref} - t_o)\ \Delta time}{L}\right] \times K_1 \times K_2 \times K_3 = (D_{2\ prod})\ \left[\frac{(212-t_o)\ \Delta time}{L}\right] \times K_3$$

$$= \left[(860)\ (.82)\ (1.0)\ (1.1)\right]\left[\frac{(212-t_o)\ \Delta time}{L}\right] \times K_3$$

$$= (775.7)\ \left[\frac{(212-\ 5)672}{23.5 \times 10^6}\right] \times 1.0 = 4.2$$

WORKSHEET B FRACTION OF TOTAL HEATING LOAD SUPPLIED BY SOLAR ENERGY, F_{Annual}

PROJECT LIQUID H & DHW EXAMPLE
MADISON, WIS.

	1	2	3	4	5
Month	Tot. Mo. Htg. Load L Btu/mo.	System Parameters D_1	System Parameters D_2	Solar Fraction/ mo. f	Actual Solar en/mo E Btu/mo.
Jan.	27.1×10^6	.71	4.1	.38	10.29×10^6
Feb.	23.5	.86	4.2	.48	11.28
March	20.9	1.33	4.9	.76	15.88
April	12.3	2.06	7.4	.95	11.68
May	7.1	3.87	12.3	1.0	7.10
June	3.5	8.34	22.5	1.0	3.50
July	2.2	14.1	35.4	1.0	2.20
Aug.	2.5	12.0	31.8	1.0	2.50
Sept.	4.7	6.09	17.3	1.0	4.70
Oct.	10.0	2.59	9.1	1.0	10.00
Nov.	17.7	.91	5.5	.45	7.96
Dec.	24.6	.69	4.4	.35	8.61

$L_{tot} = 156.1 \times 10^6$

$E_{tot} = 95.70 \times 10^6$

$$F_{Annual} = \frac{E_{tot}}{L_{tot}} = \frac{95.7 \times 10^6}{156.1 \times 10^6} = .61$$

1. From Worksheet D
2. From Worksheet C
3. From Worksheet C
4. From "f chart"
5. E = f x L

WORKSHEET C SYSTEM PERFORMANCE PARAMETERS D_1, D_2

PROJECT LIQUID H & DHW EXAMPLE
MADISON, WIS.

	1	2		3	4			5	6
Month	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo·ft^2)	Total Heating Load L Btu/Mo.	S/L	D_1	Mo. Av. Day Time Temp. t_o °F	$212-t_o$ °F	Tot. Hrs in Mo. Δ time hr.	K_3	D_2
Jan.	34.3×10^3	27.1×10^6	1.26×10^{-3}	.71	22	190	744	1.0	4.1
Feb.	35.9	23.5	1.53	.86	25	187	672		4.2
March	49.3	20.9	2.36	1.33	35	177	744		4.9
April	45.0	12.3	3.66	2.06	49	163	720		7.4
May	48.7	7.1	6.86	3.87	61	151	744		12.3
June	51.8	3.5	14.8	8.34	71	141	720		22.5
July	55.2	2.2	25.1	14.1	77	135	744		35.4
Aug.	53.0	2.5	21.2	12.0	74	138	744		31.8
Sept.	50.7	4.7	10.8	6.09	66	146	720		17.3
Oct.	45.9	10.0	4.6	2.59	54	158	744		9.1
Nov.	28.7	17.7	1.62	.91	38	174	720		5.5
Dec.	30.9	24.6	1.23	.69	25	187	744		4.4

A_c = 860 ft^2 Given data

$F'_R(\overline{\tau\alpha})$ = .69 Worksheet F

$F'_R U_L$ = .82 worksheet F

K_1 = 1.0 Worksheet G

K_2 = 1.1 Worksheet G

K_4 = .95 Worksheet G

1. From Worksheet E
2. From Worksheet D
3. $D_1 = \left[\frac{A_c\ F'_R\ (\overline{\tau\alpha})\ S}{L}\right] \times K_4 = (D_1\ \text{prod.})\ \frac{S}{L} = 563.7\ \frac{S}{L}$

   Where: $D_1\ \text{prod.} = \left[A_c\ F'_R\ (\overline{\tau\alpha})\right] \times K_4 = (860)(.69)(.95) = 563.7$
4. From Sec. 5 Table A-4
5. From Table A-14 and Worksheet G
6. $D_2 = \left[\frac{A_c\ F'_R\ U_L\ (t_{ref} - t_o)\ \Delta\text{time}}{L}\right] \times K_1 \times K_2 \times K_3 = (D_2\ \text{prod.}) \left[\frac{(212 - t_o)\ \Delta\text{time}}{L}\right] \times K_3 = 775.7 \left[\quad\right] \times K_3$

   Where: $D_2\ \text{prod.} = (A_c\ F'_R\ U_L) \times K_1 \times K_2 = (860)(.82)(1.0)(1.1) = 775.7$

4.1 (Continued)

3 Total Building Heating and Domestic Hot Water Load, L

The total heating load is equal to the sum of the space heating load and the domestic hot water heating load. Worksheet D is used for load calculations.

3.1 Space Heating Load

3.1.1 Knowing the building thermal characteristics (heat transfer coefficients and areas of surfaces exposed to the outside) and using Manual J, the design temperature difference (Δt_d) and design heat loss (q_d) were found to be 75°F and 71,700 Btu/h respectively. These are recorded on Worksheet A. An example of the Manual J calculation is presented in the air system example in section 4.2.

3.1.2 Monthly total degree days (DD) for Madison were taken from Table A-3 in section 5.

3.1.3 Monthly space heating load (Q_s) was then calculated using equations 7 and 8. In February for example,

$$Q_s = (PF)\ (24)\ (UA)\ (\text{Degree Days})$$

where:

$$PF = 0.75$$

$$UA = \frac{q_d}{\Delta t_d} = \frac{71{,}7000\ \text{Btu/h}}{75°F} = 956\ \frac{\text{Btu}}{\text{h}\cdot°F}$$

$$Q_s(\text{Feb}) = (0.75)\ (24)\ (956)\ (1274) = 21.9 \times 10^6\ \text{Btu}$$

3.2 Domestic Hot Water Heating Load

3.2.1 In this example, the hot water requirements are 82.7 gallons per day. Monthly requirements are then,

$$\left(\frac{\text{gal}}{\text{Day}}\right) \times \left(N\ \frac{\text{Days}}{\text{Month}}\right) = \left(\frac{\text{gal}}{\text{mo}}\right)$$

Values obtained are tabulated in Worksheet D for the example problem. In February for example,

$$(82.7)\ (28) = 2316\ \frac{\text{gal}}{\text{month}}$$

3.2.2 Water main temperature t_m = 55°F.

3.2.3 Domestic hot water supply temperature (t_s) in accordance with MPS requirements, was assumed to be set at (t_s = 140°F).

3.2.4 Monthly domestic hot water heating load (Q_w) is then,

$$Q_w = mc_p\ (t_s - t_m)$$

where c_p is the specific heat of water [c_p = 1Btu/(lb·°F)]. Q_w is then calculated on a monthly basis and tabulated in Worksheet D. In February for example,

$$Q_w = \left(2316\frac{\text{gal}}{\text{month}}\right) \left(8.33\ \frac{\text{lb}}{\text{gal}}\right) \left(1\ \frac{\text{Btu}}{\text{lb}\cdot°F}\right) (140°F - 55°F) = 1.63 \times 10^6\ \text{Btu}$$

3.3 Total Heating Load (L) is then the sum of space heating (Q_s) and water heating (Q_w).

$$L = Q_s + Q_w$$

In February for example,

$$L = 21.9 \times 10^6 \text{ Btu} + 1.63 \times 10^6 \text{ Btu} = 23.5 \times 10^6 \text{ Btu}$$

Values of L for each month are tabulated in Worksheet D for the example problem.

WORKSHEET D HEATING AND/OR DOMESTIC HOT WATER LOAD, L

PROJECT LIQUID H & DHW EXAMPLE
MADISON, WIS.

	1	2		3		4	5	6
Month	Monthly Degree Days DD °F·days	Monthly Space Htg Load Q_s Btu/Mo.	No. of Days/Mo. N	Vol. of DHW Used/Mo. Gal./Mo.	Temp. Water Main Sup. t_m °F	DHW Temp. Rise $t_s - t_m$ °F	Monthly DHW Load Q_w Btu/Mo.	Total Heating Load L Btu/Mo.
Jan.	1473	25.3×10^6	31	2565	55	85	1.81×10^6	27.1×10^6
Feb.	1274	21.9	28	2316			1.63	23.5
March	1113	19.1	31	2565			1.81	20.9
April	618	10.6	30	2484			1.75	12.3
May	310	5.32	31	2565			1.81	7.1
June	102	1.75	30	2484			1.75	3.5
July	25	0.42	31	2565			1.81	2.2
Aug.	40	0.68	31	2565			1.81	2.5
Sept.	174	2.99	30	2484			1.75	4.7
Oct.	474	8.15	31	2565			1.81	10.0
Nov.	930	15.9	30	2484			1.75	17.7
Dec.	1330	22.8	31	2565			1.81	24.6

q_d = 71,700 Btu/h

(Given data or calculate from Manual J or equivalent.)

$\Delta t_d = 70 - t_w$

$= 70 - (-5) = 75°$

Where: t_w = 97 1/2% winter design temperature

(From ASHRAE Fundamentals, Table A-3, section 5 or known weather data.)

70° = indoor design temperature

$UA = \frac{q_d}{\Delta t_d} = \frac{71{,}700\ Btu/h}{75\ °F} = 956 \frac{Btu}{h \cdot °F}$

t_s = 140°

1. From ASHRAE Systems, Climatic Atlas or Table A-3, section 5.
2. Q_s = (PF)(24)(UA)(Degree Day) = (0.75)(24)(956) x (Degree Day) = 17,208 x DD
   Where: PF = 0.75 or more appropriate value.
3. (Vol/day) (no. days/mo.) = 82.7 (gal./day) (no. days/mo.)
4. May be constant or may vary.
5. Q_w = (vol. of water) x 8.33 x 1 x ($t_s - t_m$).
6. $L = Q_s + Q_w$

4 Solar Energy Available (Incident Solar Radiation), S

4.1 Monthly Averages of the Daily Radiation Incident on a Horizontal Surface ($\overline{I}_H$), were taken from Table A-4, section 5 and are tabulated in Worksheet E for the example problem.

4.2 Monthly values for $\overline{K}_t$ were taken from Table A-4, section 5 and are also tabulated in Worksheet E.

4.3 Knowing the collector tilt ($\Theta = 43°$), the latitude ($\phi = 43°$), and monthly $\overline{K}_t$ values; monthly $\overline{R}$ values were taken from Table A-6, section 5 and tabulated in Worksheet E.

For instance, in February, $\overline{K} = .47$ Referring to Table A-6 ($\overline{K}_t = .5$) and determining the latitude minus tilt difference ($\phi - \Theta = 43° - 43° = 0°$) the $\overline{R}$ value under the February column opposite latitude 43° is $\overline{R} = 1.57$.

4.4 Monthly Average Daily Radiation on a Tilted Surface ($\overline{I}_T$) is calculated using equation 12.

$$\overline{I}_T = (\overline{I}_H)\ (\overline{R})$$

and tabulated in Worksheet E. For example, in February,

$$\overline{I}_T = (812)\ (1.57) = 1284\ \frac{\text{Btu}}{\text{Day}\cdot\text{ft}^2}$$

4.5 Total Average Insolation per Month (S) is calculated using equation 13.

$$S = (\overline{I}_T)\ (N)$$

where N is the number of days in the month. S is then tabulated in Worksheet E. For example, in February,

$$S = \left(1284\ \frac{\text{Btu}}{\text{Day}\cdot\text{ft}^2}\right) \times \left(28\ \frac{\text{Days}}{\text{Month}}\right)$$

$$= 35.8 \times 10^3\ \frac{\text{Btu}}{\text{Month}\cdot\text{ft}^2}$$

4.6 Assume no shading of the collector array in this example.

WORKSHEET E TOTAL MONTHLY SOLAR RADIATION AVAILABLE, S

PROJECT LIQUID H & DHW EXAMPLE MADISON, WIS.

	1	2	3	4	5		6
Month	Horizontal Insolation $\bar{I}_H$ Btu/(Day·ft^2)	Extra-terrestrial Insolation $\bar{I}_o$ Btu/(Day·ft^2)	Ratio Horizontal to Extra-terrestrial $\bar{K}_t$	Ratio Horizontal to Tilt $\bar{R}$	Monthly Avg. Daily Rad. on Tilt Surf. $\bar{I}_T$ Btu/(Day·ft^2)	No. of Days in Month N	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo · ft^2)
Jan.	565	N/A	0.49	1.96	1107	31	34.3×10^3
Feb.	812		.50	1.58	1282	28	35.9
March	1232		.55	1.29	1589	31	49.3
April	1456		.49	1.03	1499	30	45.0
May	1746		.51	.90	1571	31	48.7
June	2031		.56	.85	1726	30	51.8
July	2048		.58	.87	1782	31	55.2
Aug.	1746		.56	.98	1711	31	53.0
Sept.	1445		.58	1.17	1691	30	50.7
Oct.	994		.55	1.49	1481	31	45.9
Nov.	556		.43	1.72	956	30	28.7
Dec.	496		.48	2.01	997	31	30.9

1. From Table A-4 or Fig. A-29 section 5, or known data.
2. From Table A-5 section 5, used only for eq. 11.
3. From Table A-4 section 5, or eq. 11.
4. From Table A-6 section 5, latitude (Ø) = 43 °, with collector tilt (θ) = 43 °, and latitude - tilt = 0 °.
5. From eq. 12, $\bar{I}_T + (\bar{I}_H)(\bar{R})$.
6. From eq. 13, $S = (\bar{I}_T)(N)$.

4.1 (Continued)

5 Collector Combined Performance Characteristics $F_R'(\overline{\tau\alpha})$, $F_R'U_L$

The values and calculations developed in this section are tabulated in Worksheet E.

5.1 Collector Performance Characteristics, $F_R(\tau\alpha)_n$, F_RU_L

The collectors are constructed with a double glass cover plate and an aluminum parallel flow absorber coated with a non-selective flat black paint. Area of collector A_c = 860 ft^2.

In this case the collector manufacturer has provided a thermal performance efficiency curve as shown below for the collector, operating with a volumetric flow rate of 20 gal/min and with the reference temperature equal to the inlet temperature. This corresponds to case 1 in the calculation method and the performance characteristics are obtained directly as follows:

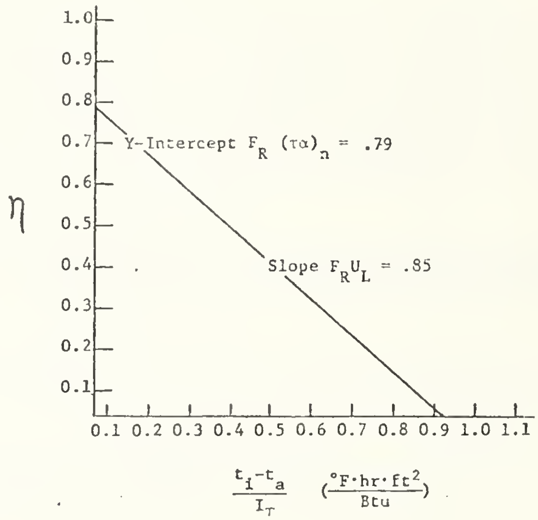


Figure A-21

F_RU_L = .85 Btu/h·°F·ft^2 determined from the slope of the efficiency curve shown in Figure A-21.

$F_R(\tau\alpha)_n$ = .79 as determined from the intercept of the efficiency curve with the y axis.

5.2 Incident Angle Modifier, $\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}$

The incident angle modifier is calculated on Worksheet F.

5.3 Collector Loop Heat Exchanger Modifier, $\frac{F_R'}{F_R}$

The collector loop heat exchanger modifier is calculated on Worksheet F.

6 Correction Factors, K_1, K_2, K_3, K_4

Correction factors K_1, K_2, K_3, K_4 are calculated on Worksheet G.

WORKSHEET F COLLECTOR COMBINED PERFORMANCE CHARACTERISTICS, $F'_R\ (\overline{\tau\alpha})$, $F'_R U_L$

PROJECT: LIQUID H & DHW EXAMPLE, MADISON, WIS.

(3.5.1) Collector Efficiency Data From Test

intercept, $b = F_R(\tau\alpha)_n$ .79 =

slope, $m = F_R U_L$ .85 =

Reference Temperature Basis: 1. t_{in}, 2. $\frac{t_{in} + t_{out}}{2}$, 3. t_{out}

Collector area, A_c = 860 ft²

Collector volumetric flow rate = 20 gal/MIN

Correction to t_{in}' basis:

Case 1: (no correction) $F_R(\tau\alpha)_n$ =

$F_R U_L$ =

Case 2: $$F_R(\tau\alpha)_n = b \times \left[\frac{1}{1 + \frac{mA_c}{2C_c}}\right] =$$

$$F_R U_L = m \times \left[\frac{1}{1 + \frac{mA_c}{2C_c}}\right] =$$

$$C_c = \dot{m}c_p = \begin{pmatrix}\text{volumetric} \\ \text{flow rate}\end{pmatrix} \left(\text{density}\right) \begin{pmatrix}\text{time} \\ \text{conversion}\end{pmatrix} \begin{pmatrix}\text{specific} \\ \text{heat}\end{pmatrix}$$

$$= \left(20 \frac{gal}{MIN}\right)\left(8.33 \frac{lb}{gal}\right)\left(1.05 \frac{lb}{lb}\right)\left(60 \frac{MIN}{h}\right)\left(.82 \frac{Btu}{lb \cdot °F}\right) = 8610 \frac{Btu}{h \cdot °F}$$

where: for liquids, density = (8.33 lb/gal) x $\begin{pmatrix}\text{specific} \\ \text{gravity}\end{pmatrix}$

for air, density = 0.75 lb/ft^3, at 70° and 1 atm.

specific heat = 0.24 Btu/lb·°F

Case 3: $$F_R(\tau\alpha)_n = b \times \left[\frac{1}{1 + \frac{mA_c}{C_c}}\right] =$$

$$F_R U_L = m \times \left[\frac{1}{1 + \frac{mA_c}{C_c}}\right] =$$

(3.5.2) Incident Angle Modifier, $\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}$ = { .91, for two cover plates; .93, for one cover plate }

WORKSHEET F (Continued)

(3.5.3) Collector Loop Heat Exchanger Modifier, $\frac{F_R'}{F_R}$

for air systems and liquid systems without a collector/storage heat exchanger,

$\frac{F_R'}{F_R} = 1$

Capacitance Rate

C_c = (from above) = $8610 \ \frac{\text{Btu}}{\text{h}\cdot{}^\circ\text{F}}$

C_s = (calc. as for C_c above) = $(16 \ \frac{\text{gal}}{\text{MIN}})(8.33)(1)(60)(1) = 8000 \ \frac{\text{Btu}}{\text{h}\cdot{}^\circ\text{F}}$

C_{min} = (lesser of C_c of C_s) = 8000

Collector Storage Heat Exchanger Effectiveness, ε_{cs} = $.70$

$$x = \frac{C_c}{\varepsilon_{cs} C_{min}} = \frac{8610}{(.70)(8000)} = 1.537$$

$$y = \frac{A_c(F_R U_L)}{C_c} = \frac{(860)(.85)}{8610} = .085$$

$$\frac{F_R'}{F_R} = \text{from figure A-11 or } = \frac{1}{1 + y(x-1)} = \frac{1}{1 + .085(1.537-1)} = .96$$

(3.5.4) $F_R'(\overline{\tau\alpha}) = F_R(\overline{\tau\alpha})_n \times \left[\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}\right] \times \left[\frac{F_R'}{F_R}\right] = (.79)(.91)(.96) = .69$

$F_R'U_L = F_RU_L \times \left[\frac{F_R'}{F_R}\right] = (.85)(.96) = .82 \ \frac{\text{Btu}}{\text{h}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$

WORKSHEET G CORRECTION FACTORS, K_1, K_2, K_3, K_4

PROJECT LIQUID H & DHW EXAMPLE, MADISON, WIS.

Air Collector Flow Capacitance Rate Factor, K_1

for liquid collectors $K_1 = 1.0$

for air collectors: C_c = (from worksheet F) =

A_c = (from worksheet A) =

$\frac{C_c}{A_c}$ =

K_1 = (from Figure A-12) = 1.0

Storage Mass Capacitance Factor, K_2

M = (vol. storage media) x (density) = $(1000 + 80)(8.33) = 8996$ lb

Note: M includes hot water storage volume where it is solar heated.

c_p = (from worksheet A) = $1.0 \frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}$

$$\frac{(Mc_p)_s}{A_c} = \frac{(8996)(1)}{860} = 10.46$$

K_2 = (from Figure A-13) = 1.1

Hot Water Factor, K_3

for liquid systems providing heating only or heating and hot water, and for all air systems $K_3 = 1.0$

for DHW only systems: t_s = (from worksheet A) = °F

t_m = (from worksheet A or if variable see worksheet D) = °F

t_o is taken from table A-4 section 5

K_3 is taken from figure A-14 and tabulated on a monthly basis on worksheet C

K_3 = (tabulated or const.) = 1.0

Load Heat Exchange Factor, K_4

for air systems and DHW only systems, $K_4 = 1.0$

ε_L = (from worksheet A) = .80

$C_{\text{hot water supply loop}} = \dot{m}c_p = \left(10\frac{\text{gal}}{\text{min}}\right)\left(8.33\frac{\text{lb}}{\text{gal}}\right)\left(60\frac{\text{min}}{\text{h}}\right)\left(1\frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}\right) = 5000\frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}$

$C_{\text{air loop}} = \dot{m}c_p = \left(1200\frac{\text{ft}^3}{\text{min}}\right)\left(.075\frac{\text{lb}}{\text{ft}^3}\right)\left(60\frac{\text{min}}{\text{h}}\right)\left(.24\frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}\right) = 1296\frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}$

C_{min} = lesser of C_H or C_A = $1296 \frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}$

UA bldg = (from worksheet D) = $956 \frac{\text{Btu}}{\text{h}\cdot{}^\circ\text{F}}$

$$\frac{UA}{C_{min}\,\varepsilon_L} = \frac{956}{(1296)(.80)} = .92$$

K_4 = (from Figure A-15) = .95

4.2 SOLAR HEATING AND DOMESTIC HOT WATER SYSTEM - AIR WORKING FLUID

Our example is the solar air heating system shown in Figure A-22. The system is designed to provide space heating and domestic hot water. This system has three modes of operation. Mode 1 occurs when solar energy is available for collection and there is a space heating load. Then, room temperature air is drawn through the solar collectors, heated, and returned to the building. The dampers will be in position 1. Mode 2 occurs when solar energy is available for collection at times when there is no space heating load. Air from the bottom of the pebble bed is drawn through the solar collectors, heated, and returned to the top of the storage unit. The hot air moving down through the bed heats the pebbles resulting in sensible heat storage. The dampers will be in position 2. Mode 3 occurs when no solar energy can be collected but there is a space heating load. Hot air is drawn from the top of the pebble bed into the house and room temperature air is returned to the bottom of the bed. The dampers will be in position 3. In modes 1 and 3, auxiliary energy from a conventional furnace may supplement the solar contribution. The diagram indicates the dampers in the mode 1 position.

The mode of operation of the solar air heating system is determined by the position of the dampers. Whenever the collector is operating, damper A is in position 1, 2; otherwise, it is in position 3. The collector operation is controlled by an on-off differential controller monitoring the temperatures of the air in the collector outlet manifold, t_o, and in the bottom of the pebble bed, t_n, as indicated in Eq. 37.

$$t_o - t_n \leq \Delta t_1 \qquad \text{Collector is operating}$$

$$t_o - t_n \leq \Delta t_2 \qquad \text{Collector is off} \tag{37}$$

Δt_1 and Δt_2 are controller deadbands* ideally chosen so that the energy collected is at least equivalent to the energy required to operate the blower. Both Δt_1 and Δt_2 have been chosen to be 9°F in the examples noted here.

Dampers B and C are controlled by the building thermostat. Whenever the building needs heat, damper B is in position 1 or 3 and damper C is in position 1, 3, Figure A-22 otherwise they are in position 2. The modeling method used, which is suitable for long-term simulation, does not follow the system mode changes exactly, but rather assumes that during any time period, the system operates in whatever modes necessary to maintain the building temperature at the desired level. Then by comparing energy rates, it is possible to determine the fraction of the time period in which the system operated in each mode.

During each time period, the rate of energy collection is compared with the rate of energy required to meet the heating load. If there is zero energy collection, the system is assumed to be in mode 3 operation. If the rate of energy collection is non-zero, but smaller than the rate of energy required by the load, it is assumed that the system is in mode 1 operation. If the rate of energy collection is greater than the rate at which energy is required, the fraction of the time period which the system would have to be in mode 1 operation to just satisfy the load is calculated; the system is assumed to be in mode 2 operation during the remainder of the period. This method of calculating system performance allows the simulation to use time steps on the order of an hour without a sacrifice in the accuracy of the calculated long-term system performance.

Grand Junction, Colorado has been selected as the location of the example problem as it represents a city with major winter heating requirements and a significantly different set of solar radiation conditions from the previous example. Project data for the example are presented in Worksheet A.

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*Deadband - Temperature range over which the controller does not initiate or terminate operation of the fan.

4.2 (Continued)

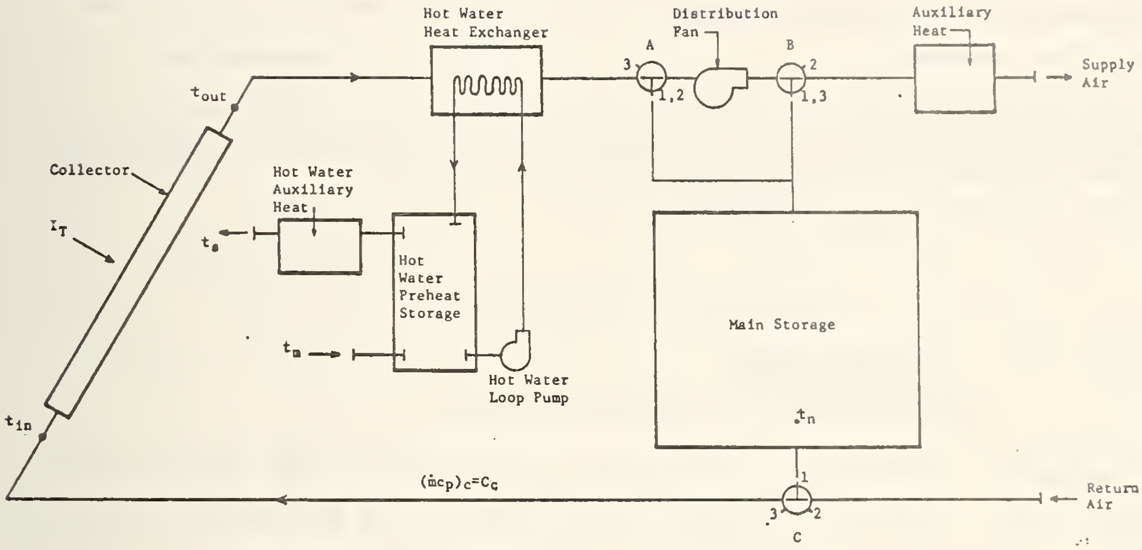

Figure A-22 Air System: Space Heating and Domestic Hot Water

WORKSHEET A PROJECT DATA

PROJECT Air H & DHW Example, Grand Junction, Colo.

Location Grand Junction, Colo. Latitude = 39 °

Building Heating and/or Hot Water Load

Design Heat Loss Rate, q_d	= 53,000	Btu/h
Winter Design Temperature (97 1/2%), t_w	= 11	°F
Average Hot Water Consumption (may vary on a monthly basis)	= 85	gal/day
Average Cold Water Supply (main) Temp., t_m (may vary on a monthly basis)	= 55	°F
Hot Water Supply Temp., t_s	= 140	°F

Collector Subsystem Data

Collector Type: Flat Plate ,

Selective or non-selective, no. cover plates 2

Collector Area, A_c	= 700	ft^2
Tilt Angle	= 54	°
Azimuth Angle	= S=180	°
Collector Shading (av. % month of Dec.)	= 0	%
Collector Efficiency Data (from manufacture): $F_R(\tau\alpha)_n$	= .69	
$F_R U_L$	= .65	$Btu/h \cdot ft^2 \cdot °F$

Reference Temp. Basis: t_{in}, $\frac{t_{in} + t_{out}}{2}$, t_{out}

Fluid:

Composition: Air

Specific Heat, c_p	= .24	Btu/lb·°F
Specific Gravity (if applicable)	= N/A	lb/lb
Volumetric Flow Rate	= 1500	gal/min or ft^3/min

Storage Subsystem Data

Volume	= 400	gal or ft^3

Storage Medium Rock

Specific Heat, c_p	= 0.2	Btu/lb·°F
~~Specific Gravity/or~~ Density	= 100	lb/lb or lb/ft^3
Circulation Loop Volumetric Flow Rate	= 1500	gal/min or ft^3/min
Collector/Storage Heat Exchange Effectiveness, ε_{cs}	= 1.0	
Hot Water Preheat Storage Volume	= 80	gal

Load Subsystem Data

Load Heat Exchanger Effectiveness, ε_L	= N/A	
Supply Loop Volumetric Flow Rate	= N/A	gal/min
Building Air Supply Volumetric Flow Rate	= 1500	ft^3/min

4.2 (Continued)

1. Fraction of Total Heating Load Supplied by Solar Energy, F_{Annual}

The values and calculations developed in this section are tabulated on Worksheet B.

1.1 Monthly Fraction (f)

By locating the system parameters D_1 and D_2 on figure A-5, (f) can be determined on a monthly basis. D_1 and D_2 are taken from Worksheet C, L is from Worksheet D and S from Worksheet E. For February, the value for (f) was 0.76 and is tabulated in Worksheet B.

1.2 Annual Fraction (F_{Annual})

1.2.1 The solar energy supplied for the example month of February is,

$$E_{Feb} = (f_{Feb})\ (L_{Feb})$$
$$= (0.76)\ (16.2 \times 10^6) = 12.31 \times 10^6 \text{Btu}$$

The total solar energy supplied for the entire year is calculated on Worksheet B

1.2.2 The total heating load for the entire year is calculated on Worksheet B

1.2.3 F_{Annual} for the entire year is equal to,

$$F_{Annual} = \frac{E_{Total}}{L_{Total}} = \frac{87.17\text{x}10^6}{112.5\text{x}10^6} = .77$$

2. System Performance Parameters, D_1, D_2

The values and calculations developed in this section are calculated on Worksheet C.

The parameters D_1 and D_2 are obtained from equations 5 and 6.

For the month of February this is done as follows:

$$D_1 = \left[\frac{A_c F_R' \ (\overline{\tau\alpha})\ S}{L}\right] \times K_4 = (D_{1\,prod})\ \frac{S}{L} = (700)\ (.48)\ (1.0)\ \frac{S}{L}$$
$$= 322\ \frac{S}{L} = 322\ \frac{56.3\text{x}10^3}{16.2\text{x}10^6} = 1.12$$

$$D_2 = \left[\frac{A_c F_R' U_L (t_{ref} - t_o)\ \Delta\text{time}}{L}\right] \times K_1 \times K_2 \times K_3 = (D_{2\,prod})\ \left[\frac{(212-t_o)\ \Delta\text{time}}{L}\right] \times K_3$$
$$= \left[(700)\ (.51)\ (1.04)\ (1.05)\right]\left[\frac{(212-t_o)\ \Delta\text{time}}{L}\right] \times K_3$$
$$= (389.8)\ \left[\frac{(212-35)672}{16.2\text{x}10^6}\right] \times 1.0 = 2.86$$

WORKSHEET B FRACTION OF TOTAL HEATING LOAD SUPPLIED BY SOLAR ENERGY, F_{Annual}

PROJECT Air H's DHW Example
Grand Junction, Colo.

	1	2	3	4	5
Month	Tot. Mo. Htg. Load L Btu/mo.	System Parameters D_1	System Parameters D_2	Solar Fraction/ mo. f	Actual Solar en/mo E Btu/mo.
Jan.	21.3×10^6	.76	2.52	.55	11.72×10^6
Feb.	16.2	1.07	2.86	.76	12.31
March	13.6	1.48	3.56	.92	12.51
April	8.0	2.30	5.47	1.0	8.0
May	4.2	4.31	10.08	1.0	4.2
June	2.1	8.88	18.18	1.0	2.1
July	1.9	9.91	19.84	1.0	1.9
Aug.	1.9	9.96	20.15	1.0	1.9
Sept.	2.3	9.38	17.21	1.0	2.3
Oct.	6.9	2.98	6.47	1.0	6.9
Nov.	14.4	1.21	3.31	.80	11.52
Dec.	19.7	.85	2.66	.60	11.82

$L_{tot} = 112.5 \times 10^6$

$E_{tot} = 87.17 \times 10^6$

$$F_{Annual} = \frac{E_{tot}}{L_{tot}} = \frac{87.17 \times 10^6}{112.5 \times 10^6} = .77$$

1. From Worksheet D
2. From Worksheet C
3. From Worksheet C
4. From "f chart"
5. E = f x L

WORKSHEET C SYSTEM PERFORMANCE PARAMETERS D_1, D_2 PROJECT Air H : DHW Example, Grand Junction, Colo.

	1	2		3	4			5	6
Month	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo·ft^2)	Total Heating Load L Btu/Mo.	S/L	D_1	Mo. Av. Day Time Temp. t_o °F	$212-t_o$ °F	Tot. Hrs in Mo. Δ time hr.	K_3	D_2
Jan.	50.5 x 10^3	21.3 x 10^6	2.37 x 10^{-3}	.76	27	185	744	1.0	2.52
Feb.	54.2	16.2	3.34	1.07	35	177	672		2.86
March	62.4	13.6	4.59	1.48	45	167	744		3.56
April	57.1	8.0	7.14	2.30	56	156	720		5.47
May	56.3	4.2	13.40	4.31	66	146	744		10.08
June	52.9	2.1	25.57	8.88	76	136	720		18.18
July	58.5	1.9	30.79	9.91	82	130	744		19.84
Aug.	58.8	1.9	30.95	9.96	80	132	744		20.15
Sept.	67.0	2.3	29.13	9.38	71	141	720		17.21
Oct.	64.0	6.9	9.27	2.98	58	154	744		6.97
Nov.	54.4	14.4	3.77	1.21	42	170	720		3.31
Dec.	52.1	19.7	2.64	.85	31	181	744		2.66

A_c = 700 ft^2 Given data
$F'_R(\overline{\tau\alpha})$ = .46 Worksheet F
$F'_R U_L$ = .51 worksheet F
K_1 = 1.04 Worksheet G
K_2 = 1.05 Worksheet G
K_4 = 1.0 Worksheet G

1. From Worksheet E
2. From Worksheet D
3. $D_1 = \left[\dfrac{A_c\ F'_R\ (\overline{\tau\alpha})\ S}{L}\right] \times K_4 = (D_1 \text{ prod.}) \dfrac{S}{L} = 322 \dfrac{S}{L}$

   Where: D_1 prod. $= \left[A_c\ F'_R\ (\overline{\tau\alpha})\right] \times K_4 = (700)(.46)(1.0) = 322$
4. From Sec. 5 Table A-4
5. From Table A-14 and Worksheet G
6. $D_2 = \left[\dfrac{A_c\ F'_R\ U_L\ (t_{ref} - t_o)\ \Delta time}{L}\right] \times K_1 \times K_2 \times K_3 = (D_2 \text{ prod.}) \left[\dfrac{(212 - t_o)\ \Delta time}{L}\right] \times K_3 = 389.8 [\ \ ] \times K_3$

   Where: D_2 prod. $= (A_c\ F'_R\ U_L) \times K_1 \times K_2 = (700)(.51)(1.04)(1.05) = 389.8$

3 Total Building Heating and Domestic Hot Water Load, L

The total heating load is equal to the sum of the space heating load and the domestic hot water heating load. Worksheet D is used for load calculations.

3.1 Space Heating Load

3.1.1 Knowing the building thermal characteristics (heat transfer coefficients and areas of surfaces exposed to the outside) and using Manual J, the design temperature difference (Δt_d) and design heat loss (q_d) were found to be 59°F and 53,000 Btu/h respectively. These are recorded on Worksheet A. An example of the Manual J calculation is presented in Figure A-23 for the example house of 1400 sq. ft. floor area.

3.1.2 Monthly total degree days (DD) for Grand Junction were taken from the Table A-3 in section 5.

3.1.3 Monthly space heating load (Q_s) was then calculated using equations 7 and 8. In February for example,

$$Q_s = (PF)\ (24)\ (UA)\ (\text{Degree Days})$$

where:

$$PF = 0.75$$

$$UA = \frac{q_d}{\Delta t_d} = \frac{53{,}000\ \text{Btu/hr}}{59°\text{F}} = 898\ \frac{\text{Btu}}{\text{h}\cdot°\text{F}}$$

$$Q_s(\text{Feb}) = (0.75)\ (24)\ (898)\ (907) = 14.5 \times 10^6\ \text{Btu}$$

3.2 Domestic Hot Water Heating Load

3.2.1 In this example, the hot water requirements are 85 gallons per day. Monthly requirements are then,

$$85\ \frac{\text{gal}}{\text{Day}} \quad \times \quad N\ \frac{\text{Days}}{\text{Month}}$$

Values obtained are tabulated in Worksheet D for the example problem. In February for example,

$$(85)\ (28) = 2380\ \frac{\text{gal}}{\text{month}}$$

3.2.2 Water main temperature t_m = 55°F.

3.2.3 Domestic hot water supply temperature (t_s) in accordance with MPS requirement, was assumed to be set at (t_s = 140°F).

3.2.4 Monthly domestic hot water heating load (Q_w) is then,

$$Q_w = mc_p\ (t_s - t_m)$$

where c_p is the specific heat of water [c_p = 1Btu/(lb·°F)]. Q_w is then calculated on a monthly basis and tabulated in Worksheet D. In February for example,

$$Q_w = \left(2380\ \frac{\text{gal}}{\text{month}}\right) \left(8.33\ \frac{\text{lb}}{\text{gal}}\right) \left(1\ \frac{\text{Btu}}{\text{lb}\cdot°\text{F}}\right) (140°\text{F} - 55°\text{F}) = 1.68 \times 10^6\ \text{Btu}$$

4.2 (Continued)

3.3 Total Heating Load (L) is then the sum of space heating (Q_s) and water heating (Q_w).

$$L = Q_s + Q_w$$

In February for example,

$$L = 14.5 \times 10^6 \text{ Btu} + 1.68 \times 10^6 \text{ Btu} = 16.2 \times 10^6 \text{ Btu}$$

Values of L for each month are tabulated in Worksheet D for the example problem.

4 Solar Energy Available (Incident Solar Radiation), S

4.1 Monthly Averages of the Daily Radiation Incident on a Horizontal Surface ($\overline{I}_H$), were taken from Table A-4, section 5 and are tabulated in Worksheet E for the example problem.

4.2 Monthly values for $\overline{K}_t$ were taken from Table A-4, section 5 and are also tabulated in Worksheet E.

4.3 Knowing the collector tilt ($\Theta = 54°$), the latitude ($\phi = 39°$), and monthly $\overline{K}_t$ values; monthly $\overline{R}$ values were taken from Table A-6, section 5 and tabulated in Worksheet E.

For instance, in February, $\overline{K} = .63$. Referring to Table A-6 ($\overline{K}_t = .6$) and determining the latitude minus tilt difference ($\phi - \Theta = 39° - 54° = -15°$) the $\overline{R}$ value under the February column opposite latitude 40° is $\overline{R} = 1.68$.

Interpolating for $\overline{K}_t = .63$ and $\phi = 39°$ gives a value of $\overline{R} = 1.66$.

4.4 Monthly Average Daily Radiation on a Tilted Surface ($\overline{I}_T$) is calculated using equation 12.

$$\overline{I}_T = (\overline{I}_H)\ (\overline{R})$$

and tabulated in Worksheet E. For example, in February,

$$\overline{I}_T = (1211)\ (1.66) = 2010 \frac{\text{Btu}}{\text{Day}\cdot\text{ft}^2}$$

4.5 Total Average Insolation per Month (S) is calculated using equation 13.

$$S = (\overline{I}_T)\ (N)$$

where N is the number of days in the month. S is then tabulated in Worksheet E. For example, in February,

$$S = \left(2010 \frac{\text{Btu}}{\text{Day}\cdot\text{ft}^2}\right) \times \left(28 \frac{\text{Days}}{\text{Month}}\right)$$

$$= 56.3 \times 10^3 \frac{\text{Btu}}{\text{Month}\cdot\text{ft}^2}$$

4.6 Assume no shading of the collector array in this example.

1	Name of Room					Entire House			1 LIV			2 HALL'D' & DIN			3 LAUN			4 HALL'C' & KIT			5 BATH #1		
2	Running Ft Exposed Wall								21			12 & 13			11 & 7			11			9		
3	Room Dimensions, Ft								14 x 21			7x18 & 4x4			7x11			8x11 & 3x17			6x8 & 3x5		
4	Ceiling Ht, Ft		Directions Room Faces						8	W		8	N & W		8	N & E		8	E		8	E	
	TYPE OF EXPOSURE		Const. No.	HTM Htg	HTM Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg
5	Gross	a	8(d)	5					168			104			56			88			72		
	Exposed	b	10(c)	10								96			88								
	Walls and	c	11(a)	36																			
	Partitions	d	11(f)	5																			
6	Windows	a	2(c)	65														11	560		8	400	
	and Glass	b	4(b)	105					40	3320		20	1650										
	Doors (Htg)	c	3(a)	195																			
7	Windows		North																				
	and Glass		E&W or NE & NW																				
	Doors (Clg)		South or SE & SW																				
8	Other Doors		7(b)	180											17	2430							
9	Net	a	8(d)	5					128	510		84	330		39	150		77	290		64	250	
	Exposed	b	10(c)	10								96	760		88	700							
	Walls and	c	11(a)	36																			
	Partitions	d	11(f)	5																			
10	Ceilings	a	12(c)	6					294	1390		142	660		77	360		139	650		63	300	
		b																					
11	Floors	a	17	2																			
		b																					
12	Ventilation		22	80		60	3800																
13	Sub Total Btuh Loss						3800			5220			3400			3640			1500			950	
14	Duct Btuh Loss																						
15	Total Btuh Loss						53,000																
16	People @ 300 and Appliances 1200																						
17	Sensible Btuh Gain (Structure)																						
18	Duct Btuh Gain																						
19	Sum of Lines 17 and 18 (Cl2)																						
20	Total Btuh Gain (Line 19 x 1.3)			1.3																			
21	Btuh for Air Quantities																						

5 BR #3			7 BR #2			8 BATH #2			9 BR #1			10 HALL 'A' & 'B'			11 REC RM			12 WORK & UTIL			1
10			24			5			29			7			82			74			2
10x11 & 3x6			10x14 & 2x5			5x5			14x15, 2x5, & 3x6			4x14, 3x5, ~~4x20~~ 2x4, 1x3, 2x3			23x28 & 8x16			19x28 & 8x12			3
8	E		8	S & E		8	S		8	S & W		8	W		3/5	E, S, & W		3/5	W, N, & E		1
Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	Area or Length	Btuh Htg	Btuh Clg	
80			192			40			232			56									5
															246			222			
															410			370			
22	1140		28	1420		8	400		28	1450											6
															16	2470		4	620		
																					7
												20	2870								8
58	230		164	650		32	120		204	810		36	140								9
															230	7130		218	6190		
															410	1620		370	1440		
128	610		150	700		25	110		238	1140		168	790		28	130					10
															772	1230		628	1000		11
																					12
	1980			2770			630			3400			3800			12580			9250		13
																					14
																					15
																					16
																					17
																					18
																					19
																					20
																					21

Figure A-23 Example Heat Loss Rate Calculation (Manual J)

WORKSHEET D HEATING AND/OR DOMESTIC HOT WATER LOAD, L

PROJECT Air H & DHW Example
Grand Junction, Colo.

	1	2		3		4	5	6
Month	Monthly Degree Days DD °F·days	Monthly Space Htg Load Qs Btu/Mo.	No. of Days/ Mo. N	Vol. of DHW Used/Mo. Gal./Mo.	Temp. Water Main Sup. t_m °F	DHW Temp. Rise $t_s - t_m$ °F	Monthly DHW Load Q_w Btu/Mo.	Total Heating Load L Btu/Mo.
Jan.	1209	19.4 x 10^6	31	2635	55	85	1.86 x 10^6	21.3 x 10^6
Feb.	907	14.5	28	2380			1.68	16.2
March	729	11.7	31	2635			1.86	13.6
April	387	6.2	30	2550			1.80	8.0
May	146	2.3	31	2635			1.86	4.2
June	21	0.3	30	2550			1.80	2.1
July	0	0	31	2635			1.86	1.9
Aug.	0	0	31	2635			1.86	1.9
Sept.	30	0.5	30	2550			1.80	2.3
Oct.	313	5.0	31	2635			1.86	6.9
Nov.	786	12.6	30	2550			1.80	14.4
Dec.	1113	17.4	31	2635			1.86	19.7

q_d = 53,000 Btu/h

(Given data or calculate from Manual J or equivalent.)

$\Delta t_d = 70 - t_w$

$= 70 - 11 = 59°$

Where: t_w = 97 1/2% winter design temperature

(From ASHRAE Fundamentals, Table A-3, section 5 or known weather data.)

70° = indoor design temperature

$UA = \frac{q_d}{\Delta t_d} = \frac{53{,}000 \text{ Btu/h}}{59\ °F} = 898 \frac{\text{Btu}}{\text{h}\cdot °F}$

t_s = 140 °F

1. From ASHRAE Systems, Climatic Atlas or Table A-3, section 5.
2. Q_s = (PF)(24)(UA)(Degree Day) = (.75)(24)(898) x (Degree Day) = 16,164 x DD
   Where: PF = 0.75 or more appropriate value.
3. (Vol/day) (no. days/mo.) = 85 (gal./day) (no. days/mo.)
4. May be constant or may vary.
5. Q_w = (vol. of water) x 8.33 x 1 x ($t_s - t_m$).
6. $L = Q_s + Q_w$

WORKSHEET E TOTAL MONTHLY SOLAR RADIATION AVAILABLE, S

PROJECT Air H; DHW Example, Grand Junction Colo.

	1	2	3	4	5		6
Month	Horizontal Insolation $\overline{I}_H$ Btu/(Day·ft^2)	Extra-terrestrial Insolation $\overline{I}_o$ Btu/(Day·ft^2)	Ratio Horizontal to Extra-terrestrial $\overline{K}_t$	Ratio Horizontal to Tilt $\overline{R}$	Monthly Avg. Daily Rad. on Tilt Surf. $\overline{I}_T$ Btu/(Day·ft^2)	No. of Days in Month N	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo · ft^2)
Jan.	848	N/A	.60	1.92	1628	31	50.5 x 10^3
Feb.	1211		.63	1.60	1938	28	54.2
March	1623		.64	1.24	2012	31	62.4
April	2002		.63	.95	1902	30	57.1
May	2300		.64	.79	1817	31	56.3
June	2645		.70	.73	1930	30	57.9
July	2518		.69	.75	1888	31	58.5
Aug.	2157		.65	.88	1898	31	58.8
Sept.	1958		.71	1.14	2232	30	67.0
Oct.	1395		.65	1.48	2064	31	64.0
Nov.	970		.59	1.87	1814	30	54.4
Dec.	793		.62	2.12	1681	31	52.1

1. From Table A-4 or Fig. A-29 section 5, or known data.
2. From Table A-5 section 5, used only for eq. 11.
3. From Table A-4 section 5, or eq. 11.
4. From Table A-6 section 5, latitude ($\emptyset$) = 39 °, with collector tilt (θ) = 54 °, and latitude - tilt = -15 °.
5. From eq. 12, $\overline{I}_T + (\overline{I}_H)(\overline{R})$.
6. From eq. 13, $S = (\overline{I}_T)(N)$.

4.2 (Continued)

5 Collector Combined Performance Characteristics $F_R'(\overline{\tau\alpha})$, $F_R'U_L$

The values and calculations developed in this section are tabulated in Worksheet E.

5.1 Collector Performance Characteristics, $F_R(\tau\alpha)_n$, F_RU_L

The collectors are constructed with a double glass cover plate and an aluminum parallel flow absorber coated with a non-selective flat black paint. Area of collector $A_c = 700\ ft^2$.

In this case the collector manufacturer has provided a thermal performance efficiency curve as shown below for the collector, operating with a volumetric flow rate of 2.1 $ft^3/min \cdot ft^2$ and with reference temperature equal to fluid outlet temperature. This corresponds to case 3 in the calculation method and the performance characteristics are calculated in case 3 on Worksheet F.

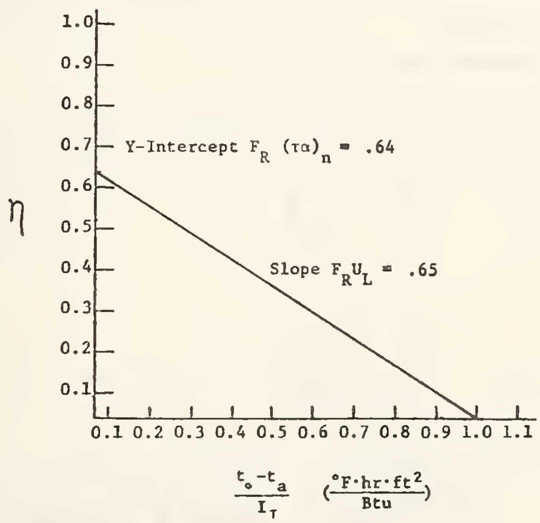

Figure A-24

5.2 Incident Angle Modifier, $\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}$

The incident angle modifier is calculated on Worksheet F.

5.3 Collector Loop Heat Exchanger Modifier, $\frac{F_R'}{F_R}$

The collector loop heat exchanger modifier is calculated on Worksheet F.

6 Correction Factors, K_1, K_2, K_3, K_4

Correction factors K_1, K_2, K_3, K_4 are calculated on Worksheet G.

WORKSHEET F COLLECTOR COMBINED PERFORMANCE CHARACTERISTICS, $F_R'(\overline{\tau\alpha})$, $F_R'U_L$

PROJECT: Air H & DHW Example, Grand Junction, Colo.

(3.5.1) Collector Efficiency Data From Test

intercept, $b = F_R(\tau\alpha)_n$ = .64

slope, $m = F_R U_L$ = .65 Btu/h·ft²·°F

Reference Temperature Basis: 1. t_{in}, 2. $\frac{t_{in} + t_{out}}{2}$, 3. t_{out}

Collector area, A_c = 700 ft²

Collector volumetric flow rate = 1500 ft³/min

Correction to t_{in} basis:

Case 1: (no correction) $F_R(\tau\alpha)_n$ =

$F_R U_L$ =

Case 2: $F_R(\tau\alpha)_n = b \times \left[\frac{1}{1 + \frac{mA_c}{2C_c}}\right]$ =

$F_R U_L = m \times \left[\frac{1}{1 + \frac{mA_c}{2C_c}}\right]$ =

$C_c = \dot{m}c_p = \begin{pmatrix}\text{volumetric}\\\text{flow rate}\end{pmatrix} \begin{pmatrix}\text{density}\end{pmatrix} \begin{pmatrix}\text{time}\\\text{conversion}\end{pmatrix} \begin{pmatrix}\text{specific}\\\text{heat}\end{pmatrix}$

$= \left(1500 \frac{ft^3}{min}\right)\left(.075 \frac{lb}{ft^3}\right)\left(60 \frac{min}{h}\right)\left(.24 \frac{Btu}{lb \cdot °F}\right) = 1620 \frac{Btu}{h \cdot °F}$

where: for liquids, density $= (8.33\ lb/gal) \times \begin{pmatrix}\text{specific}\\\text{gravity}\end{pmatrix}$

for air, density = 0.75 lb/ft^3, at 70° and 1 atm.

specific heat = 0.24 Btu/lb·°F

Case 3: $F_R(\tau\alpha)_n = b \times \left[\frac{1}{1 + \frac{mA_c}{C_c}}\right] = .64 \frac{1}{1 + \frac{(.65)(700)}{1620}} = .50$

$F_R U_L = m \times \left[\frac{1}{1 + \frac{mA_c}{C_c}}\right] = .65 \frac{1}{1 + \frac{(.65)(700)}{1620}} = .51 \frac{Btu}{h \cdot ft^2 \cdot °F}$

(3.5.2) Incident Angle Modifier, $\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}$ = $\begin{cases} .91, & \text{for two cover plates} \\ .93, & \text{for one cover plate} \end{cases}$

4.2 (Continued)

WORKSHEET F (Continued)

(3.5.3) Collector Loop Heat Exchanger Modifier, $\frac{F'_R}{F_R}$

for air systems and liquid systems without a collector/storage heat exchanger,

$$\frac{F'_R}{F_R} = 1$$

Capacitance Rate

C_c = (from above) =

C_s = (calc. as for C_c above) =

C_{min} = (lesser of C_c of C_s) =

Collector Storage Heat Exchanger Effectiveness, ε_{cs} =

$$x = \frac{C_c}{\varepsilon_{cs}\ C_{min}} =$$

$$y = \frac{A_c(F_R U_L)}{C_c} =$$

$$\frac{F'_R}{F_R} = \text{from figure A-11 or} = \frac{1}{1 + y(x-1)} = 1.0$$

(3.5.4) $F'_R\ (\overline{\tau\alpha}) = F_R(\overline{\tau\alpha})_n \times \left[\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}\right] \times \left[\frac{F'_R}{F_R}\right] = (.50)(.91)(1.0) = .46$

$F'_R U_L = F_R U_L \times \left[\frac{F'_R}{F_R}\right] = .51$

WORKSHEET G CORRECTION FACTORS, K_1, K_2, K_3, K_4

PROJECT Air H: DHW Example, Grand Junction, Colo.

Air Collector Flow Capacitance Rate Factor, K_1

for liquid collectors K_1 = 1.0

for air collectors: C_c = (from worksheet F) = 1620 Btu/h · °F

A_c = (from worksheet A) = 700 ft²

$$\frac{C_c}{A_c} = \frac{1620}{700} = 2.31 \frac{Btu}{h \cdot ft^2 \cdot °F}$$

K_1 = (from Figure A-12) = 1.04

Storage Mass Capacitance Factor, K_2

M = (vol. storage media) x (density) = (400 ft³)(100 lb/ft³) = 40,000 lb (rock)

Note: M includes hot water storage volume where it is solar heated. (80 gal)(8.33 lb/gal) = 666 lb (water)

c_p = (from worksheet A) = .2 Btu/lb (rock), 1 Btu/lb (water)

$$\frac{(Mc_p)_s}{A_c} = \frac{(40,000 \times .2) + (66.6 \times 1)}{700} = 12.4$$

K_2 = (from Figure A-13) = 1.05

Hot Water Factor, K_3

for liquid systems providing heating only or heating and hot water, and for all air systems K_3 = 1.0

for DHW only systems: t_s = (from worksheet A) = °F

t_m = (from worksheet A or if variable see worksheet D) = °F

t_o is taken from table A-4 section 5

K_3 is taken from figure A-14 and tabulated on a monthly basis on worksheet C

K_3 = (tabulated or const.) = 1.0

Load Heat Exchange Factor, K_4

for air systems and DHW only systems, K_4 = 1.0

ε_L = (from worksheet A) =

$C_{\text{hot water supply loop}} = \dot{m}c_p$ =

$C_{\text{air loop}} = \dot{m}c_p$ =

C_{min} = lesser of C_H or C_A =

UA bldg = (from worksheet D) =

$$\frac{UA}{C_{min}\ \varepsilon_L} =$$

K_4 = (from Figure A-15) = 1.0

4.3 SOLAR DOMESTIC HOT WATER SYSTEM - LIQUID WORKING FLUID

Our typical example of solar energy systems for a domestic hot water heating application is a relatively simple device consisting of a collector, hot water storage or preheater tank and associated pumps, piping and controls as depicted in Figure A-25. The design of a solar energy hot water heater differs from a building air-conditioning system because the demand is not a function of seasonal ambient temperature and the collector operating temperature can be lower. Either liquid or air collecting systems are available for use with domestic hot water heating.

The City of Fort Worth was selected for the hot water calculation example because it represents a climatic region with varying seasonal water main temperatures and it has a relatively warm climate in contrast to the other examples. Utilizing the average monthly water main temperature in Table A-8 and assuming a constant hot water demand of 70 gallons per day for the year at a design storage temperature of 140°F resulted in average daily and monthly loads significantly higher in winter than in summer. The large winter load resulted in selecting a collector tilt angle of latitude plus 15° ($\Theta = 48°$) to position the collector more normal to the sun in the winter.

A single glazed flat black type collector was chosen because of the relatively high ambient temperature conditions and the resultant good thermal performance in the range of 100 to 140°F. The use of corrosion inhibited water with the collector loop implies the need for a double wall heat exchanger to transfer the heat to the stored domestic hot water.

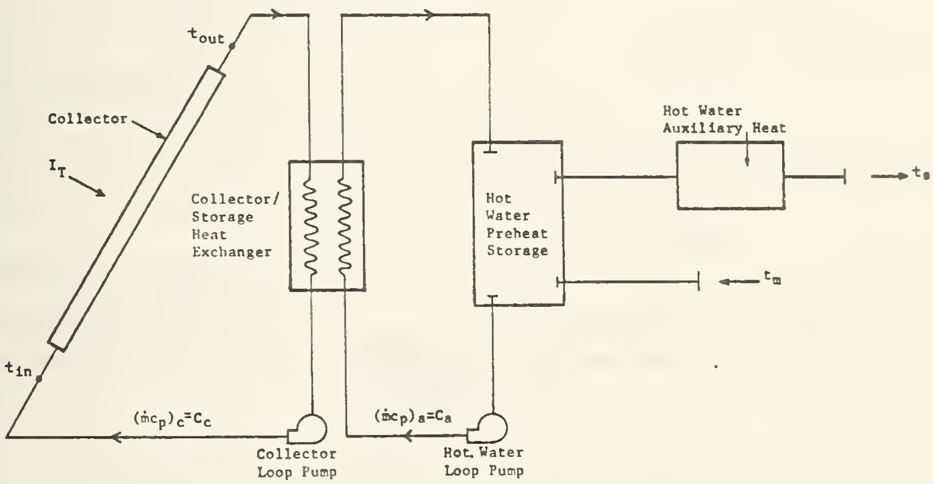

Figure A-25 Liquid System: Domestic Hot Water Only

WORKSHEET A PROJECT DATA

PROJECT DHW Example, Ft. Worth, Tx

Location Ft. Worth, Tx Latitude = 32°-50'

Building Heating and/or Hot Water Load

Design Heat Loss Rate, q_d	=		Btu/h
Winter Design Temperature (97 1/2%), t_w	=		°F
Average Hot Water Consumption (may vary on a monthly basis)	=	70	gal/day
Average Cold Water Supply (main) Temp., t_m (may vary on a monthly basis)	=	see D	°F
Hot Water Supply Temp., t_s	=	140	°F

Collector Subsystem Data

Collector Type: Flat Plate,

Selective or non-selective, no. cover plates 1

Collector Area, A_c	=	56	ft^2
Tilt Angle	=	48	°
Azimuth Angle	=	S=180	°
Collector Shading (av. % month of Dec.)	=	0	%
Collector Efficiency Data (from manufacture): $F_R(\tau\alpha)_n$	=	.81	
F_RU_L	=	1.35	$Btu/h\cdot ft^2\cdot °F$

Reference Temp. Basis: t_{in}, $\frac{t_{in} + t_{out}}{2}$, t_{out}

Fluid:

Composition: water

Specific Heat, c_p	=	1.0	Btu/lb·°F
Specific Gravity (if applicable)	=	1.0	lb/lb
Volumetric Flow Rate per sq. ft. of collector	=	1.8	gal/ft²·h ~~gal/min or ft³/min~~

Storage Subsystem Data

Volume	=		gal or ft^3
Storage Medium			
Specific Heat, c_p	=		Btu/lb·°F
Specific Gravity/or Density	=		lb/lb or lb/ft^3
Circulation Loop Volumetric Flow Rate	=	1.8	gal/min or ft^3/min
Collector/Storage Heat Exchange Effectiveness, ε_{cs}	=		
Hot Water Preheat Storage Volume	=	110	gal

Load Subsystem Data

Load Heat Exchanger Effectiveness, ε_L	=		
Supply Loop Volumetric Flow Rate	=		gal/min
Building Air Supply Volumetric Flow Rate	=		ft^3/min

4.3 **(Continued)**

1. Fraction of Total Heating Load Supplied by Solar Energy, F_{Annual}

The values and calculations developed in this section are tabulated on Worksheet B.

1.1 Monthly Fraction (f)

By locating the system parameters D_1 and D_2 on figure A-6, (f) can be determined on a monthly basis. D_1 and D_2 are taken from Worksheet C, L is from Worksheet D and S from Worksheet E. For February, the value for (f) was 0.76 and is tabulated in Worksheet E.

1.2 Annual Fraction (F_{Annual})

1.2.1 The solar energy supplied for the example month of February is,

$$E_{Feb} = (f_{Feb})\ (L_{Feb})$$
$$= (0.65)\ (1.486 \times 10^6) = .966 \quad \times 10^6 \text{Btu}$$

The total solar energy supplied for the entire year is calculated on Worksheet B

1.2.2 The total heating load for the entire year is calculated on Worksheet B

1.2.3 F_{Annual} for the entire year is equal to,

$$F_{Annual} = \frac{E_{Total}}{L_{Total}} = \frac{11.661 \times 10^6}{15.499 \times 10^6} = .75$$

2. System Performance Parameters, D_1, D_2

The values and calculations developed in this section are calculated on Worksheet C.

The parameters D_1 and D_2 are obtained from equations 5 and 6.

For the month of February this is done as follows:

$$D_1 = \left[\frac{A_c F_R' \ (\tau\alpha)\ S}{L}\right] \times K_4 = (D_{1\ prod})\ \frac{S}{L} = (\ 60\ )\ (.737)\ (1\ )\ \frac{S}{L}$$
$$= (40.88)\ \frac{S}{L} = 40.88 \quad \frac{45.95 \times 10^3}{1.49 \times 10^6} = 1.26$$

$$D_2 = \left[\frac{A_c F_R' U_L (t_{ref} - t_o)\ \Delta time}{L}\right] \times K_1 \times K_2 \times K_3 = (D_{2\ prod})\ \left[\frac{(212 - t_o)\ \Delta time}{L}\right] \times K_3$$
$$= \left[\ 56\ (1.320)\ (1.0)\ (1.0)\ \right] \left[\frac{(212 - t_o)\ \Delta time}{L}\right] \times K_3$$
$$= (73.36) \left[\frac{(212-57)672}{1.49 \times 10^6}\right] \times 1.10 = 5.84$$

WORKSHEET B FRACTION OF TOTAL HEATING LOAD SUPPLIED BY SOLAR ENERGY, F_{Annual}

PROJECT DHW Example
Ft. Worth, Tx.

	1	2	3	4	5
Month	Tot. Mo. Htg. Load L Btu/mo.	System Parameters D_1	System Parameters D_2	Solar Fraction/ mo. f	Actual Solar en/mo E Btu/mo.
Jan.	1.578×10^6	1.27	7.66	.57	0.865×10^6
Feb.	1.486	1.26	5.84	.65	.966
March	1.500	1.54	6.75	.76	1.140
April	1.225	1.69	8.94	.74	.906
May	1.175	1.79	10.11	.75	.881
June	1.032	2.11	11.14	.84	.867
July	1.103	2.00	10.12	.82	.993
Aug.	1.030	2.35	11.41	.90	.927
Sept.	1.032	2.35	11.53	.89	.918
Oct.	1.229	1.99	9.02	.86	1.057
Nov.	1.470	1.50	6.71	.75	1.102
Dec.	1.649	1.17	5.29	.63	1.039

$L_{tot} = 15.50 \times 10^6$

$E_{tot} = 11.66 \times 10^6$

1. From Worksheet D
2. From Worksheet C
3. From Worksheet C
4. From "f chart"
5. E = f x L

$$F_{Annual} = \frac{E_{tot}}{L_{tot}} = \frac{11.66 \times 10^6}{15.50 \times 10^6} = .75$$

WORKSHEET C SYSTEM PERFORMANCE PARAMETERS D_1, D_2 PROJECT DHW Example, Ft. Worth, Tx.

	1	2		3	4			5	6
Month	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo·ft^2)	Total Heating Load L Btu/Mo.	S/L	D_1	Mo. Av. Day Time Temp. t_o °F	$212-t_o$ °F	Tot. Hrs in Mo. Δ time hr.	K_3	D_2
Jan.	47.0 x 10^3	1.518 x 10^6	3.10 x 10^{-2}	1.27	48	164	744	1.30	7.66
Feb.	46.0	1.486	3.09	1.26	52	160	672	1.10	5.84
March	56.5	1.500	3.77	1.54	60	152	744	1.22	6.75
April	50.5	1.225	4.12	1.69	69	143	720	1.45	8.94
May	51.6	1.175	4.39	1.79	76	136	744	1.60	10.11
June	53.3	1.032	5.17	2.11	84	128	720	1.70	11.14
July	54.0	1.103	4.90	2.00	88	124	744	1.65	10.12
Aug.	59.1	1.030	5.74	2.35	89	123	744	1.75	11.41
Sept.	59.3	1.032	5.74	2.35	81	131	720	1.72	11.53
Oct.	59.9	1.229	4.88	1.99	72	140	744	1.45	9.02
Nov.	54.1	1.470	3.67	1.50	59	153	720	1.22	6.71
Dec.	48.7	1.694	2.87	1.17	51	161	744	1.02	5.29

A_c = 56 ft^2 Given data

$F'_R(\overline{\tau\alpha})$ = .730 Worksheet F

$F'_R U_L$ = 1.31 worksheet F

K_1 = 1.0 Worksheet G

K_2 = 1.0 Worksheet G

K_4 = 1.0 Worksheet G

1. From Worksheet E
2. From Worksheet D
3. $D_1 = \left[\frac{A_c\ F'_R\ (\overline{\tau\alpha})\ S}{L}\right] \times K_4 = (D_1 \text{ prod.}) \frac{S}{L} = 40.88 \frac{S}{L}$

   Where: $D_1 \text{ prod.} = \left[A_c\ F'_R\ (\overline{\tau\alpha})\right] \times K_4 = (56)(.730)(1.0) = 40.88$
4. From Sec. 5 Table A-4
5. From Table A-14 and Worksheet G
6. $D_2 = \left[\frac{A_c\ F'_R\ U_L\ (t_{ref} - t_o)\ \Delta\text{time}}{L}\right] \times K_1 \times K_2 \times K_3 = (D_2 \text{ prod.}) \left[\frac{(212 - t_o)\ \Delta\text{time}}{L}\right] \times K_3 = 73.36 [\quad] \times K_3$

   Where: $D_2 \text{ prod.} = (A_c\ F'_R\ U_L) \times K_1 \times K_2 = (56)(1.31)(1.0)(1.0) = 73.36$

3 Total Building Heating and Domestic Hot Water Load, L

The total heating load is equal to the sum of the space heating load and the domestic hot water heating load. Worksheet D is used for load calculations.

3.1 Space Heating Load - Not Applicable

3.2 Domestic Hot Water Heating Load

3.2.1 In this example, the hot water requirements are 70 gallons per day. Monthly requirements are then,

$$\left(70\ \frac{\text{gal}}{\text{Day}}\right) \times \left(\text{N}\ \frac{\text{Days}}{\text{Month}}\right)$$

Values obtained are tabulated in Worksheet D for the example problem. In February for example,

$$(70)\ (28) = 1960\,\frac{\text{gal}}{\text{month}}$$

3.2.2 Water main temperature (t_m), varies and is tabulated on Worksheet D.

3.2.3 Domestic hot water supply temperature (t_s) in accordance with MPS requirements, was assumed to be set at (t_s = 140°F).

3.2.4 Monthly domestic hot water heating load (Q_w) is then,

$$Q_w = mc_p\ (t_s - t_m)$$

where c_p is the specific heat of water [c_p = 1Btu/(lb·°F)]. Q_w is then calculated on a monthly basis and tabulated in Worksheet D. In February for example,

$$Q_w = \left(1960\,\frac{\text{gal}}{\text{month}}\right)\ \left(8.33\ \frac{\text{lb}}{\text{gal}}\right)\ \left(1\ \frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}\right)\ (140^\circ\text{F} - 49^\circ\text{F}) = 1.486\text{x}10^6\text{Btu}$$

3.3 Total Heating Load (L) equals the hot water load (L).

WORKSHEET D HEATING AND/OR DOMESTIC HOT WATER LOAD, L

PROJECT DHW Exampk Ft. Worth TX.

	1	2		3		4	5	6
Month	Monthly Degree Days DD °F·days	Monthly Space Htg Load Qs Btu/Mo.	No. of Days/ Mo. N	Vol. of DHW Used/Mo. Gal./Mo.	Temp. Water Main Sup. t_m °F	DHW Temp. Rise $t_s - t_m$ °F	Monthly DHW Load Q_w Btu/Mo.	Total Heating Load L Btu/Mo.
Jan.	N/A	N/A	31	2170	56	84	1.518×10^6	Same
Feb.			28	1960	49	91	1.486	
March			31	2170	57	83	1.500	
April			30	2100	70	70	1.225	
May			31	2170	75	65	1.175	
June			30	2100	81	59	1.032	
July			31	2170	79	61	1.103	
Aug.			31	2170	83	57	1.130	
Sept.			30	2100	81	59	1.032	
Oct.			31	2170	72	68	1.229	
Nov.			30	2100	56	84	1.470	
Dec.			31	2170	46	94	1.649	

q_d = N/A Btu/h

(Given data or calculate from Manual J or equivalent.)

$\Delta t_d = 70 - t_w$

$= 70 -$ N/A $=$

Where: t_w = 97 1/2% winter design temperature

(From ASHRAE Fundamentals, Table A-3, section 5 or known weather data.)

70° = indoor design temperature

$UA = \frac{q_d}{\Delta t_d} =$ N/A

$t_s =$ 140°F

1. From ASHRAE Systems, Climatic Atlas or Table A-3, section 5.
2. Q_s = (PF)(24)(UA)(Degree Day) = N/A x (Degree Day) =
   Where: PF = 0.75 or more appropriate value.
3. (Vol/day) (no. days/mo.) = 70 (gal./day) (no. days/mo.)
4. May be constant or may vary.
5. Q_w = (vol. of water) x 8.33 x 1 x ($t_s - t_m$).
6. $L = Q_s + Q_w$

4 <u>Solar Energy Available (Incident Solar Radiation), S</u>

4.1 Monthly Averages of the Daily Radiation Incident on a Horizontal Surface ($\overline{I}_H$), were taken from Table A-4, section 5 and are tabulated in Worksheet E for the example problem.

4.2 Monthly values for $\overline{K}_t$ were taken from Table A-4, section 5 and are also tabulated in Worksheet E.

4.3 Knowing the collector tilt (Θ =.48°), the latitude (ϕ =33°), and monthly $\overline{K}_t$ values; monthly $\overline{R}$ values were taken from Table A-6, section 5 and tabulated in Worksheet E.

For instance, in February, $\overline{K}$ = .54 Referring to Table A-6 ($\overline{K}_t$ =.5) and determining the latitude minus tilt difference (ϕ - Θ = 33° -48° = -15°) the $\overline{R}$ value under the February column opposite latitude 33° is $\overline{R}$ = 1.37.

Interpolating for $\overline{K}_t$ = .63 and ϕ = 39° gives a value of $\overline{R}$ = 1.66.

4.4 Monthly Average Daily Radiation on a Tilted Surface ($\overline{I}_T$) is calculated using equation 12.

$$\overline{I}_T = (\overline{I}_H)\ (\overline{R})$$

and tabulated in Worksheet E. For example, in February,

$$\overline{I}_T = (1198)\ (.137) = 1641\ \frac{\text{Btu}}{\text{Day}\cdot\text{ft}^2}$$

4.5 Total Average Insolation per Month (S) is calculated using equation 13.

$$S = (\overline{I}_T)\ (N)$$

where N is the number of days in the month. S is then tabulated in Worksheet E. For example, in February,

$$S = \left(1641\frac{\text{Btu}}{\text{Day}\cdot\text{ft}^2}\right) \times \left(28\ \frac{\text{Days}}{\text{Month}}\right)$$

$$= 45.9 \times 10^3\ \frac{\text{Btu}}{\text{Month}\cdot\text{ft}^2}$$

4.6 Assume no shading of the collector array in this example.

WORKSHEET E TOTAL MONTHLY SOLAR RADIATION AVAILABLE, S

PROJECT *DHW Example, Ft. Worth, Tx.*

	1	2	3	4	5		6
Month	Horizontal Insolation $\bar{I}_H$ Btu/(Day·ft^2)	Extra-terrestrial Insolation $\bar{I}_o$ Btu/(Day·ft^2)	Ratio Horizontal to Extra-terrestrial $\bar{K}_t$	Ratio Horizontal to Tilt $\bar{R}$	Monthly Avg. Daily Rad. on Tilt Surf. $\bar{I}_T$ Btu/(Day·ft^2)	No. of Days in Month N	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo · ft^2)
Jan.	936	N/A	.53	1.62	1516	31	47.0 x 10^3
Feb.	1198		.54	1.37	1641	28	46.0
March	1599		.58	1.14	1823	31	56.5
April	1829		.56	0.92	1683	30	50.5
May	2105		.59	0.79	1663	31	51.6
June	2438		.65	0.73	1780	30	53.3
July	2293		.62	0.76	1743	31	54.0
Aug.	2217		.65	0.86	1907	31	59.1
Sept.	1881		.63	1.05	1975	30	59.3
Oct.	1976		.61	1.31	1933	31	59.9
Nov.	1148		.58	1.57	1802	30	54.1
Dec.	914		.56	1.72	1572	31	48.7

1. From Table A-4 or Fig. A-29 section 5, or known data.
2. From Table A-5 section 5, used only for eq. 11.
3. From Table A-4 section 5, or eq. 11.
4. From Table A-6 section 5, latitude (Ø) = 32°-50', with collector tilt (θ) = 48 °, and latitude - tilt = -15 °.
5. From eq. 12, $\bar{I}_T$ + $(\bar{I}_H)(\bar{R})$.
6. From eq. 13, S = $(\bar{I}_T)(N)$.

4.3 (Continued)

5 Collector Combined Performance Characteristics $F_R'(\overline{\tau\alpha})$, $F_R'U_L$

The values and calculations developed in this section are tabulated in Worksheet F.

5.1 Collector Performance Characteristics, $F_R(\tau\alpha)_n$, F_RU_L

The collectors are constructed with a single glass cover plate and an aluminum parallel flow absorber coated with a non-selective flat black paint. Area of collector A_c = 56 ft^2.

In this case the collector manufacturer has provided a thermal performance efficiency curve as shown below for the collector, operating with a volumetric flow rate of 1.8 gal/ft^2 of collector/hour and with the reference temperature equal to the inlet fluid temperature. This corresponds to case 1 in the calculation method and the performance characteristics are obtained directly as follows:

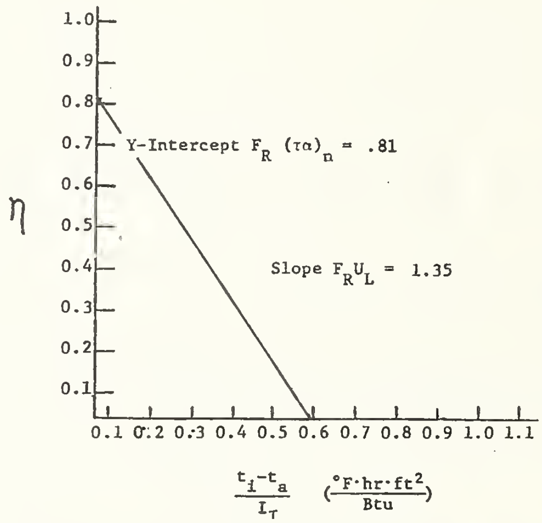

Figure A-26

F_RU_L = .81Btu/h·°F·ft^2 as determined from the slope of the efficiency curve shown in Figure A-26.

$F_R(\tau\alpha)_n$ = 1.35 as determined from the intercept of the efficiency curve with the y axis.

5.2 Incident Angle Modifier, $\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}$

The incident angle modifier is calculated on Worksheet F.

5.3 Collector Loop Heat Exchanger Modifier, $\frac{F_R'}{F_R}$

The collector loop heat exchanger modifier is calculated on Worksheet F.

6 Correction Factor, K_1, K_2, K_3, K_4

Correction factors K_1, K_2, K_3, K_4 are calculated on Worksheet G.

WORKSHEET F COLLECTOR COMBINED PERFORMANCE CHARACTERISTICS, $F_R'(\overline{\tau\alpha})$, $F_R'U_L$

PROJECT: DHW Example, Ft. Worth, Tx.

(3.5.1) Collector Efficiency Data From Test

intercept, $b = F_R(\tau\alpha)_n$ = .81

slope, $m = F_R U_L$ = 1.35

Reference Temperature Basis: 1. t_{in} 2. $\frac{t_{in} + t_{out}}{2}$, 3. t_{out}

Collector area, A_c = 56 ft²

Collector volumetric flow rate = 1.8 gal/ft²·h

Correction to t_{in} basis:

Case 1: (no correction) $F_R(\tau\alpha)_n$ =

$F_R U_L$ =

Case 2: $F_R(\tau\alpha)_n = b \times \left[\dfrac{1}{1 + \dfrac{mA_c}{2C_c}}\right]$ =

$F_R U_L = m \times \left[\dfrac{1}{1 + \dfrac{mA_c}{2C_c}}\right]$ =

given in h

$C_c = \dot{m}c_p = \begin{pmatrix}\text{volumetric}\\ \text{flow rate}\end{pmatrix} (\text{density}) \begin{pmatrix}\text{time}\\ \text{conversion}\end{pmatrix} \begin{pmatrix}\text{specific}\\ \text{heat}\end{pmatrix}$

$= \left(1.8 \frac{gal}{ft^2 \cdot h}\right)(56\ ft^2)\left(8.33 \frac{lb}{gal}\right)\left(1 \frac{Btu}{lb}\right) = 839.66 \frac{Btu}{h}$

where: for liquids, density = (8.33 lb/gal) x (specific gravity) water = 1 lb/lb

for air, density = 0.75 lb/ft³, at 70° and 1 atm.

specific heat = 0.24 Btu/lb·°F

Case 3: $F_R(\tau\alpha)_n = b \times \left[\dfrac{1}{1 + \dfrac{mA_c}{C_c}}\right]$ =

$F_R U_L = m \times \left[\dfrac{1}{1 + \dfrac{mA_c}{C_c}}\right]$ =

(3.5.2) Incident Angle Modifier, $\dfrac{(\overline{\tau\alpha})}{(\tau\alpha)_n}$ = .91, for two cover plates; .93, for one cover plate

WORKSHEET F (Continued)

(3.5.3) Collector Loop Heat Exchanger Modifier, $\frac{F_R'}{F_R}$

for air systems and liquid systems without a collector/storage heat exchanger,

$$\frac{F_R'}{F_R} = 1$$

Capacitance Rate

C_c = (from above) $= 839.7 \ \frac{Btu}{h}$

C_s = (calc. as for C_c above) $= \left(1.8 \ \frac{gal}{min}\right)\left(8.33 \ \frac{lb}{gal}\right)\left(60 \ \frac{min}{h}\right)\left(1 \ \frac{Btu}{lb}\right) = 899.6 \ \frac{Btu}{h}$

C_{min} = (lesser of C_c of C_s) $= 839.7 \ \frac{Btu}{h}$

Collector Storage Heat Exchanger Effectiveness, $\varepsilon_{cs} = 0.8$

$$x = \frac{C_c}{\varepsilon_{cs} \ C_{min}} = \frac{899.6}{(.8)(839.7)} = 1.339 \quad \text{(double wall, counter flow)}$$

$$y = \frac{A_c(F_R U_L)}{C_c} = \frac{(56)(1.35)}{839.7} = .090$$

$$\frac{F_R'}{F_R} = \text{from figure A-11 or} = \frac{1}{1 + y(x-1)} = \frac{1}{1 + .09(1.339-1)} = .970$$

(3.5.4) $$F_R'(\overline{\tau\alpha}) = F_R(\overline{\tau\alpha})_n \times \left[\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}\right] \times \left[\frac{F_R'}{F_R}\right] = (.81)(.93)(.97) = .730$$

$$F_R'U_L = F_R U_L \times \left[\frac{F_R'}{F_R}\right] = (1.35)(.97) = 1.31$$

4.3 (Continued)

WORKSHEET G CORRECTION FACTORS, K_1, K_2, K_3, K_4

PROJECT DHW Example, Ft. Worth, Tx.

Air Collector Flow Capacitance Rate Factor, K_1

for liquid collectors K_1 = 1.0

for air collectors: C_c = (from worksheet F) =

A_c = (from worksheet A) =

$\frac{C_c}{A_c}$ = K_1 = (from Figure A-12) = 1.0

Storage Mass Capacitance Factor, K_2

M = (vol. storage media) x (density) = (110) (8.33) (1.0) = 916.3

Note: M includes hot water storage volume where it is solar heated.

c_p = (from worksheet A) = 1.0

$\frac{(Mc_p)_s}{A_c} = \frac{(916.3)(1)}{56} = 16.36$ K_2 = (from Figure A-13) = 1.0

Hot Water Factor, K_3

for liquid systems providing heating only or heating and hot water, and for all air systems K_3 = 1.0

for DHW only systems: t_s = (from worksheet A) = 140°F

t_m = (from worksheet A or if variable see worksheet D) = °F

t_o is taken from table A-4 section 5

K_3 is taken from figure A-14 and tabulated on a monthly basis on worksheet C

K_3 = (tabulated or const.) =

Load Heat Exchange Factor, K_4

for air systems and DHW only systems, K_4 = 1.0

ε_L = (from worksheet A) =

$C_{\text{hot water supply loop}} = \dot{m}c_p$ =

$C_{\text{air loop}} = \dot{m}c_p$ =

C_{min} = lesser of C_H or C_A =

UA bldg = (from worksheet D) =

$\frac{UA}{C_{min}\,\varepsilon_L}$ = K_4 = (from Figure A-15) = 1.0

5 REFERENCE MATERIAL

5.1 NOMENCLATURE

A_c - Collector area (aperture or gross basis)(ft^2)

$(AU)_{HX}$ - Heat exchanger heat transfer factor [Btu/(h·°F)]

$C_c = (\dot{m}c_p)_c$ - Fluid capacitance rate of the collector working fluid [Btu/(h·°F)]

$C_{min} = (\dot{m}c_p)_{min}$ - Min. fluid capacitance rate [Btu/(h·°F)]

$C_s = (\dot{m}\,c_p)_s$ = Fluid capacitance rate of the storage loop [Btu/(h·°F)]

c_p - Fluid specific heat [Btu/(lb·°F)]

D_1, D_2 - System performance parameters (dimensionless)

E - Solar energy supplied for a particular month (Btu/Month)

E_{Total} - Solar energy supplied for an entire year (Btu/Year)

f - Monthly fraction of total heating load supplied by solar energy

F_{Annual} - Yearly fraction of the total heating load supplied by solar energy (Btu/Year)

F_R - Collector heat removal factor

F_R' - Combined form of the collector heat exchanger effectiveness (ε_c) and the collector heat removal factor (F_R)

$\bar{I}_H$ - Monthly average of the daily radiation incident on a horizontal surface [Btu/(Day·ft^2)]

$\bar{I}_o$ - Monthly average of the daily extraterrestrial radiation on a horizontal surface [Btu/(Day·ft^2)]

$\bar{I}_T$ - Monthly average of the daily radiation incident normal to a tilted surface [Btu/(Day·ft^2)]

I_{sc} - Solar constant, 429.2 Btu/ft^2

$\bar{K}_t$ - Ratio of the monthly averages of the daily radiation on a horizontal surface to the extraterrestrial radiation on a horizontal surface

K_1 - Air collector flow capacitance rate factor

K_2 - Storage mass capacitance factor

K_3 - Hot water factor

K_4 - Load heat exchanger factor

L Total heating and hot water load for a particular month (Btu/Month)

L_{Total} - Total heating and hot water load for an entire year (Btu/Year)

m - Mass of domestic hot water used for a particular month (lb)

$\dot{m}$ - Mass flow rate of the working fluid either air or liquid (lb/h)

M - Mass of thermal storage (lb)

N - Number of days in a particular month

NTU - Number of heat transfer units (dimensionless)

Q_s - Space heating load for a particular month (Btu/Month)

Q_w - Domestic hot water heating load for a particular month (Btu/Month)

q_d - Building design rate of sensible heat loss (Btu/h)

$\bar{R}$ - Ratio of the monthly average-daily radiation on a tilted surface to that on a horizontal surface

R_1, R_2 - Heat exchanger temperature ratios

S - Monthly incident solar radiation on a tilted surface [Btu/(month·ft^2)]

t_a - Ambient air temperature (°F)
t_{in} - Collector inlet temperature (°F)
t_m - Temperature of water main supply (°F)
t_n - Storage temperature (°F)
t_o - Average day-time temperature (°F)
t_{out} - Collector outlet temperature (°F)
t_{ref} - Reference temperature, 212°F
t_s - Temperature of domestic hot water supply (°F)
t_w - 97 1/2% winter design temperature (°F)
UA - Building heat loss factor [Btu/(h·°F)]
U_L - Collector heat loss factor [Btu/h·°F·ft^2)]

Δt_d - Design temperature difference for determining heating load (°F)
Δt_{LM} - Log-mean temperature difference
Δtime - Total number of hours in a month (h)
ε_{cs} - Effectiveness of the collector-storage heat exchanger
ε_{HX} - Heat exchanger effectiveness
ε_L - Effectiveness of the load heat exchanger
θ - Collector tilt (°)
γ - Solar collector azimuth angle (For Due South = 180°)
η - Thermal efficiency (ratio of the thermal energy removed from the collector, to the total incident solar radiation on the collector aperture area or collector gross area, see section 3.5.1)
ϕ - Latitude
$(\overline{\tau\alpha})$ - Average transmittance-absorptance product for design purposes
$(\tau\alpha)_n$ - Transmittance-absorptance product at normal incidence

5.2 REFERENCES CITED

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5.3 TABLES AND GRAPHS

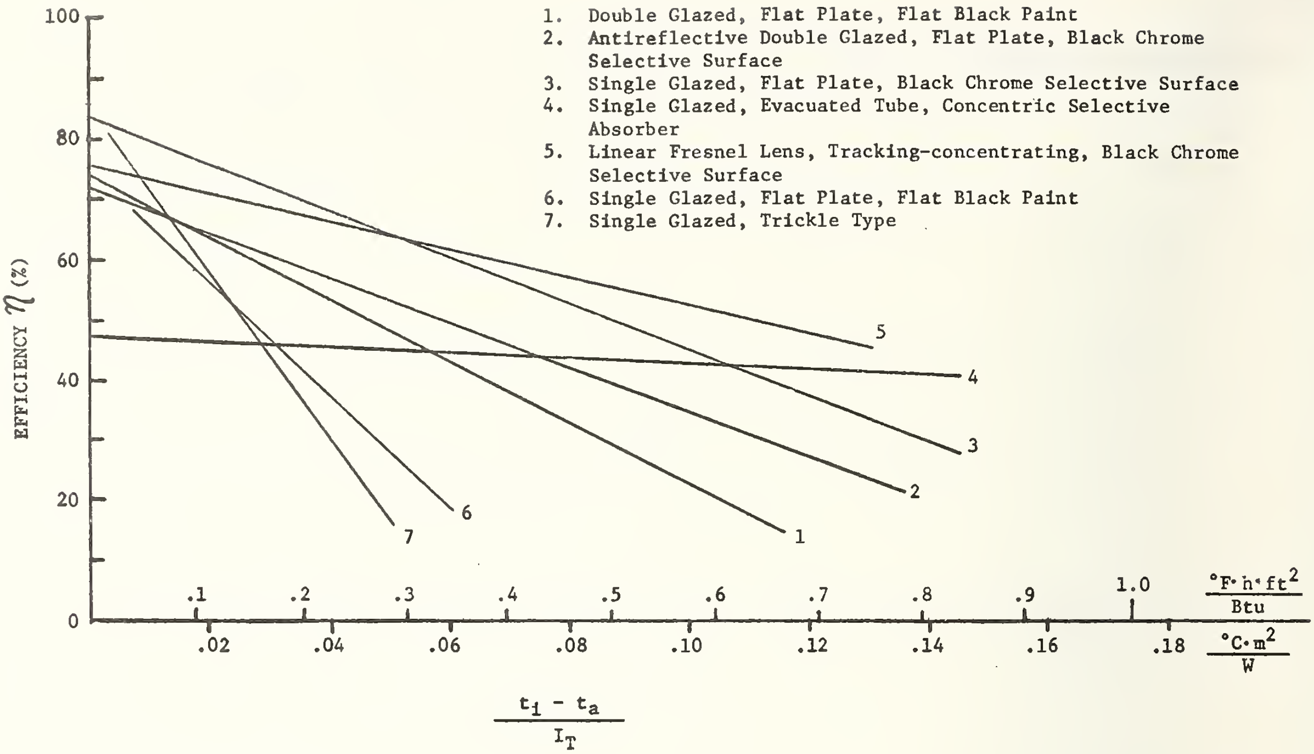


Figure A-27a Typical Thermal Efficiency Curves for Liquid Collectors Based on Collector Aperture Area

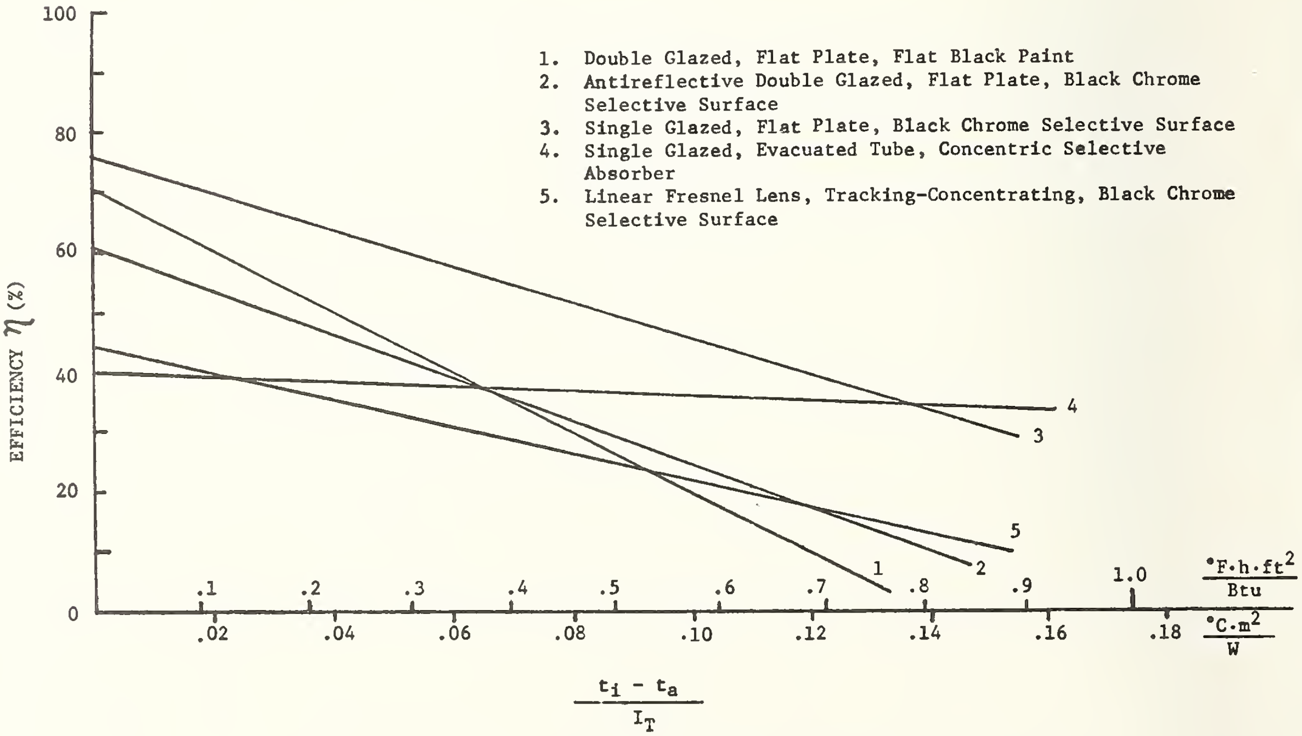


Figure A-27b Typical Thermal Efficiency Curves for Liquid Collectors Based on Collector Gross Frontal Area

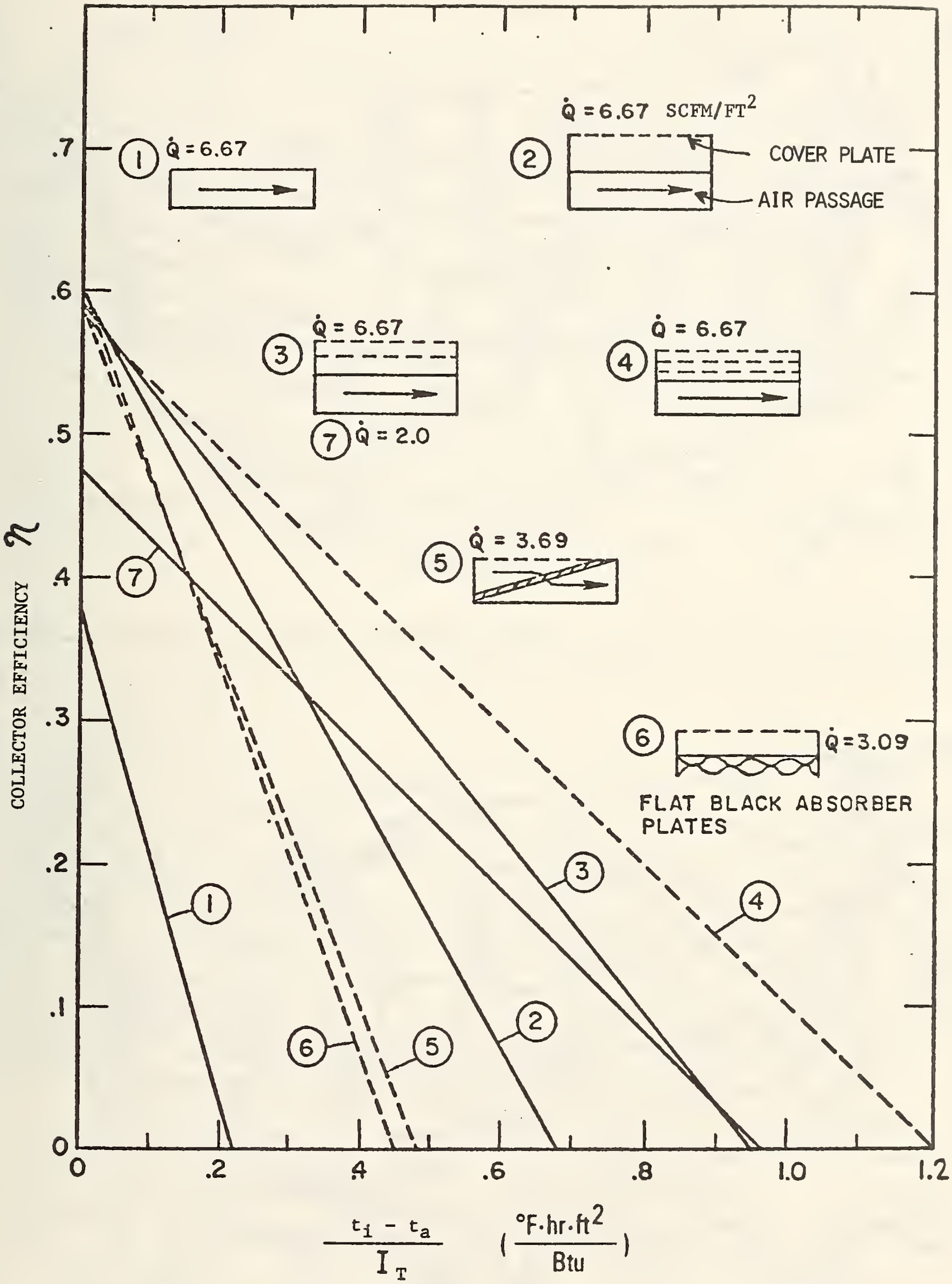
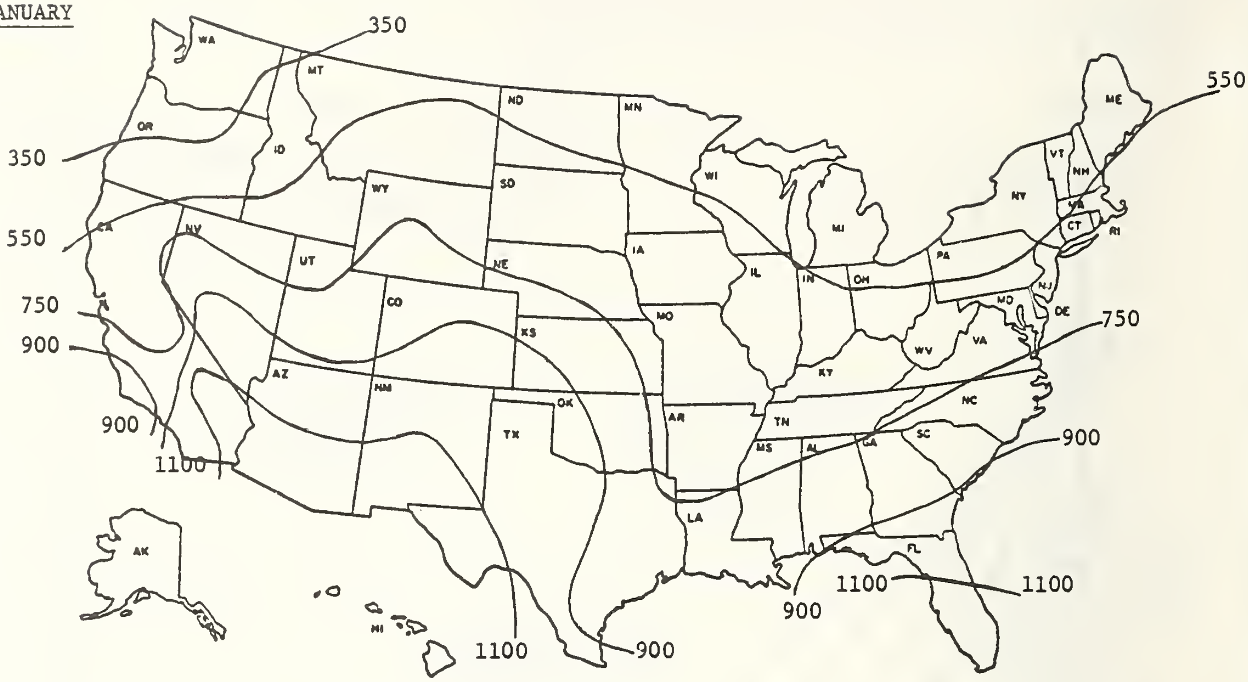


Figure A-28 Typical Thermal Efficiency Curves for Flat Plate Collectors Using Air as the Working Liquid [12] (Q̇ indicates flow rate in standard cubic feet per minute (scfm) per unit collector area)

JANUARY



FEBRUARY

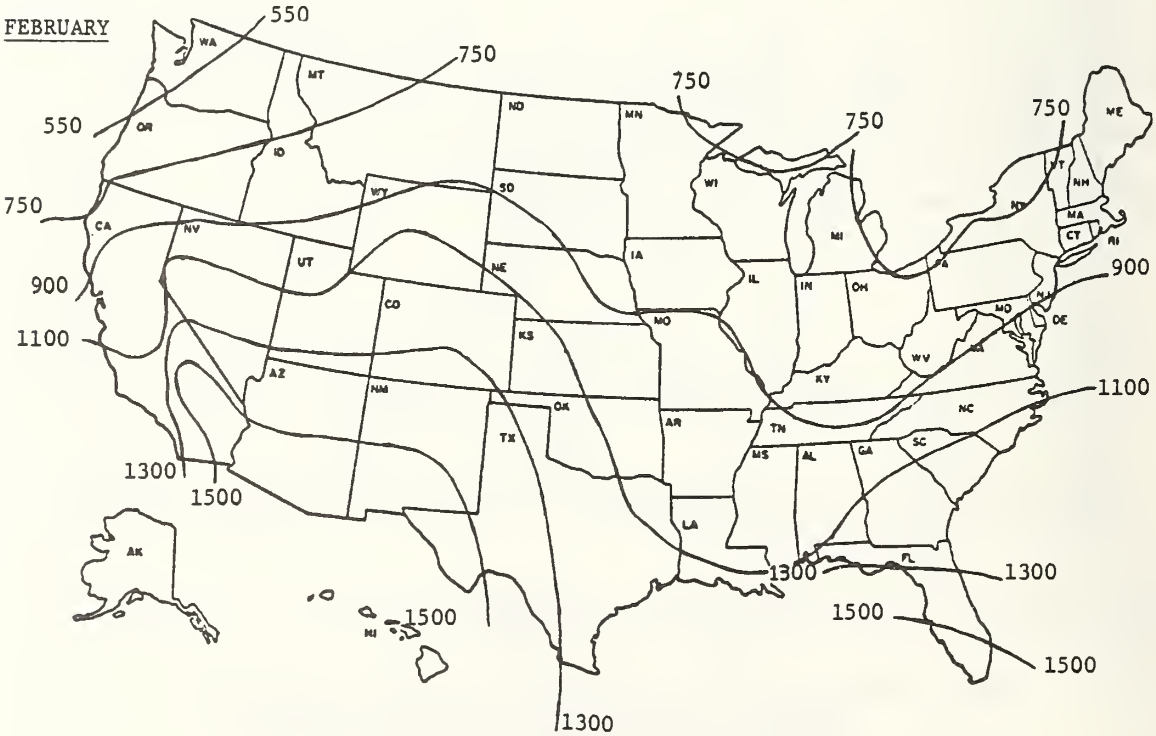
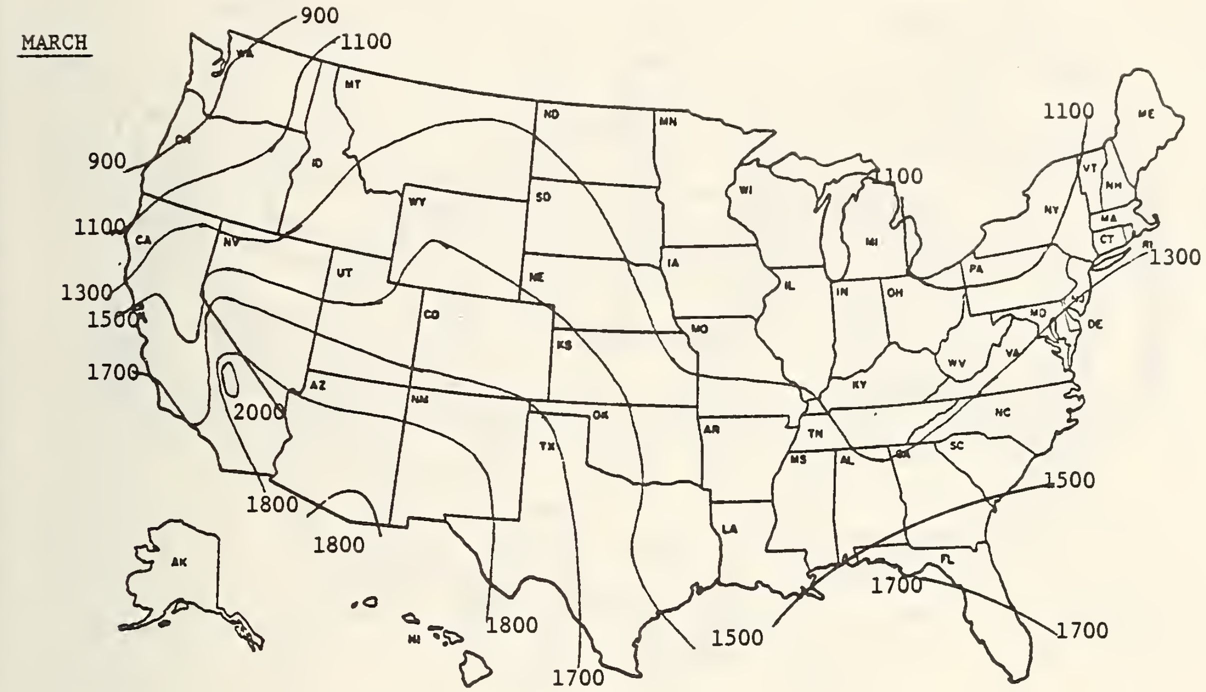


Figure A-29 Mean Daily Insolation ($\bar{I}_H$) Btu/day·Ft^2 for January and February [11]



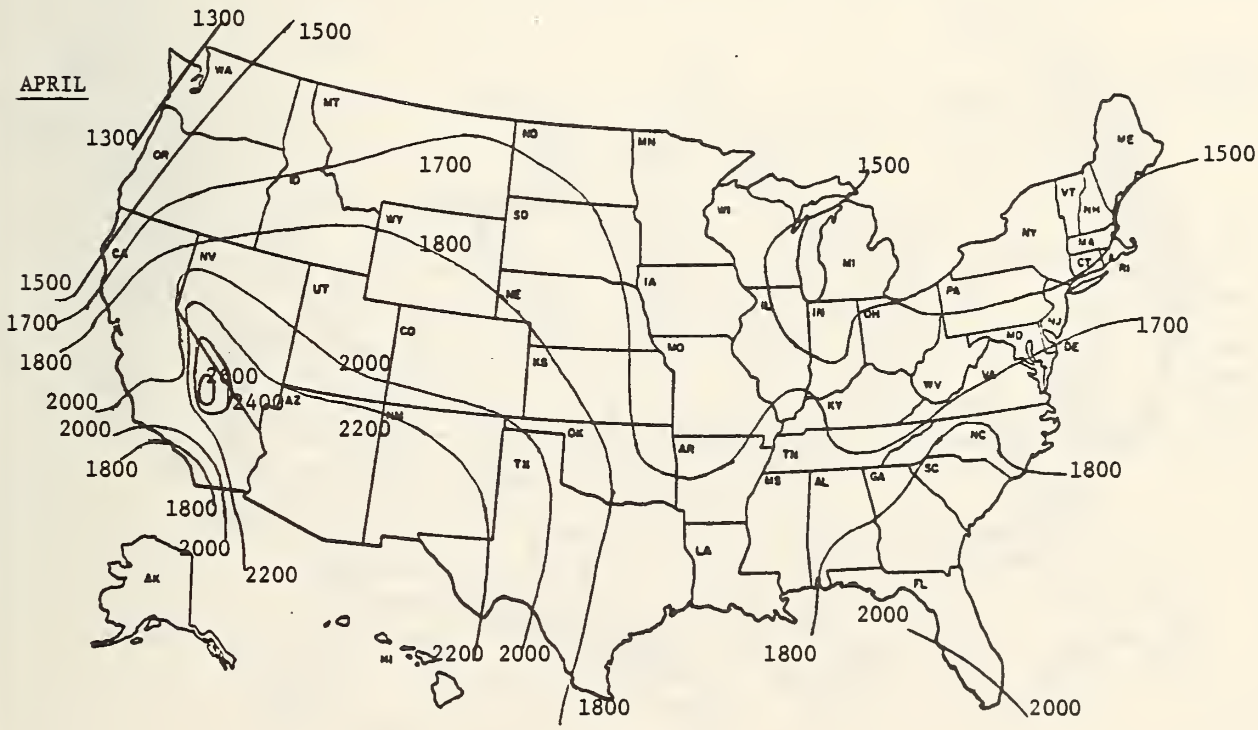
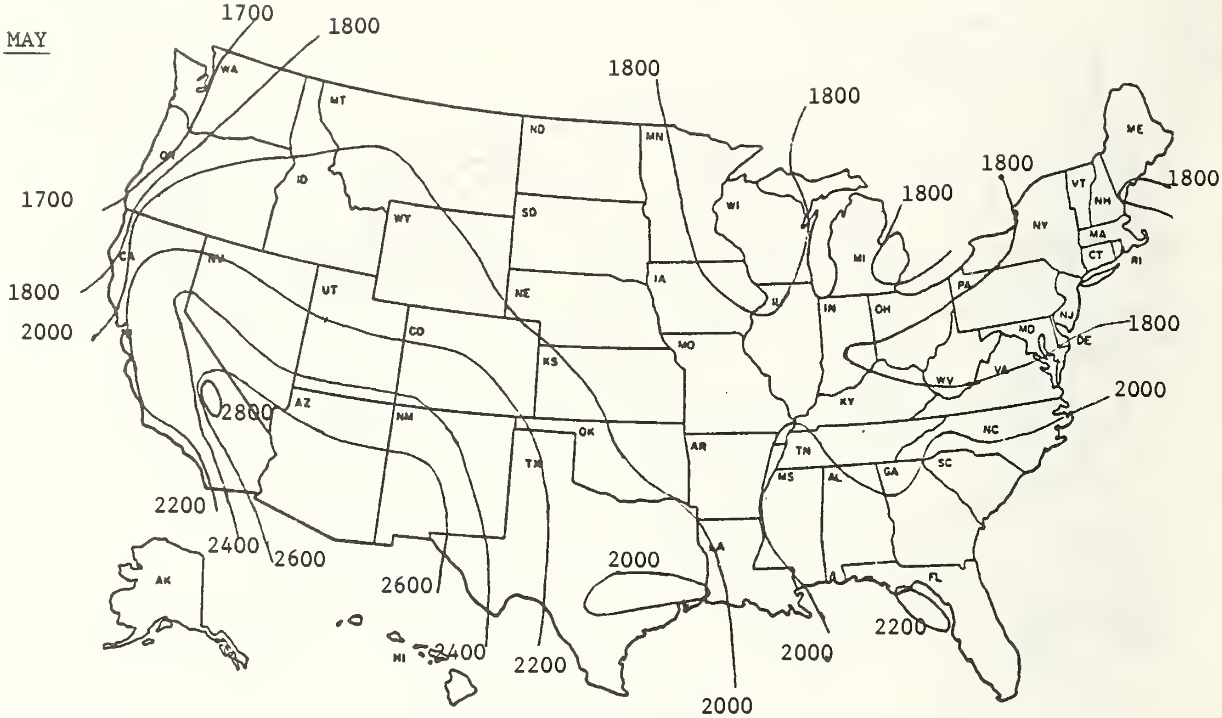


Figure A-29 (cont.) Mean Daily Insolation ($\bar{I}_H$) Btu/day·Ft^2 for March and April

MAY



JUNE

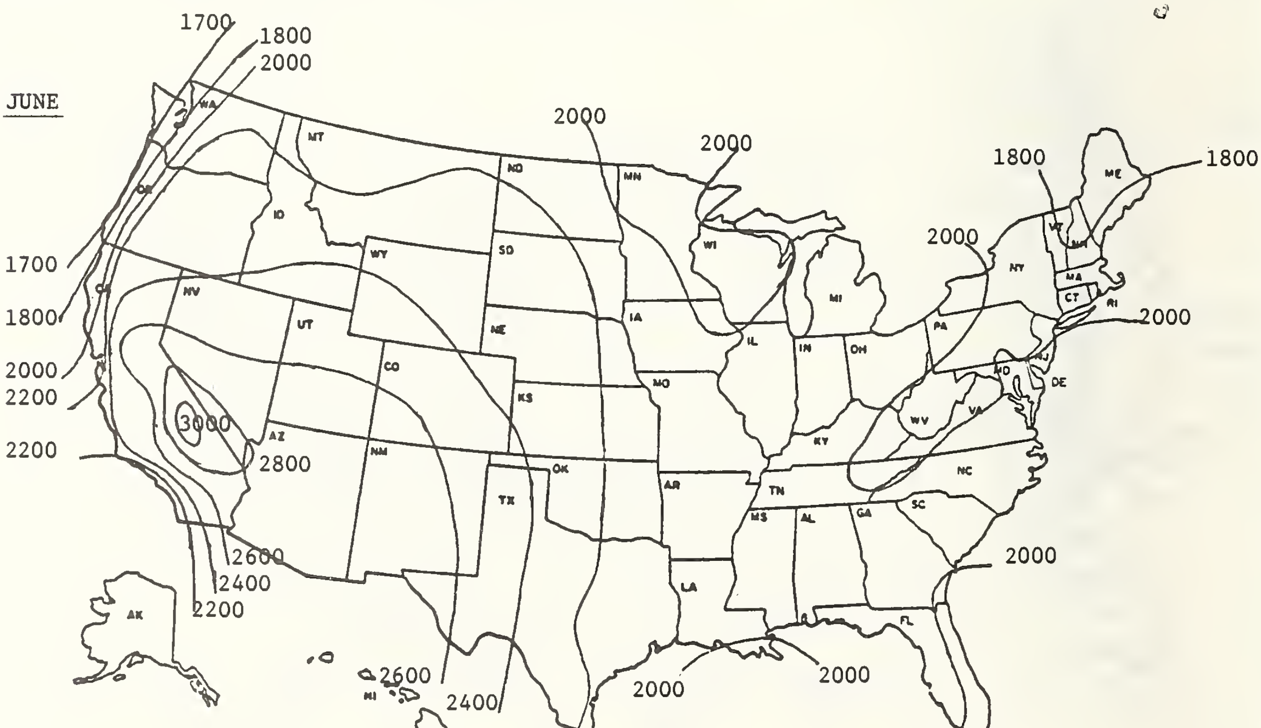
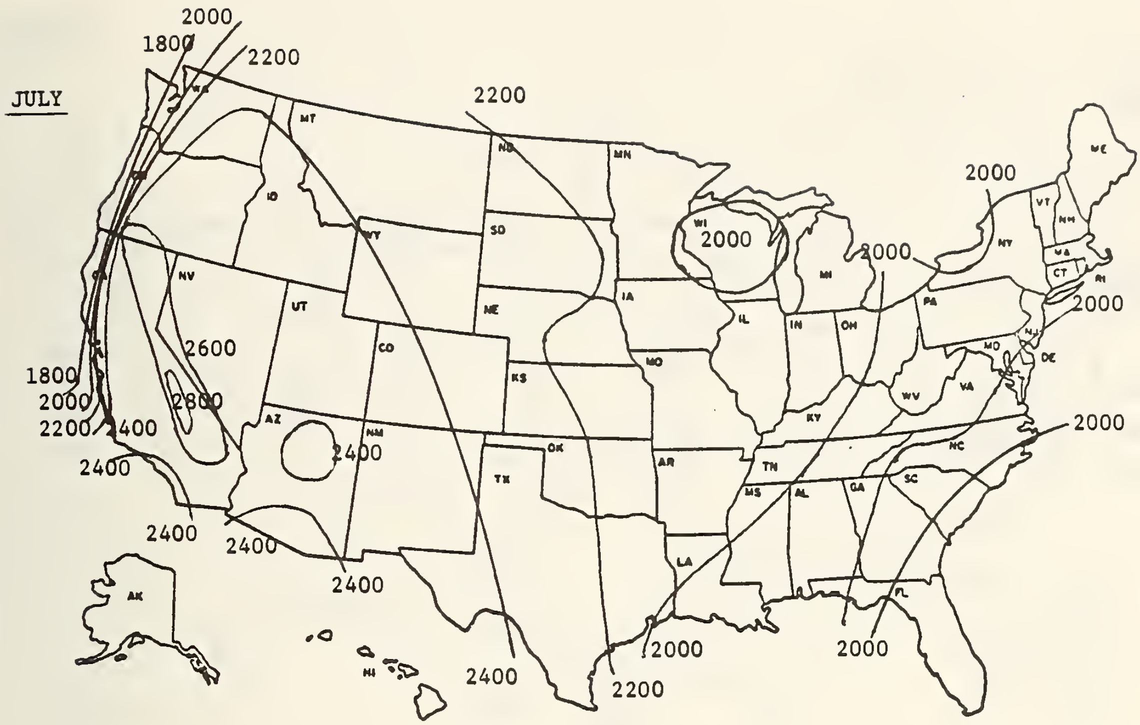


Figure A-29 (cont.) Mean Daily Insolation ($\bar{I}_H$) Btu/day$\cdot$Ft^2 for May and June



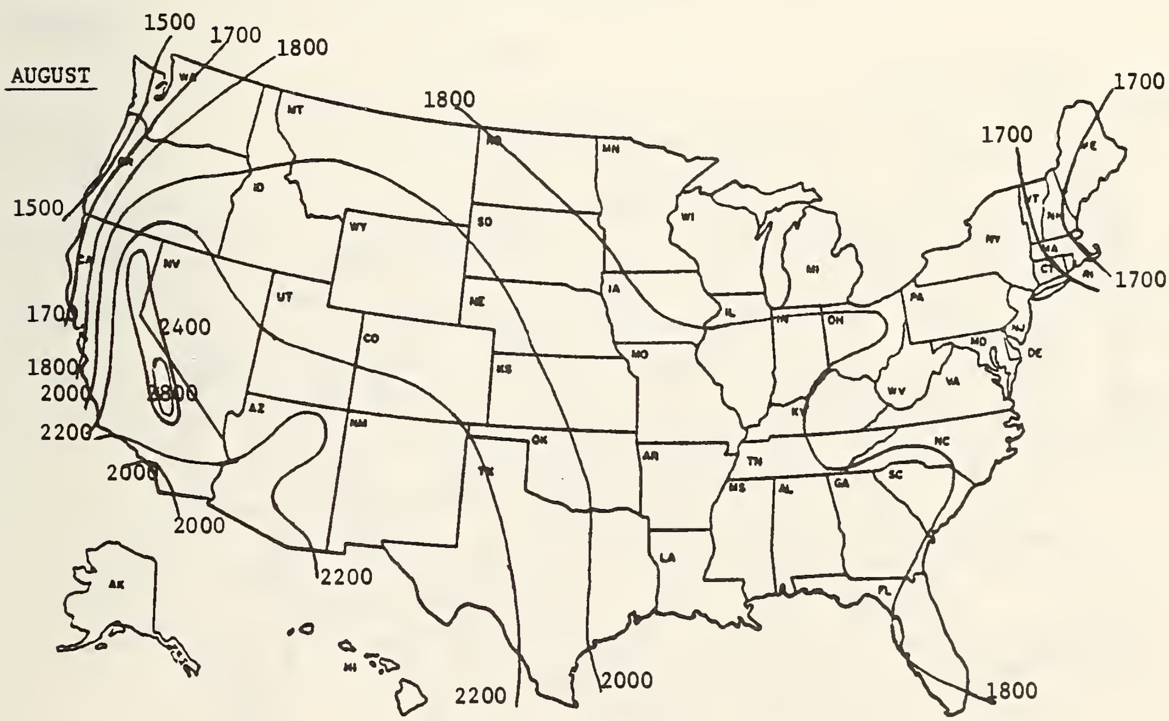
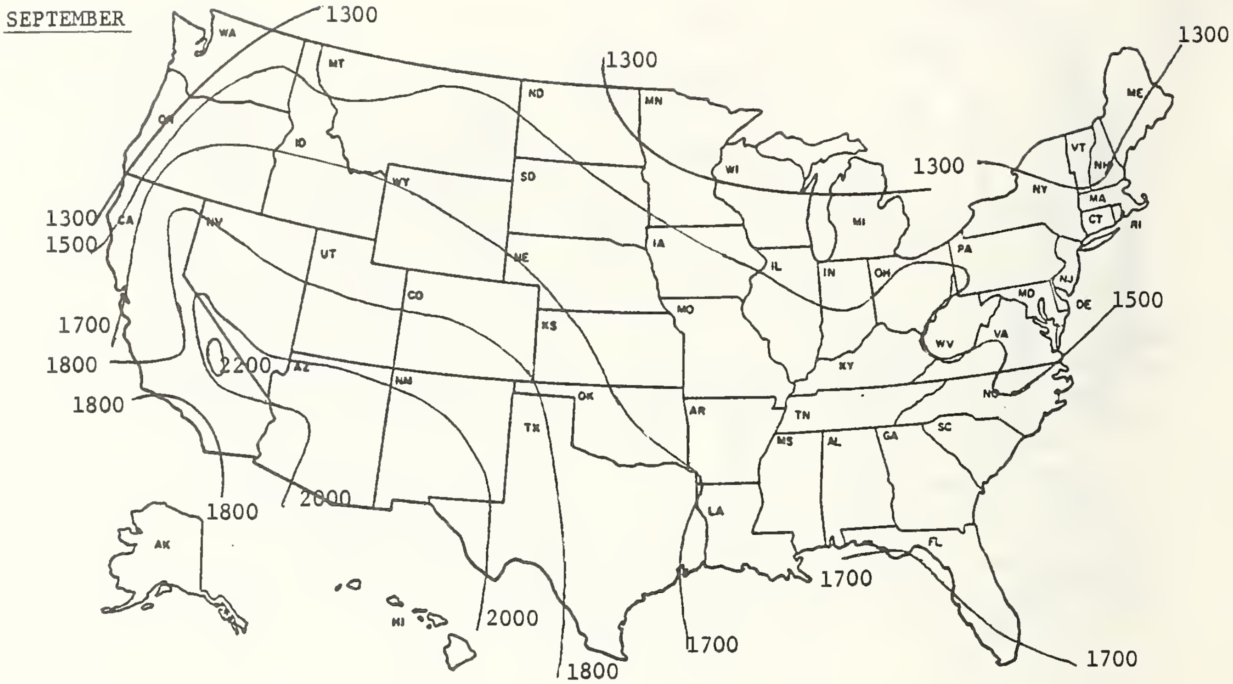
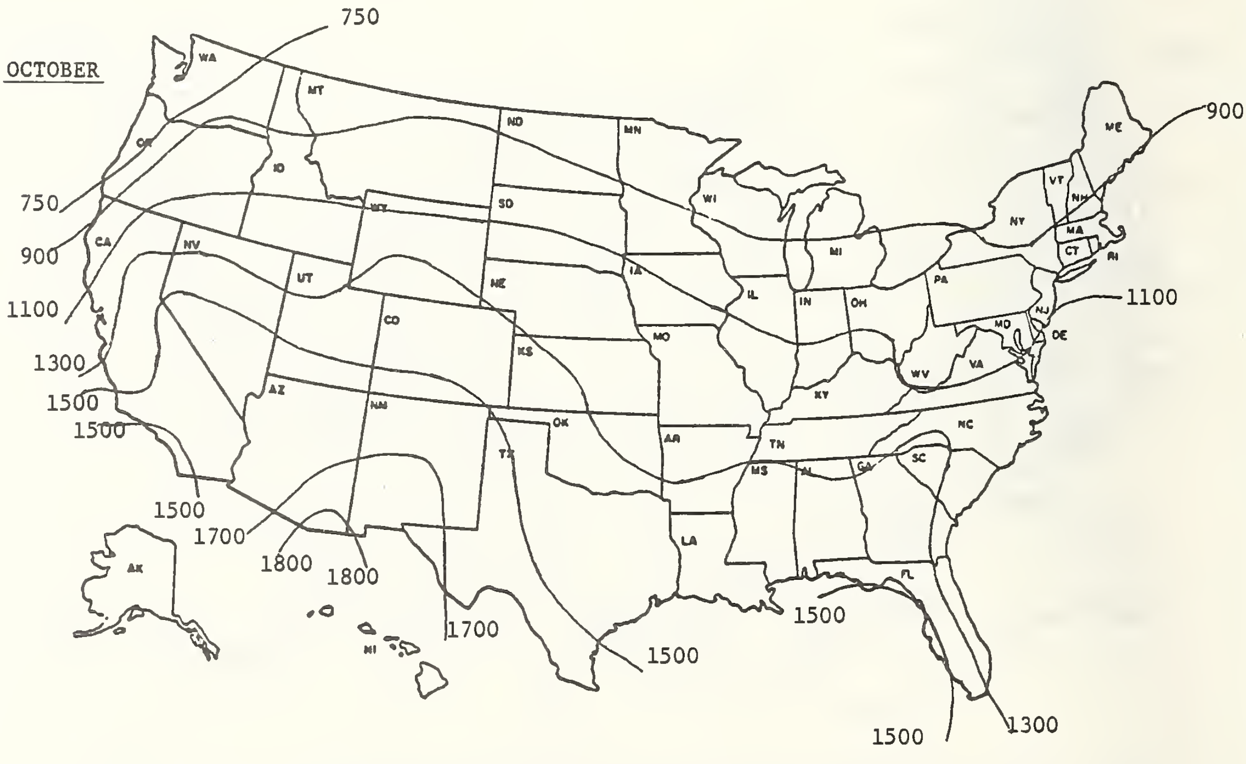


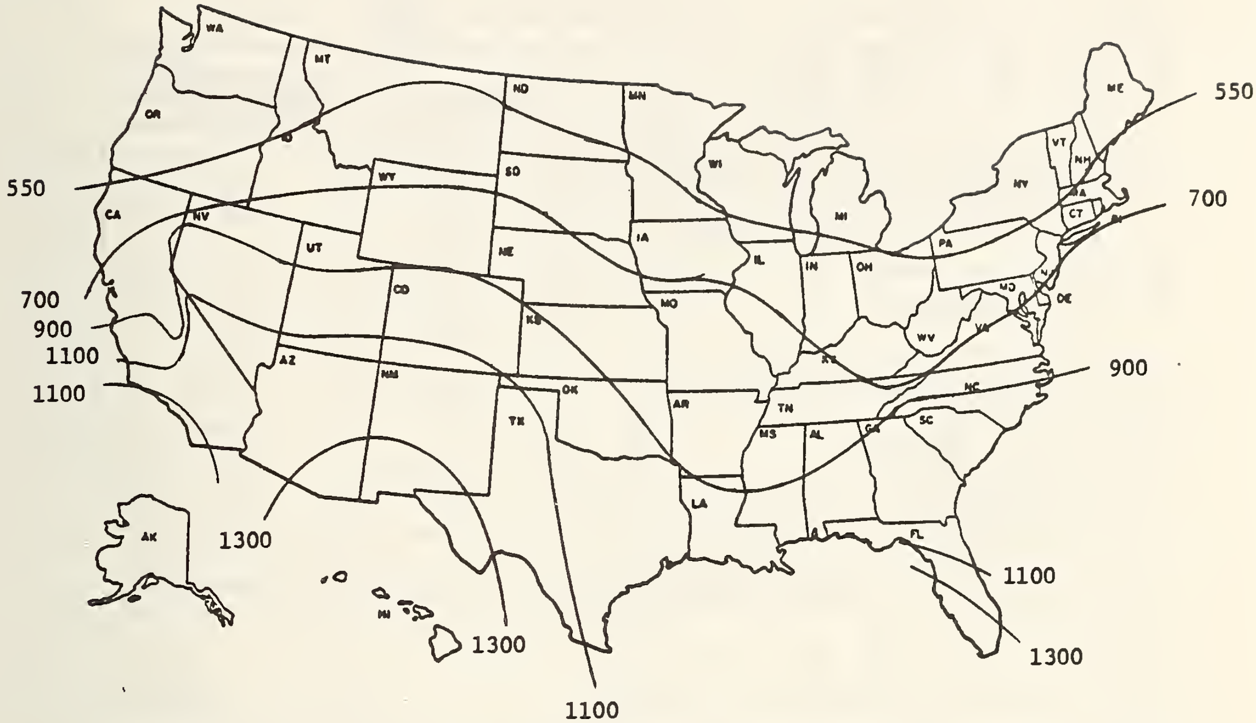
Figure A-29 (cont.) Mean Daily Insolation ($\overline{I}_H$) Btu/day·Ft^2 for July and August





Figute A-29 (cont.) Mean Daily Insolation ($\overline{I}_H$) Btu/day·Ft^2 for September and October

NOVEMBER



DECEMBER

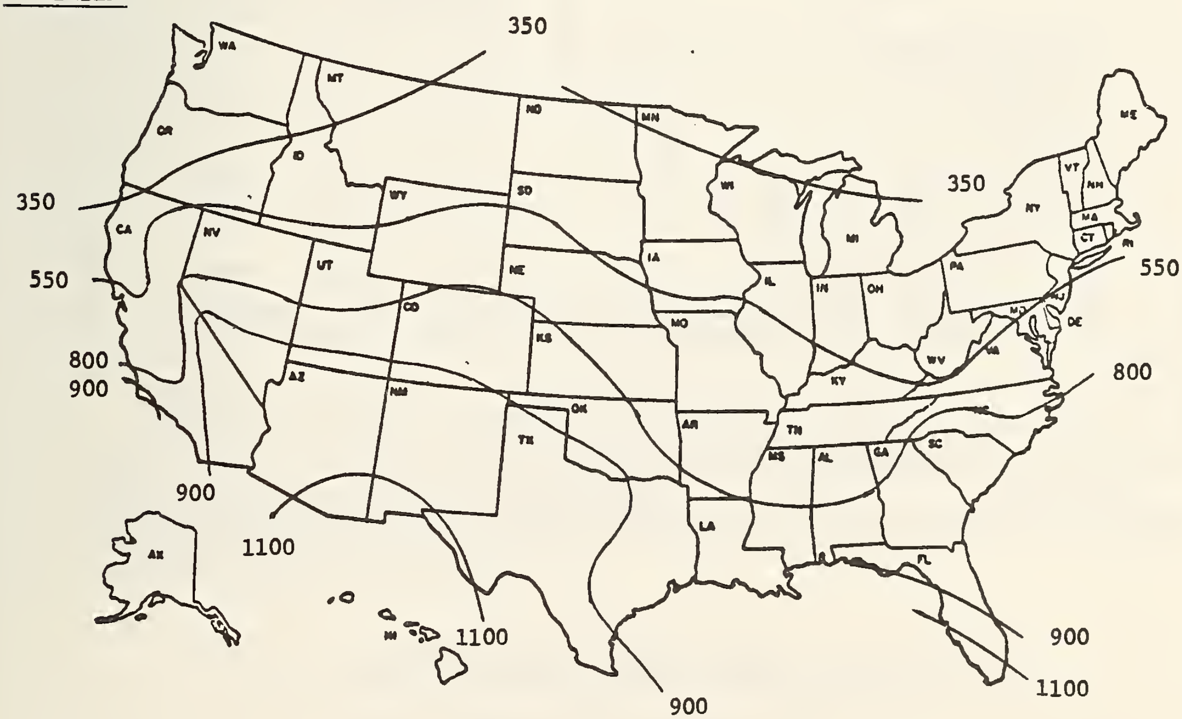


Figure A-29 (cont.) Mean Daily Insolation ($\overline{I}_H$) Btu/day·Ft^2 for November and December

Material	Thickness (inches)	Solar (τ) Transmittance (per cent)
Glass, water white crystal	.156	0.91
Glass, untreated sheet	.125	.86
Glass, untreated plate	.250	.78
Polycarbonate	0.80	.84
Fiberglass	.040	.90
Polyvinyl fluoride	.004	.92
Polymethyl methacrylate	.125	.89
FEP Teflon	.001	.96
Polyimide	.00025	.80
Polyethyelene Terephthalate	.002	.84

Table A-1 Solar Transmittance of various cover materials.

Material	Solar* Absorptance (α) (per cent)
Black Chrome	0.87 to 0.93
Black Nickel	.87 to .92
Anodize	.82 to .99
Copper Oxide	.83 to .91
Black Paint, Inorganic	.89 to .96
Black Paint, Acrylic	.92 to .97
Black Paint, Silicone	.86 to .94

*Dependent upon thickness and vehicle-to- binder ratio

Table A-2 Solar Absorptance of several absorber coating materials.

State	Stotion	97 1/2% Winter Design Temp.[d]	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jon.	Feb.	Mor.	Apr.	May	June	Yeorly Totol
Ala.	Birmingham .... A	22	0	0	6	93	363	555	592	462	363	108	9	0	2551
	Huntsville .... A	17	0	0	12	127	426	663	694	557	434	138	19	0	3070
	Mobile .... A	29	0	0	0	22	213	357	415	300	211	42	0	0	1560
	Montgomery .... A	26	0	0	0	68	330	527	543	417	316	90	0	0	2291
Alaska	Anchorage .... A	-22	245	291	516	930	1284	1572	1631	1316	1293	879	592	315	10864
	Fairbanks .... A	-50	171	332	642	1203	1833	2254	2359	1901	1739	1068	555	222	14279
	Juneau .... A	- 4	301	338	483	725	921	1135	1237	1070	1073	810	601	381	9075
	Nome .... A	-28	481	496	693	1094	1455	1820	1879	1666	1770	1314	930	573	14171
Ariz.	Flagstaff .... A	5	46	68	201	558	867	1073	1169	991	911	651	437	180	7152
	Phoenix .... A	34	0	0	0	22	234	415	474	328	217	75	0	0	1765
	Tucson .... A	32	0	0	0	25	231	406	471	344	242	75	6	0	1800
	Winslow .... A	13	0	0	6	245	711	1008	1054	770	601	291	96	0	4782
	Yuma .... A	40	0	0	0	0	108	264	307	190	90	15	0	0	974
Ark.	Fort Smith .... A	19	0	0	12	127	450	704	781	596	456	144	22	0	3292
	Little Rock .... A	23	0	0	9	127	465	716	756	577	434	126	9	0	3219
	Texarkana .... A	26	0	0	0	78	345	561	626	468	350	105	0	0	2533
Calif.	Bakersfield .... A	33	0	0	0	37	282	502	546	364	267	105	19	0	2122
	Bishop .... A		0	0	48	260	576	797	874	680	555	306	143	36	4275
	Blue Canyon .... A		28	37	108	347	594	781	896	795	806	597	412	195	5596
	Burbank .... A	38	0	0	6	43	177	301	366	277	239	138	81	18	1646
	Eureka C	35	270	257	258	329	414	499	546	470	505	438	372	285	4643
	Fresno .... A	31	0	0	0	84	354	577	605	426	335	162	62	6	2611
	Long Beach .... A	38	0	0	9	47	171	316	397	311	264	171	93	24	1803
	Los Angeles .... A	43	28	28	42	78	180	291	372	302	288	219	158	81	2061
	Los Angeles C	44	0	0	6	31	132	229	310	230	202	123	68	18	1349
	Mt. Shasta C		25	34	123	406	696	902	983	784	738	525	347	159	5722
	Oakland .... A	37	53	50	45	127	309	481	527	400	353	255	180	90	2870
	Red Bluff .... A		0	0	0	53	318	555	605	428	341	168	47	0	2515
	Sacramento .... A	32	0	0	0	56	321	546	583	414	332	178	72	0	2502
	Sacramento C		0	0	0	62	312	533	561	392	310	173	76	0	2419
	Sandberg C		0	0	30	202	480	691	778	661	620	426	264	57	4209
	San Diego .... A	44	9	0	21	43	135	236	298	235	214	135	90	42	1458
	San Francisco .... A	37	81	78	60	143	306	462	508	395	363	279	214	126	3015
	San Francisco C	42	192	174	102	118	231	388	443	336	319	279	239	180	3001
	Santa Maria .... A	34	99	93	96	146	270	391	459	370	363	282	233	165	2967
Colo.	Alamosa .... A	-13	65	99	279	639	1065	1420	1476	1162	1020	696	440	168	8529
	Colorado Springs .... A	4	9	25	132	456	825	1032	1128	938	893	582	319	84	6423
	Denver .... A	3	6	9	117	428	819	1035	1132	938	887	558	288	66	6283
	Denver C		0	0	90	366	714	905	1004	851	800	492	254	48	5524
	Grand Junction .... A	11	0	0	30	313	786	1113	1209	907	729	387	146	21	5641
	Pueblo .... A	- 1	0	0	54	326	750	986	1085	871	772	429	174	15	5462
Conn.	Bridgeport .... A	8	0	0	66	307	615	986	1079	966	853	510	208	27	5617
	Hartford .... A	5	0	12	117	394	714	1101	1190	1042	908	519	205	33	6235
	New Haven .... A	9	0	12	87	347	648	1011	1097	991	871	543	245	45	5897
Del.	Wilmington .... A	15	0	0	51	270	588	927	980	874	735	387	112	6	4930
D.C.	Washington .... A	19	0	0	33	217	519	834	871	762	626	288	74	0	4224
Fla.	Apalachicola C		0	0	0	16	153	319	347	260	180	33	0	0	1308
	Daytona Beach .... A	36	0	0	0	0	75	211	248	190	140	15	0	0	879
	Fort Myers .... A	42	0	0	0	0	24	109	146	101	62	0	0	0	442
	Jacksonville .... A	32	0	0	0	12	144	310	332	246	174	21	0	0	1239
	Key West .... A	58	0	0	0	0	0	28	40	31	9	0	0	0	108
	Lakeland C	39	0	0	0	0	57	164	195	146	99	0	0	0	661
	Miami .... A	47	0	0	0	0	0	65	74	56	19	0	0	0	214

[a] Data for United States cities from a publication of the United States Weather Bureau, *Monthly Normals of Temperature, Precipitation and Heating Degree Days*, 1962, are for the period 1931 to 1960 inclusive. These data also include information from the 1963 revisions to this publication, where available.
[b] Data for airport stations, A, and city stations, C, are both given where available.
[c] Data for Canadian cities were computed by the Climatology Division, Department of Transport from normal monthly mean temperatures, and the monthly values of heating degree days data were obtained using the National Research Council computer and a method devised by H. C. S. Thom of the United States Weather Bureau. The heating degree days are based on the period from 1931 to 1960.

[d] Date from ASHRAE Handbook of Fundamentals, 1972

Table A-3 Average Monthly and Yearly Degree Days (Base 65°F) and 97 1/2% Winter Design Temperatures (a, b, c, d)

From: ASHRAE Systems Handbook 1976

State	Station	97 1/2% Winter Design Temp. d/	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Fla. (Cont'd)	Miami Beach C	48	0	0	0	0	0	40	56	36	9	0	0	0	141
	Orlando .... A	37	0	0	0	0	72	198	220	165	105	6	0	0	766
	Pensacola .... A	32	0	0	0	19	195	353	400	277	183	36	0	0	1463
	Tallahassee .... A	29	0	0	0	28	198	360	375	286	202	36	0	0	1485
	Tampa .... A	39	0	0	0	0	60	171	202	148	102	0	0	0	683
	West Palm Beach .... A	44	0	0	0	0	6	65	87	64	31	0	0	0	253
Ga.	Athens .... A	21	0	0	12	115	405	632	642	529	431	141	22	0	2929
	Atlanta .... A	23	0	0	18	124	417	648	636	518	428	147	25	0	2961
	Augusta .... A	23	0	0	0	78	333	552	549	445	350	90	0	0	2397
	Columbus .... A	26	0	0	0	87	333	543	552	434	338	96	0	0	2383
	Macon .... A	27	0	0	0	71	297	502	505	403	295	63	0	0	2136
	Rome .... A	20	0	0	24	161	474	701	710	577	468	177	34	0	3326
	Savannah .... A	27	0	0	0	47	246	437	437	353	254	45	0	0	1819
	Thomasville C		0	0	0	25	198	366	394	305	208	33	0	0	1529
Hawaii	Lihue .... A		0	0	0	0	0	0	0	0	0	0	0	0	0
	Honolulu .... A	62	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hilo .... A	61	0	0	0	0	0	0	0	0	0	0	0	0	0
Idaho	Boise .... A	10	0	0	132	415	792	1017	1113	854	722	438	245	81	5809
	Lewiston .... A	12	0	0	123	403	756	933	1063	815	694	426	239	90	5542
	Pocatello .... A	– 2	0	0	172	493	900	1166	1324	1058	905	555	319	141	7033
Ill.	Cairo C		0	0	36	164	513	791	856	680	539	195	47	0	3821
	Chicago (O'Hare) .... A	0	0	12	117	381	807	1166	1265	1086	939	534	260	72	6639
	Chicago (Midway) .... A	1	0	0	81	326	753	1113	1209	1044	890	480	211	48	6155
	Chicago C	1	0	0	66	279	705	1051	1150	1000	868	489	226	48	5882
	Moline .... A	– 3	0	9	99	335	774	1181	1314	1100	918	450	189	39	6408
	Peoria .... A	2	0	6	87	326	759	1113	1218	1025	849	426	183	33	6025
	Rockford .... A	– 3	6	9	114	400	837	1221	1333	1137	961	516	236	60	6830
	Springfield .... A	4	0	0	72	291	696	1023	1135	935	769	354	136	18	5429
Ind.	Evansville .... A	10	0	0	66	220	606	896	955	767	620	237	68	0	4435
	Fort Wayne .... A	5	0	9	105	378	783	1135	1178	1028	890	471	189	39	6205
	Indianapolis .... A	4	0	0	90	316	723	1051	1113	949	809	432	177	39	5699
	South Bend .... A	3	0	6	111	372	777	1125	1221	1070	933	525	239	60	6439
Iowa	Burlington .... A	0	0	0	93	322	768	1135	1259	1042	859	426	177	33	6114
	Des Moines .... A	– 3	0	6	96	363	828	1225	1370	1137	915	438	180	30	6588
	Dubuque .... A	– 7	12	31	156	450	906	1287	1420	1204	1026	546	260	78	7376
	Sioux City .... A	– 6	0	9	108	369	867	1240	1435	1198	989	483	214	39	6951
	Waterloo .... A	– 8	12	19	138	428	909	1296	1460	1221	1023	531	229	54	7320
Kans.	Concordia .... A		0	0	57	276	705	1023	1163	935	781	372	149	18	5479
	Dodge City .... A	7	0	0	33	251	666	939	1051	840	719	354	124	9	4986
	Goodland .... A	4	0	6	81	381	810	1073	1166	955	884	507	236	42	6141
	Topeka .... A	6	0	0	57	270	672	980	1122	893	722	330	124	12	5182
	Wichita .... A	9	0	0	33	229	618	905	1023	804	645	270	87	6	4620
Ky.	Covington .... A	8	0	0	75	291	669	983	1035	893	756	390	149	24	5265
	Lexington .... A	10	0	0	54	239	609	902	946	818	685	325	105	0	4683
	Louisville .... A	12	0	0	54	248	609	890	930	818	682	315	105	9	4660
La.	Alexandria .... A	29	0	0	0	56	273	431	471	361	260	69	0	0	1921
	Baton Rouge .... A	30	0	0	0	31	216	369	409	294	208	33	0	0	1560
	Lake Charles .... A	33	0	0	0	19	210	341	381	274	195	39	0	0	1459
	New Orleans .... A	35	0	0	0	19	192	322	363	258	192	39	0	0	1385
	New Orleans C		0	0	0	12	165	291	344	241	177	24	0	0	1254
	Shreveport .... A	26	0	0	0	47	297	477	552	426	304	81	0	0	2184
Me.	Caribou .... A	–14	78	115	336	682	1044	1535	1690	1470	1308	858	468	183	9767
	Portland .... A	0	12	53	195	508	807	1215	1339	1182	1042	675	372	111	7511
Md.	Baltimore .... A	15	0	0	48	264	585	905	936	820	679	327	90	0	4654
	Baltimore C	20	0	0	27	189	486	806	859	762	629	288	65	0	4111
	Frederich .... A	11	0	0	66	307	624	955	995	876	741	384	127	12	5087
Mass.	Boston .... A	10	0	9	60	316	603	983	1088	972	846	513	208	36	5634
	Nantucket .... A		12	22	93	332	573	896	992	941	896	621	384	129	5891
	Pittsfield .... A	– 1	25	59	219	524	831	1231	1339	1196	1063	660	326	105	7578
	Worcester .... A	0	6	34	147	450	774	1172	1271	1123	998	612	304	78	6969

Table A-3 (contd)

State	Station	97 1/2% Winter Design Temp. d/	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Mich.	Alpena .... A	- 1	68	105	273	580	912	1268	1404	1299	1218	777	446	156	8506
	Detroit (City) .... A	8	0	0	87	360	738	1088	1181	1058	936	522	220	42	6232
	Detroit (Wayne) .... A		0	0	96	353	738	1088	1194	1061	933	534	239	57	6293
	Detroit (Willow Run) .... A		0	0	90	357	750	1104	1190	1053	921	519	229	45	6258
	Escanaba C	- 3	59	87	243	539	924	1293	1445	1296	1203	777	456	159	8481
	Flint .... A	3	16	40	159	465	843	1212	1330	1198	1066	639	319	90	7377
	Grand Rapids .... A	6	9	28	135	434	804	1147	1259	1134	1011	579	279	75	6894
	Lansing .... A	6	6	22	138	431	813	1163	1262	1142	1011	579	273	69	6909
	Marquette C	- 4	59	81	240	527	936	1268	1411	1268	1187	771	468	177	8393
	Muskegon .... A	8	12	28	120	400	762	1088	1209	1100	995	594	310	78	6696
	Sault Ste. Marie .... A	- 8	96	105	279	580	951	1367	1525	1380	1277	810	477	201	9048
Minn.	Duluth .... A	-15	71	109	330	632	1131	1581	1745	1518	1355	840	490	198	10000
	Minneapolis .... A	-10	22	31	189	505	1014	1454	1631	1380	1166	621	288	81	8382
	Rochester .... A	-13	25	34	186	474	1005	1438	1593	1366	1150	630	301	93	8295
Miss.	Jackson .... A	24	0	0	0	65	315	502	546	414	310	87	0	0	2239
	Meridian .... A	24	0	0	0	81	339	518	543	417	310	81	0	0	2289
	Vicksburg C	26	0	0	0	53	279	462	512	384	282	69	0	0	2041
Mo.	Columbia .... A	6	0	0	54	251	651	967	1076	874	716	324	121	12	5046
	Kansas City .... A	8	0	0	39	220	612	905	1032	818	682	294	109	0	4711
	St. Joseph .... A	3	0	6	60	285	708	1039	1172	949	769	348	133	15	5484
	St. Louis .... A	8	0	0	60	251	627	936	1026	848	704	312	121	15	4900
	St. Louis C	11	0	0	36	202	576	884	977	801	651	270	87	0	4484
	Springfield .... A	10	0	0	45	223	600	877	973	781	660	291	105	6	4900
Mont.	Billings .... A	- 6	6	15	186	487	897	1135	1296	1100	970	570	285	102	7049
	Glasgow .... A	-20	31	47	270	608	1104	1466	1711	1439	1187	648	335	150	8996
	Great Falls .... A	-16	28	53	258	543	921	1169	1349	1154	1063	642	384	186	7750
	Havre .... A		28	53	306	595	1065	1367	1584	1364	1181	657	338	162	8700
	Havre C	-15	19	37	252	539	1014	1321	1528	1305	1116	612	304	135	8182
	Helena .... A	-13	31	59	294	601	1002	1265	1438	1170	1042	651	381	195	8129
	Kalispell .... A	- 3	50	99	321	654	1020	1240	1401	1134	1029	639	397	207	8191
	Miles City .... A	-15	6	6	174	502	972	1296	1504	1252	1057	579	276	99	7723
	Missoula .... A	- 3	34	74	303	651	1035	1287	1420	1120	970	621	391	219	8125
Neb.	Grand Island .... A	- 2	0	6	108	381	834	1172	1314	1089	908	462	211	45	6530
	Lincoln C	0	0	6	75	301	726	1066	1237	1016	834	402	171	30	5864
	Norfolk .... A	- 7	9	0	111	397	873	1234	1414	1179	983	498	233	48	6979
	North Platte .... A	- 2	0	6	123	440	885	1166	1271	1039	930	519	248	57	6684
	Omaha .... A	- 1	0	12	105	357	828	1175	1355	1126	939	465	208	42	6612
	Scottsbluff .... A	- 4	0	0	138	459	876	1128	1231	1008	921	552	285	75	6673
	Valentine .... A		9	12	165	493	942	1237	1395	1176	1045	579	288	84	7425
Nev.	Elko .... A	- 7	9	34	225	561	924	1197	1314	1036	911	621	409	192	7433
	Ely .... A	- 2	28	43	234	592	939	1184	1308	1075	977	672	456	225	7733
	Las Vegas .... A	26	0	0	0	78	387	617	688	487	335	111	6	0	2709
	Reno .... A	7	43	87	204	490	801	1026	1073	823	729	510	357	189	6332
	Winnemucca .... A	5	0	34	210	536	876	1091	1172	916	837	573	363	153	6761
N.H.	Concord .... A	- 7	6	50	177	505	822	1240	1358	1184	1032	636	298	75	7383
	Mt. Washington Obsv.		493	536	720	1057	1341	1742	1820	1663	1652	1260	930	603	13817
N.J.	Atlantic City .... A	18	0	0	39	251	549	880	936	848	741	420	133	15	4812
	Newark .... A	15	0	0	30	248	573	921	983	876	729	381	118	0	4589
	Trenton C	16	0	0	57	264	576	924	989	885	753	399	121	12	4980
N. M.	Albuquerque .... A	17	0	0	12	229	642	868	930	703	595	288	81	0	4348
	Clayton .... A		0	6	66	310	699	899	986	812	747	429	183	21	5158
	Raton .... A	2	9	28	126	431	825	1048	1116	904	834	543	301	63	6228
	Roswell .... A	19	0	0	18	202	573	806	840	641	481	201	31	0	3793
	Silver City .... A	18	0	0	6	183	525	729	791	605	518	261	87	0	3705
N.Y.	Albany .... A	0	0	19	138	440	777	1194	1311	1156	992	564	239	45	6875
	Albany C	5	0	9	102	375	699	1104	1218	1072	908	498	186	30	6201
	Binghamton .... A		22	65	201	471	810	1184	1277	1154	1045	645	313	99	7286
	Binghamton C	2	0	28	141	406	732	1107	1190	1081	949	543	229	45	6451
	Buffalo .... A	6	19	37	141	440	777	1156	1256	1145	1039	645	329	78	7062
	New York (Cent. Park) C	15	0	0	30	233	540	902	986	885	760	408	118	9	4871
	New York (La Guardia) .... A	16	0	0	27	223	528	887	973	879	750	414	124	6	4811

Table A-3 (contd)

State	Station	97 1/2% Winter Design Temp. a/	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
	New York (Kennedy) .... A	21	0	0	36	248	564	933	1029	935	815	480	167	12	5219
	Rochester .... A	5	9	31	126	415	747	1125	1234	1123	1014	597	279	48	6748
	Schenectady C	− 1	0	22	123	422	756	1159	1283	1131	970	543	211	30	6650
	Syracuse .... A	2	6	28	132	415	744	1153	1271	1140	1004	570	248	45	6756
N. C.	Asheville C	17	0	0	48	245	555	775	784	683	592	273	87	0	4042
	Cape Hatteras		0	0	0	78	273	521	580	518	440	177	25	0	2612
	Charlotte .... A	22	0	0	6	124	438	691	691	582	481	156	22	0	3191
	Greensboro .... A	17	0	0	33	192	513	778	784	672	552	234	47	0	3805
	Raleigh .... A	20	0	0	21	164	450	716	725	616	487	180	34	0	3393
	Wilmington .... A	27	0	0	0	74	291	521	546	462	357	96	0	0	2347
	Winston-Salem .... A	17	0	0	21	171	483	747	753	652	524	207	37	0	3595
N. D.	Bismarck .... A	−19	34	28	222	577	1083	1463	1708	1442	1203	645	329	117	8851
	Devils Lake C	−19	40	53	273	642	1191	1634	1872	1579	1345	753	381	138	9901
	Fargo .... A	−17	28	37	219	574	1107	1569	1789	1520	1262	690	332	99	9226
	Williston .... A	−17	31	43	261	601	1122	1513	1758	1473	1262	681	357	141	9243
Ohio	Akron-Canton .... A	6	0	9	96	381	726	1070	1138	1016	871	489	202	39	6037
	Cincinnati C	12	0	0	39	208	558	862	915	790	642	294	96	6	4410
	Cleveland .... A	7	9	25	105	384	738	1088	1159	1047	918	552	260	66	6351
	Columbus .... A	7	0	6	84	347	714	1039	1088	949	809	426	171	27	5660
	Columbus C		0	0	57	285	651	977	1032	902	760	396	136	15	5211
	Dayton .... A	6	0	6	78	310	696	1045	1097	955	809	429	167	30	5622
	Mansfield .... A	3	9	22	114	397	768	1110	1169	1042	924	543	245	60	6403
	Sandusky C	8	0	6	66	313	684	1032	1107	991	868	495	198	36	5796
	Toledo .... A	5	0	16	117	406	792	1138	1200	1056	924	543	242	60	6494
	Youngstown .... A	6	6	19	120	412	771	1104	1169	1047	921	540	248	60	6417
Okla.	Oklahoma City .... A	15	0	0	15	164	498	766	868	664	527	189	34	0	3725
	Tulsa .... A	16	0	0	18	158	522	787	893	683	539	213	47	0	3860
Ore.	Astoria .... A	30	146	130	210	375	561	679	753	622	636	480	363	231	5186
	Burns C		12	37	210	515	867	1113	1246	988	856	570	366	177	6957
	Eugene .... A	26	34	34	129	366	585	719	803	627	589	426	279	135	4726
	Meacham .... A		84	124	288	580	918	1091	1209	1005	983	726	527	339	7874
	Medford .... A	23	0	0	78	372	678	871	918	697	642	432	242	78	5008
	Pendleton .... A	10	0	0	111	350	711	884	1017	773	617	396	205	63	5127
	Portland .... A	24	25	28	114	335	597	735	825	644	586	396	245	105	4635
	Portland C	29	12	16	75	267	534	679	769	594	536	351	198	78	4109
	Roseburg .... A	29	22	16	105	329	567	713	766	608	570	405	267	123	4491
	Salem .... A	25	37	31	111	338	594	729	822	647	611	417	273	144	4754
Pa.	Allentown .... A	5	0	0	90	353	693	1045	1116	1002	849	471	167	24	5810
	Erie .... A	11	0	25	102	391	714	1063	1169	1081	973	585	288	60	6451
	Harrisburg .... A	13	0	0	63	298	648	992	1045	907	766	396	124	12	5251
	Philadelphia .... A	15	0	0	60	297	620	965	1016	889	747	392	118	40	5144
	Philadelphia C		0	0	30	205	513	856	924	823	691	351	93	0	4486
	Pittsburgh .... A	9	0	9	105	375	726	1063	1119	1002	874	480	195	39	5987
	Pittsburgh C	11	0	0	60	291	615	930	983	885	763	390	124	12	5053
	Reading C	9	0	0	54	257	597	939	1001	885	735	372	105	0	4945
	Scranton .... A	6	0	19	132	434	762	1104	1156	1028	893	498	195	33	6254
	Williamsport .... A	5	0	9	111	375	717	1073	1122	1002	856	468	177	24	5934
R. I.	Block Island .... A		0	16	78	307	594	902	1020	955	877	612	344	99	5804
	Providence .... A	10	0	16	96	372	660	1023	1110	988	868	534	236	51	5954
S. C.	Charleston .... A	27	0	0	0	59	282	471	487	389	291	54	0	0	2033
	Charleston C	30	0	0	0	34	210	425	443	367	273	42	0	0	1794
	Columbia .... A	23	0	0	0	84	345	577	570	470	357	81	0	0	2484
	Florence .... A	25	0	0	0	78	315	552	552	459	347	84	0	0	2387
	Greenville-Spartenburg .... A	23	0	0	6	121	399	651	660	546	446	132	19	0	2980
S. D.	Huron .... A	−12	9	12	165	508	1014	1432	1628	1355	1125	600	288	87	8223
	Rapid City .... A	− 6	22	12	165	481	897	1172	1333	1145	1051	615	326	126	7345
	Sioux Falls .... A	−10	19	25	168	462	972	1361	1544	1285	1082	573	270	78	7839
Tenn.	Bristol .... A	16	0	0	51	236	573	828	828	700	598	261	68	0	4143
	Chattanooga .... A	19	0	0	18	143	468	698	722	577	453	150	25	0	3254
	Knoxville .... A	17	0	0	30	171	489	725	732	613	493	198	43	0	3494
	Memphis .... A	21	0	0	18	130	447	698	729	585	456	147	22	0	3232

Table A-3 (contd)

State or Prov.	Station	97 1/2% Winter Design Temp. a/	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
	Memphis C		0	0	12	102	396	648	710	568	434	129	16	0	3015
	Nashville .... A	16	0	0	30	158	495	732	778	644	512	189	40	0	3578
	Oak Ridge C		0	0	39	192	531	772	778	669	552	228	56	0	3817
Tex.	Abilene .... A	21	0	0	0	99	366	586	642	470	347	114	0	0	2624
	Amarillo .... A	12	0	0	18	205	570	797	877	664	546	252	56	0	3985
	Austin .... A	29	0	0	0	31	225	388	468	325	223	51	0	0	1711
	Brownsville .... A	40	0	0	0	0	66	149	205	106	74	0	0	0	600
	Corpus Christi .... A	36	0	0	0	0	120	220	291	174	109	0	0	0	914
	Dallas .... A	24	0	0	0	62	321	524	601	440	319	90	6	0	2363
	El Paso .... A	25	0	0	0	84	414	648	685	445	319	105	0	0	2700
	Fort Worth .... A	24	0	0	0	65	324	536	614	448	319	99	0	0	2405
	Galveston .... A	36	0	0	0	6	147	276	360	263	189	33	0	0	1274
	Galveston C		0	0	0	0	138	270	350	258	189	30	0	0	1235
	Houston .... A	32	0	0	0	6	183	307	384	288	192	36	0	0	1396
	Houston C	33	0	0	0	0	165	288	363	258	174	30	0	0	1278
	Laredo .... A	36	0	0	0	0	105	217	267	134	74	0	0	0	797
	Lubbock .... A	15	0	0	18	174	513	744	800	613	484	201	31	0	3578
	Midland .... A	23	0	0	0	87	381	592	651	468	322	90	0	0	2591
	Port Arthur .... A	33	0	0	0	22	207	329	384	274	192	39	0	0	1447
	San Angelo .... A	25	0	0	0	68	318	536	567	412	288	66	0	0	2255
	San Antonio .... A	30	0	0	0	31	204	363	428	286	195	39	0	0	1546
	Victoria .... A	32	0	0	0	6	150	270	344	230	152	21	0	0	1173
	Waco .... A	26	0	0	0	43	270	456	536	389	270	66	0	0	2030
	Wichita Falls .... A	19	0	0	0	99	381	632	698	518	378	120	6	0	2832
Utah	Milford .... A		0	0	99	443	867	1141	1252	988	822	519	279	87	6497
	Salt Lake City .... A	9	0	0	81	419	849	1082	1172	910	763	459	233	84	6052
	Wendover .... A		0	0	48	372	822	1091	1178	902	729	408	177	51	5778
Vt.	Burlington .... A	- 7	28	65	207	539	891	1349	1513	1333	1187	714	353	90	8269
Va.	Cape Henry C		0	0	0	112	360	645	694	633	536	246	53	0	3279
	Lynchburg .... A	19	0	0	51	223	540	822	849	731	605	267	78	0	4166
	Norfolk .... A	23	0	0	0	136	408	698	738	655	533	216	37	0	3421
	Richmond .... A	18	0	0	36	214	495	784	815	703	546	219	53	0	3865
	Roanoke .... A	18	0	0	51	229	549	825	834	722	614	261	65	0	4150
Wash.	Olympia .... A	25	68	71	198	422	636	753	834	675	645	450	307	177	5236
	Seattle-Tacoma .... A	24	56	62	162	391	633	750	828	678	657	474	295	159	5145
	Seattle C	32	50	47	129	329	543	657	738	599	577	396	242	117	4424
	Spokane .... A	4	9	25	168	493	879	1082	1231	980	834	531	288	135	6655
	Walla Walla C	16	0	0	87	310	681	843	986	745	589	342	177	45	4805
	Yakima .... A	10	0	12	144	450	828	1039	1163	868	713	435	220	69	5941
W. Va.	Charleston .... A	14	0	0	63	254	591	865	880	770	648	300	96	9	4476
	Elkins .... A	5	9	25	135	400	729	992	1008	896	791	444	198	48	5675
	Huntington .... A	14	0	0	63	257	585	856	880	764	636	294	99	12	4446
	Parkersburg C	12	0	0	60	264	606	905	942	826	691	339	115	6	4754
Wisc.	Green Bay .... A	- 7	28	50	174	484	924	1333	1494	1313	1141	654	335	99	8029
	La Crosse .... A	- 8	12	19	153	437	924	1339	1504	1277	1070	540	245	69	7589
	Madison .... A	- 5	25	40	174	474	930	1330	1473	1274	1113	618	310	102	7863
	Milwaukee .... A	- 2	43	47	174	471	876	1252	1376	1193	1054	642	372	135	7635
Wyo.	Casper .... A	- 5	6	16	192	524	942	1169	1290	1084	1020	657	381	129	7410
	Cheyenne .... A	- 2	28	37	219	543	909	1085	1212	1042	1026	702	428	150	7381
	Lander .... A	-12	6	19	204	555	1020	1299	1417	1145	1017	654	381	153	7870
	Sheridan .... A	- 7	25	31	219	539	948	1200	1355	1154	1051	642	366	150	7680
Alta.	Banff C		220	295	498	797	1185	1485	1624	1364	1237	855	589	402	10551
	Calgary .... A	-25	109	186	402	719	1110	1389	1575	1379	1268	798	477	291	9703
	Edmonton .... A	-26	74	180	411	738	1215	1603	1810	1520	1330	765	400	222	10268
	Lethbridge .... A	-24	56	112	318	611	1011	1277	1497	1291	1159	696	403	213	8644
B. C.	Kamloops .... A	-10	22	40	189	546	894	1138	1314	1057	818	462	217	102	6799
	Prince George* .... A	-31	236	251	444	747	1110	1420	1612	1319	1122	747	468	279	9755
	Prince Rupert C	15	273	248	339	539	708	868	936	808	812	648	493	357	7029
	Vancouver* .... A	19	81	87	219	456	657	787	862	723	676	501	310	156	5515
	Victoria* .... A		136	140	225	462	663	775	840	718	691	504	341	204	5699
	Victoria C	23	172	184	243	426	607	723	805	668	660	487	354	250	5579

Table A-3 (contd)

State or Prov.	Station	97 1/2% Winter Design Temp. a/	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Man.	Brandon* .... A	−26	47	90	357	747	1290	1792	2034	1737	1476	837	431	198	11036
	Churchill.............................. A	−38	360	375	681	1082	1620	2248	2558	2277	2130	1569	1153	675	16728
	The Pas.............................. C	−32	59	127	429	831	1440	1981	2232	1853	1624	969	508	228	12281
	Winnipeg .... A	−25	38	71	322	683	1251	1757	2008	1719	1465	813	405	147	10679
N. B.	Fredericton* .... A	−10	78	68	234	592	915	1392	1541	1379	1172	753	406	141	8671
	Moncton C	− 7	62	105	276	611	891	1342	1482	1336	1194	789	468	171	8727
	St. John C	− 7	109	102	246	527	807	1194	1370	1229	1097	756	490	249	8219
Nfld.	Argentia .... A		260	167	294	564	750	1001	1159	1085	1091	879	707	483	8440
	Corner Brook C	− 5	102	133	324	642	873	1194	1358	1283	1212	885	639	333	8978
	Gander .... A	− 1	121	152	330	670	909	1231	1370	1266	1243	939	657	366	9254
	Goose* .... A	−25	130	205	444	843	1227	1745	1947	1689	1494	1074	741	348	11887
	St. John's* .... A	6	186	180	342	651	831	1113	1262	1170	1187	927	710	432	8991
N. W. T.	Aklavik C		273	459	807	1414	2064	2530	2632	2336	2282	1674	1063	483	18017
	Fort Norman C		164	341	666	1234	1959	2474	2592	2209	2058	1386	732	294	16109
	Resolution Island C		843	831	900	1113	1311	1724	2021	1850	1817	1488	1181	942	16021
N. S.	Halifax C	4	58	51	180	457	710	1074	1213	1122	1030	742	487	237	7361
	Sydney .... A	5	62	71	219	518	765	1113	1262	1206	1150	840	567	276	8049
	Yarmouth .... A	9	102	115	225	471	696	1029	1156	1065	1004	726	493	258	7340
Ont.	Cochrane C		96	180	405	760	1233	1776	1978	1701	1528	963	570	222	11412
	Fort William .... A	−23	90	133	366	694	1140	1597	1792	1557	1380	876	543	237	10405
	Kapuskasing C	−28	74	171	405	756	1245	1807	2037	1735	1562	978	580	222	11572
	Kitchener C	1	16	59	177	505	855	1234	1342	1226	1101	663	322	66	7566
	London .... A	3	12	43	159	477	837	1206	1305	1198	1066	648	332	66	7349
	North Bay C	−17	37	90	267	608	990	1507	1680	1463	1277	780	400	120	9219
	Ottawa C	−13	25	81	222	567	936	1469	1624	1441	1231	708	341	90	8735
	Toronto C	1	7	18	151	439	760	1111	1233	1119	1013	616	298	62	6827
P.E.I.	Charlottetown C	− 3	40	53	198	518	804	1215	1380	1274	1169	813	496	204	8164
	Summerside C	− 3	47	84	216	546	840	1246	1438	1291	1206	841	518	216	8488
Que.	Arvida C		102	136	327	682	1074	1659	1879	1619	1407	891	521	231	10528
	Montreal* .... A	−10	9	43	165	521	882	1392	1566	1381	1175	684	316	69	8203
	Montreal C		16	28	165	496	864	1355	1510	1328	1138	657	288	54	7899
	Quebec* .... A	−13	56	84	273	636	996	1516	1665	1477	1296	819	428	126	9372
	Quebec C		40	68	243	592	972	1473	1612	1418	1228	780	400	111	8937
Sasks	Prince Albert .... A	−35	81	136	414	797	1368	1872	2108	1763	1559	867	446	219	11630
	Regina .... A	−29	78	93	360	741	1284	1711	1965	1687	1473	804	409	201	10806
	Saskatoon C	−30	56	87	372	750	1302	1758	2006	1689	1463	798	403	186	10870
Y. T.	Dawson C		164	326	645	1197	1875	2415	2561	2150	1838	1068	570	258	15067
	Mayo Landing C		208	366	648	1135	1794	2325	2427	1992	1665	1020	580	294	14454

*The data for these normals were from the full ten-year period 1951–1960, adjusted to the standard normal period 1931–1960.

Table A-3 (contd)

Table A-4

Radiation and Other Data for 80 Locations in the United States

($\overline{I}_H$ Monthly average daily total radiation on a horizontal aurface, Btu/day-ft^2; $\overline{K}_t$=the fraction of the extra terrestrial radiation transmitted through the atmosphere; t_o=average daytime ambient temperature, °F)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ALASKA													
Annette Is..............	$\overline{I}_H$	236.2	428.4	883.4	1357.2	1634.7	1638.7	1632.1	1269.4	962	454.6	220.3	152
Lat 55°02'N	$\overline{K}_t$	0.427	0.415	0.492	0.507	0.484	0.441	0.454	0.427	0.449	0.347	0.304	0.361
El. 110 ft.............	t_o	35.8	37.5	39.7	44.4	51.0	56.2	58.6	59.8	54.8	48.2	41.9	37.4
Barrow.................	$\overline{I}_H$	13.3	143.2	713.3	1491.5	1883	2055.3	1602.2	953.5	428.4	152.4	22.9	-
Lat. 71°20'N	$\overline{K}_t$	-	0.776	0.773	0.726	0.553	0.533	0.448	0.377	0.315	0.35	-	-
El. 22 ft..............	t_o	-13.2	-15.9	-12.7	2.1	20.5	35.4	41.6	40.0	31.7	18.6	2.6	-8.6
Bethel.................	$\overline{I}_H$	142.4	404.8	1052:4	1662.3	1711.8	1698.1	1401.8	938.7	755	430.6	164.9	83
Lat.60°47'N............	$\overline{K}_t$	0.536	0.557	0.704	0.675	0.519	0.458	0.398	0.336	0.406	0.432	0.399	0.459
El. 125 ft.............	t_o	9.2	11.6	14.2	29.4	42.7	55.5	56.9	54.8	47.4	33.7	19.0	9.4
Fairbanks..............	$\overline{I}_H$	66	283.4	860.5	1481.2	1806.2	1970.8	1702.9	1247.6	699.6	323.6	104.1	20.3
Lat.64°49'N............	$\overline{K}_t$	0.639	0.556	0.674	0.647	0.546	0.529	0.485	0.463	0.419	0.416	0.47	0.458
El. 436 ft.............	t_o	-7.0	0.3	13.0	32.2	50.5	62.4	63.8	58.3	47.1	29.6	5.5	-6.6
Matanuska..............	$\overline{I}_H$	119.2	345	-	1327.6	1628.4	1727.6	1526.9	1169	737.3	373.8	142.8	56.4
Lat.61°30'N............	$\overline{K}_t$	0.513	0.503	-	0.545	0.494	0.466	0.434	0.419	0.401	0.390	0.372	0.36′
El. 180 ft.............	t_o	13.9	21.0	27.4	38.6	50.3	57.6	60.1	58.1	50.2	37.7	22.9	13.9
ALBERTA													
Edmonton...............	$\overline{I}_H$	331.7	652.4	1165.3	1541.7	1900.4	1914.4	1964.9	1528	1113.3	704.4	413.6	245
Lat.53°35'N	$\overline{K}_t$	0.529	0.585	0.624	0.564	0.558	0.514	0.549	0.506	0.506	0.504	0.510	0.492
El. 2219 ft............	t_o	10.4	14	26.3	42.9	55.4	61.3	66.6	63.2	54.2	44.1	26.7	14.0
ARKANSAS													
Little Rock............	$\overline{I}_H$	704.4	974.2	1335.8	1669.4	1960.1	2091.5	2081.2	1938.7	1640.6	1282.6	913.6	701.1
Lat.34°44'N	$\overline{K}_t$	0.424	0.458	0.496	0.513	0.545	0.559	0.566	0.574	0.561	0.552	0.484	0.463
El. 265 ft.............	t_o	44.6	48.5	56.0	65.8	73.1	76.7	85.1	84.6	78.3	67.9	54.7	46.7
ARIZONA													
Phoenix................	$\overline{I}_H$	1126.6	1514.7	1967.1	2388.2	2709.6	2781.5	2450.5	2299.6	2131.3	1688.9	1290	1040.9
Lat.33°26'N............	$\overline{K}_t$	0.65	0.691	0.716	0.728	0.753	0.745	0.667	0.677	.722	0.708	0.657	0.652
El. 1112 ft............	t_o	54.2	58.8	64.7	72.2	80.8	89.2	94.6	92.5	87.4	75.8	63.6	56.7
Tucaon.................	$\overline{I}_H$	1171.9	1453.8	-	2434.7	-	2601.4	2292.2	2179.7	2122.5	1640.9	1322.1	1132.1
Lat. 32°07'N...........	$\overline{K}_t$	0.648	0.646	-	0.738	-	0.698	0.625	0.640	0.710	0.672	0.650	0.679
El. 2556 ft............	t_o	53.7	57.3	62.3	69.7	78.0	87.0	90.1	87.4	84.0	73.9	62.5	56.1
CALIFORNIA													
Davis..................	$\overline{I}_H$	599.2	945	1504	1959	2368.6	2619.2	2565.6	2287.8	1856.8	1238.5	795.6	550.5
Lat. 38°33'N...........	$\overline{K}_t$	0.416	0.490	0.591	0.617	0.662	0.697	0.697	0.687	0.664	0.598	0.477	0.421
El. 51 ft..............	t_o	47.6	52.1	56.8	63.1	69.6	75.7	81	79.4	76.7	67.8	57	48.7
Fresno.................	$\overline{I}_H$	712.9	1116.6	1652.8	2049.4	2409.2	2641.7	2512.2	2300.7	1897.8	1415.5	906.6	616.6
Lat. 36°46'N...........	$\overline{K}_t$	0.462	0.551	0.632	0.638	0.672	0.703	0.682	0.686	0.665	0.635	0.512	0.44
El. 331 ft.............	t_o	47.3	53.9	59.1	65.6	73.5	80.7	87.5	84.9	78.6	68.7	57.3	48.9
Inyokern...............	$\overline{I}_H$	1148.7	1554.2	2136.9	2594.8	2925.4	3108.8	2908.8	2759.4	2409.2	1819.2	3170.1	1094.4
Lat. 35° 39'N..........	$\overline{K}_t$	0.716	0.745	0.803	0.8	0.815	0.830	0.790	0.820	0.834	0.795	0.743	0.742
El. 2440 ft............	t_o	47.3	53.9	59.1	65.6	73.5	80.7	87.5	84.9	78.6	68.7	57.3	48.9
Los Angeles, (WBO)......	$\overline{I}_H$	911.8	1223.6	1640.9	1866.8	2061.2	2259	2428.4	2198.9	1891.5	1362.3	1053.1	877.8
Lat.34°03'N	$\overline{K}_t$	0.538	0.568	0.602	0.571	0.573	0.605	0.66	0.648	0.643	0.578	0.548	0.566
El. 99 ft..............	t_o	57.9	59.2	61.8	64.3	67.6	70.7	75.8	76.1	74.2	69.6	65.4	60.2
Los Angelea,(WBAS)	$\overline{I}_H$	930.6	1284.1	1729.5	1948	2196.7	2272.3	2413.6	2155.3	1898.1	1372.7	1082.3	901.1
Lat. 33°56'N............	$\overline{K}_t$	0.547	0.596	0.635	0.595	0.610	0.608	0.657	0.635	0.641	0.574	0.551	0.566
El. 99 ft..............	t_o	56.2	56.9	59.2	61.4	64.2	66.7	69.6	70.2	69.1	66.1	62.6	58.7
Riverside..............	$\overline{I}_H$	999.6	1335	1750.5	1943.2	2282.3	2492.6	2443.5	2263.8	1955.3	1509.6	1169	979.7
Lat. 33°57'N...........	$\overline{K}_t$	0.589	0.617	0.643	0.594	0.635	0.667	0.665	0.668	0.665	0.639	0.606	0.626
El. 1020 ft............	t_o	55.3	57.0	60.6	65.0	69.4	74.0	81.0	81.0	78.5	71.0	63.1	57.2
Santa Maria............	$\overline{I}_H$	983.8	1296.3	1805.9	2067.9	2375.6	2599.6	2540.6	2293.3	1965.7	1566.4	1169	943.9
Lat. 34°54'N...........	$\overline{K}_t$	0.595	0.613	0.671	0.636	0.661	0.695	0.690	0.678	0.674	0.676	0.624	0.627
El. 238 ft.............	t_o	54.1	55.3	57.6	59.5	61.2	63.5	65.3	65.7	65.9	64.1	60.8	56.1
COLORADO													
Grand Junction.........	$\overline{I}_H$	848	1210.7	1622.9	2002.2	2300.3	2645.4	2517.7	2157.2	1957.5	1394.8	969.7	793.4
Lat. 39°07'N...........	$\overline{K}_t$	0.597	0.633	0.643	0.632	0.643	0.704	0.690	0.65	0.705	0.654	0.59	0.621
El. 4849 ft............	t_o	26.9	35.0	44.6	55.8	66.3	75.7	82.5	79.6	71.4	58.3	42.0	31.4
Grand Lake...........	$\overline{I}_H$	735	1135.4	1579.3	1876.7	1974.9	2369.7	2103.3	1708.5	1715.8	1212.2	775.6	660.5
Lat. 40°15'N..........	$\overline{K}_t$	0.541	0.615	0.637	0.597	0.553	0.63	0.572	0.516	0.626	0.583	0.494	0.542
El. 8389 ft...........	t_o	18.5	23.1	28.5	39.1	48.7	56.6	62.8	61.5	55.5	45.2	30.3	22.6

From: Applications of Solar Energy for Heating and Cooling of Buildings, ASHRAE [17]

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
DISTRICT OF COLUMBIA													
Washington (WBCO).......	$\bar{I}_H$	632.4	901.5	1255	1600.4	1846.8	2080.8	1929.9	1712.2	1446.1	1083.4	763.5	594.1
Lat. 38°51'N...........	$\bar{K}_t$	0.445	0.470	0.496	0.504	0.516	0.553	0.524	0.516	0.520	0.506	0.464	0.460
El. 64 ft..............	t_o	38.4	39.6	48.1	57.5	67.7	76.2	79.9	77.9	72.2	60.9	50.2	40.2
FLORIDA													
Apalachicola...........	$\bar{I}_H$	1107	1378.2	1654.2	2040.9	2268.6	2195.9	1978.6	1912.9	1703.3	1544.6	1243.2	982.3
Lat. 29°45'N...........	$\bar{K}_t$	0.577	0.584	0.576	0.612	0.630	0.594	0.542	0.558	0.559	0.608	0.574	0.543
El. 35 ft..............	t_o	57.3	59.0	62.9	69.5	76.4	81.8	83.1	83.1	80.6	73.2	63.7	58.55
Gainesville............	$\bar{I}_H$	1036.9	1324.7	1635	1956.4	1934.7	1960.9	1895.6	1873.8	1615.1	1312.2	1169.7	919.5
Lat. 29°39'N...........	$\bar{K}_t$	0.535	0.56	0.568	0.587	0.538	0.531	0.519	0.547	0.529	0.515	0.537	0.508
El. 165 ft.............	t_o	62.1	63.1	67.5	72.8	79.4	83.4	83.8	84.1	82	75.7	67.2	62.4
Miami..................	$\bar{I}_H$	1292.2	1554.6	1828.8	2020.6	2068.6	1991.5	1992.6	1890.8	1646.8	1436.5	1321	1183.4
Lat. 25°47'N...........	$\bar{K}_t$	0.604	0.616	0.612	0.600	0.578	0.545	0.552	0.549	0.525	0.534	0.559	0.588
El. 9 ft...............	t_o	71.6	72.0	73.8	77.0	79.9	82.9	84.1	84.5	83.3	80.2	75.6	72.6
Tampa..................	$\bar{I}_H$	1223.6	1461.2	1771.9	2016.2	2228	2146.5	1991.9	1845.4	1687.8	1493.3	1328.4	1119.5
Lat. 27°55'N...........	$\bar{K}_t$	0.605	0.600	0.606	0.602	0.620	0.583	0.548	0.537	0.546	0.572	0.590	0.589
El. 11 ft..............	t_o	64.2	65.7	68.8	74.3	79.4	83.0	84.0	84.4	82.9	77.2	69.6	65.5
GEORGIA													
Atlanta................	$\bar{I}_H$	848	1080.1	1426.9	1807	2618.1	2002.6	2002.9	1898.1	1519.2	1290.8	997.8	751.(
Lat. 33°39'N...........	$\bar{K}_t$	0.493	0.496	0.522	0.551	0.561	0.564	0.545	0.559	0.515	0.543	0.510	0.474
El. 976 ft.............	t_o	47.2	49.6	55.9	65.0	73.2	80.9	82.4	81.6	77.4	66.5	54.8	47.7
Griffin................	$\bar{I}_H$	889.6	1135.8	1450.9	1923.6	2163.1	2176	2064.9	1961.2	1605.9	1352.4	1073.8	781.5
Lat. 33°15'N...........	$\bar{K}_t$	0.513	0.517	0.528	0.586	0.601	0.583	0.562	0.578	0.543	0.565	0.545	0.487
El. 980 ft.............	t_o	48.9	51.0	59.1	66.7	74.6	81.2	83.0	82.2	78.4	68	57.3	49.4
IDAHO													
Boise..................	$\bar{I}_H$	518.8	884.9	1280.4	1814.4	2189.3	2376.7	2500.3	2149.4	1717.7	1128.4	678.6	456.8
Lat. 43°34'N...........	$\bar{K}_t$	0.446	0.533	0.548	0.594	0.619	0.631	0.684	0.660	0.656	0.588	0.494	0.442
El. 2844 ft............	t_o	29.5	36.5	45.0	53.5	62.1	69.3	79.6	77.2	66.7	56.3	42.3	33.1
ILLINOIS													
Lemont.................	$\bar{I}_H$	(590)	879	1255.7	1481.5	1866	2041.7	1990.8	1836.9	1469.4	1015.5	(639)	(531)
Lat. 41°40'N...........	$\bar{K}_t$	(0.464)	0.496	0.520	0.477	0.525	0.542	0.542	0.559	0.547	0.506	(0.433)	(0.467)
El 595 ft..............	t_o	28.9	30.3	39.5	49.7	59.2	70.8	75.6	74.3	67.2	57.6	43.0	30.6
INDIANA													
Indianapolis...........	$\bar{I}_H$	526.2	797.4	1184.1	1481.2	1828	2042	2039.5	1832.1	1513.3	1094.4	662.4	491.1
Lat. 39°44'N...........	$\bar{K}_t$	0.380	0.424	0.472	0.47	0.511	0.543	0.554	0.552	0.549	0.520	0.413	0.391
El. 793 ft.............	t_o	31.3	33.9	43.0	54.1	64.9	74.8	79.6	77.4	70.6	59.3	44.2	33.4
KANSAS													
Dodge City.............	$\bar{I}_H$	953.1	1186.3	1565.7	1975.6	2126.5	2459.8	2400.7	2210.7	1841.7	1421	1065.3	873.8
Lat. 37°46'N...........	$\bar{K}_t$	0.639	0.598	0.606	0.618	0.594	0.655	0.652	0.663	0.654	0.650	0.625	0.652
El. 2592 ft............	t_o	33.8	38.7	46.5	57.7	66.7	77.2	83.8	82.4	73.7	61.7	46.5	36.8
KENTUCKY													
Lexington..............	$\bar{I}_H$	-	-	-	1834.7	2171.2	-	2246.5	2064.9	1775.6	1315.8	-	681.5
Lat. 38°02'N...........	$\bar{K}_t$	-	-	-	0.575	0.606	-	0.610	0.619	0.631	0.604	-	0.513
El. 979 ft.............	t_o	36.5	38.8	47.4	57.8	67.5	76.2	79.8	78.2	72.8	61.2	47.6	38.5
LOUISIANA													
Lake Charles...........	$\bar{I}_H$	899.2	1145.7	1487.4	1801.8	2080.4	2213.3	1968.6	1910.3	1678.2	1505.5	1122.1	875.6
Lat. 30°13'N...........	$\bar{K}_t$	0.473	0.492	0.521	0.542	0.578	0.597	0.538	0.558	0.553	0.597	0.524	0.494
El. 12 ft..............	t_o	55.3	58.7	63.5	70.9	77.4	83.4	84.8	85.0	81.5	73.8	62.6	56.9
MAINE													
Caribou................	$\bar{I}_H$	497	861.6	1360.1	1495.9	1779.7	1779.7	1898.1	1675.6	1254.6	793	415.5	398.9
Lat. 46°52'N...........	$\bar{K}_t$	0.504	0.579	0.619	0.507	0.509	0.473	0.522	0.527	0.506	0.455	0.352	0.470
El. 628 ft.............	t_o	11.5	12.8	24.4	37.3	51.8	61.6	67.2	65.0	56.2	44.7	31.3	16.8
Portland...............	$\bar{I}_H$	565.7	874.5	1329.5	1528.4	1923.2	2017.3	2095.6	1799.2	1428.8	1035	591.5	507.7
Lat. 43°39'N...........	$\bar{K}_t$	0.482	0.524	0.569	0.500	0.544	0.536	0.572	0.554	0.546	0.539	0.431	0.491
El. 63 ft..............	t_o	23.7	24.5	34.4	44.8	55.4	65.1	71.1	69.7	61.9	51.8	40.3	28.0
MANITOBA													
Winnipeg...............	$\bar{I}_H$	488.2	835.4	1354.2	1641.3	1904.4	1962	2123.6	1761.2	1190.4	767.5	444.6	345 '
Lat. 49°54'N...........	$\bar{K}_t$	0.601	0.636	0.661	0.574	0.550	0.524	0.587	0.567	0.504	0.482	0.436	0.503
El. 786 ft.............	t_o	3.2	7.1	21.3	40.9	55.9	65.3	71.9	69.4	58.6	45.6	25.2	10.1
MASSACHUSETTS													
Blue Hill..............	$\bar{I}_H$	555.3	797	1143.9	1438	1776.4	1943.9	1881.5	1622.1	1314	941	592.2	482.3
Lat. 42°13'N...........	$\bar{K}_t$	0.445	0.458	0.477	0.464	0.501	0.516	0.513	0.495	0.492	0.472	0.406	0.436
El. 629 ft.............	t_o	28.3	28.3	36.9	46.9	58.5	67.2	72.3	70.6	64.2	54.1	43.3	31.5
Boston.................	$\bar{I}_H$	505.5	738	1067.1	1355	1769	1864	1860.5	1570.1	1267.5	896.7	535.8	442.8
Lat. 42°22'N...........	$\bar{K}_t$	0.410	0.426	0.445	0.438	0.499	0.495	0.507	0.480	0.477	0.453	0.372	0.400
El. 29 ft..............	t_o	31.4	31.4	39.9	49.5	60.4	69.8	74.5	73.8	66.8	57.4	46.6	34.9

Table A-4 (Continued)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MASSACHUSETTS (Contd.)													
East Wareham............	$\bar{I}_H$	504.4	762.4	1132.1	1392.6	1704.8	1958.3	1873.8	1607.4	1363.8	996.7	636.2	521
Lat. 41°46'N............	$\bar{K}_t$	0.398	0.431	0.469	0.449	0.480	0.520	0.511	0.489	0.508	0.496	0.431	0.461
El. 18 ft..............	t_o	32.2	31.6	39.0	48.3	58.9	67.5	74.1	72.8	65.9	56	46	34.8
MICHIGAN													
East Lansing............	$\bar{I}_H$	425.8	739.1	1086	1249.8	1732.8	1914	1884.5	1627.7	1303.3	891.5	473.1	379.7
Lat. 42°44'N............	$\bar{K}_t$	0.35	0.431	0.456	0.406	0.489	0.508	0.514	0.498	0.493	0.456	0.333	0.349
El. 856 ft..............	t_o	26.0	26.4	35.7	48.4	59.8	70.3	74.5	72.4	65.0	53.5	40.0	29.0
Sault Ste. Marie........	$\bar{I}_H$	488.6	843.9	1336.5	1559.4	1962.3	2064.2	2149.4	1767.9	1207	809.2	392.2	359.8
Lat. 46°28'N............	$\bar{K}_t$	0.490	0.560	0.606	0.526	0.560	0.549	0.590	0.554	0.481	0.457	0.323	0.408
El. 724 ft..............	t_o	16.3	16.2	25.6	39.5	52.1	61.6	67.3	66.0	57.9	46.8	33.4	21.9
MINNESOTA													
St. Cloud...............	$\bar{I}_H$	632.8	976.7	1383	1598.1	1859.4	2003.3	2087.8	1828.4	1369.4	890.4	545.4	463.1
Lat. 45°35'N............	$\bar{K}_t$	0.595	0.629	0.614	0.534	0.530	0.533	0.573	0.570	0.539	0.490	0.435	0.504
El. 1034 ft.............	t_o	13.6	16.9	29.8	46.2	58.8	68.5	74.4	71.9	62.5	50.2	32.1	18.3
MISSOURI													
Columbia................	$\bar{I}_H$	651.3	941.3	1315.8	1631.3	1999.6	2129.1	2148.7	1953.1	1689.6	1202.6	839.5	590.4
Lat. 38°58'N............	$\bar{K}_t$	0.458	0.492	0.520	0.514	0.559	0.566	0.585	0.588	0.606	0.562	0.510	0.457
El. 785 ft..............	t_o	32.5	36.5	45.9	57.7	66.7	75.9	81.1	79.4	71.9	61.4	46.1	35.8
MONTANA													
Glasgow.................	$\bar{I}_H$	572.7	965.7	1437.6	1741.3	2127.3	2261.6	2414.7	1984.5	1531	997	574.9	428.4
Lat. 48°13'N............	$\bar{K}_t$	0.621	0.678	0.672	0.597	0.611	0.602	0.666	0.630	0.629	0.593	0.516	0.548
El. 2277 ft.............	t_o	13.3	17.3	31.1	47.8	59.3	67.3	76	73.2	61.2	49.2	31.0	18.6
Great Falls.............	$\bar{I}_H$	524	869.4	1369.7	1621.4	1970.8	2179.3	2383	1986.3	1536.5	984.9	575.3	420.7
Lat. 47°29'N............	$\bar{K}_t$	0.552	0.596	0.631	0.551	0.565	0.580	0.656	0.627	0.626	0.574	0.503	0.518
El. 3664 ft.............	t_o	25.4	27.6	35.6	47.7	57.5	64.3	73.8	71.3	60.6	51.4	38.0	29.1
NEBRASKA													
Lincoln.................	$\bar{I}_H$	712.5	955.7	1299.6	1587.8	1856.1	2040.6	2011.4	1902.6	1543.5	1215.8	773.4	643.2
Lat. 40°51'N............	$\bar{K}_t$	0.542	0.528	0.532	0.507	0.522	0.542	0.547	0.577	0.568	0.596	0.508	0.545
El. 1189 ft.............	t_o	27.8	32.1	42.4	55.8	65.8	76.0	82.6	80.2	71.5	59.9	43.2	31.8
NEVADA													
Ely.....................	$\bar{I}_H$	871.6	1255	1749.8	2103.3	2322.1	2649	2417	2307.7	1935	1473	1078.6	814.8
Lat. 39°17'N............	$\bar{K}_t$	0.618	0.660	0.692	0.664	0.649	0.704	0.656	0.695	0.696	0.691	0.658	0.64
El. 6262 ft.............	t_o	27.3	32.1	39.5	48.3	57.0	65.4	74.5	72.3	63.7	52.1	39.9	31.1
Las Vegas...............	$\bar{I}_H$	1035.8	1438	1926.5	2322.8	2629.5	2799.2	2524	2342	2062	1602.6	1190	964.2
Lat. 36°05'N............	$\bar{K}_t$	0.654	0.697	0.728	0.719	0.732	0.746	0.685	0.697	0.716	0.704	0.657	0.668
El. 2162 ft.............	t_o	47.5	53.9	60.3	69.5	78.3	88.2	95.0	92.9	85.4	71.7	57.8	50.2
NEW JERSEY													
Seabrook................	$\bar{I}_H$	591.9	854.2	1195.6	1518.8	1800.7	1964.6	1949.8	1715	1445.7	1071.9	721.8	522.5
Lat. 39°30'N............	$\bar{K}_t$	0.426	0.453	0.476	0.481	0.504	0.522	0.530	0.517	0.524	0.508	0.449	0.416
El. 100 ft..............	t_o	39.5	37.6	43.9	54.7	64.9	74.1	79.8	77.7	69.7	61.2	48.5	39.3
NEW MEXICO													
Albuquerque.............	$\bar{I}_H$	1150.9	1453.9	1925.4	2343.5	2560.9	2757.5	2561.2	2387.8	2120.3	1639.8	1274.2	1051.6
Lat. 35°03'N............	$\bar{K}_t$	0.704	0.691	0.719	0.722	0.713	0.737	0.695	0.708	0.728	0.711	0.684	0.704
El. 5314 ft.............	t_o	37.3	43.3	50.1	59.6	69.4	79.1	82.8	80.6	73.6	62.1	47.8	39.4
NEW YORK													
Ithaca..................	$\bar{I}_H$	434.3	755	1074.9	1322.9	1779.3	2025.8	2031.3	1736.9	1320.3	918.4	466.4	370.8
Lat. 42°27'N............	$\bar{K}_t$	0.351	0.435	0.45	0.428	0.502	0.538	0.554	0.530	0.497	0.465	0.324	0.337
El. 950 ft..............	t_o	27.2	26.5	36	48.4	59.6	68.9	73.9	71.9	64.2	53.6	41.5	29.6
New York................	$\bar{I}_H$	539.5	790.8	1180.4	1426.2	1738.4	1994.1	1938.7	1605.9	1349.4	977.8	598.1	476
Lat. 40°46'N............	$\bar{K}_t$	0.406	0.435	0.480	0.455	0.488	0.53	0.528	0.486	0.500	0.475	0.397	0.403
El. 52 ft...............	t_o	35.0	34.9	43.1	52.3	63.3	72.2	76.9	75.3	69.5	59.3	48.3	37.7
Sayville................	$\bar{I}_H$	602.9	936.2	1259.4	1560.5	1857.2	2123.2	2040.9	1734.7	1446.8	1087.4	697.8	533.9
Lat. 40°30'N............	$\bar{K}_t$	0.453	0.511	0.510	0.498	0.522	0.564	0.555	0.525	0.530	0.527	0.450	0.447
El. 20 ft...............	t_o	35	34.9	43.1	52.3	63.3	72.2	76.9	75.3	69.5	59.3	48.3	37.7
Schenectady.............	$\bar{I}_H$	488.2	753.5	1026.6	1272.3	1553.1	1687.8	1662.3	1494.8	1124.7	820.6	436.2	356.8
Lat. 42°50'N............	$\bar{K}_t$	0.406	0.441	0.433	0.413	0.438	0.448	0.454	0.458	0.426	0.420	0.309	0.331
El. 217 ft..............	t_o	24.7	24.6	34.9	48.3	61.7	70.8	76.9	73.7	64.6	53.1	40.1	28.0
Upton...................	$\bar{I}_H$	583	872.7	1280.4	1609.9	1891.5	2159	2044.6	1789.6	1472.7	1102.6	686.7	551.3
Lat. 40°52'N............	$\bar{K}_t$	0.444	0.483	0.522	0.514	0.532	0.574	0.557	0.542	0.542	0.538	0.448	0.467
El. 75 ft...............	t_o	35.0	34.9	43.1	52.3	63.3	72.2	76.9	75.3	69.5	59.3	48.3	37.7
NORTH CAROLINA													
Greensboro..............	$\bar{I}_H$	743.9	1031.7	1323.2	1755.3	1988.5	2111.4	2033.9	1810.3	1517.3	1202.6	908.1	690.8
Lat. 36°05'N............	$\bar{K}_t$	0.469	0.499	0.499	0.543	0.554	0.563	0.552	0.538	0.527	0.531	0.501	0.479
El. 891 ft..............	t_o	42.0	44.2	51.7	60.8	69.9	78.0	80.2	78.9	73.9	62.7	51.5	43.2

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NORTH CAROLINA (Contd.)													
Hatteras................	$\bar{I}_H$	891.9	1184.1	1590.4	2128	2376.4	2438	2334.3	2085.6	1758.3	1337.6	1053.5	798.1
Lat. 35°13'N............	$\bar{K}_t$	0.546	0.563	0.593	0.655	0.661	0.652	0.634	0.619	0.605	0.58	0.566	0.535
El. 7 ft................	t_o	49.9	49.5	54.7	61.5	69.9	77.2	80.0	79.8	76.7	67.9	59.1	51.3
NORTH DAKOTA													
Bismarck................	$\bar{I}_H$	587.4	934.3	1328.4	1668.2	2056.1	2173.8	2305.5	1929.1	1441.3	1018.1	600.4	464.2
Lat. 46°47'N............	$\bar{K}_t$	0.594	0.628	0.605	0.565	0.588	0.579	0.634	0.606	0.581	0.584	0.510	0.547
El. 1660 ft.............	t_o	12.4	15.9	29.7	46.6	58.6	67.9	76.1	73.5	61.6	49.6	31.4	18.4
OHIO													
Cleveland...............	$\bar{I}_H$	466.8	681.9	1207	1443.9	1928.4	2102.6	2094.4	1840.6	1410.3	997	526.6	427.3
Lat. 41°24'N............	$\bar{K}_t$	0.361	0.383	0.497	0.464	0.543	0.559	0.571	0.559	0.524	0.491	0.351	0.371
El.805 ft...............	t_o	30.8	30.9	39.4	50.2	62.4	72.7	77.0	75.1	68.5	57.4	44.0	32.8
Columbus................	$\bar{I}_H$	486.3	746.5	1112.5	1480.8	1839.1	(2111)	2041.3	1572.7	1189.3	919.5	479	430.2
Lat. 40°00'N............	$\bar{K}_t$	0.356	0.401	0.447	0.470	0.515	(0.561)	0.555	0.475	0.433	0.441	0.302	0.351
El. 833 ft..............	t_o	32.1	33.7	42.7	53.5	64.4	74.2	78	75.9	70.1	58	44.5	34.0
OKLAHOMA													
Oklahoma City...........	$\bar{I}_H$	938	1192.6	1534.3	1849.4	2005.1	2355	2273.8	2211	1819.2	1409.6	1085.6	897.4
Lat. 35°24'N............	$\bar{K}_t$	0.580	0.571	0.576	0.570	0.558	0.629	0.618	0.565	0.628	0.614	0.588	0.608
El. 1304 ft.............	t_o	40.1	45.0	53.2	63.6	71.2	80.6	85.5	85.4	77.4	66.5	52.2	43.1
Stillwater..............	$\bar{I}_H$	763.8	1081.5	1463.8	1702.6	1879.3	2235.8	2224.3	2039.1	1724.3	1314	991.5	783
Lat. 36°09'N............	$\bar{K}_t$	0.484	0.527	0.555	0.528	0.523	0.596	0.604	0.607	0.599	0.581	0.548	0.544
El. 910 ft..............	t_o	41.2	45.6	53.8	64.2	71.6	81.1	85.9	85.9	77.5	67.6	52.6	43.9
ONTARIO													
Ottawa..................	$\bar{I}_H$	539.1	852.4	1250.5	1506.6	1857.2	2084.5	2045.4	1752.4	1326.6	826.9	458.7	408.5
Lat. 45°20'N............	$\bar{K}_t$	0.499	0.540	0.554	0.502	0.529	0.554	0.560	0.546	0.521	0.450	0.359	0.436
El. 339 ft..............	t_o	14.6	15.6	27.7	43.3	57.5	67.5	71.9	69.8	61.5	48.9	35	19.6
Toronto.................	$\bar{I}_H$	451.3	674.5	1088.9	1388.2	1785.2	1941.7	1968.6	1622.5	1284.1	835	458.3	352.8
Lat. 43°41'N............	$\bar{K}_t$	0.388	0.406	0.467	0.455	0.506	0.516	0.539	0.500	0.493	0.438	0.336	0.346
El. 379 ft..............	t_o	26.5	26.0	34.2	46.3	58	68.4	73.8	71.8	64.3	52.6	40.9	30.2
OREGON													
Astoria.................	$\bar{I}_H$	338.4	607	1008.5	1401.5	1838.7	1753.5	2007.7	1721	1322.5	780.4	413.6	295.2
Lat. 46°12'N............	$\bar{K}_t$	0.330	0.397	0.454	0.471	0.524	0.466	0.551	0.538	0.526	0.435	0.336	0.332
El. 8 ft................	t_o	41.3	44.7	46.9	51.3	55.0	59.3	62.6	63.6	62.2	55.7	48.5	43.9
Medford.................	$\bar{I}_H$	435.4	804.4	1259.8	1807.4	2216.2	2440.5	2607.4	2261.6	1672.3	1043.5	558.7	346.5
Lat. 42°23'N............	$\bar{K}_t$	0.353	0.464	0.527	0.584	0.625	0.648	0.710	0.689	0.628	0.526	0.384	0.313
El. 1329 ft.............	t_o	39.4	45.4	50.8	56.3	63.1	69.4	76.9	76.4	69.6	58.7	47.1	40.5
PENNSYLVANIA													
State College...........	$\bar{I}_H$	501.8	749.1	1106.6	1399.2	1754.6	2027.6	1968.2	1690	1336.1	1017	580.1	443.9
Lat. 40°48'N............	$\bar{K}_t$	0.381	0.413	0.451	0.448	0.493	0.539	0.536	0.512	0.492	0.496	0.379	0.376
El. 1175 ft.............	t_o	31.3	31.4	39.8	51.3	63.4	71.8	75.8	73.4	66.1	55.6	43.2	32.6
RHODE ISLAND													
New Port................	$\bar{I}_H$	565.7	856.4	1231.7	1484.8	1849	2019.2	1942.8	1687.1	1411.4	1035.4	656.1	527.7
Lat. 41°29'N............	$\bar{K}_t$	0.438	0.482	0.507	0.477	0.520	0.536	0.529	0.513	0.524	0.512	0.44	0.460
El. 60 ft...............	t_o	29.5	32.0	39.6	48.2	58.6	67.0	73.2	72.3	66.7	56.2	46.5	34.4
SOUTH CAROLINA													
Charleston..............	$\bar{I}_H$	946.1	1152.8	1352.4	1918.8	2063.4	2113.3	1649.4	1933.6	1557.2	1332.1	1073.8	952
Lat. 32°54'N............	$\bar{K}_t$	0.541	0.521	0.491	0.584	0.574	0.567	0.454	0.569	0.525	0.554	0.539	0.586
El. 46 ft...............	t_o	53.6	55.2	60.6	67.8	74.8	80.9	82.9	82.3	79.1	69.8	59.8	54.0
SOUTH DAKOTA													
Rapid City..............	$\bar{I}_H$	687.8	1032.5	1503.7	1807	2028	2193.7	2235.8	2019.9	1628	1179.3	763.1	590.4
Lat. 44°09'N............	$\bar{K}_t$	0.601	0.627	0.649	0.594	0.574	0.583	0.612	0.622	0.628	0.624	0.566	0.588
El. 3218 ft.............	t_o	24.7	27.4	34.7	48.2	58.3	67.3	76.3	75.0	64.7	52.9	38.7	29.2
TEXAS													
Brownsville............	$\bar{I}_H$	1105.9	1262.7	1505.9	1714	2092.2	2288.5	2345	2124	1774.9	1536.5	1104.8	982.3
Lat. 25°55'N...........	$\bar{K}_t$	0.517	0.500	0.505	0.509	0.584	0.627	0.650	0.617	0.566	0.570	0.468	0.488
El. 20 ft..............	t_o	63.3	66.7	70.7	76.2	81.4	85.1	86.5	86.9	84.1	78.9	70.7	65.2
El Paso................	$\bar{I}_H$	1247.6	1612.9	2048.7	2447.2	2673	2731	2391.1	2350.5	2077.5	1704.8	1324.7	1051.6
Lat. 31°48'N...........	$\bar{K}_t$	0.686	0.714	0.730	0.741	0.743	0.733	0.652	0.669	0.693	0.695	0.647	0.626
El. 3916 ft............	t_o	47.1	53.1	58.7	67.3	75.7	84.2	84.9	83.4	78.5	69.0	56.0	48.5
Fort Worth.............	$\bar{I}_H$	936.2	1198.5	1597.8	1829.1	2105.1	2437.6	2293.3	2216.6	1880.8	1476	1147.6	913.6
Lat. 32°50'N...........	$\bar{K}_t$	0.530	0.541	0.577	0.556	0.585	0.654	0.624	0.653	0.634	0.612	0.576	0.563
El. 544 ft.............	t_o	48.1	52.3	59.8	68.8	75.9	84.0	87.7	88.6	81.3	71.5	58.8	50.8

Table A-4 (Continued)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TEXAS (Contd.)													
Midland...............	$\bar{I}_H$	1066.4	1345.7	1784.8	2036.1	2301.1	2317.7	2301.8	2193	1921.8	1470.8	1244.3	1023.2
Lat. 31°56'N..........	$\bar{K}_t$	0.587	0.596	0.638	0.617	0.639	0.622	0.628	0.643	0.642	0.600	0.609	0.611
El. 2854 ft...........	t_o	47.9	52.8	60.0	68.8	77.2	83.9	85.7	85.0	78.9	70.3	56.6	49.1
San Antonio...........	$\bar{I}_H$	1045	1299.2	1560.1	1664.6	2024.7	2250*	2364.2	2185.2	1844.6	1487.4	1104.4	954.6
Lat. 29°32'N..........	$\bar{K}_t$	0.541	0.550	0.542	0.500	0.563	0.62	0.647	0.637	0.603	0.584	0.507	0.528
El. 794 ft............	t_o	53.7	58.4	65.0	72.2	79.2	85.0	87.4	87.8	82.6	74.7	63.3	56.5
TENNESSEE													
Nashville.............	$\bar{I}_H$	589.7	907	1246.8	1662.3	1997	2149.4	2079.7	1862.7	1600.7	1223.6	823.2	614.4
Lat. 36°07'N..........	$\bar{K}_t$	0.373	0.440	0.472	0.514	0.556	0.573	0.565	0.554	0.556	0.540	0.454	0.426
El. 605 ft............	t_o	42.6	45.1	52.9	63.0	71.4	80.1	83.2	81.9	76.6	65.4	52.3	44.3
Oak Ridge.............	$\bar{I}_H$	604	895.9	1241.7	1689.6	1942.8	2066.4	1972.3	1795.6	1559.8	1194.8	796.3	610
Lat. 36°01'N..........	$\bar{K}_t$	0.382	0.435	0.471	0.524	0.541	0.551	0.536	0.534	0.542	0.527	0.438	0.422
El. 905 ft............	t_o	41.9	44.2	51.7	61.4	69.8	77.8	80.2	78.8	74.5	62.7	50.4	42.5
UTAH													
Salt Lake City........	$\bar{I}_H$	622.1	986	1301.1	1813.3	-	-	-	-	1689.3	1250.2	-	552.8
Lat. 40°46'N..........	$\bar{K}_t$	0.468	0.909	0.529	0.579	-	-	-	-	0.621	0.610	-	0.467
El. 4227 ft...........	t_o	29.4	36.2	44.4	53.9	63.1	71.7	81.3	79.0	68.7	57.0	42.5	34.0
WASHINGTON													
Seattle...............	$\bar{I}_H$	282.6	520.6	992.2	1507	1881.5	1909.9	2110.7	1688.5	1211.8	702.2	386.3	239.5
Lat. 47°27'N..........	$\bar{K}_t$	0.296	0.355	0.456	0.510	0.538	0.508	0.581	0.533	0.492	0.407	0.336	0.292
El. 386 ft............	t_o	42.1	45.0	48.9	54.1	59.8	64.4	68.4	67.9	63.3	56.3	48.4	44.4
Seattle...............	$\bar{I}_H$	252	471.6	917.3	1375.6	1664.9	1724	1805.1	1617	1129.1	638	325.5	218.1
Lat. 47°36'N..........	$\bar{K}_t$	0.266	0.324	0.423	0.468	0.477	0.459	0.498	0.511	0.459	0.372	0.284	0.269
El. 14 ft.............	t_o	38.9	42.9	46.9	51.9	58.1	62.8	67.2	66.7	61.6	54.0	45.7	41.5
Spokane...............	$\bar{I}_H$	446.1	837.6	1200	1864.6	2104.4	2226.5	2479.7	2076	1511	844.6	486.3	279
Lat. 47°40'N..........	$\bar{K}_t$	0.478	0.579	0.556	0.602	0.603	0.593	0.684	0.656	0.616	0.494	0.428	0.345
El.1968 ft............	t_o	26.5	31.7	40.5	49.2	57.9	64.6	73.4	71.7	62.7	51.5	37.4	30.5
WISCONSIN													
Madison...............	$\bar{I}_H$	564.6	812.2	1232.1	1455.3	1745.4	2031.7	2046.5	1740.2	1443.9	993	555.7	495.9
Lat. 43°08'N..........	$\bar{K}_t$	0.4 0	0.478	0.522	0.474	0.493	0.540	0.559	0.534	0.549	0.510	0.396	0.467
El. 866 ft............	t_o	21.8	24.6	35.3	49.0	61.0	70.9	76.8	74.4	65.6	53.7	37.8	25.4
WYOMING													
Lander................	$\bar{I}_H$	786.3	1146.1	1638	1988.5	2114	2492.2	2438.4	2120.6	1712.9	1301.8	837.3	694.8
Lat. 42°48'N..........	$\bar{K}_t$	0.65	0.672	0.691	0.647	0.597	0.662	0.665	0.649	0.647	0.666	0.589	0.643
El. 5370 ft...........	t_o	20.2	26.3	34.7	45.5	56.0	65.4	74.6	72.5	61.4	48.3	33.4	23.8

*Original values incorrect. Values estimated from insolation maps.

$\overline{I}_o$, Monthly Average Daily Extraterrestrial Radiation Btu/Day·ft^2

Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20	2349	2671	3019	3301	3421	3445	3423	3332	3106	2763	2421	2246
25	2103	2747	2891	3266	3463	3524	3485	3329	3013	2588	2192	1995
30	1851	2260	2740	3206	3482	3581	3526	3303	2877	2395	1950	1735
35	1590	2030	2570	3124	3479	3619	3546	3254	2759	2184	1698	1468
40	1324	1788	2380	3019	3454	3637	3545	3183	2600	1958	1438	1149
45	1056	1535	2172	2892	3409	3636	3525	3090	2421	1720	1174	931
50	791	1275	1948	2746	3346	3621	3489	2979	2225	1470	910	669
55	535	1011	1769	2582	3269	3596	3441	2856	2012	1212	651	422
60	299	747	1459	2403	3185	3571	3389	2709	1784	950	405	200

Table A-5 Monthly Average Daily Extraterrestrial Radiation Btu/Day·ft^2, $\overline{I}_o$

$\overline{R}$ for $\overline{K}_t$ = .30

LATITUDE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
						(Latitude-Tilt) = 15.0						
25	1.09	1.06	1.03	1.00	.98	.98	.98	.99	1.02	1.05	1.08	1.09
30	1.15	1.10	1.05	1.01	.98	.97	.97	.99	1.03	1.08	1.13	1.16
35	1.23	1.15	1.07	1.01	.97	.96	.96	1.00	1.05	1.12	1.20	1.25
40	1.34	1.22	1.11	1.02	.97	.95	.96	1.00	1.07	1.18	1.30	1.38
45	1.51	1.31	1.15	1.03	.97	.94	.95	1.00	1.10	1.25	1.45	1.58
50	1.77	1.44	1.21	1.05	.97	.93	.95	1.01	1.13	1.35	1.67	1.91
55	2.24	1.65	1.29	1.07	.96	.93	.94	1.02	1.18	1.50	2.04	2.53
						(Latitude-Tilt) = .0						
25	1.17	1.11	1.04	.97	.93	.91	.92	.95	1.01	1.08	1.16	1.19
30	1.24	1.15	1.05	.97	.92	.90	.91	.95	1.02	1.11	1.21	1.27
35	1.33	1.20	1.08	.97	.91	.89	.90	.95	1.03	1.16	1.29	1.38
40	1.46	1.27	1.11	.98	.90	.87	.89	.94	1.05	1.21	1.41	1.53
45	1.65	1.37	1.15	.99	.90	.86	.88	.94	1.08	1.29	1.57	1.76
50	1.96	1.52	1.21	1.00	.89	.85	.87	.95	1.11	1.40	1.82	2.14
55	2.51	1.75	1.29	1.01	.89	.84	.86	.95	1.16	1.56	2.25	2.88
						(Latitude-Tilt = -15.0						
25	1.21	1.11	1.00	.91	.84	.82	.83	.88	.96	1.07	1.18	1.24
30	1.28	1.15	1.01	.90	.83	.80	.81	.87	.97	1.10	1.24	1.32
35	1.37	1.20	1.03	.90	.82	.79	.80	.86	.97	1.14	1.32	1.43
40	1.51	1.27	1.06	.90	.81	.77	.79	.86	.99	1.19	1.44	1.60
45	1.71	1.37	1.10	.90	.80	.76	.77	.85	1.01	1.27	1.61	1.84
50	2.04	1.52	1.15	.91	.79	.74	.76	.85	1.04	1.38	1.88	2.26
55	2.63	1.76	1.23	.92	.78	.73	.75	.85	1.08	1.54	2.33	3.05
						Vertical Surface						
25	.94	.78	.62	.48	.42	.40	.41	.45	.56	.73	.90	.99
30	1.04	.85	.67	.52	.44	.42	.43	.48	.60	.79	.99	1.10
35	1.17	.94	.72	.55	.47	.44	.45	.51	.65	.86	1.10	1.24
40	1.33	1.04	.78	.59	.50	.47	.48	.55	.70	.95	1.25	1.44
45	1.57	1.18	.86	.64	.53	.49	.51	.59	.76	1.06	1.45	1.72
50	1.93	1.36	.95	.68	.56	.52	.54	.63	.82	1.20	1.75	2.17
55	2.55	1.62	1.06	.74	.60	.55	.57	.67	.91	1.40	2.24	3.00

Table A-6 Ratio of Monthly Average - Daily Radiation on a Tilted Surface to that on a Horizontal Surface

$\overline{R}$ for $\overline{K}_t$ = .40

LATITUDE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
							(Latitude-Tilt) = 15.0					
25	1.11	1.08	1.04	1.01	.98	.97	.98	1.00	1.03	1.07	1.10	1.13
30	1.20	1.13	1.07	1.01	.98	.96	.97	1.00	1.05	1.11	1.18	1.22
35	1.31	1.20	1.11	1.03	.97	.95	.96	1.00	1.07	1.17	1.28	1.34
40	1.46	1.30	1.15	1.04	.97	.94	.96	1.01	1.10	1.25	1.41	1.52
45	1.69	1.43	1.21	1.06	.97	.94	.95	1.02	1.15	1.35	1.61	1.79
50	2.04	1.61	1.30	1.09	.98	.94	.95	1.04	1.20	1.49	1.90	2.22
55	2.68	1.89	1.41	1.12	.98	.93	.95	1.06	1.27	1.70	2.41	3.06
							(Latitude-Tilt) = .0					
25	1.24	1.15	1.06	.98	.92	.90	.91	.95	1.03	1.12	1.22	1.27
30	1.34	1.21	1.09	.98	.91	.88	.90	.95	1.04	1.17	1.30	1.38
35	1.46	1.29	1.13	.99	.91	.87	.89	.95	1.07	1.23	1.41	1.52
40	1.64	1.39	1.17	1.00	.90	.86	.88	.96	1.10	1.31	1.57	1.73
45	1.90	1.53	1.23	1.02	.90	.86	.88	.96	1.14	1.42	1.79	2.04
50	2.32	1.74	1.32	1.04	.90	.85	.87	.98	1.19	1.58	2.13	2.56
55	3.05	2.04	1.43	1.07	.90	.84	.87	.99	1.27	1.80	2.71	3.54
							(Latitude-Tilt) = 15.0					
25	1.31	1.17	1.03	.91	.82	.79	.80	.87	.98	1.12	1.27	1.35
30	1.41	1.23	1.06	.91	.81	.77	.79	.86	.99	1.17	1.36	1.46
35	1.54	1.31	1.09	.91	.80	.76	.78	.86	1.01	1.23	1.47	1.62
40	1.73	1.41	1.13	.92	.80	.75	.77	.86	1.04	1.31	1.64	1.84
45	2.01	1.56	1.19	.93	.79	.74	.76	.87	1.08	1.42	1.87	2.18
50	2.45	1.77	1.27	.95	.79	.73	.76	.88	1.12	1.58	2.23	2.74
55	3.24	2.08	1.39	.98	.79	.72	.75	.89	1.19	1.81	2.85	3.80
							Vertical Surface					
25	1.05	.84	.63	.44	.36	.34	.35	.40	.54	.77	.99	1.12
30	1.18	.94	.69	.49	.39	.36	.37	.44	.60	.85	1.11	1.26
35	1.35	1.05	.76	.54	.43	.39	.41	.49	.66	.95	1.26	1.45
40	1.57	1.18	.84	.59	.47	.42	.44	.53	.73	1.06	1.46	1.71
45	1.88	1.36	.94	.65	.51	.46	.48	.58	.81	1.21	1.73	2.08
50	2.36	1.60	1.06	.71	.55	.50	.52	.63	.90	1.39	2.12	2.68
55	3.18	1.95	1.21	.78	.60	.54	.56	.69	1.00	1.66	2.76	3.78

Table A-6 (continued) Ratio of Monthly Average - Daily Radiation on a Tilted Surface to that on a Horizontal Surface

$\overline{R}$ for $\overline{K}_t$ = .50

LATITUDE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
							(Latitude-Tilt) = 15.0					
25	1.14	1.09	1.05	1.01	.98	.97	.97	1.00	1.03	1.08	1.12	1.15
30	1.23	1.16	1.08	1.02	.97	.96	.96	1.00	1.06	1.13	1.21	1.26
35	1.37	1.24	1.13	1.03	.97	.95	.96	1.01	1.09	1.20	1.33	1.41
40	1.55	1.36	1.19	1.05	.97	.94	.96	1.02	1.13	1.30	1.49	1.62
45	1.82	1.51	1.26	1.08	.98	.94	.96	1.03	1.18	1.42	1.72	1.93
50	2.24	1.73	1.36	1.12	.99	.94	.96	1.06	1.25	1.59	2.08	2.45
55	2.99	2.06	1.50	1.16	1.00	.94	.96	1.08	1.34	1.83	2.67	3.44
							(Latitude-Tilt) = .0					
25	1.29	1.19	1.08	.98	.91	.88	.90	.95	1.04	1.15	1.26	1.32
30	1.40	1.26	1.11	.99	.91	.87	.89	.95	1.06	1.21	1.36	1.45
35	1.56	1.35	1.16	1.00	.90	.86	.88	.96	1.09	1.28	1.50	1.63
40	1.77	1.48	1.22	1.02	.90	.86	.88	.97	1.13	1.38	1.68	1.87
45	2.08	1.65	1.30	1.04	.90	.85	.87	.98	1.18	1.52	1.95	2.25
50	2.57	1.89	1.40	1.08	.91	.85	.87	1.00	1.25	1.70	2.36	2.86
55	3.44	2.26	1.54	1.12	.92	.85	.88	1.02	1.34	1.97	3.04	4.02
							(Latitude-Tilt) = -15.0					
25	1.38	1.22	1.05	.91	.81	.77	.79	.86	.99	1.16	1.33	1.43
30	1.50	1.29	1.09	.91	.80	.76	.78	.86	1.01	1.22	1.44	1.57
35	1.66	1.39	1.13	.92	.80	.75	.77	.86	1.04	1.30	1.58	1.75
40	1.89	1.52	1.19	.94	.79	.74	.76	.87	1.08	1.40	1.78	2.02
45	2.22	1.69	1.26	.96	.79	.73	.76	.88	1.12	1.53	2.06	2.43
50	2.75	1.94	1.36	.98	.79	.73	.76	.89	1.19	1.72	2.49	3.09
55	3.68	2.32	1.50	1.02	.80	.72	.75	.91	1.27	1.99	3.22	4.34
							Vertical Surface					
25	1.13	.89	.63	.42	.32	.29	.30	.37	.53	.80	1.06	1.21
30	1.29	1.00	.71	.47	.35	.32	.33	.41	.60	.89	1.20	1.38
35	1.48	1.13	.79	.53	.40	.35	.37	.47	.67	1.01	1.38	1.60
40	1.74	1.29	.89	.59	.44	.39	.41	.52	.75	1.14	1.61	1.91
45	2.11	1.50	1.00	.66	.49	.44	.46	.56	.84	1.31	1.92	2.34
50	2.67	1.78	1.14	.73	.54	.48	.51	.64	.95	1.54	2.39	3.04
55	3.64	2.19	1.32	.81	.60	.53	.56	.71	1.08	1.84	3.15	4.34

Table A-6 (continued) Ratio of Monthly Average - Daily Radiation on a Tilted Surface to that on a Horizontal Surface

$\overline{R}$ for $\overline{K}_t$ = .60

LATITUDE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
(Latitude-Tilt) = 15.0												
25	1.15	1.11	1.06	1.01	.98	.96	.97	1.00	1.04	1.09	1.14	1.17
30	1.27	1.18	1.10	1.02	.97	.95	.96	1.00	1.07	1.15	1.24	1.29
35	1.41	1.28	1.15	1.04	.97	.94	.96	1.01	1.10	1.23	1.37	1.46
40	1.62	1.40	1.21	1.07	.98	.94	.95	1.02	1.15	1.34	1.56	1.70
45	1.92	1.58	1.30	1.10	.98	.94	.96	1.04	1.21	1.48	1.82	2.05
50	2.40	1.83	1.41	1.14	.99	.94	.96	1.07	1.29	1.67	2.22	2.64
55	3.24	2.20	1.57	1.19	1.01	.94	.97	1.10	1.39	1.95	2.89	3.75
(Latitude-Tilt) = .0												
25	1.33	1.21	1.09	.98	.91	.87	.89	.95	1.05	1.17	1.30	1.37
30	1.46	1.30	1.13	.99	.90	.86	.88	.95	1.08	1.24	1.41	1.51
35	1.63	1.40	1.19	1.01	.90	.85	.87	.96	1.11	1.33	1.57	1.71
40	1.88	1.55	1.26	1.03	.90	.85	.87	.97	1.16	1.44	1.78	1.99
45	2.23	1.74	1.35	1.06	.91	.85	.87	.99	1.22	1.59	2.08	2.41
50	2.78	2.02	1.47	1.10	.92	.85	.88	1.01	1.30	1.81	2.54	3.10
55	3.76	2.43	1.63	1.15	.93	.85	.88	1.05	1.40	2.11	3.31	4.41
(Latitude-Tilt) = -15.0												
25	1.43	1.26	1.07	.91	.80	.75	.77	.86	1.00	1.19	1.39	1.49
30	1.57	1.34	1.11	.92	.79	.74	.76	.86	1.03	1.26	1.51	1.65
35	1.76	1.45	1.16	.93	.79	.73	.76	.86	1.06	1.35	1.67	1.86
40	2.02	1.60	1.23	.95	.79	.73	.75	.87	1.11	1.47	1.90	2.17
45	2.40	1.80	1.32	.98	.79	.72	.75	.89	1.16	1.62	2.22	2.62
50	2.99	2.09	1.44	1.01	.80	.72	.75	.91	1.24	1.84	2.70	3.37
55	4.04	2.52	1.59	1.05	.81	.72	.76	.93	1.34	2.15	3.52	4.78
Vertical Surface												
25	1.20	.92	.63	.39	.28	.25	.26	.34	.53	.82	1.12	1.28
30	1.37	1.04	.72	.46	.32	.28	.30	.39	.60	.93	1.28	1.48
35	1.59	1.19	.81	.52	.37	.32	.34	.45	.68	1.06	1.48	1.73
40	1.88	1.37	.92	.59	.42	.37	.39	.51	.77	1.21	1.73	2.07
45	2.30	1.61	1.05	.66	.48	.42	.44	.58	.87	1.40	2.09	2.56
50	2.93	1.93	1.21	.75	.54	.47	.50	.65	.99	1.65	2.61	3.34
55	4.01	2.39	1.41	.84	.60	.52	.55	.72	1.13	2.00	3.46	4.80

Table A-6 (continued) Ratio of Monthly Average - Daily Radiation on a Tilted Surface to that on a Horizontal Surface

$\overline{R}$ for $\overline{K}_t$ = .70

LATITUDE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
							(Latitude-Tilt) = 15.0					
25	1.17	1.12	1.06	1.01	.98	.96	.97	1.00	1.04	1.10	1.16	1.19
30	1.30	1.20	1.11	1.03	.97	.95	.96	1.00	1.07	1.17	1.27	1.33
35	1.46	1.31	1.17	1.05	.97	.94	.95	1.01	1.12	1.26	1.42	1.51
40	1.69	1.45	1.24	1.08	.98	.94	.95	1.03	1.17	1.38	1.62	1.78
45	2.03	1.65	1.34	1.11	.99	.94	.96	1.06	1.24	1.53	1.92	2.18
50	2.56	1.93	1.47	1.16	1.00	.94	.97	1.09	1.33	1.75	2.36	2.83
55	3.50	2.34	1.64	1.22	1.02	.94	.98	1.13	1.45	2.06	3.11	4.06
							(Latitude-Tilt) = .0					
25	1.37	1.24	1.11	.98	.90	.86	.88	.95	1.06	1.20	1.34	1.41
30	1.52	1.34	1.16	1.00	.90	.85	.87	.95	1.09	1.27	1.47	1.58
35	1.71	1.46	1.22	1.02	.90	.85	.87	.96	1.13	1.37	1.64	1.80
40	1.98	1.62	1.30	1.05	.90	.84	.87	.98	1.19	1.50	1.88	2.11
45	2.38	1.84	1.40	1.08	.91	.84	.87	1.00	1.26	1.67	2.21	2.58
50	3.00	2.15	1.53	1.13	.92	.85	.88	1.03	1.35	1.91	2.73	3.35
55	4.09	2.61	1.72	1.19	.94	.85	.89	1.07	1.47	2.25	3.58	4.80
							(Latitude-Tilt) = -15.0					
25	1.49	1.30	1.09	.91	.78	.73	.76	.85	1.01	1.23	1.44	1.56
30	1.65	1.39	1.14	.92	.78	.72	.75	.86	1.04	1.30	1.58	1.73
35	1.86	1.52	1.20	.94	.78	.72	.75	.87	1.09	1.41	1.76	1.98
40	2.15	1.69	1.28	.96	.78	.72	.74	.88	1.14	1.54	2.01	2.32
45	2.58	1.91	1.38	.99	.79	.71	.75	.90	1.20	1.71	2.37	2.83
50	3.24	2.23	1.51	1.04	.80	.72	.75	.92	1.29	1.96	2.92	3.66
55	4.41	2.71	1.69	1.09	.81	.72	.76	.96	1.40	2.31	3.83	5.23
							Vertical Surface					
25	1.26	.96	.64	.37	.25	.21	.23	.31	.52	.85	1.18	1.36
30	1.46	1.09	.73	.44	.29	.25	.27	.37	.60	.97	1.35	1.57
35	1.70	1.26	.84	.51	.35	.29	.32	.43	.69	1.11	1.57	1.85
40	2.03	1.46	.96	.59	.41	.34	.37	.50	.79	1.28	1.86	2.23
45	2.48	1.72	1.10	.67	.47	.40	.43	.57	.90	1.49	2.25	2.77
50	3.18	2.07	1.27	.76	.53	.45	.48	.65	1.03	1.77	2.83	3.65
55	4.39	2.59	1.50	.87	.60	.51	.55	.73	1.19	2.15	3.78	5.26

Table A-6 (continued) Ratio of Monthly Average - Daily Radiation on a Tilted Surface to that on a Horizontal Surface

5.4 WORKSHEETS FOR THE CALCULATION PROCEDURE

WORKSHEET A PROJECT DATA

PROJECT ______________________________

Location	Latitude	=	
Building Heating and/or Hot Water Load			
Design Heat Loss Rate, q_d		=	Btu/h
Winter Design Temperature (97 1/2%), t_w		=	°F
Average Hot Water Consumption (may vary on a monthly basis)		=	gal/day
Average Cold Water Supply (main) Temp., t_m (may vary on a monthly basis)		=	°F
Hot Water Supply Temp., t_s		=	°F
Collector Subsystem Data			
Collector Type: ______________________,			
Selective or non-selective, no. cover plates _____			
Collector Area, A_c		=	ft^2
Tilt Angle		=	°
Azimuth Angle		=	°
Collector Shading (av. % month of Dec.)		=	%
Collector Efficiency Data (from manufacture): $F_R(\tau\alpha)_n$		=	
F_RU_L		=	$Btu/h \cdot ft^2 \cdot °F$
Reference Temp. Basis: t_{in}, $\frac{t_{in} + t_{out}}{2}$, t_{out}			
Fluid:			
Composition: ______________________			
Specific Heat, c_p		=	Btu/lb·°F
Specific Gravity (if applicable)		=	lb/lb
Volumetric Flow Rate		=	gal/min or ft^3/min
Storage Subsystem Data			
Volume		=	gal or ft^3
Storage Medium ______________________			
Specific Heat, c_p		=	Btu/lb·°F
Specific Gravity/or Density		=	lb/lb or lb/ft^3
Circulation Loop Volumetric Flow Rate		=	gal/min or ft^3/min
Collector/Storage Heat Exchange Effectiveness, ε_{cs}		=	
Hot Water Preheat Storage Volume		=	gal
Load Subsystem Data			
Load Heat Exchanger Effectiveness, ε_L		=	
Supply Loop Volumetric Flow Rate		=	gal/min
Building Air Supply Volumetric Flow Rate		=	ft^3/min

WORKSHEET B FRACTION OF TOTAL HEATING LOAD SUPPLIED BY SOLAR ENERGY, F_{Annual} PROJECT ______

	1	2	3	4	5
Month	Tot. Mo. Htg. Load L Btu/mo.	System Parameters D_1	System Parameters D_2	Solar Fraction/ mo. f	Actual Solar en/mo E Btu/mo.
Jan.					
Feb.					
March					
April					
May					
June					
July					
Aug.					
Sept.					
Oct.					
Nov.					
Dec.					

L_{tot} =

E_{tot} =

$$F_{Annual} = \frac{E_{tot}}{L_{tot}} = \underline{\qquad} = \underline{\qquad}$$

1. From Worksheet D
2. From Worksheet C
3. From Worksheet C
4. From "f chart"
5. E = f x L

WORKSHEET C SYSTEM PERFORMANCE PARAMETERS D_1, D_2 PROJECT ______

	1	2		3	4			5	6
Month	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo·ft^2)	Total Heating Load L Btu/Mo.	S/L	D_1	Mo. Av. Day Time Temp. t_o °F	$212-t_o$ °F	Tot. Hrs in Mo. Δ time hr.	K_3	D_2
Jan.							744		
Feb.							672		
March							744		
April							720		
May							744		
June							720		
July							744		
Aug.							744		
Sept.							720		
Oct.							744		
Nov.							720		
Dec.							744		

A_c = Given data
$F_R'(\overline{\tau\alpha})$ = Worksheet F
$F_R'U_L$ = worksheet F
K_1 = Worksheet G
K_2 = Worksheet G
K_4 = Worksheet G

1. From Worksheet E
2. From Worksheet D
3. $D_1 = \left[\frac{A_c\ F_R'\ (\overline{\tau\alpha})\ S}{L}\right] \times K_4 = (D_1 \text{ prod.})\ \frac{S}{L} =$

   Where: D_1 prod. $= \left[A_c\ F_R'\ (\overline{\tau\alpha})\right] \times K_4 =$
4. From Sec. 5 Table A-4
5. From Table A-14 and Worksheet G
6. $D_2 = \left[\frac{A_c\ F_R'\ U_L\ (t_{ref} - t_o)\ \Delta time}{L}\right] \times K_1 \times K_2 \times K_3 = (D_2 \text{ prod.}) \left[\frac{(212 - t_o)\ \Delta time}{L}\right] \times K_3 =$

   Where: D_2 prod. $= (A_c\ F_R'\ U_L) \times K_1 \times K_2 =$

WORKSHEET D <u>HEATING AND/OR DOMESTIC HOT WATER LOAD, L</u>

PROJECT ______________________

	1	2		3		4	5	6
Month	Monthly Degree Days DD °F·days	Monthly Space Htg Load Qs Btu/Mo.	No. of Days/ Mo. N	Vol. of DHW Used/Mo. Gal./Mo.	Temp. Water Main Sup. t_m °F	DHW Temp. Rise $t_s - t_m$ °F	Monthly DHW Load Q_w Btu/Mo.	Total Heating Load L Btu/Mo.
Jan.			31					
Feb.			28					
March			31					
April			30					
May			31					
June			30					
July			31					
Aug.			31					
Sept.			30					
Oct.			31					
Nov.			30					
Dec.			31					

q_d = ______________ Btu/h

(Given data or calculate from Manual J or equivalent.)

$\Delta t_d = 70 - t_w$

$= 70 -$ ______ =

Where: t_w = 97 1/2% winter design temperature

(From ASHRAE Fundamentals, Table A-3, section 5 or known weather data.)

70° = indoor design temperature

$UA = \frac{q_d}{\Delta t_d} =$

t_s = __________

1. From ASHRAE Systems, Climatic Atlas or Table A-3, section 5.
2. Q_s = (PF)(24)(UA)(Degree Day) = ________________________ x (Degree Day) =
   Where: PF = 0.75 or more appropriate value.
3. (Vol/day) (no. days/mo.) = ______________(gal./day) (no. days/mo.)
4. May be constant or may vary.
5. Q_w = (vol. of water) x 8.33 x 1 x ($t_s - t_m$).
6. $L = Q_s + Q_w$

WORKSHEET E TOTAL MONTHLY SOLAR RADIATION AVAILABLE, S PROJECT ______________

	1	2	3	4	5		6
Month	Horizontal Insolation $\bar{I}_H$ Btu/(Day·ft^2)	Extra-terrestrial Insolation $\bar{I}_o$ Btu/(Day·ft^2)	Ratio Horizontal to Extra-terrestrial $\bar{K}_t$	Ratio Horizontal to Tilt $\bar{R}$	Monthly Avg. Daily Rad. on Tilt Surf. $\bar{I}_T$ Btu/(Day·ft^2)	No. of Days in Month N	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo · ft^2)
Jan.						31	
Feb.						28	
March						31	
April						30	
May						31	
June						30	
July						31	
Aug.						31	
Sept.						30	
Oct.						31	
Nov.						30	
Dec.						31	

1. From Table A-4 or Fig. A-29 section 5, or known data.
2. From Table A-5 section 5, used only for eq. 11.
3. From Table A-4 section 5, or eq. 11.
4. From Table A-6 section 5, latitude (ϕ) = ________°, with collector tilt (θ) = ______°, and latitude − tilt = ______°.
5. From eq. 12, $\bar{I}_T + (\bar{I}_H)(\bar{R})$.
6. From eq. 13, $S = (\bar{I}_T)(N)$.

PROJECT: ____

(3.5.1) Collector Efficiency Data From Test

intercept, $b = F_R(\tau\alpha)_n$ =

slope, $m = F_R U_L$ =

Reference Temperature Basis: 1. t_{in}, 2. $\frac{t_{in} + t_{out}}{2}$, 3. t_{out}

Collector area, A_c =

Collector volumetric flow rate =

Correction to t_{in} basis:

Case 1: (no correction) $F_R(\tau\alpha)_n$ =

$F_R U_L$ =

Case 2: $$F_R(\tau\alpha)_n = b \times \left[\frac{1}{1 + \frac{mA_c}{2C_c}}\right] =$$

$$F_R U_L = m \times \left[\frac{1}{1 + \frac{mA_c}{2C_c}}\right] =$$

$$C_c = \dot{m}c_p = \begin{pmatrix}\text{volumetric} \\ \text{flow rate}\end{pmatrix} \begin{pmatrix}\text{density}\end{pmatrix} \begin{pmatrix}\text{time} \\ \text{conversion}\end{pmatrix} \begin{pmatrix}\text{specific} \\ \text{heat}\end{pmatrix}$$

=

where: for liquids, density = $(8.33 \text{ lb/gal}) \times \begin{pmatrix}\text{specific} \\ \text{gravity}\end{pmatrix}$

for air, density = 0.75 lb/ft^3, at 70° and 1 atm.

specific heat = 0.24 Btu/lb·°F

Case 3: $$F_R(\tau\alpha)_n = b \times \left[\frac{1}{1 + \frac{mA_c}{C_c}}\right] =$$

$$F_R U_L = m \times \left[\frac{1}{1 + \frac{mA_c}{C_c}}\right] =$$

(3.5.2) Incident Angle Modifier, $\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n} = \begin{cases} .91, \text{ for two cover plates} \\ .93, \text{ for one cover plate} \end{cases}$

WORKSHEET F (Continued)

(3.5.3) Collector Loop Heat Exchanger Modifier, $\frac{F'_R}{F_R}$

for air systems and liquid systems without a collector/storage heat exchanger,

$$\frac{F'_R}{F_R} = 1$$

Capacitance Rate

C_c = (from above) =

C_s = (calc. as for C_c above) =

C_{min} = (lesser of C_c of C_s) =

Collector Storage Heat Exchanger Effectiveness, ε_{cs} =

$$x = \frac{C_c}{\varepsilon_{cs}\, C_{min}} =$$

$$y = \frac{A_c(F_R U_L)}{C_c} =$$

$$\frac{F'_R}{F_R} = \text{from figure A-11 or} = \frac{1}{1 + y(x-1)} =$$

(3.5.4) $F'_R\,(\overline{\tau\alpha}) = F_R(\overline{\tau\alpha})_n \times \left[\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}\right] \times \left[\frac{F'_R}{F_R}\right] =$

$F'_R U_L = F_R U_L \times \left[\frac{F'_R}{F_R}\right] =$

WORKSHEET G CORRECTION FACTORS, K_1, K_2, K_3, K_4

PROJECT ______________________________

Air Collector Flow Capacitance Rate Factor, K_1

for liquid collectors $K_1 = 1.0$

for air collectors: C_c = (from worksheet F) =

A_c = (from worksheet A) =

$\frac{C_c}{A_c}$ = K_1 = (from Figure A-12) =

Storage Mass Capacitance Factor, K_2

M = (vol. storage media) x (density) =

Note: M includes hot water storage volume where it is solar heated.

c_p = (from worksheet A) =

$\frac{(Mc_p)_s}{A_c}$ = K_2 = (from Figure A-13) =

Hot Water Factor, K_3

for liquid systems providing heating only or heating and hot water, and for all air systems $K_3 = 1.0$

for DHW only systems: t_s = (from worksheet A) = °F

t_m = (from worksheet A or if variable see worksheet D) = °F

t_o is taken from table A-4 section 5

K_3 is taken from figure A-14 and tabulated on a monthly basis on worksheet C

K_3 = (tabulated or const.) =

Load Heat Exchange Factor, K_4

for air systems and DHW only systems, $K_4 = 1.0$

ε_L = (from worksheet A) =

$C_{\text{hot water supply loop}} = \dot{m}c_p$ =

$C_{\text{air loop}} = \dot{m}c_p$ =

C_{min} = lesser of C_H or C_A =

UA bldg = (from worksheet D) =

$\frac{UA}{C_{min}\,\varepsilon_L}$ = K_4 = (from Figure A-15) =

APPENDIX B

MATERIALS TABLES

Material / Property	Poly(vinyl fluoride)	Poly(ethylene terephthalate)	Polycarbonate	Fiberglass Reinforced Plastics	Poly(methyl methacrylate)	Fluorinated ethylene-propylene	Clear Lime Glass (Float)	Sheet Lime Glass	Water White Glass
% Solar Transmittance (for thickness listed below)	92-94	85	82-89	77-90	89	97	83-85	84-87	85-91
Maximum Operating Temperature (°F)	227°	220°	230-270°	200°	180-190°	248°	400°	400°	400°
Tensile Strength (psi) (ASTM D-638)	13000	24000	9500	15000-17000	10500	2700-3100	4000 annealed 10000 tempered	4000 annealed 10000 tempered	4000 annealed 10000 tempered
Thermal Expansion Coefficient (in/in/°F x 10^{-6})	24	15	37.5	18-22	41.0	8.3-10.5	4.8	5.0	4.7-8.6
Elastic Modulus (psi x 10^6) (D-638)	.26	.55	.345	1.1	.45	.5	10.5	10.5	10.5
Thickness (in)	.004	.001	.125	.040	.125	.002	.125	.125	.125
Weight (lb/ft^2) For above thickness	.028	.007	.77	.30	.75	.002	1.63	1.63	1.65
Refractive Index	1.45	1.64	1.59	-	1.49	1.34	1.52	1.52	1.52

*These values were obtained from the following references:

Grimmer, D. P., Moore, S. W., "Practical Aspects of Solar Heating: A Review of Materials Used in Solar Heating Applications." LA-UR-75-1952, paper presented at SAMPE Meeting, October 14-16, 1975, Hilton Inn.

Kobayashi, T., Sargent, L., "A Survey of Breakage-Resistant Materials for Flat-Plate Solar Collector Covers," paper presented at U.S. Section-ISES Meeting, Ft. Collins, Colorado, August 20-23, 1974.

Scoville, A. E., "An Alternate Cover Material for Solar Collectors," paper presented at ISES Congress and Exposition, Los Angeles, California, July, 1975.

Clarkson, C. W., Herbert, J. S., "Transparent Glazing Media for Solar Energy Collectors," paper presented at U.S. Section-ISES Meeting, Ft. Collins, Colorado, August 21-23, 1974.

Modern Plastics Encyclopedia, 1975-1976, McGraw-Hill Publishing Company.

Toenjes, R. B., "Integrated Solar Energy Collector Final Summary Report," LA-6143-MS, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, November, 1975.

Appendix Table B-2 : Characteristics of Absorptive Coatings

Property / Material	Absorptance* α	Emittance ε	$\frac{\alpha}{\varepsilon}$	Breakdown Temperature °F (°C)	Comments
Black Chrome	.87-.93	.1	∿9		
Alkyd Enamel	.9	.9	1		Durability Limited at High Temperatures
Black Acrylic Paint	.92-.97	.84-.90	∿1		
Black Inorganic Paint	.89-.96	.86-.93	∿1		
Black Silicone Paint	.86-.94	.83-.89	∿1		Silicone Binder
PbS/Silicone Paint	.94	.4	2.5	662 (350)	Has a High Emittance for Thicknesses >10μm
Flat Black Paint	.95-.98	.89-.97	∿1		
Ceramic Enamel	.9	.5	1.8		Stable at High Temperatures
Black Zinc	.9	.1	9		
Copper Oxide over Aluminum	.93	.11	8.5	392 (200)	
Black Copper over Copper	.85-.90	.08-.12	7-11	842 (450)	Patinates with Moisture
Black Chrome over Nickel	.92-.94	.07-.12	8-13	842 (450)	Stable at High Temperatures
Black Nickel over Nickel	.93	.06	15	842 (450)	May be Influenced by Moisture at Elevated Temperatures
Ni-Zn-S over Nickel	.96	.97	14	536 (280)	
Black Iron over Steel	.90	.10	9		

*Dependent on thickness and vehicle to binder ratio.

G. E. McDonald, "Survey of Coatings for Solar Collectors", NASA TMX-71730, paper presented at Workshop on Solar Collectors for Heating and Cooling of Buildings, November 21-23, 1974, New York City.

G. E. McDonald, "Variation of Solar-Selective Properties of Black Chrome with Plating Time", NASA TMX-71731, May 1975.

S. W. Moore, J. D. Balcomb, J. C. Hedstrom, "Design and Testing of a Structurally Integrated Steel Solar Collector Unit Based on Expanded Flat Metal Plates", LA-UR-74-1093, paper presented at U. S. Section-ISES Meeting, Ft. Collins, Colorado, August 19-23, 1974.

D. P. Grimmer, S. W. Moore, "Practical Aspects of Solar Heating: A Review of Materials Use in Solar Heating Applications", paper presented at SAMPE Meeting, October 14-16, 1975, Hilton Inn.

R. B. Toenjes, "Integrated Solar Energy Collector Final Summary Report", LA-6143-MS, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, November 1975.

G. L. Merrill, "Solar Heating Proof-of-Concept Experiment for a Public School Building", Honeywell Inc., Minneapolis, Minnesota National Science Foundation Contract No. C-870.

D. L. Kirkpatrick, "Solar Collector Design and Performance Experience", for the Grover Cleveland School, Boston, Massachusetts. paper presented at Workshop on Solar Collectors for Heating and Cooling of Buildings, November 21-23, 1974, New York City.

Appendix Table B-3: Properties of Typical Absorber Substrate Materials*

Property \ Material	Aluminum	Copper	Mild Carbon Steel	Stainless Steel
Elastic Modulus, Tension psi x 10^6	10	19	29	28
Density lbs/cu.in.	0.098	0.323	0.283	0.280
Expansion Coefficient (68-212°F) in/in/°F x 10^{-6}	13.1	9.83	8.4	5.5
Thermal Conductivity (77-212°F) Btu/hr·ft^2·°F·ft	128	218	27	12
Specific Heat (212 °F) Btu/lb·°F	0.22	0.09	0.11	0.11

*Typical valves: standard specifications or manufacturer's literature should be consulted for specific types or alloys.

Appendix Table B-4: Standards for Piping, Valves and Ducts

Description	ANSI	ASTM	Federal Specifications	Other
Ferrous pipe & fittings				
Steel pipe, black and hot dipped zinc-coated (galvanized) welded and seamless for ordinary use	B125.2-1972	A120-73	WW-P-406D-1973 WW-P-406D-1-1974	---
Steel pipe welded and seamless	B125.1-1972	A53-73	---	ASME SA53
Nipples, Pipe, threaded	---	---	WW-N-351b-1967 WW-N-351b[1]-1970	CS5-65
Pipe fittings: (bushings, locknuts and plugs) iron, steel and aluminum (threaded) 125-150 lbs.	---	---	WW-P-471B-1970	---
Malleable-iron threaded fittings, 150 and 300 lbs.	B16.3-1971	---	WW-P-521F-1968	---
Unions, pipe, steel or malleable iron; threaded connection, 150 lbs. and 250 lbs.	---	---	WW-U-531D	---
Standard Specification for Seamless and Welded Ferritic Stainless Steel Tubing for General Service	B125.14	A268-73		
Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service	B125.15	A269-73		
Nonferrous metallic pipe and fittings				
Copper pipe, seamless	H26.1-1973	B42-75	WW-P-377d-1962	ASME SB42
Copper pipe, threadless	H26.2-1973	B302-74a	---	---
Copper tube, seamless	H23.3-1973	B74-74b	---	ASME SB75
Copper tube, seamless, for refrigeration and general use	H23.5-1974	B280-75	WW-T-775a-1962	---
Copper water tube seamless	H23.1-1973	B88-75	WW-T-799D-1971	---
General requirements for wrought seamless copper and copper alloy tube	H23.4-1973	B251-75	---	ASME SB251
Seamless brass tube	H36.1-1973	B136-74	WW-T-791A-1971	ASME SB135
Seamless red brass pipe	H27.1-1973	B43-75	WW-P-351a-1963	ASME SB43
Bronze flanges and flanged fittings, 150 and 300 lbs.	B16.24-1971	---	---	---
Cast-bronze fittings for flared copper tubes	B16.26-1967	---	---	---
Cast-bronze solder joint drainage fittings-DMV	B16.23-1969 B16.23a-1973	---	---	---
Cast bronze solder joint pressure fittings	B16.18-1972	---	---	---
Cast bronze threaded fittings, 125 and 250 lbs.	B16.15-1971		WW-P-460b-1967 WW-P-460b-1-1972	
Copper tube fittings, solder ends	---	---	WW-T-725a-1973	
Unions, brass or bronze, threaded pipe connections and solder-joint tube connections	---	---	WW-U-516B	---
Unions, pipe, bronze or naval brass, threaded pipe connection 250 lbs.	---	---	WW-U-516a-1967	---

Appendix Table B-4: continued

Description	ANSI	ASTM	Federal Specifications	Other
Welded Copper Tube	---	B-447	---	---
Welded Copper Nickel Pipe and Tube	---	B-467	---	---
Welded Copper and Copper Alloy Tube	---	B-543	---	---
Welded Copper Alloy Water Tube	---	B-586	---	---
Welded Brass Tube	---	B-587	---	---
Welded Copper Alloy Pipe	---	B-608	---	---
Copper-silicon alloy seamless pipe and tube	H26.3-1973	B315-75	---	---
Wrought copper and bronze solder-joint pressure fitting	B16.22-1973	---	---	---
Wrought copper and wrought copper alloy solder-joint drainage fittings	B16.29-1973	---	---	---
Aluminum-alloy seamless pipe and seamless extruded tube	H38.7	B241	---	---
Aluminum-alloy drawn seamless tubes	H38.7	B310-74a	---	---
Aluminum-alloy drawn tubes for general purpose application	H38.17-1974	B483-73	---	---
Aluminum-alloy extruded round coiled tubes for general purpose application	H38.18-1974	B491-73	---	---
Wrought aluminum and aluminum alloy welding fittings	H38.19-1974	B361-73	---	---
Pipe hangers and supports	---	---	WW-H-171D-1970	---
Pipe hangers and supports, materials, design and manufacture	---	---	---	MSS SP-58-1975 2/
Pipe hangers and supports, selection and application	---	---	---	MSS SP-69-1966 2/
Polybutylene (PB) plastic hot-water distribution systems (180°F Max.)	---	D3309-74	---	---
Plastic hot-water distribution systems: chlorinated poly (vinyl chloride) (CPVC) for water service (180°F Max.)	---	D2846-73	---	NSF 14-1965
Cold water service, clamps, hose, low pressure	---	---	WW-C-440B(2)	---
Standard methods of testing rubber hose	J2.5	D380-75	---	---
Standard method of test for sealability of gasket materials	Z193.1-1970	F37-68	---	---
Standard method of test for fluid resistance of gasket materials	---	F146-72	---	---

Appendix Table B-4: continued

Description	ANSI	ASTM	Federal Specifications	Other
Valves				
Standard for solenoid valves for use with volatile refrigerants and water	---	---	---	ARI 760, 1975
Valves, pressure, reducing and regulating for installation on domestic water supply lines	---	---	---	IAPMO PS15-71 1/
Water pressure reducing valves for domestic water supply systems	---	---	---	ASSE 1003, 1970
Valves, automatic relief (For water/ steam).	ANSI 21.22-1971	---	---	---
Valves, cast iron gate, 125 & 250 lb; threaded and flanged	---	---	WW-V-58a-1966	---
Combination check and relief valves	---	---	---	IAPMO TSC-8-66 1/
Valves, ball	---	---	WW-V-35a-1965	---
Valves, bronze, angle, check and globe, 125 and 150 lb, threaded and flanged or soldered	---	---	WW-V-51d-1967	---
Valves, water heater drain	---	---	---	ASSE 1005
Globe type loglighter valves, angle or straight pattern	---	---	---	IAPMO PS10-66 1/
Valves, electrically operated	---	---	---	UL 429, 1955
Valves (125 pound bronze gate)	---	---	---	MSS SP 37, 1969
Valves (150 pound corrosion resistant, cast, flanged)	---	---	---	MSS SP 42 2/
Valves (butterfly)	---	---	---	MSS SP 67, 1966 2/
Low velocity duct construction standards	---	---	---	SMACNA
High velocity duct construction standards	---	---	---	SMACNA
Fibrous glass duct construction standards	---	---	---	SMACNA
Pressure sensitive tape standards for fibrous glass duct	---	---	---	SMACNA
Duct liner application standard	---	---	---	SMACNA
Fire damper guide	---	---	---	SMACNA

1/ International Association of Plumbing and Mechanical Officials, 5032 Alhambra Avenue, Los Angeles, California 90032

2/ Manufacturers Standardization Society of the Valve and Fitting Industry, 1815 North Fort Meyer Drive, Arlington, Virginia 22209

Appendix Table B-5: Temperature and Pressure Ratings for Ball Valves[1/]

Size (inches)	Temperature, °F	Materials (Pressure in psi)			
		Bronze	Iron	Carbon Steel	Alloy Steel
1/2	-20 to 100	200 and 400		1000	1000
	150	400		850	850
	200	150 and 400		700	700
TO	250	15[2/] and 400		500	500
	300	300		300	300
	325	200		200	200
3/4	353	125		125	125
	375	90		90	90
	400	60		60	60
1	-20 to 100	400		720	720
	150	400		710	710
	200	400		700	700
TO	250	400		500	500
	300	300		300	300
2	325	200		200	200
	353	125		125	125
	375	90		90	90
	400	60		60	60
2-1/2	-20 to 100		220	275	275
	150		205	255	255
TO	200		190	240	240
12	250		180	225	225

1/ These ratings for ball valves, presented in Federal Specification WW-V-35a-1975, are intended for guidance and are not intended to be restrictive. Valves should not be used for pressures and temperatures exceeding the manufacturer's rating.

2/ 15 pounds saturated steam temperature.

Appendix Table B-6: Thermal Storage Unit Containers 1/

Container / Material	Usage: Above Ground	Usage: Below Ground	Transfer Media: Air	Transfer Media: Liquid	Pressure Conditions: High	Pressure Conditions: Low 2/	Recommended 3/ Container Standard Compliance	Protective Coating: Ext.	Protective Coating: Int.	Recommended Coating Standard Compliance
Aluminum	X	X	X	X	X	X	ANSI B96.1 1973	-	-	-
Concrete	X	X	X	X	X	X	IAPMO PSI (1966)	X	X	Ext. MPS 609-7.3 Int. TTP-95A(3) 27 May 66
Earth		X	X			X	Vapor Barrier Materials as per ASTM E154.68	Vapor Barrier Covering of Solids Required		MPS 507.2.2
Plastics	X	X	X	X		X	MIL-T-52777 4/ 21 Feb 1974	-	-	-
Steel	X	X	X	X	X	X	AWWA D-100 (1967)	X	X	Ext. MPS 609-7.4 5/ Ext. & Int. AWWA D102 (1964)
Wood	X		X	X		X	NFO 8 (1965)	-	-	-

1/ Thermal Storage Unit - any container, space, or device which has the capacity to store transfer media (liquid or solid) containing thermal energy for later use.

2/ Low pressure systems are those subjected to atmospheric pressure only, i.e. vented.

3/ When applicable, ASME Boiler and Pressure Vessel Code, Section VIII may be used.

4/ Refers to fiber reinforced polyester containers

5/ In lieu of interior galvanized, glass-lined or stone-lined tanks.

Appendix Table B-7: Examples of Typical Heat Transfer Liquids [1/]

	Water	50% Ethylene Glycol/Water	50% Propylene Glycol/Water	Silicone Fluid	Aromatics	Paraffinic Oil
Freezing Point, °F (°C)	32 (0)	-33 (-36)	-28 (-33)	-58 (-50)	-100 to -25 (-73 to -32)	--
Boiling Point, °F (°C) (at atm. pressure)	212 (100)	230 (110)	--	None	300-400 (149-204)	700 (371)
Fluid Stability	Requires pH or inhibitor monitoring	Requires pH or inhibitor monitoring	Requires pH or inhibitor monitoring	Good	Good	Good
Flash Point, [2/] °F (°C)	None	None	600 (315)	600 (315)	145-300 (63-149)	455 (235)
Specific Heat (73°F) [Btu/(lb·°F)]	1.0	0.80	0.85	0.34-0.48	0.36-0.42	0.46
Viscosity (cstk at 77°F)	0.9	21	5	50-50000	1-100	--
Toxicity	Depends on inhibitor used	Depends on inhibitor used	Depends on inhibitor used	Low	Moderate	--

1/ These data are extracted from manufacturers literature to illustrate the properties of a few types of liquid that have been used as transfer fluids.

2/ It is important to identify the conditions of tests for measuring flash point. Since the manufacturers literature does not always specify the test, these values may not be directly comparable.

Appendix Table B-8: Comparative Characteristics and Properties of Sealing Compounds

	Butyls		Acrylics		Polysulfides		Polyurethanes		Silicones
	Oil Base	Skinning Type	Non-Skinning Type	Solvent-Release Type	Water-Release Type	One Component	Two Component	One-Component	Two-Component	One and Two Component
Chief ingredients	Selected oils, fillers, plasticizers, binders, pigment	Butyl polymers, inert reinforcing pigments, non-volatile plasticizers and polymerizable dryers	Butyl polymers, inert reinforcing pigments, non-volatizing and non-drying plasticizers	Acrylic polymers with limited amounts of fillers & plasticizers	Acrylic polymers with fillers and plasticizers	Polysulfide polymers, activators, pigments, inert fillers, curing agents, and non-volatilizing plasticizers	Base polysulfide polymers, activators, pigments, plasticizers, fillers. Activator: accelerators, extenders, activators	Polyurethane prepolymer, filler pigments & plasticizers	Base: polyurethane prepolymer, filler, pigment, plasticizers. Activator: accelerators, extenders, activators	Silicone polymer, pigment & fillers
Primer required	in certain applications	none	none	none	none	usually	usually	usually	always	usually
Curing process	solvent release, oxidation	solvent release, oxidation	no curing: remains permanently tacky	solvent release	water evaporation	chemical reaction with moisture in air & oxidation	chemical reaction with curing agent	chemical reaction with moisture in the air	chemical reaction with curing agent	chemical reaction and/or moisture
Tack-free time (hrs)	6	24	remains indefinitely tacky	36	36	24	36-48	36	24	0.3 to 1
1/ Cure time days	continuing	continuing	N/A	14	5	14-21	7	14	3-5	1 to 7
Max. cured elongation	15%	40%	N/A	60%	not available	300%	600%	300%	400%	100 to 450%
Recommended max. joint width movement, %	23% decreasing with age	±7 1/2%	N/A	±10%	±5%	±25%	±15%	±15%	±25%	±25%
Max. joint width	1"	3/4"	N/A	3/4"	5/8"	1"	1"	3/4"	1"	5/8"
Resiliency	low	low	low	low	low	high	high	high	high	high
Resistance to compression	very low	moderate	low	very low	low	moderate	moderate	high	high	high
2/ Resistance to extension	very low	low	low	very low	low	moderate	high	moderate	high	high
Service temp. range °F	-20° to 150°	-20° to 180°	-20° to 180°	-20° to 180°	-20° to 180°	-40° to 200°	-60° to 200°	-25° to 250°	-40° to 250°	-85 to 500°
Normal application temp. range (surface) (°F)	+40 to +120°	+40° to 120°	+40° to 120°	+40° to 120°	+40° to 120°	+40° to 120°	+40° to 120°	+40° to 120°	+40° to 120°	0° to +160°
Weather resistance	poor	fair	fair	very good	not available	very good	very good	very good	very good	excellent
Ultra-violet resistance, direct	poor	good	good	very good	not available	good	good	poor to good	poor to good	excellent
Cut, tear, abrasion resistance	N/A	N/A	N/A	N/A	N/A	good	good	excellent	excellent	fair
3/ Life expectancy	5 to 10 years	10 years +	10 years +	20 years +	not available	20 years +	20 years +	20 years +	20 years +	20 years +
Hardness Shore A	20-80	20-40	N/A	20-40	30-35	25-35	24-45	25-45	25-45	20 to 60
Applicable specifications	TT-C-598C	TT-S-001657	NAAMM SS-1s-68	TT-S-00230C	none	TT-S-00230C	TT-S-00227e	TT-S-00230C	TT-S-00227e	TT-S-00230C TT-S-001543 TT-S-00227E

1/ Cure time as well as pot life are greatly affected by temperature and humidity. Low temperatures and low humidity create longer pot life and longer cure time; conversely, high temperatures and high humidity create shorter pot life and shorter cure time.

2/ Resistance to extension is better known in technical terms as modulus. Modulus is defined as the unit stress required to produce a given strain. It is not constant but, rather, changes in values as the amount of elongation changes.

3/ Life expectancy is directly related to joint design, workmanship and conditions imposed on any sealant. The length of time illustrated is based on joint design within the limitations outlined by the manufacturer, and good workmanship based on accepted field practices and average job conditions. A violation of any one of the above would shorten the life expectancy to a degree. A total disregard for all would render any sealant useless within a very short period of time.

APPENDIX C

ILLUSTRATED DEFINITIONS

AN ILLUSTRATED SOLAR APPENDIX

Table of Contents

Solar Heating and Hot Water Systems: Functional Description

The basic function of a solar heating and domestic hot water system is the collection and conversion of solar radiation into usable energy. This is accomplished — in general terms — in the following manner. Solar radiation is absorbed by a collector, placed in storage as required, with or without the use of a transport medium, and distributed to point of use. The performance of each operation is maintained by automatic or manual controls. An auxiliary energy system is usually available for operation, both to supplement the output provided by the solar system and to provide for the total energy demand should the solar system become inoperable.

The conversion of solar radiation to thermal energy and the use of this energy to meet all or part of a dwelling's heating and domestic hot water requirements has been the primary application of solar energy in buildings.

The parts of a solar system — collector, storage, distribution, transport, controls and auxiliary energy — may vary widely in design, operation, and performance. They may, in fact, be one and the same element (a south-facing masonry wall can be seen as a collector, although a relatively inefficient one, which stores and then radiates or "distributes" heat directly to the building interior). They may also be arranged in numerous combinations dependent on function, component compatibility, climatic conditions, required performance, site characteristics, and architectural requirements.

Of the numerous concepts presently being developed for the collection of solar radiation, the relatively simple flat-plate collector has the widest application. It consists first of an absorber plate, usually made of metal coated black to increase absorption of the sun's energy. The plate is then insulated on its underside and covered with a transparent cover plate to trap heat within the collector and reduce convective losses from the absorber. The captured heat is removed from the absorber by means of a working fluid, generally air or water. The fluid is heated as it passes through or near the absorber plate and then transported to points of use, or to storage, depending on energy demand.

The storage of thermal energy is the second item of importance since there will be an energy demand during the evening, or on sunless days when solar collection cannot occur. Heat is stored when the energy delivered by the sun and captured by the collector exceeds the demand at the point of use. The storage element may be as simple as a masonry floor that stores and then re-radiates captured heat, or as relatively complex as a latent heat storage. In some cases, it is necessary to transfer heat from the collector to storage by means of a heat exchanger (primarily in systems with a liquid working fluid). In other cases, transfer is made by direct contact of the working fluid with the storage medium (i.e., heated air passing through a rock pile).

The distribution component receives energy from the collector or storage, and dispenses it at points of use. Within a building, heat is usually distributed in the form of warm air or warm water.

The controls of a solar system perform the sensing, evaluation and response functions required to operate the system in the desired mode. For example, if the collector temperature is sufficiently higher than storage temperature, the controls can cause the working fluid in storage to circulate in the collector and accumulate solar heat.

An auxiliary energy system provides the supply of energy when stored energy is depleted due to severe weather or clouds. The auxiliary system, using conventional fuels such as oil, gas, electricity, or wood provides the required heat until solar energy is available again.

The organization of components into solar heating and domestic hot water systems has led to two general characterizations of solar systems: active and passive. The terms active and passive solar systems have not yet developed universally accepted meanings. However, each classification possesses characteristics that are distinctively different from each other. These differences significantly influence solar dwelling and system design.

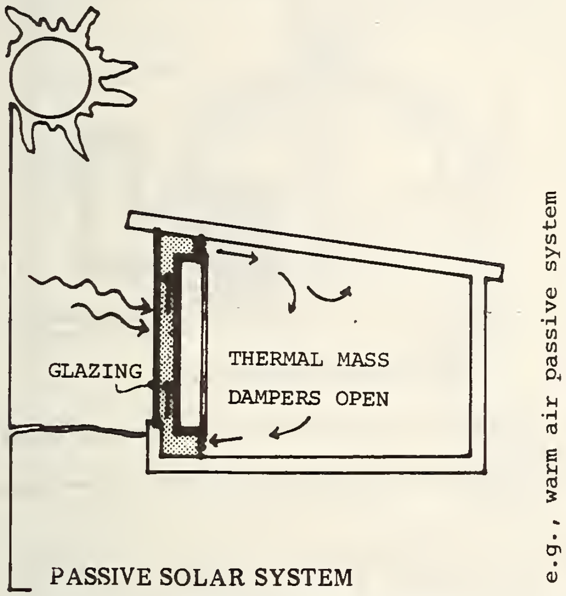
An <u>active solar system</u> can be characterized as one in which an energy resource — in addition to solar — is used for the transfer of thermal energy. This additional energy, generated on or off the site, is required for pumps, blowers, or other heat transfer medium moving devices for system operation. Generally, the collection, storage, and distribution of thermal energy is achieved by moving a transfer medium throughout the system with the assistance of pumping power.

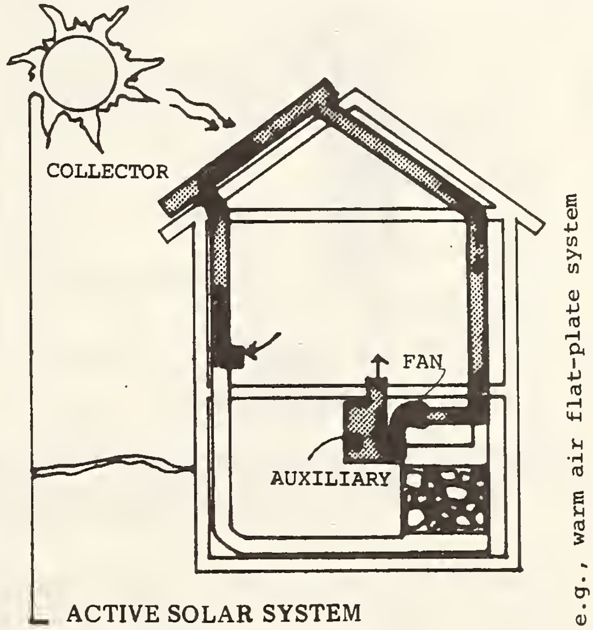
A <u>passive solar system</u>, on the other hand, can be characterized as one where solar energy alone is used for the transfer of thermal energy. Energy other than solar is not required for pumps, blowers, or other heat transfer medium moving devices for system operation. The major component in a passive solar system generally utilizes some form of thermal capacitance, where heat is collected, stored, and distributed to the building without additional pumping power. Collection, storage, and distribution is achieved by natural heat transfer phenomena employing convection, radiation, conduction, in conjunction with the use of thermal capacitance as a heat flow control mechanism.

Solar Heating and Hot Water Systems: Operational Description

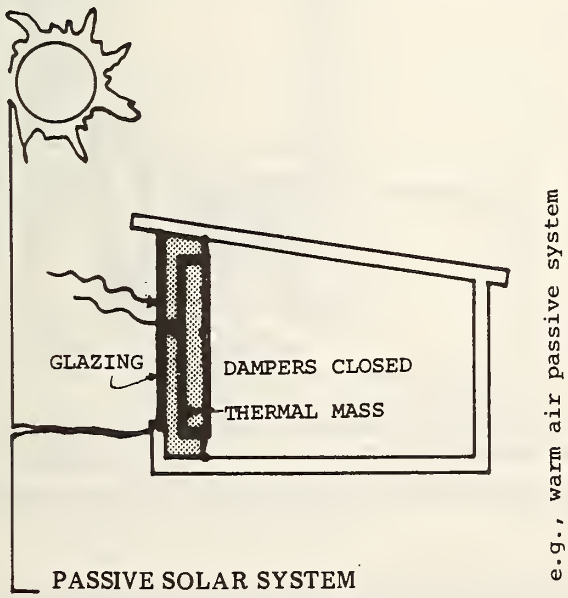
A. Solar Heating System

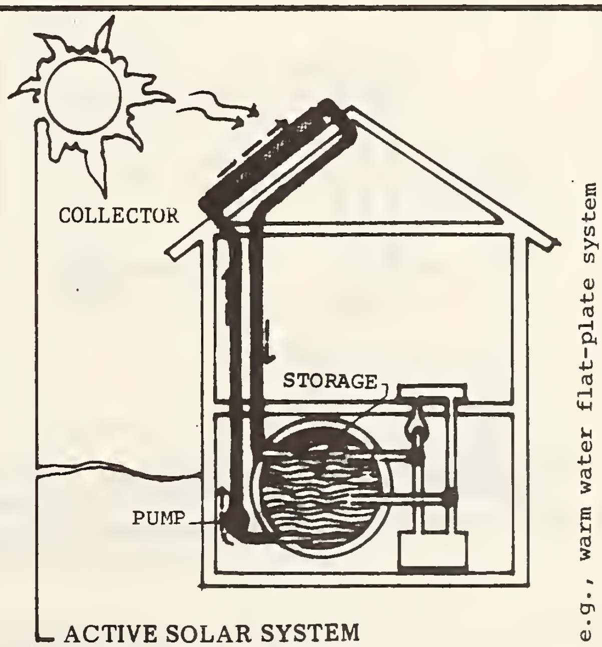
Solar systems may be designed to operate in a number of different ways depending on function, required performance, climatic conditions, component and system design, and architectural requirements. Usually, however, solar systems are designed to operate in four modes. In a very basic manner, the four modes of solar system operation for both active and passive systems are described and illustrated below.



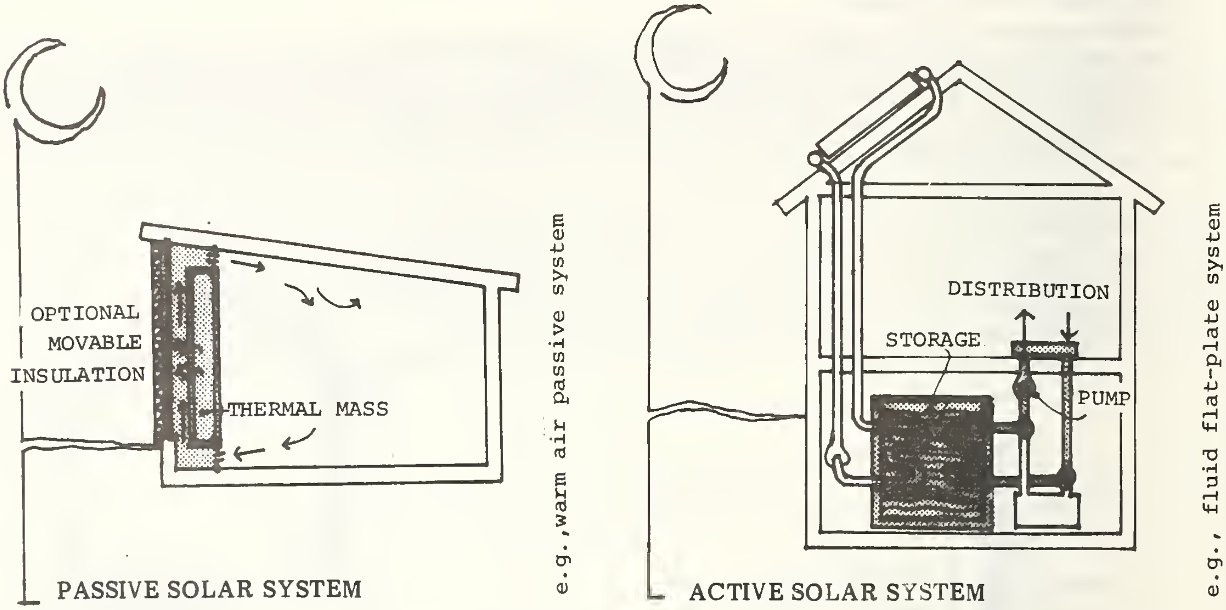


1. HEATING HOUSE FROM COLLECTOR Solar radiation captured by the collectors and converted to thermal energy can be used to directly heat the house.

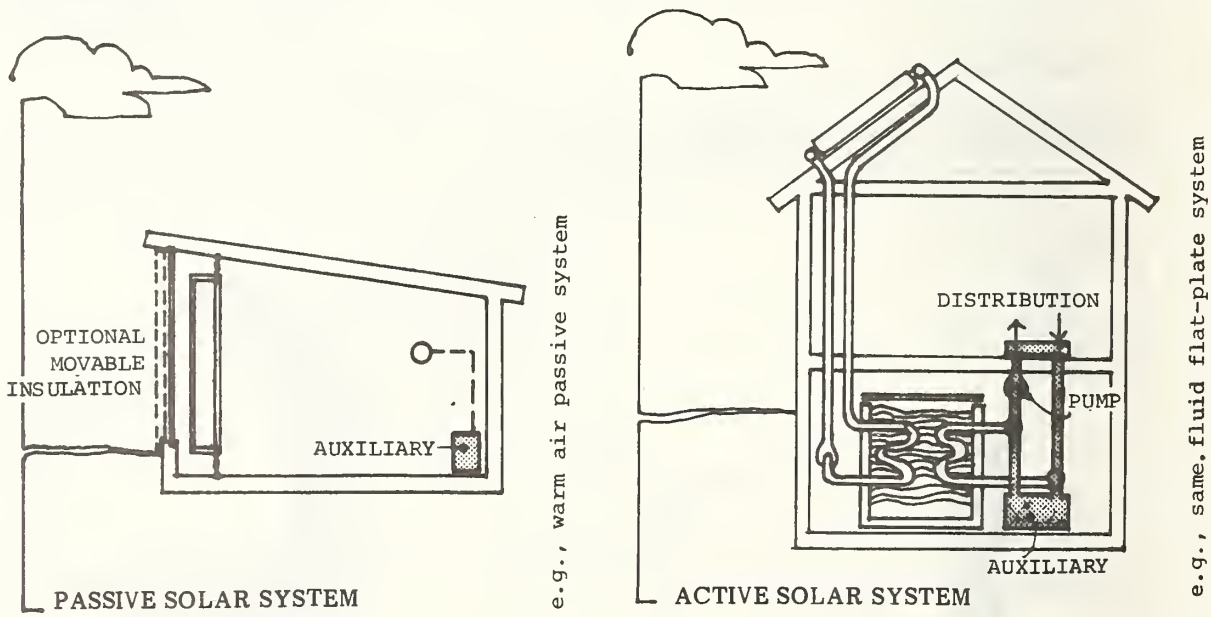




2. HEATING STORAGE FROM COLLECTOR If the house does not require heat, the captured (collected) thermal energy can be placed in storage for later use.



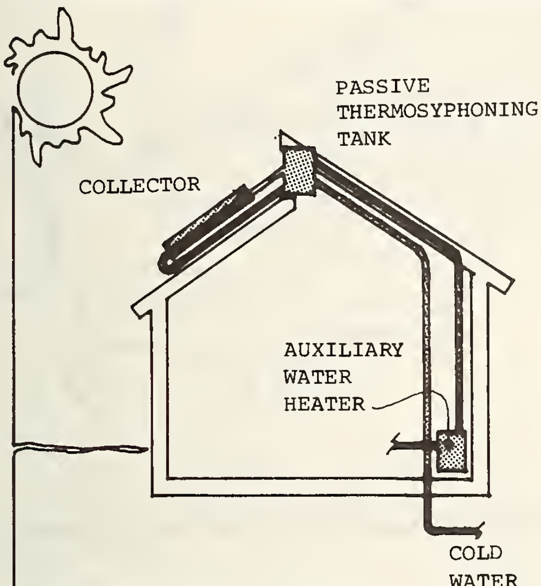
3. <u>HEATING HOUSE FROM STORAGE</u> Heat from storage can be removed to heat the house when the sun is not shining — at night or on consecutive sunless days.



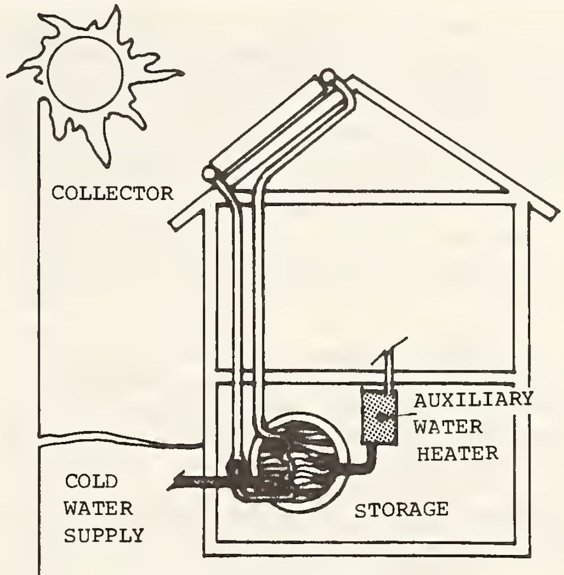
4. <u>HEATING HOUSE FROM AUXILIARY</u> If heat from the collector and storage is not sufficient to totally heat the house, an auxiliary system supplies all or part of the house's heating requirement.

B. Domestic Hot Water System

The solar system may also be designed to preheat water from the incoming water supply prior to passage through a conventional water heater. The domestic hot water preheat system can be combined with the solar heating system or designed as a separate system. Both situations are illustrated below.



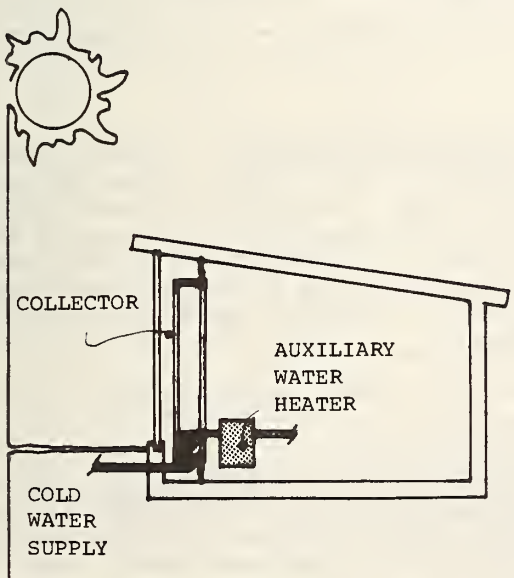
PASSIVE SOLAR SYSTEM



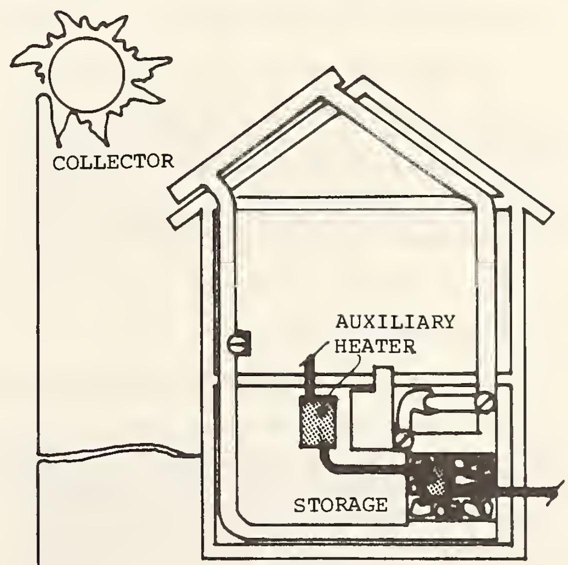
ACTIVE SOLAR SYSTEM

e.g., warm water flat-plate preheat system

1. DOMESTIC HOT WATER PREHEATING - SEPARATE SYSTEM Domestic hot water preheating may be the only solar system included in some designs. A passive thermosyphoning arrangement is shown above.



PASSIVE SOLAR SYSTEM



ACTIVE SOLAR SYSTEM

e.g., warm air flat-plate system with preheat

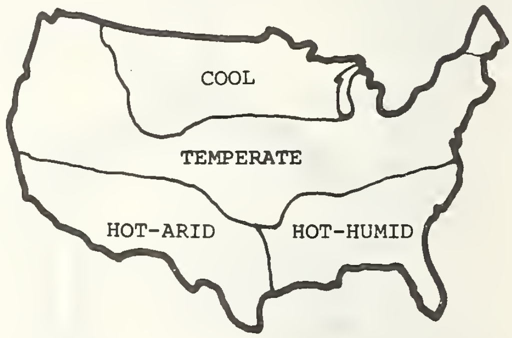
2. DOMESTIC HOT WATER PREHEATING - COMBINED SYSTEM Domestic hot water is preheated as it passes through heat storage enroute to the conventional water heater.

Basics of Solar Utilization

A. Climate

Solar radiation, wind, temperature, humidity and many other factors shape the climate of the United States. Basic to using solar energy for space heating and domestic hot water heating is understanding the relationship of solar radiation, climate and dwelling design.

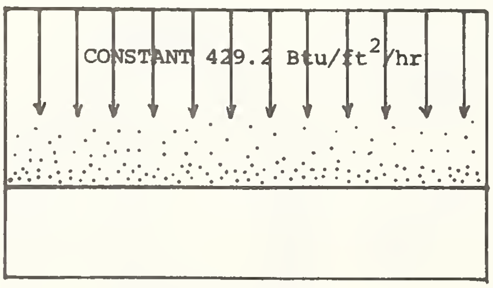
The amount and type of solar radiation varies between and within climatic regions: from hot-dry climates where clear skies enable a large percentage of direct radiation to reach the ground, to temperate and humid climates where up to 40 percent of the total radiation received may be diffuse sky radiation, reflected from clouds and atmospheric dust, to cool climates where snow reflection from the low winter sun may result in a greater amount of incident radiation than in warmer but cloudier climates.



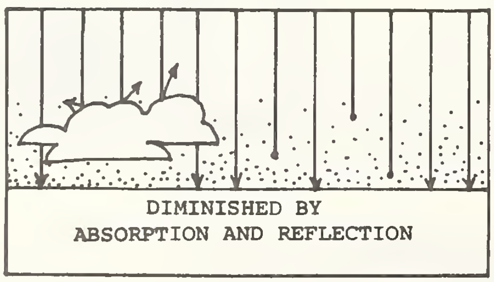
As a result of these differences in the amount and type of radiation reaching a building site, as well as in climate, season and application — heating or domestic hot water — the need for and the design of solar system components will vary in each locale.

B. Solar Radiation

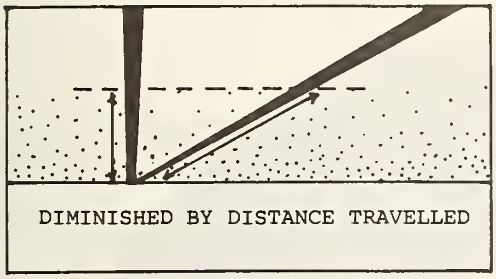
The sun provides almost all of the earth's energy in the form of radiation. Solar energy, also known as solar radiation reaches the earth's surface in two ways : by direct (parallel) rays, and by diffuse (nonparallel) sky radiation. The solar radiation reaching a building includes not only direct and diffuse but also radiation reflected from adjacent ground and building surfaces. It is these three sources of solar radiation that may be used for space and domestic hot water heating.



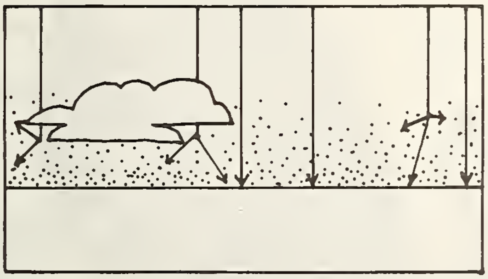
1. THE SOLAR CONSTANT A nearly constant amount of solar energy strikes the outer atmosphere = 429.2 BTU per square foot per hour. This quantity is known as the solar constant. A large amount of this energy, however, is lost in the earth's atmosphere,and cannot be regained regardless of collector design.



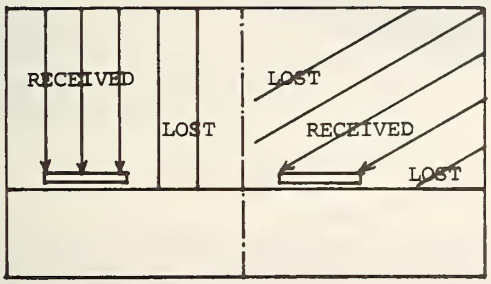
2. ABSORPTION AND REFLECTION On the average, almost half of the solar radiation reaching the earth's outer atmosphere is lost by absorption in the atmosphere and by reflection from clouds, as it passes through the atmosphere to the earth's surface. The radiation lost actually varies between 60% in Seattle, Washington to only 30% in Albuquerque, New Mexico.



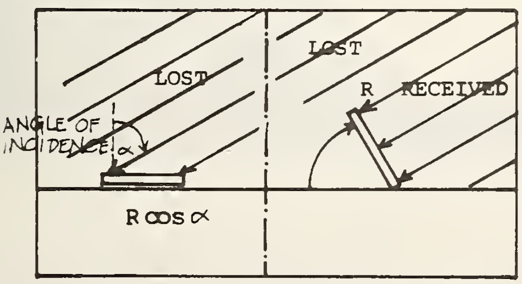
3. EARTH'S ATMOSPHERE As already stated, the radiation reaching the earth's surface is diminished by the condition of the earth's atmosphere: its vapor, dust and smoke content. At lower sun angles, the length of travel through the atmosphere is greatly increased, so the relative amount of radiation received is further diminished.



4. DIFFUSE RADIATION Clouds and particles in the atmosphere not only absorb solar energy, but scatter it in all directions. As a result, a part of the solar radiation reaching the earth's surface is diffused, and received from all parts of the sky. Diffuse radiation, as opposed to direct radiation, is more predominant on hazy days than clear ones. At most, however, diffuse radiation can only be about one quarter of the solar constant, or about 100 BTU/hr./sq. ft.

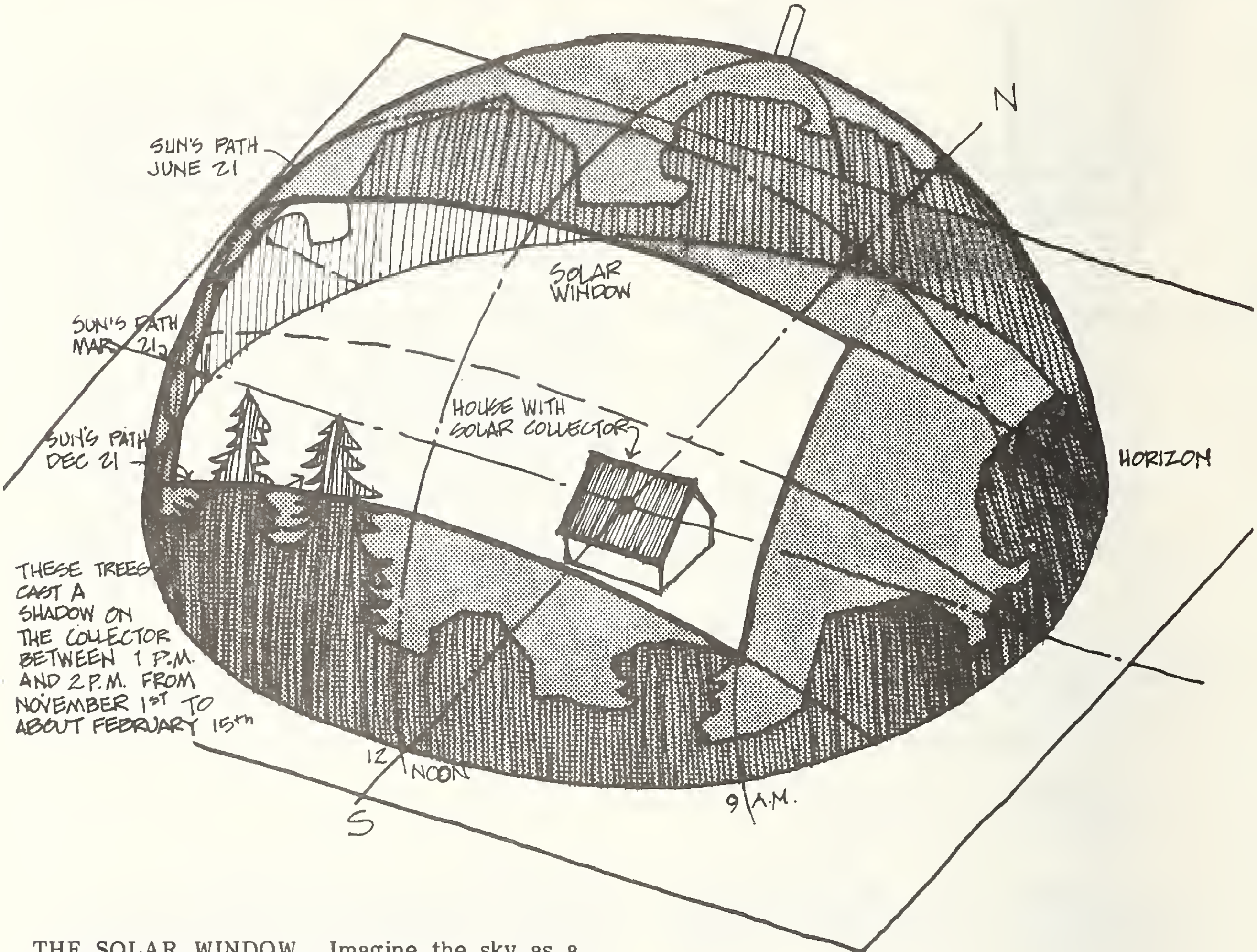


5. DIRECT RADIATION ON A HORIZONTAL SURFACE Although the amount of radiation remains constant, less radiation strikes a given horizontal area as the sun gets lower in the sky.

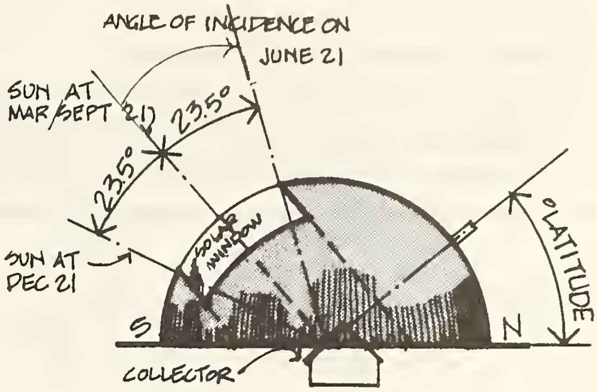


6. DIRECT SOLAR RADIATION ON A TILTED SURFACE The same principle applies to a tilted surface such as a collector. By tilting the collector so that it is nearly perpendicular to the sun's ray, more energy strikes its surface, undiminished by a cosine factor.

C. Solar Window

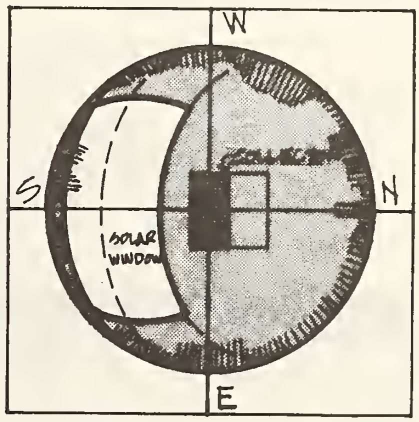


<u>THE SOLAR WINDOW</u> Imagine the sky as a transparent dome with its center at the solar collector of a house. The path of the sun can be painted (projected) onto the dome, as can be the outline of surrounding houses and trees. The morning and afternoon limits of useful solar collection (roughly 9 A.M. and 3 P.M.) and the sun's path between those hours throughout the year scribes a "solar window" on the dome. Almost all of the useful sun that reaches the collector must come through this window except for the added effect of diffuse radiation. If any of the surrounding houses, trees, etc., intrude into this "solar window," the intrusion will cast a shadow on the collector. The isometric drawing above illustrates the "solar window" for a latitude 40° N. The solar window will change for different latitudes.

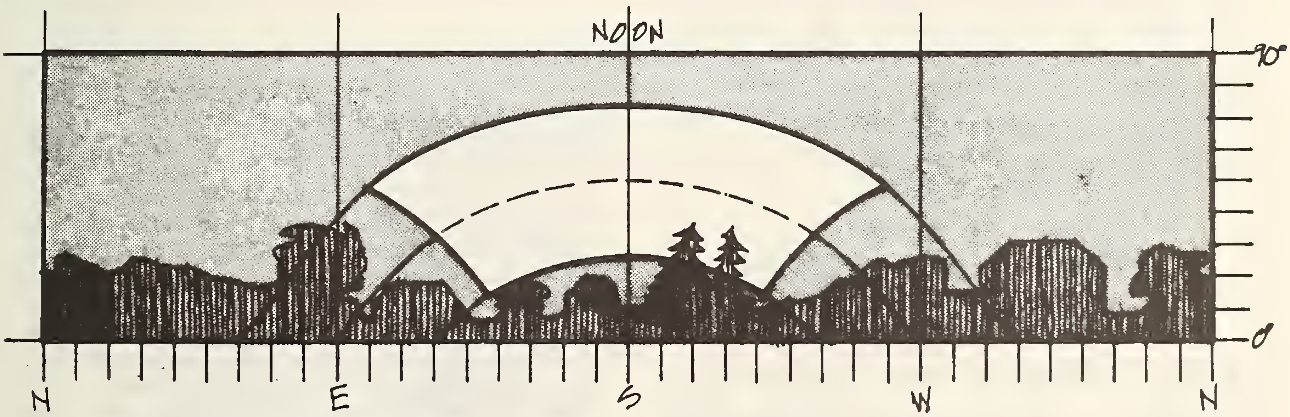


SIDE VIEW OF SKY DOME WITH "SOLAR WINDOW" A side view of the sky dome from the east illustrates the relative position and angle of the sun throughout the year that defines the boundaries of the "solar window."

ANGLE OF INCIDENCE, a term often used in solar collector design, is the angle measured from the normal of the collector surface to the line indicating the sun's altitude at a particular time. The diagram specifically identifies the angle of incidence for June 21.



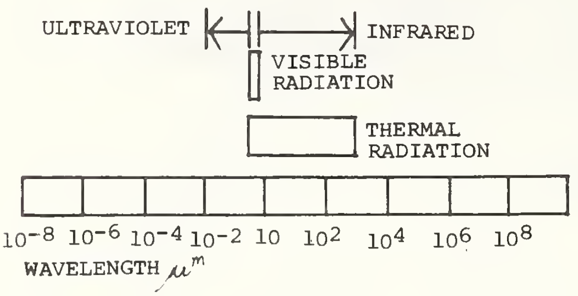
PLAN VIEW OF SKY DOME WITH "SOLAR WINDOW" Viewed from above the sky dome, the seasonal path of the sun can be plotted thus defining the boundaries of the "solar window." This is easily accomplished by the use of a standard sun path diagram for the proper latitude. Sun path diagrams are widely reproduced and used for determining the azimuth and altitude of the sun at any time during the year, and give the points which can be plotted to determine the solar window.

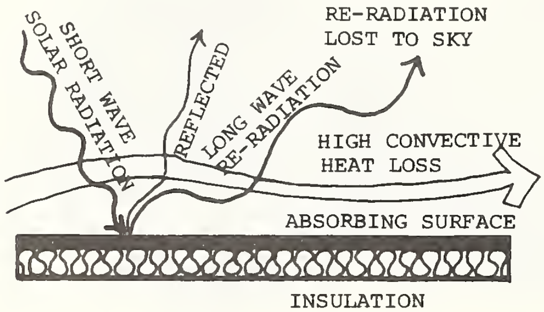


PANORAMA OF THE SKY DOME As with the spherical earth, the spherical sky dome with its "solar window" can be mapped using a Mercator projection, in which all latitude and longitude lines are straight lines. Such a map is very useful for comparing the site surroundings with the "solar window" outline, since both can be easily plotted on the map. Any elements surrounding the site that intrude into the "solar window" will cast shadows on the collector.

D. Solar Collection and Conversion

Basic to the utilization of solar energy for space and domestic hot water heating is the process by which solar radiation is converted to thermal energy. This conversion process is the basic link between the energy supply -- the sun -- and the energy load -- the dwelling. The process is best understood by briefly explaining solar radiation and then discussing the characteristics of collection.

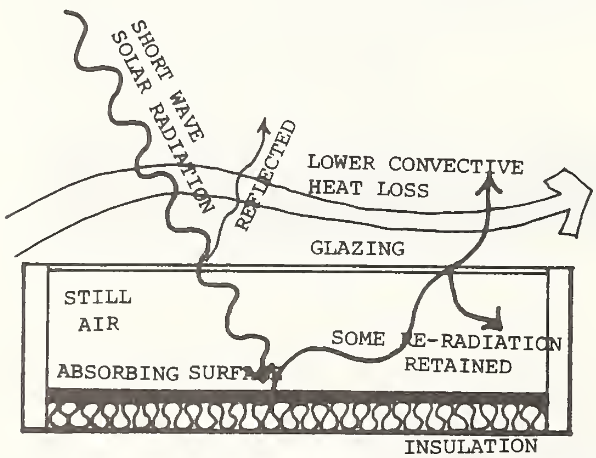




1. SOLAR ENERGY CONVERSION Solar radiation is electromagnetic radiation generated by the sun, which reaches the earth's surface with a wavelength distribution of .3 to 2.4 micrometers. Radiation is perceived as visible light between ultraviolet and infrared, specifically between .36 and .76 micrometers. For most solar applications, solar radiation in the visible and near-infrared range is the most important.

The drawings to the left show the principle of solar energy collection and conversion. When incoming solar radiation impinges on the surface of a body, it is partially absorbed, partially reflected, and, if the body is transparent, partially transmitted. The relative magnitude of each varies with the surface characteristics, body geometry, material composition, and wavelength.

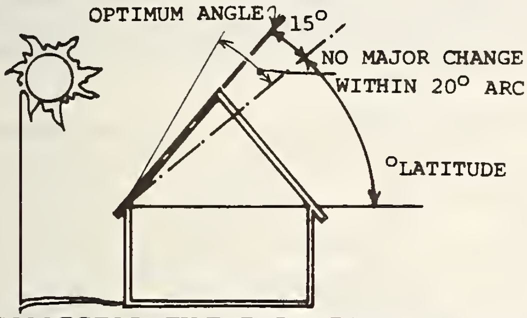
For solar applications, energy must be first absorbed, then converted into thermal energy and, finally removed by a heat transfer mechanism in order to be useful. Absorbed radiation heats up the absorbing body, which then re-emits energy in the form of thermal radiation in the infrared (longwave) part of the spectrum. If the absorbing surface is exposed to the atmosphere, part of the absorbed energy will be lost by convection or radiation.



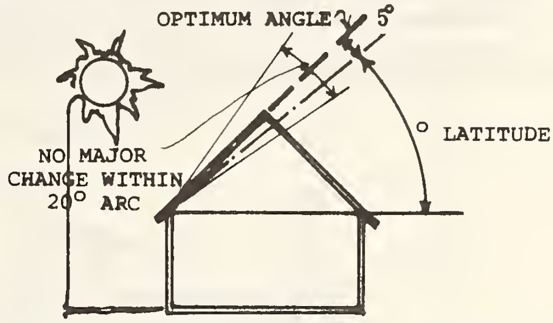
2. THE GREENHOUSE EFFECT Most glass and some plastics are transparent in the solar wavelength region and hence are used as windows. At the same time, this glazing has low transmission in the infrared (longwave) region. By placing glass or plastic over the absorber in a collector, energy is trapped in two ways: first, the infrared radiation emitted by the absorbing surface is stopped by the glazing, with a portion re-radiated back toward the absorber, and thereby trapped. Second, the glazing also traps a layer of still air next to the absorber and reduces the convective heat loss. This behavior of glazing is called the "greenhouse effect" and is used in most solar collectors.

E. Collector Orientation and Tilt

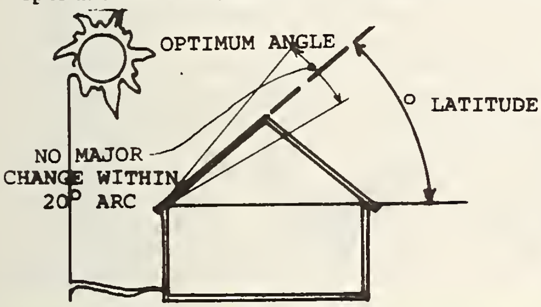
Solar collectors must be oriented and tilted within prescribed limits to receive the optimum level of solar radiation for system operation and performance.



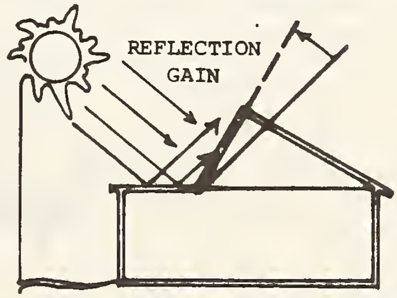
1. COLLECTOR TILT FOR HEATING The optimum collector tilt for heating is usually equal to the site latitude plus 10 to 15 degrees. Variations of 10 degrees on either side of this optimum are acceptable.



2. COLLECTOR TILT FOR HEATING AND COOLING The optimum collector tilt for heating and cooling is usually equal to site latitude plus 5 degrees. Variations of 10 degrees on either side of the optimum are acceptable.

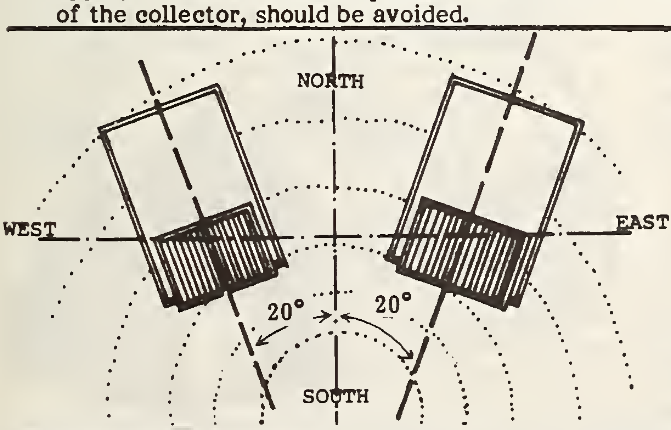


3. COLLECTOR TILT FOR DOMESTIC HOT WATER The optimum collector tilt for domestic water heating alone is usually equal to the site latitude. Again, variations of 10 degrees on either side of the optimum are acceptable.



4. MODIFICATION OF OPTIMUM COLLECTOR TILT A greater gain in solar radiation collection sometimes may be achieved by tilting the collector away from the optimum in order to capture radiation reflected from adjacent ground or building surfaces. The corresponding reduction of radiation directly striking the collector, due to non-optimum tilt, should be recognized when considering this option.

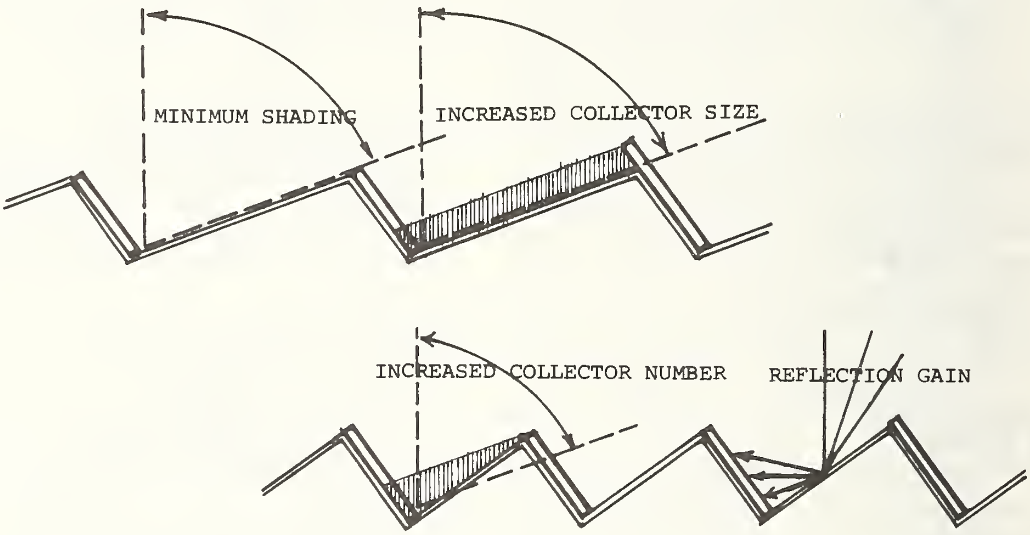
5. SNOWFALL CONSIDERATION The snowfall characteristics of an area may influence the appropriateness of these optimum collector tilts. Snow buildup on the collector, or drifting in front of the collector, should be avoided.



COLLECTOR ORIENTATION A collector orientation of 20 degrees to either side of true South is acceptable. However, local climate and collector type may influence the choice between East or West deviations.

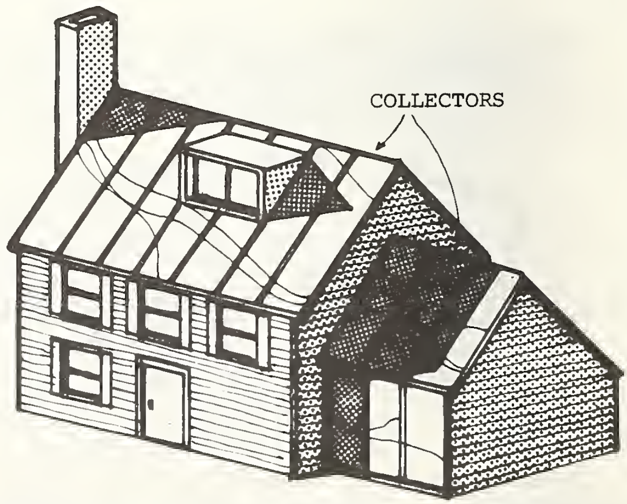
F. Shading of Collector

Another issue related to both collector orientation and tilt is shading. Solar collectors should be located on the building or site so that unwanted shading of the collectors by adjacent structures, landscaping or building elements does not occur. In addition, considerations for avoiding shading of the collector by other collectors should also be made. Collector shading by elements surrounding the site may be addressed by considering the "solar window" concept.



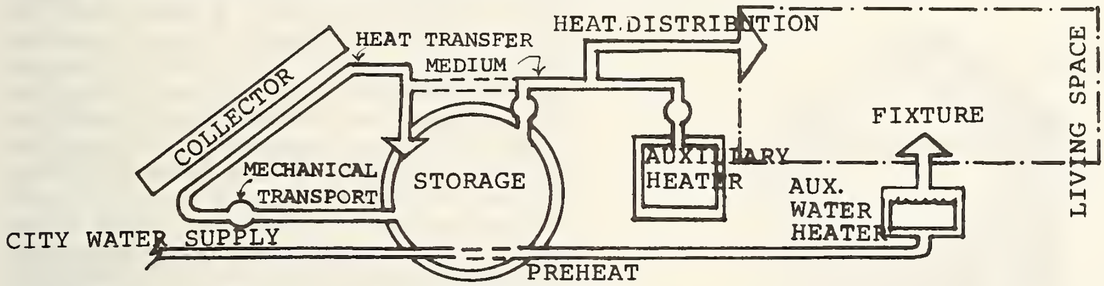
1. SELF-SHADING OF COLLECTOR Avoiding all shelf-shading for a bank of parallel collectors during useful collection hours (9 AM and 3 PM) results in designing for the lowest angle of incidence with large spaces between collectors. It may be desirable therefore to allow some self-shading at the end of solar collection hours, in order to increase collector size or to design a closer spacing of collectors, thus increasing solar collection area. By making the collector's back slope reflective, one could increase the amount of solar radiation striking the adjacent collector, thus negating some of the shading loss.

2. SHADING OF COLLECTOR BY BUILDING ELEMENTS Chimneys, parapets, fire walls, dormers, and other building elements can cast shadows on adjacent roof-mounted solar collectors, as well as on vertical wall collectors. The drawing to the right shows a house with a 45° south-facing collector at latitude 40° North. By mid-afternoon portions of the collector are shaded by the chimney, dormer, and the offset between the collector on the garage. Careful attention to the placement of building elements and to floor plan arrangement is required to assure that unwanted collector shading does not occur.



Solar Heating and Hot Water Systems:
Active Systems

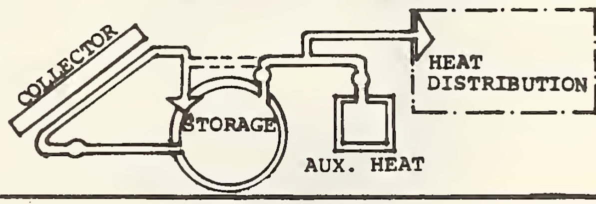
Active solar systems are characterized by collectors, thermal storage units and transfer media, in an assembly which requires additional mechanical energy to convert and transfer the solar energy into thermal energy. The following discussion of active solar systems serves as an introduction to a range of active concepts which have been constructed.



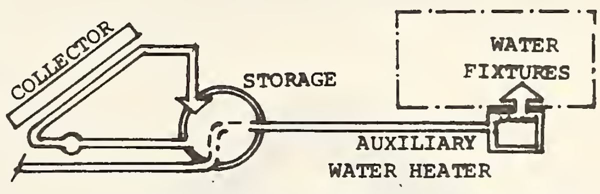
A. Heating and Domestic Hot Water Diagrams

In common use today is the combined solar heating and domestic hot water system. The system operates as follows: solar radiation is absorbed by a collector or series of collectors, and removed to storage in the form of thermal energy by a heat transfer medium. The heat is later removed from storage and distributed to the living spaces, again by a heat transfer medium, which may or may not be the same medium as that flowing through the collector. Circulation throughout the system is aided by pumps, blowers, or other medium moving devices. An auxiliary heating system should be available both to supplement the output supplied by the solar system and to provide for the total energy demand should the solar system become inoperative. Manual or automatic controls monitor both the solar and auxiliary system operation. In a solar heating and hot water combined system, the domestic water supply is preheated in the heat storage, and then passed through the conventional water heater before distribution.

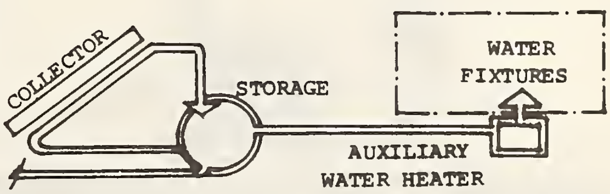
1. SOLAR HEATING SYSTEM: PROCESS DIAGRAM A space heating system alone can be developed by simply removing the domestic hot water preheating unit from the heat storage. The operation of the solar heating system is then the same as described above.



2. SOLAR DOMESTIC HOT WATER SYSTEM: PROCESS DIAGRAM 1 The combined system diagram can be modified into a domestic hot water system alone by eliminating the heating distribution and the auxiliary heating unit, and also reducing the size of the storage tank. Only the domestic water supply would then pass through the heat storage, preheating the hot water supply, enroute to a conventional water heater.

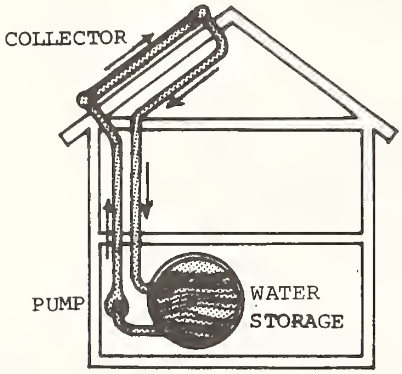


3. SOLAR DOMESTIC HOT WATER SYSTEM: PROCESS DIAGRAM 2 Another method of preheating the domestic hot water involves passing the potable water supply itself through the collectors. The heated water is stored in the water storage tank until a demand is initiated. An auxiliary heat source is usually present to boost the water temperature when preheat has been inadequate. The preheated water is either pumped from storage, or flows by supply pressure to the house.

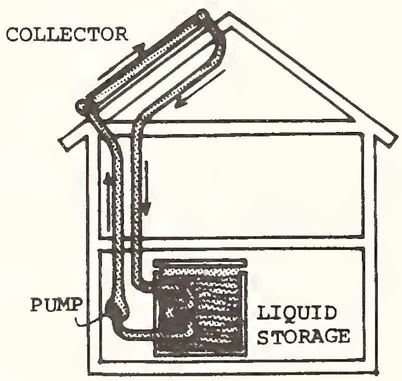


B. Collector - Storage

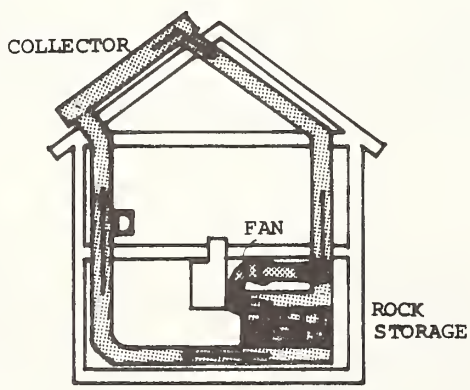
The removal of heat from the collector and its placement in heat storage involves the circulation of a heat transfer medium in a transport loop. Several collector-storage conditions are shown below.



1. OPEN CIRCUIT LIQUID COLLECTOR In this system, storage water itself, treated as necessary to prevent corrosion, is drawn from the bottom of storage , pumped through the collector and then returned to the top of storage. The circulating water, which runs through, on top of or under the absorber plate, is distributed to the absorber by a manifold at the top of the collector, or pumped up from below the collector through tubes attached to or integral with the absorber plate. When the system is not running, air is allowed to enter into the collector and piping, and the water drains into storage. In open circuit collectors, storage is at atmospheric pressure, a condition that should be considered in the design of the distribution system.



2. CLOSED CIRCUIT LIQUID COLLECTOR In this system, a heat transfer liquid — such as treated water, anti-freeze solution or another liquid — is pumped through the collector and then through a heat exchanger in storage and back to the collector, in a closed loop. In this system of separate transfer and storage mediums, the storage may be pressurized. The loop may remain filled with fluid, and therefore must be protected from freezing, or may be drained and replaced with pressurized inert gas.



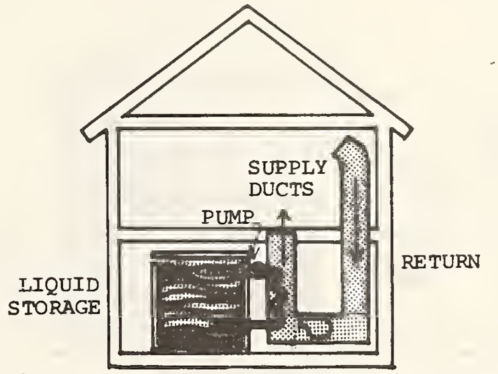
3. AIR COLLECTOR Although many arrangements of air collector-rock storage and warm-air distribution systems are possible, the one diagrammed is typical of the most popular system in use. Air from the cold end of the rock storage bin is pumped through the collector, gaining heat, and returned to the hot end of storage.

Warm air distribution systems are usually used with air collectors to enable direct heating from the collector. In this case, the dampers must be adjusted to supply heat directly to the house, returning air to the collector, thereby bypassing storage. (See diagram page C3.)

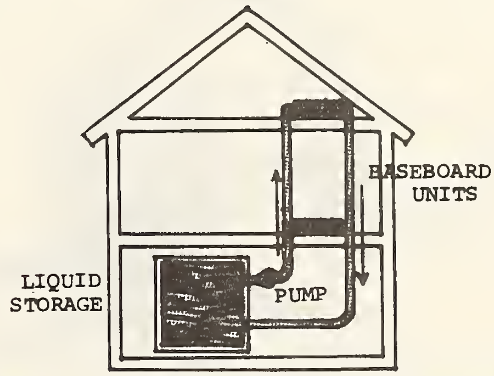
C. Storage-Distribution Diagrams

Heat is removed from storage and circulated to the house by the distribution component. There are numerous ways this storage–distribution function can be performed, and in numerous combinations with the preceding collector–storage circuits. Six typical storage–distribution methods are diagrammed.

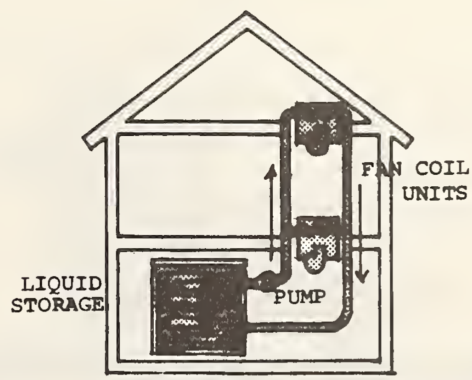
1. WARM AIR DISTRIBUTION - HOT WATER COIL IN DUCT A warm-air distribution system can be used with liquid heat storage, by pumping the heated storage medium through a suitably sized heat exchange coil in the main supply duct of the distribution system.

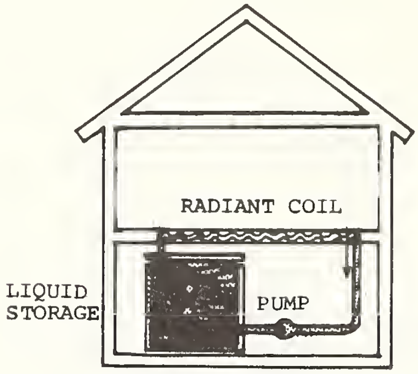


2. HYDRONIC DISTRIBUTION In a hydronic system, with a pressurized storage, liquid from storage is pumped directly through standard baseboard convector units. Because of the relatively low temperatures that usually occur in solar systems during winter conditions, the size of baseboard units, and possibly the piping may change from ordinary hydronic systems.

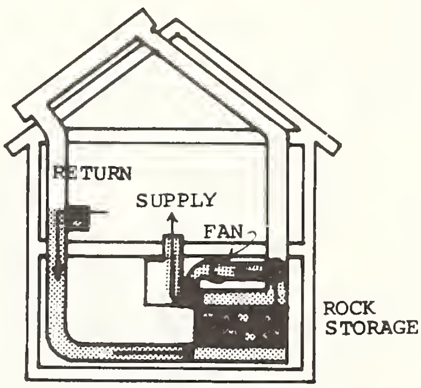


3. INDIVIDUAL FAN-COIL UNIT DISTRIBUTION When storage is not pressurized, in a fan coil distribution system (as well as a hydronic system), a secondary, heat transfer fluid is often circulated in a closed loop to prevent air binding. This fluid is pumped through storage to individual fan-coil units located throughout the dwelling for heat distribution. The design and sizing considerations are similar to those for ordinary hydronic distribution.

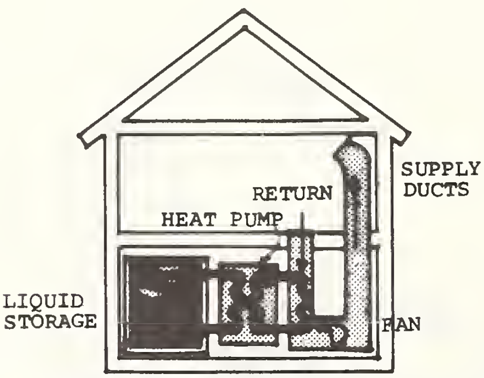




4. RADIANT HEAT DISTRIBUTION In a radiant heating system, with a non-pressurized storage, a secondary heat transfer fluid is circulated in a closed loop from heat storage to coils or panels located in the floor, walls and or ceiling of the living space. Besides the liquid temperature, the size and spacing of the coils is critical for effective radiant heat distribution.



5. WARM AIR DISTRIBUTION FROM ROCK STORAGE For an air-collector system employing rock storage, it is advantageous to employ the natural high level of temperature stratification in storage and distribute air to the living space from the hottest section of storage. As diagrammed, this will require reversing the flow of air through storage relative to the collection cycle. The most common method for doing this is diagrammed. Using the same fan that supplies the collector along with two automatic dampers, the direction of air flow is reversed from storage, forcing air in a house loop to return, thereby bypassing the collector ducts.

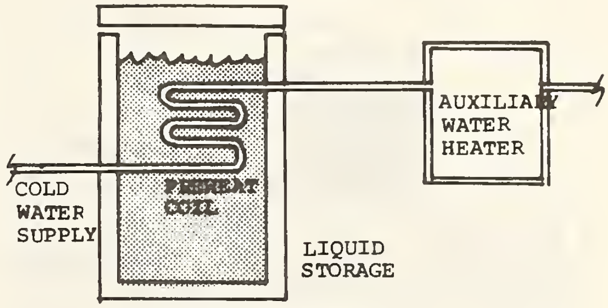


6. HEAT PUMP ASSISTED DISTRIBUTION Either air or liquid collector-storage systems can be used as the source of thermal energy for a heat pump distribution system. As diagrammed, liquid from storage is circulated through a heat exchanger in the heat pump unit, and heat is transferred to the heat pump's working fluid. By means of its compression cycle, the heat pump further elevates the working fluid temperature and it functions as the auxiliary heat source. This high temperature fluid then transfers heat through another exchanger to either an air or hydronic distribution system. The heat pump may also be used in parallel with thermal energy storage to remove heat from the outside air when storage is depleted.

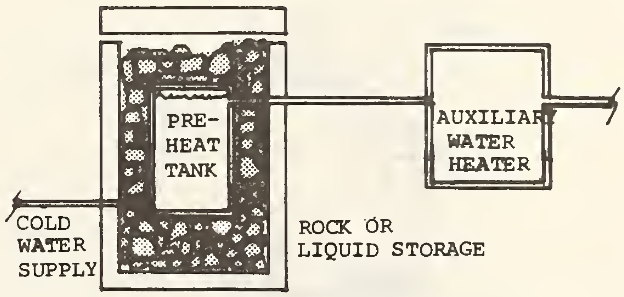
D. Domestic Hot Water Preheating

Domestic hot water can be preheated either by circulating the potable water supply itself through the collector, or by passing the supply line through storage enroute to a conventional water heater. Three storage related preheat systems are shown below.

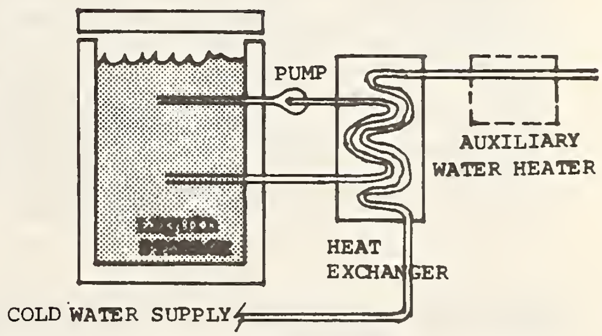
1. PREHEAT COIL IN STORAGE Water is passed through a suitably sized coil placed in storage enroute to the conventional water heater. Unless the preheat coil has a protective double-wall construction, this method can only be used for solar systems employing non-toxic storage media.



2. PREHEAT TANK IN STORAGE In this system, the domestic hot water preheat tank is located within the heat storage. The water supply passes through storage to the preheat tank where it is heated and stored, and later piped to a conventional water heater as needed. A protective double-wall construction again will be necessary unless a non-toxic storage medium is used.

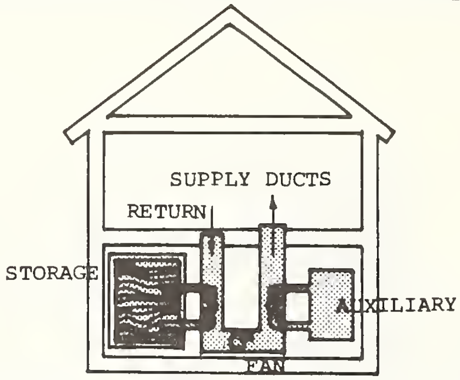


3. PREHEAT OUTSIDE OF STORAGE In this preheat method, the heat transfer liquid in storage is pumped through a separate heat exchanger to be used for domestic hot water preheating. This separate heat exchanger could be the conventional water heater itself. However, if the liquid from storage is toxic, the required separation of liquids is achieved by the use of a double-wall exchanger, as diagrammed, in which the water supply simply passes through enroute to the conventional water heater.

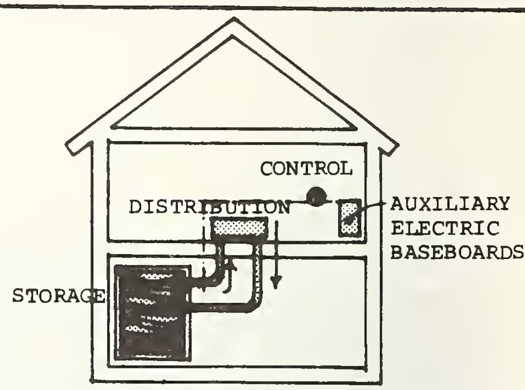


E. Auxiliary Energy Diagrams

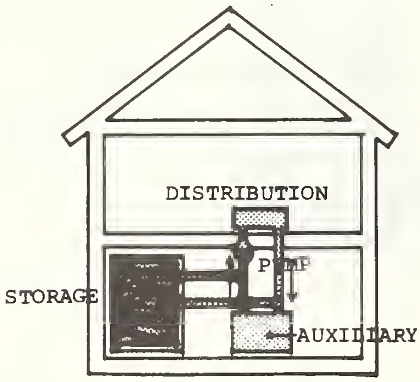
The provision of auxiliary energy to the dwelling is needed when the solar heating system becomes inoperative or cannot meet the dwelling's total energy demand. The auxiliary heating component may operate independently or in conjunction with the solar storage and distribution systems. The control of solar and auxiliary system operation becomes an important consideration for the effectiveness of both. Four possible combinations are shown below.



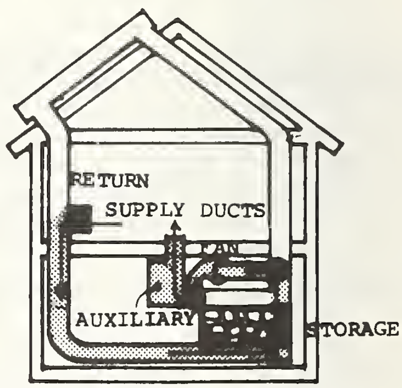
1. AUXILIARY HEAT COILS IN AIR DISTRIBUTION SUPPLY DUCT Two heat exchange coils — one from solar storage and one from the auxiliary unit — are located in the primary distribution supply duct. Depending on the temperature in storage, the auxiliary energy system may provide a full or partial temperature boost to the supply of air. The need for auxiliary energy is determined typically by a two contact room thermostat.



2. AUXILIARY WITH SEPARATE DISTRIBUTION The auxiliary energy system may be a totally separate component not integrated with solar storage or distribution. This may involve a totally separate distribution network, such as individual electric baseboard units placed in the dwelling in locations and numbers as required. The two separate heating systems, however, are linked by temperature controls.



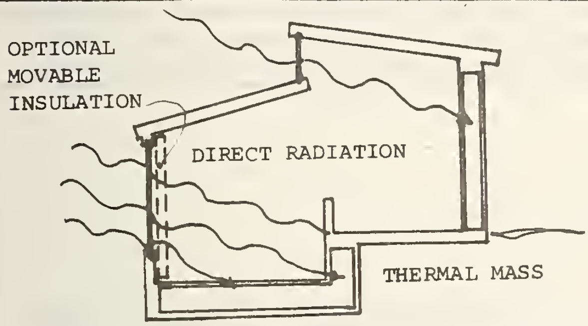
3. AUXILIARY HEATING WITH COMBINED DISTRIBUTION In this system, the auxiliary energy source is located between the storage and distribution components. In this way, an integrated control component monitors whether heat from storage or heat from the auxiliary source is in use. Pumps and valves located at the connection points between the systems regulate the auxiliary energy supply use, and prevents the auxiliary from heating storage.



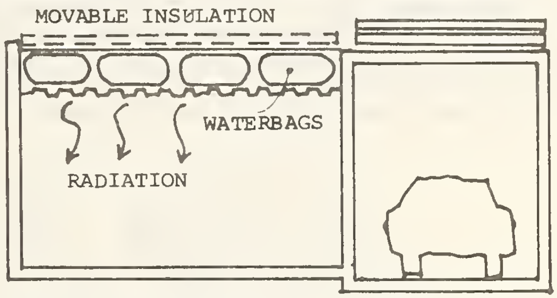
4. AUXILIARY HEATING WITH AIR COLLECTION-DISTRIBUTION In this system, the auxiliary heat unit is located within the distribution air ducts downstream from the system's fan or blower. In this way, the auxiliary subsystem provides an energy boost to the heated air coming either: 1) from storage, or 2) directly from the collector. The auxiliary unit may be a coil in the duct, containing boiler-heated water, or an electric resistance element, or it may be a furnace. The auxiliary and solar system operation is maintained and monitored by an integrated control component.

Solar Heating and Hot Water Systems: Passive Systems

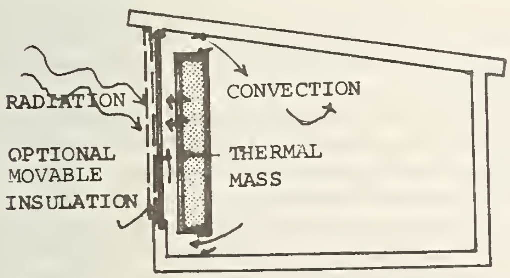
Passive solar systems are characterized by the use of the sun's energy alone for the transfer of thermal energy throughout the system. Four passive systems are discussed below — three space heating and one domestic hot water preheating system. There are innumerable other concepts, but the following will serve as an introduction to passive solar systems.



SPACE AND BUILDING-SURFACE HEATING This concept relies on a large transparent surface for the southern exposure, to increase heat gain directly into the building — thus heating the space. To avoid daytime overheating, an adequate area and thickness of a thermal mass, such as heavy masonry, should be used on the floors or walls to absorb heat during the day and release it to the space after the sun has set. Insulation devices should also be available to regulate daytime solar exposure and to minimize nighttime heat loss.

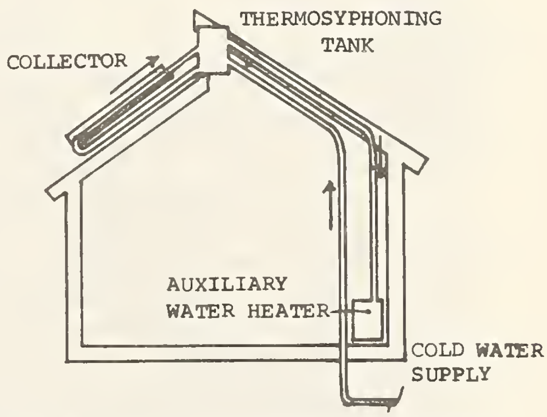


LIQUID ROOF MASS This concept is similar to the previous passive system except that the thermal mass — water — is now located in containers above the living space. In some climates, both heating and cooling can be provided by this system. Like the previous concept, proper control must be maintained over the heat exchange process. This can be accomplished by the use of movable insulating panels to expose or cover the containers, or by filling and draining them according to heating or cooling demand.



COMBINED COLLECTOR-STORAGE-DISTRIBUTION WALL This passive concept relies on the solar exposure of a south facing thermal mass (containerized water, masonry or concrete) located behind a transparent surface and a separating air space. The thermal mass acts as the collector, storage, and distribution components. Solar radiation collected and stored in the thermal mass is distributed to the space by: 1) radiation, 2) convection, and 3) conduction.

When collection ceases due to lack of solar radiation, it is advantageous to prevent heat loss through the transparent surface to the outside, by an insulating device. In this example air valves or dampers allow air to circulate across the hot face of the storage mass for convective heat transfer.

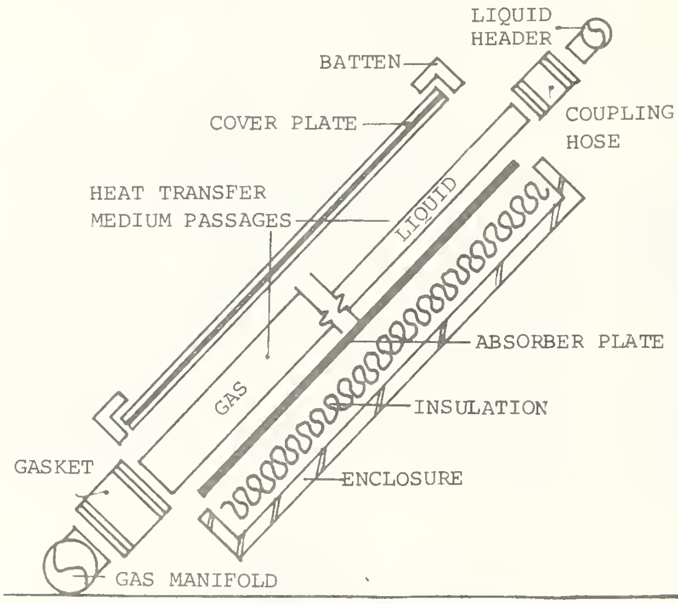


THERMOSYPHONING SYSTEM: DOMESTIC HOT WATER PREHEATING This passive concept utilizes the natural upward movement of heated fluids for the collection and storage of domestic hot water. The cold water supply is pressure fed to the bottom of a storage tank located above a solar collector. Exposure of the collector to solar radiation allows the cold water to circulate by convection — through the collector -- from bottom to top -- and, once heated back into storage. The heated water is stored in the tank until a demand is initiated; then water is drawn off the top and fed directly to the dwelling or to a conventional water heater.

Solar Heating and Hot Water Systems: Component Description

A solar heating and domestic hot water system is composed of numerous individual parts and pieces including: collectors; storage; a distribution network with ducts and/or pipes, pumps and/or blowers, valves and/or dampers; fixed or movable insulation; a system of manual or automatic controls; and possibly heat exchangers, expansion tanks and filters. These parts are assembled in a variety of combinations depending on function, component compatibility, climatic conditions, required performance, site characteristics and architectural requirements, to form a solar heating and/or domestic hot water system. Some components that are unique to the collector system or that are used in an unconventional manner are briefly illustrated and discussed in the next few pages.

A. Flat-Plate Collectors: An Exploded View

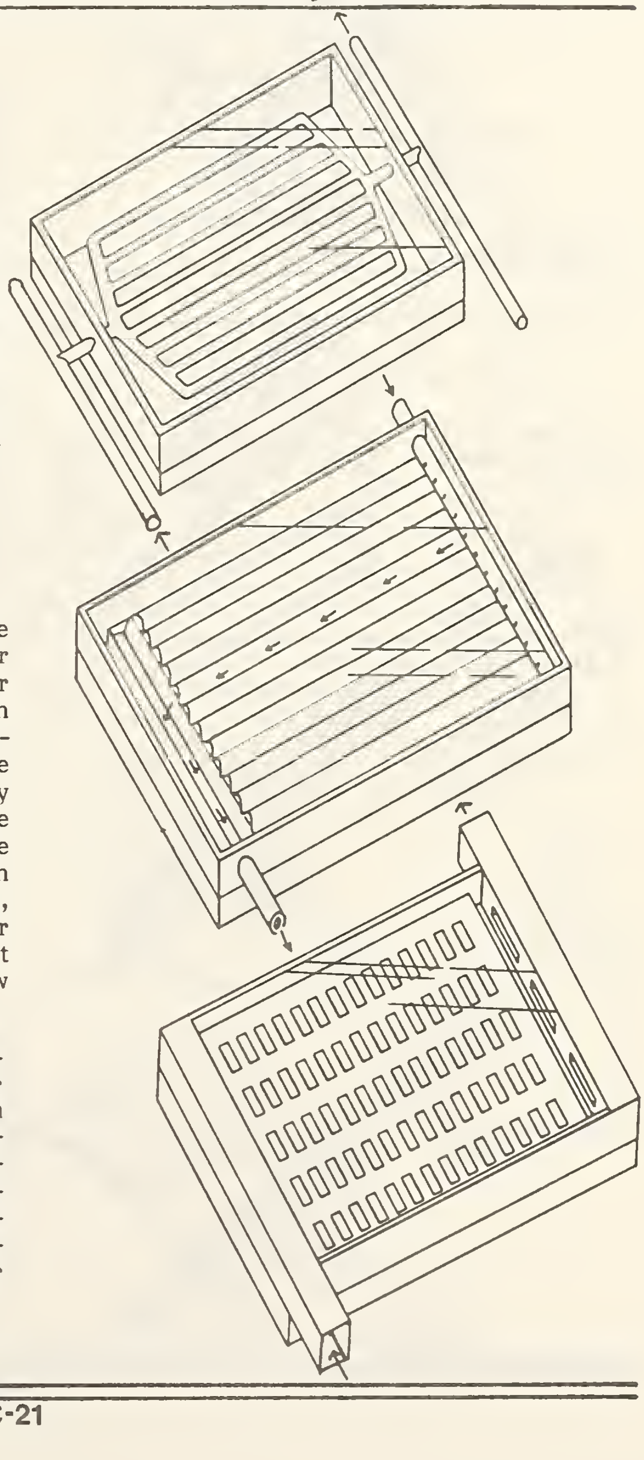


The flat-plate collector is a common solar collection device used for space heating and domestic water heating. The collector may be designed to use either gas (generally air) or liquid (usually treated water) as the heat transfer medium. Regardless of the medium used, most flat-plate collectors consist of the same general components, as illustrated below.

1. BATTEN Battens serve to hold down the cover plate(s) and provide a weather tight seal between the enclosure and the cover.
2. COVER PLATE The cover plate usually consists of one or more layers of glass or plastic film or combinations thereof. The cover plate is separated from the absorber plate to reduce reradiation and to create an air space, which traps heat by reducing convective losses. This space between the cover and absorber can be evacuated to further reduce convective losses.
3. HEAT TRANSFER FLUID PASSAGE Tubes or fins are attached above, below or integral with an absorber plate for the purpose of transferring thermal energy from the absorber plate to a heat transfer medium. The largest variation in flat-plate collector design occurs with this component and its combination with the absorber plate. Tube on plate, integral tube and sheet, open channel flow, corrugated sheets, deformed sheets, extruded sheets and finned tubes are some of the techniques used for liquid collectors. Air collectors employ such configurations as gauze or screens, overlapping plates, corrugated sheets, and finned plates and tubes.
4. ABSORBER PLATE Since the absorber plate must have a good thermal bond with the fluid passages, an absorber plate integral with the heat transfer media passages is common. The absorber plate is usually metallic, and normally treated with a surface coating which improves absorptivity. Black or dark paints or selective coatings are used for this purpose. The design of this passage and plate combination is of significance in a solar system's effectiveness.
5. INSULATION Insulation is employed to reduce heat loss through the back of the collector. The insulation must be suitable for the high temperature that may occur under no-flow or dry-plate conditions, or even normal collection operation. Thermal decomposition and outgassing of the insulation must be considered
6. ENCLOSURE The enclosure is a container for all the above components. The assembly is usually weatherproof. Preventing dust, wind and water, from coming in contact with the cover plate and insulation, is essential to maintaining collector performance.

B. Flat-Plate Collectors

A flat-plate collector generally consists of an absorbing plate, often metallic; which may be flat, corrugated or grooved; coated black to increase absorption of solar radiation; insulated on its backside to minimize heat loss from the plate; and covered with a transparent cover plate to trap heat within the collector and reduce cooling of the absorber plate. The captured solar heat is then removed from the absorber by means of a working fluid, generally air or treated water, which is heated as it passes through or over the absorbing plate. Although there are innumerable variants, three types of flat-plate collectors will be discussed here as an introductory classification.



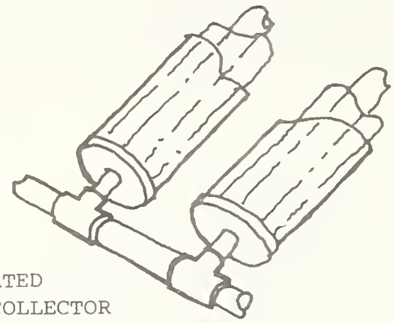
1. FLUID TUBE AND PLATE COLLECTOR Most flat-plate collectors in use today employ water, oil or an antifreeze solution as the heat transfer medium. The liquid is pumped through fluid passage ways attached to or integral with the absorber plate. There it is solar heated before being circulated through storage in either a closed or open circuit. Freeze protection and prevention of corrosion and leaks require special consideration.

2. TRICKLING WATER COLLECTOR This type of collector uses corrugated metal panels for the exposed circulation of the heat transfer medium. The transfer medium "trickles" down the channels from a manifold or spray distribution at the top to a trough to the bottom of the collector. The heated water then flows by gravity to the storage tank. Because of the heat transfer fluid's exposure to the atmosphere in this collector, it is always used with the open circuit collector–storage system. Therefore, when collection is not occurring, the transfer medium drains back into storage. Efficient operation of this collector is limited to low temperatures because of evaporation effects.

3. FLAT-PLATE AIR COLLECTOR Air collectors circulate air or other gases through or over the absorber plate, returning heated air through the ducts to storage or the living space. Compared with liquid collectors, leakage, maintenance, and freeze protection problems are minimal. However, air collectors do require relatively large ducts for their heat transfer medium and often require more mechanical transfer energy per unit of solar energy delivered.

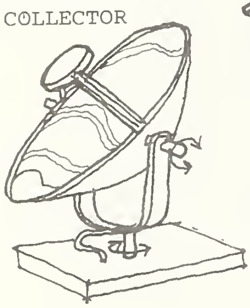
C. High Temperature Collectors

For heating and cooling systems requiring higher operating temperatures, evacuated tube or concentrating collectors are available. Depending upon the optical and thermal insulation design, the performance of these systems is influenced by the ratio of the diffuse to total available solar radiation.

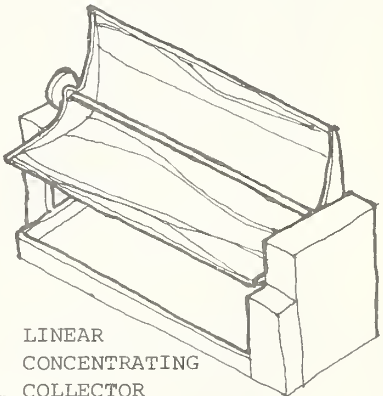


EVACUATED TUBE COLLECTOR

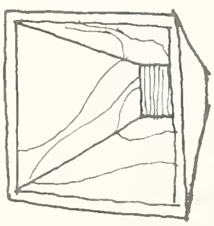
EVACUATED TUBE COLLECTOR These collectors employ a vacuum tube to contain the absorber. The vacuum serves to reduce convective heat losses allowing higher working temperatures and efficiencies. The absorber consists of metal or glass tubes or fins which transfers captured thermal energy to the heat transfer medium (which may be a liquid or gas). The basic modes of heat transfer within the collector are analogous to those illustrated for flat-plate collection. No insulation is required for the tubular collector itself; however, the manifold and connecting piping require insulation similar to flat-plate units. Both direct and diffuse radiation can be collected.



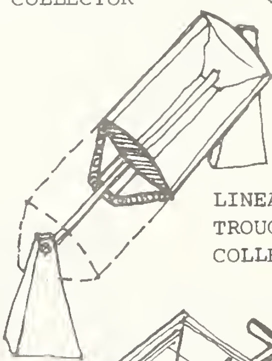
CIRCULAR CONCENTRATING COLLECTOR



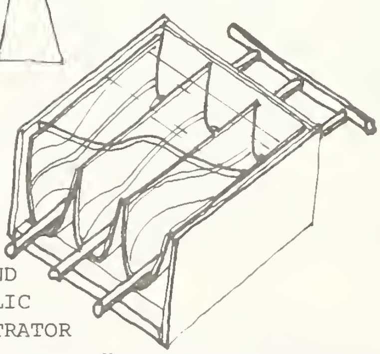
LINEAR CONCENTRATING COLLECTOR



SHED LINEAR FOCUSING COLLECTOR



LINEAR TROUGH COLLECTOR



COMPOUND PARABOLIC CONCENTRATOR

CONCENTRATING COLLECTORS Concentrating collectors (also known as focussing collectors) employ curved and multiple point target reflectors to focus radiation on a small area. The area where solar radiation is absorbed can be a point -- the focal point -- or a line -- the focal axis.

A concentrating collector consists of three basic components: the reflector and/or lens, the absorber, and the housing which maintains alignment and contains insulation for the absorber and connecting piping. Often a mechanism is required to allow the collector/reflector or the absorber to follow or track the sun's movement across the sky. Maintenance of the reflective surface, particularly in dusty or air polluted areas, and of the tracking mechanism are important considerations for collector performance.

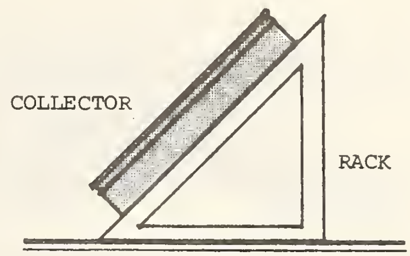
Concentrating collectors are usually best suited for areas with clear skies where most solar radiation is direct. The high temperatures generated may make concentrating collectors particularly viable with solar cooling systems.

As with flat-plate collectors, numerous variations of concentrating collectors have been developed including linear and circular concentrators, lens focussing collectors, collectors with directional and non-directional focussing and tube concentrators. A number of concentrating configurations are shown to the left.

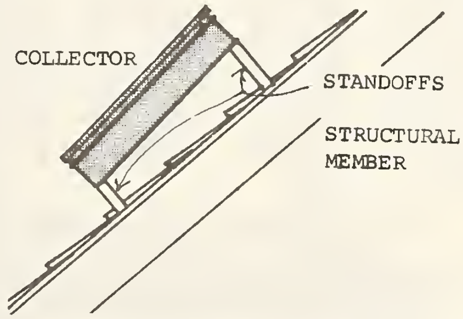
D. Collector Mounting

Flat-plate collectors are generally mounted on the ground or on a building in a fixed position at prescribed angles of solar exposure — angles which vary according to the geographic location, collector type, and the use of the absorbed heat. Flat-plate collectors may be mounted in four general ways as illustrated below.

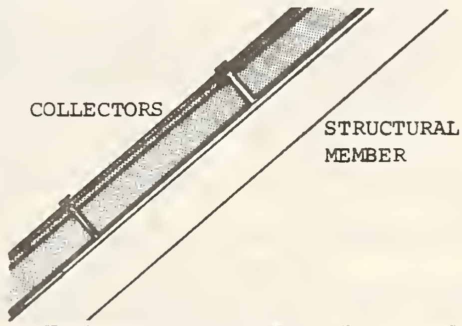
1. RACK MOUNTING Collectors can be mounted at the prescribed angle on a structural frame located on the ground or attached to the building. The structural connection between the collector and the frame and the frame and the building or site must be adequate to resist any impact loads such as wind.



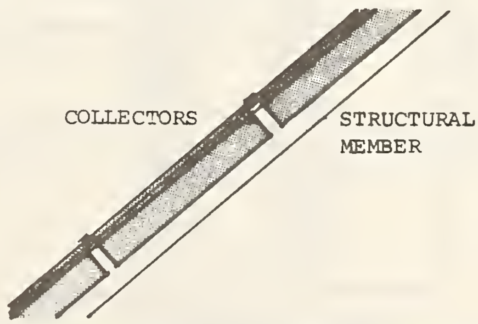
2. STAND-OFF MOUNTING Elements that separate the collector from the finished roof surface are known as stand-offs. They allow air and rain water to pass under the collector thus minimizing problems of mildew and leakage. The stand-offs must also have adequate structural properties. Stand-offs are often used to support collectors at an angle other than that of the roof to optimize collector tilt.



3. DIRECT MOUNTING Collectors can be mounted directly on the roof surface. Generally, the collectors are placed on a water-proof membrane on top of the roof sheathing. The finished roof surface, together with the necessary collector structural attachments and flashing, are then built up around the collector. A weatherproof seal between the collector and the roof must be maintained, or leakage, mildew, and rotting may occur.

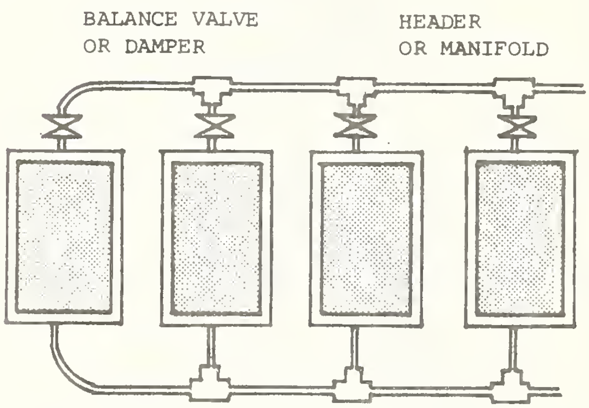


4. INTEGRAL MOUNTING Unlike the previous three component collectors which can be applied or mounted separately, integral mounting places the collector within the roof construction itself. Thus, the collector is attached to and supported by the structural framing members. In addition, the top of the collector serves as the finished roof surface. Weather tightness is again crucial to avoid problems of water damage and mildew. This method of mounting is frequently used for site built collectors.

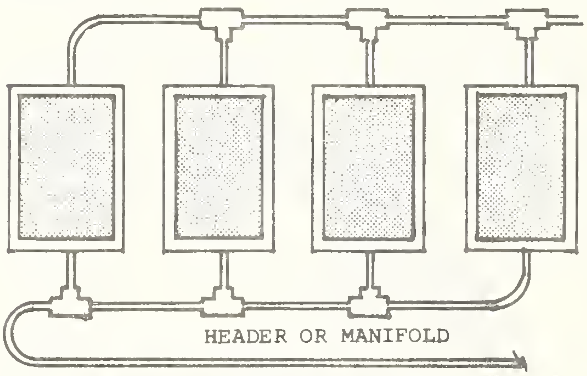


E. Multiple Collectors

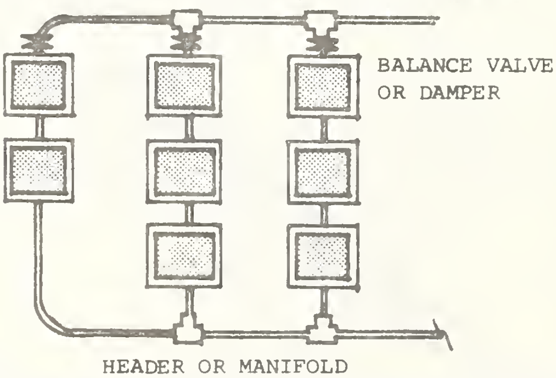
In active systems, a building's solar collector area is generally composed of individual collector units or panels arranged to operate as a single system. The arrangement and relationship of one collector unit to another, sometimes known as collector ganging, is extremely important for effective solar collection and efficient system operation. Three basic multiple collector arrays are shown below.



1. PARALLEL FLOW - DIRECT RETURN A direct return distribution circuit circulates the transfer medium from the bottom of the collector to a return header or manifold at the top. This arrangement may cause severe operating problems by allowing wide temperature variations from collector to collector due to flow imbalance. Although the pressure drops across each collector are essentially the same and at the same flow rate, high pressure drops occurring along the supply/return header or manifold will cause flow imbalance. This problem can be reduced by sizing each header for minimum pressure drop, although this may be prohibitive because of economic and space limitations. Even manual balancing valves may be difficult to adjust, so automatic devices or orifices might be required for efficient system performance. Provisions must also be made to measure the pressure drop in order to adjust the flow rate to prevent collectors closer to the circulating pump from exceeding design flow rates and those farther away from receiving less.



2. PARALLEL FLOW - REVERSE RETURN Reverse return piping systems are considered preferable to direct return for their ease of balancing. Because the total length of supply piping and return piping serving each collector is the same and the pressure drop across each collector is equal, the pressure drop across each manifold are also theoretically equal. The major advantage of reverse return piping is that balancing is seldom required since flow through each collector is the same. Provisions for flow balancing may still be required in some reverse return piping systems depending on overall size of the collector array and type of collector.

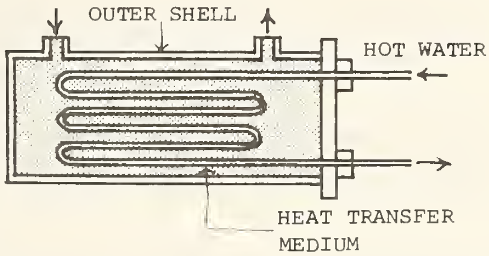


3. SERIES FLOW Series flow is often used in large planar arrays, to reduce the amount of piping required, by allowing several collector assemblies to be served by the same supply return headers or manifolds. Series flow can also be employed to increase the output temperature of the collector system or to allow the placement of collectors on non-rectangular surfaces. Either direct or reverse return distribution circuits can be employed, but unless each collector branch has the same number of collectors, the reverse return system has no advantage over direct return — each would require flow balancing.

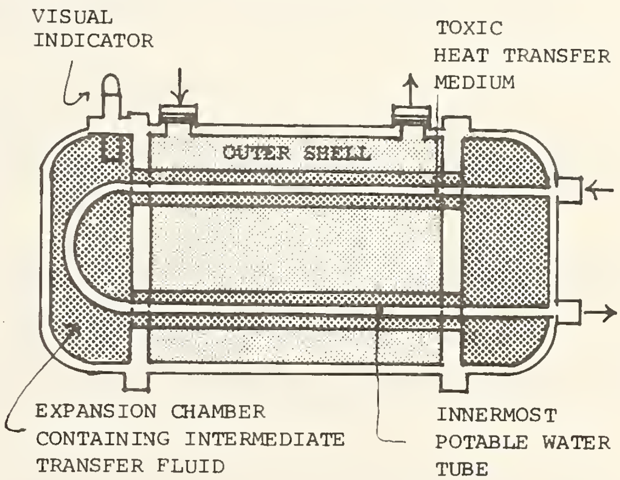
F. Heat Exchangers

A heat exchanger is a device for transferring thermal energy from one fluid to another. In some solar systems, a heat exchanger may be required between the transfer medium circulated through the collector and the storage medium or between the storage and the distribution medium. Three types of heat exchangers that are most commonly used for these purposes are illustrated below.

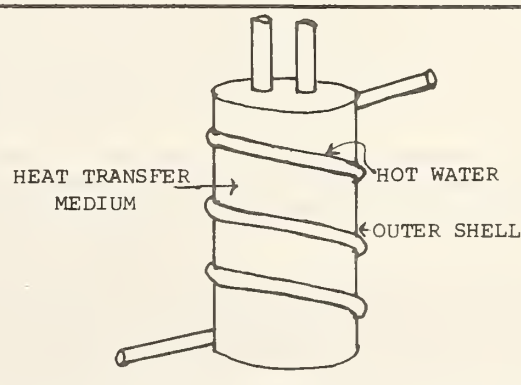
1. SHELL AND TUBE This type of heat exchanger is used to transfer heat from a circulating transfer medium to another medium used in storage or in distribution. Shell and tube heat exchangers consist of an outer casing or shell surrounding a bundle of tubes. The water to be heated is normally circulated in the tubes and the hot liquid is circulated in the shell. Tubes are usually metal such as steel, copper or stainless steel. A single shell and tube heat exchanger cannot be used for heat transfer from a toxic liquid to potable water because double separation is not provided and the toxic liquid may enter the potable water supply, in the case of tube failure.



2. SHELL AND DOUBLE TUBE This type of heat exchanger is similar to the previous one except that a secondary chamber is located within the shell to surround the potable water tube. The heated toxic liquid then circulates inside the shell but around this second tube. An intermediary non-toxic heat transfer liquid is then located between the two tube circuits. As the toxic heat transfer medium circulates through the shell, the intermediary liquid is heated, which in turn heats the potable water supply circulating through the innermost tube. This heat exchanger can be equipped with a sight glass to detect leaks by a change in color - toxic liquid often contains a dye - or by a change in the liquid level in the intermediary chamber, which would indicate a failure in either the outer shell or intermediary tube lining.



3. DOUBLE WALL Another method of providing a double separation between the transfer medium and the potable water supply consists of tubing or a plate coil wrapped around and bonded to a tank. The potable water is heated as it circulates through the coil or through the tank. When this method is used, the tubing coil must be adequately insulated to reduce heat losses.



APPENDIX D

DEFINITIONS

General: Abbreviations, terms, phrases, and words and their derivatives used in these Intermediate Standards for solar application shall have the meanings given in this Appendix. The terms defined herein apply only for The Department of Housing and Urban Development (HUD) purposes and may differ in some respects from definitions prepared for building codes or other purposes. Wherever possible, the meaning in common use in the residential construction field is used.

Active Solar System: An assembly of collectors, thermal storage device(s), and transfer liquid which converts solar energy into thermal energy, and in which energy in addition to solar is used to accomplish the transfer of thermal energy.

Air Gap: An air gap in a potable water distribution system is the unobstructed vertical distance through the free atmosphere between the lowest opening from any pipe or faucet supplying water to a tank, plumbing fixture, or other device and the flood level rim of the receptacle. (NSPC)*

Auxiliary Energy Subsystem: Equipment utilizing energy other than solar both to supplement the output provided by the solar energy system as required by the design conditions, and to provide full energy backup requirements during periods when the solar H, or DHW systems are inoperable.

Backflow: The unintentional reversal of flow in a potable water distribution system which may result in the transport of foreign materials or substances into the other branches of the distribution system. (NBS)

Backflow Preventer: A device or means to prevent backflow.

Back Pressure: Pressure created by any means in the water distribution system on the premises, which by being in excess of the pressure in the water supply main could cause backflow. (NBS)

Back Siphonage: The backflow of possibly contaminated water into the potable water supply system as a result of the pressure in the potable water system becoming unintentionally less than the atmospheric pressure in the plumbing fixtures, pools, tanks, or vats that may be connected to the potable water distribution piping. (NBS)

Chemical Compatibility: The ability of materials and components in contact with each other to resist mutual chemical degradation, such as that caused by electrolytic action or plasticizer migration.

Collector, Combined: The collector and storage are constructed and operated such that they functionally perform as one unit and the thermal performance of the individual components cannot be meaningfully measured.

Collector, Component: Collector that is not structurally integrated with the storage or building. The collector performance can be thermally characterized as an individual component with a moving heat transfer fluid.

Collector Efficiency (instantaneous): The ratio of the amount of energy removed by the heat transfer fluid per unit of aperture over a time period of 5 minutes or less to the total incident solar radiation on the collector for the same time period under steady state conditions (test method details described in ASHRAE 93).

Collector, Integral (Passive): The collector is constructed and operated as part of the building structure and heating system. The thermal performance is considered a part of the building heating load and solar energy provides a significant fraction of the building heat requirements.

* Abbreviations in parentheses indicate the sources of the definitions used here. (See Appendices E and F)

Collector Subsystem: The assembly used for absorbing solar radiation, converting it into useful thermal energy, and transferring the thermal energy to a heat transfer fluid.

Components: An individually distinguishable product that forms part of a more complex product (i.e., subsystem or system).

Contaminants (hazardous): Materials (solids or liquids or gasses) which when added unintentionally (or intentionally) to the potable water supply cause it to be unfit for human or animal consumption. (ASSE 1013)

Control Subsystem: The assembly of devices and their electrical, pneumatic or hydraulic auxiliaries used to regulate the processes of collecting, transporting, storing, and utilizing energy in response to the thermal, safety, and health requirements of the building occupants.

Creep: A time-dependent deformation resulting from sustained loads which can be influenced by local environmental factors such as, thermal atmosphere and/or cycling, and solar radiation.

Cross Connection: Any physical connection or arrangement between two otherwise separate piping systems, one of which contains potable water and the other either water of unknown or questionable safety or steam, gas, chemicals, or other substances whereby there may be a flow from one system to the other, the direction of flow depending on the pressure differential between the two systems.

Design Life: The period of time during which an H, and DHW system is expected to perform its intended function without requiring major maintenance or replacement.

DHW: Domestic hot water system.

DWV: Drain, Waste, Vent.

Emittance: The ratio of the radiant energy emitted by a body to the energy emitted by a black body at the same temperature.

Energy Transport Subsystem: That portion of the H, and DHW systems which contains heat transfer fluids and transports energy throughout the system.

Failure (structural): Failure of a structure or any structural element is defined as one of the following:

(a) Sudden, locally-increased curvature, major spalling, or structural collapse.

(b) The inability of the structure to resist a further increase in load.

(c) Structural deflections under design loads that cause significant performance degradation of the component or subsystem.

Flow Condition: The condition obtained when the heat transfer fluid is flowing through the collector array under normal operating conditions.

H: Heating system.

Heat Capacity: The amount of heat necessary to raise the temperature of a given mass one degree.

Heat Transfer Medium: A medium, liquid, or air or solid, which is used to transport thermal energy.

Laminated Glass: Consists of two or more sheets of glass held together by an intervening layer or layers of plastic material.

MAP: Manual of acceptable Practices. A HUD Document providing information and guidance to assist in the use of the MPS.

Maximum "Flow" Temperature: The maximum temperature that will be obtained in a component when the heat transfer fluid is not flowing through the system.

Maximum Service Temperature: The maximum temperature to which a component will be exposed in actual service, either with or without the flow of heat transfer fluid.

Minimum Service Temperature: The minimum temperature to which a component will be exposed in actual service, either with or without the flow of heat transfer fluid.

MPS 4900.1: FHA "Minimum Property Standards For One and Two Family Dwellings."

MPS 4910.1: FHA "Minimum Property Standards For Multifamily Housing."

"No-Flow" Condition: That condition obtained when the heat transfer fluid is not flowing through the collector array due to shut-down or malfunction and the collector is exposed to the amount of solar radiation that it would receive under normal operating conditions.

Non-Potable Water: Water containing impurities in amounts sufficient to cause disease or harmful physiological effects and not conforming in its bacteriological and chemical quality to the requirements of the Public Health Service Drinking Water Standards or the regulations of the public health authority having jurisdiction.

Outgassing: The emission of gases by materials and components usually during exposure to elevated temperature or reduced pressure.

Passive Solar System: An assembly of natural and architectural components including collectors, thermal storage device(s) and tranfer fluid which converts solar energy into thermal energy in a controlled manner and in which no fans or pumps are used to accomplish the transfer of thermal energy. The prime elements in a passive solar system are usually some form of thermal capacitance and solar energy control.

Pitting: The process by which localized material loss is caused in materials or components by erosion or chemical decomposition.

Physical Compatibility: The ability of materials and components in contact with each other to resist degradation by physical actions such as differential thermal expansion.

Plasticizer migration: The process by which plasticizers used in plastics migrate within the specimen and either concentrate in a narrow boundary area or migrate to another material in connection with the specimen.

Potable Water: Water free from impurities present in amounts sufficient to cause disease or harmful physiological effects and conforming in its bacteriological and chemical quality to the requirements of the Public Health Service Drinking Water Standards or the regulations of the public health authority having jurisdiction.

Pphm: Parts per hundred million.

Premature Failure: Failure that occurs before the design lifetime.

Safety Glass: Glazing materials predominately inorganic in character which meet the appropriate requirements of the ANSI Standard and includes laminated glass, tempered glass and wired glass.

Safety Glazing Materials: Glazing materials so constructed, treated or combined with other materials as to minimize the likelihood of cutting and piercing injuries resulting from human contact with these glazing materials.

Significant (Deterioration Loss, etc.): Deterioration that either results in a decrease in performance greater than that allowed for in the design or in the creation of a hazard.

Solar Absorptance: The ratio of the amount of solar radiation absorbed by a surface to the amount of radiation incident on it (for terrestrial applications usually calculated for Air Mass 2 characteristics).

Solar Building: A building which utilizes solar energy by means of an active or passive solar system.

Solar Degradation: The process by which exposure to sunlight deteriorates the properties of materials and components.

Solar Energy: The photon energy originating from the sun's radiation in the wavelength region from 0.3 to 2.7 micrometers.

Solar Heating System: The complete assembly of subsystems and components necessary to convert solar energy into thermal energy for heating purposes in combination with auxiliary energy when required.

Solar Time: The hours of the day as reckoned by the apparent position of the sun. Solar noon is that instant on any day at which time the sun reaches its maximum altitude for that day. Solar time is very rarely the same as local standard time in any locality.

Storage Subsystem: The assembly used for storing thermal energy so that it can be used when required.

Subsystem: A major, separable, functional assembly of a system such as complete collector, or storage, assembly, etc.

System: The complete assembly necessary to supply heat and/or domestic hot water to the dwelling.

Thermal Energy: Heat possessed by a material resulting from the motion of molecules which can do work.

TLV, Threshold Limit Values: Threshold limit values refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. Threshold limit values refer to time-weighted concentrations for a 7 or 8-hour workday and 40-hour workweek.

Toxic Fluids: Gases or liquids which are poisonous, irritating and/or suffocating, as classified in the Hazardous Substances Act, Code of Federal Regulations, Title 16, Part 1500.

Transmittance: The ratio of the radiant flux transmitted through and emerging from a body to the total flux incident on it.

UV: Ultra-violet radiation, that part of the terrestrial solar spectrum between 0.3 and 0.4 micrometers.

Water Hammer: The term used to identify the hammering noises and severe shocks that may occur in pressurized water supply systems when flow is halted abruptly by the rapid closure of a valve or faucet (NBS).

Water Hammer Arrester: A manufactured device, other than an air chamber, containing a permanently sealed cushion of gas or air designed to provide protection against excessive shock pressure without maintenance.

97 1/2% Winter Design Temperature: The outdoor air temperature will be lower than the stated values for not more than 65 hours per year (2 1/2% of the 2,160 hours in December, January and February).

APPENDIX E

REFERENCED STANDARDS

AASHTO H20-44 Standard Specification for Highway Bridges

ANSI A13.1 (1956) Scheme for the Identification of Piping Systems

ANSI A58.1 (1972) Building Code Requirements for Minimum Design Loads in Buildings and Other Structures

ANSI A112.1.1 (1971) Performance Requirements, Methods of Test for (ASSE 1001-1970) Pipe-Applied Atmospheric-Type Anti-Siphon Vacuum Breakers

ANSI A112.1.2 Air Gaps in Plumbing Systems (Reaffirmation and redesignation of A40.4-1942)

ANSI B9.1 (1971) Safety Code for Mechanical Refrigeration

ANSI B15.1 (1972) Safety Standard for Mechanical Power Transmission Apparatus

ANSI B16.18 (1972) Cast Bronze Solder Joint Pressure Fittings

ANSI B31.1, Section I (1973) Power Piping

ANSI B96.1 (1973) Specification for Welded Aluminum-Alloy Field-Erected Storage Tanks

ANSI B124.1 (1971) Safety Standard for Air Filter Units (UL 900-April 1971)

ANSI B137.1 (1971) Steel Underground Tanks for Flammable and Combustible Liquids (UL 58-July 1971)

ANSI B191.1 (1976) Standard for Heat Pumps (UL 559)

ANSI S2.8 (1972) Guide for Describing the Characteristics of Resilient Mountings

ANSI Z95.1 (1974) Oil Burning Equipment (NFPA 31-1972)

ANSI Z97.1 (1975) Performance Specifications and Methods of Test for Safety Glazing Material Used in Buildings

ARI Standard 240 (1975) Standard for Unitary Heat Pump Equipment

ARI Standard 260 (1967) Standard for Application, Installation, and Servicing of Unitary Systems

ARI Standard 410 Forced Circulation Air-Cooling and Air-Heating Coils

ARI Standard 760 (1975) Standard for Solenoid Valves for Use with Volatile Refrigerants and Water

ASHRAE 37-69 Method of Testing for Unitary Air Conditioning and Heat Pump Equipment

ASHRAE 55-74 (1974) Thermal Environmental Conditions for Human Occupancy

ASHRAE 90-75 (1975) Energy Conservation in New Building Design

ASHRAE 93-77 (1977) Methods of Testing Solar Collectors Based on Thermal Performance

ASHRAE 94-77 (1977) Method of Testing Thermal Storage Devices Based on Thermal Performance

ASHRAE Handbook of Fundamentals

ASME SA-53, Section VIII Boiler and Pressure Vessel Code

ASSE 1011 Performance Requirements for Hose Connection Vacuum Breakers

ASSE 1012 Performance Requirements for Backflow Preventers with Intermediate Atomospheric Vent

ASSE 1013 Performance Requirements for Reduced Pressure Principle Back Pressure Backflow Preventers

ASSE 1015 Performance Requirements for Double Check Valve Type Back Pressure Backflow Preventers

ASSE 1020 Performance Requirements for Vacuum Breakers, Anti-Siphon, Pressure Type

ASTM A53-75 Specification for Welded and Seamless Steel Pipe

ASTM C739-73, Section 10.4 (1973) Flame Resistance Permanency

ASTM D471-75 Test for Rubber Property - Effect of Liquids

ASTM D660-44 (1970) Evaluating Degree of Resistance to Checking of Exterior Paints

ASTM D661-44 (1975) Evaluating Degree of Resistance to Cracking of Exterior Paints

ASTM D714-56 (1974) Evaluating Degree of Blistering of Paints

ASTM D750-68 (1974) Recommended Practice for Operating Light-and-Weather Exposure Apparatus (Carbon-Arc Type) for Artificial Weather Testing of Rubber Compounds

ASTM D772-47 (1975) Evaluating Degree of Flaking (Scaling) of Exterior Paint

ASTM D822-60 (1973) Recommended Practice for Operating Light-and-Water-Exposure Apparatus (Carbon-Arc Type) for Testing Paint, Varnish, Lacquer, and Related Products

ASTM D1081-60 (1974) Test for Evaluating Pressure Sealing Properties of Rubber and Rubber-Like Materials

ASTM D1149-64 (1970) Test for Accelerated Ozone Cracking of Vulcanized Rubber

ASTM D1308-57 (1973) Test for Effect of Household Chemical on Clear and Pigmented Organic Finishes

ASTM D1384-70 Corrosion Test for Engine Antifreeze in Glassware

ASTM D2247-68 (1973) Testing Coated Metal Specimens at 100 Percent Relative Humidity

ASTM D2570-73 Simulated Service Corrosion Testing of Engine Antifreeze

ASTM D2776-72 Tests for Corrosivity of Water in the Absence of Heat Transfer (Electrical Methods)

ASTM E72-74a Conducting Strength Tests of Panels for Building Construction

ASTM E84-70 (1970) Surface Burning Characteristics of Building Materials

ASTM E108-75 (1975) Methods of Fire Tests of Roof Coverings (NFPA 256-1970)

ASTM E154-68 Testing Materials for Use as Vapor Barriers Under Concrete Slabs and as Ground Cover in Crawl Spaces

ASTM E424-71 Test for Solar Energy Transmittance and Reflectance (Terrestrial) of Sheet Materials

ASTM F146-72 Test for Fluid Resistance of Gasket Materials

ASTM G1-72 Recommended Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

ASTM G16-71 Recommended Practice for Applying Statistics to Analysis of Corrosion Data

ASTM G46-76 Recommended Practice for Examination and Evaluation of Pitting Corrosion

AWWA C203-73 Standard for Coal-Tar Protective Coatings and Linings for Steel Water Pipelines

AWWA C506-69 Backflow Prevention Devices-Reduced Pressure Principle and Double Check Valve Types

AWWA D100 (1967) Steel Tanks - Standpipes, Reservoirs and Elevated Tanks for Water Storage

AWWA D102 Painting and Repainting Steel Tanks, Standpipes, Reservoirs, and Elevated Tanks for Water Storage

BMC, Section M302 (1975) Specific Requirements for the Materials, Design, and Fabrication of Ductwork

CPSC 16 CFR, Part 1201 (1976) Architectural Glazing (Code of Federal Regulation)

Federal Hazardous Substances Act, Code of Federal Regulations, Title 16, Part 1500

FCCCHR, Chapter 10 Manual of Cross-Connection Control (Foundation for Cross Connection Control Research)

FS-DD-G-451C (1972) Glass, Plate, Sheet, Figured (Float, Flat, for Glazing, Corrugated, Mirrors and Other Uses)

FS-TT-C-00598C(1) Caulking Compound, Oil and Resin Base Type (For Building Construction) (18 March 1971)

FS-TT-S-001543A Sealing Compound: Silicone Rubber Base (For Caulking, Sealing, and Glazing in Buildings and Other Structures) (9 June 1971)

FS-TT-S-001657 Sealing Compound: Single Component, Butyl Rubber Based, Solvent Release Type (for Buildings and Other Types of Construction) (8 October 1970)

FS-TT-S-00227E(3) Sealing Compound Elastomeric Type, Multi-compound (For Caulking, Sealing and Glazing in Buildings and Other Structures) (9 October 1970)

FS-TT-S-00230C(2) Sealing Compound: Elastomeric Type, Single Component (For Caulking, Sealing and Glazing in Buildings and Other Structures) (9 October 1970)

FS-TT-P-95A(3) Paint, Rubber: For Swimming Pools and Other Concrete and Masonry Surfaces, 27 May 1966

FS-WW-U-516B Unions, Brass or Bronze, Threaded Pipe Connections and Solder-Joint Tube Connections

FS-WW-U-531D Unions, Pipe, Steel or Malleable Iron; Threaded Connection, 150 lbs. and 250 lbs.

FS-WW-V-35B (1973) Valve, Ball

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NACE TM-01-71 Autoclave Corrosion Testing of Metals in High Temperature Water

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NFPA 72A (1974) Local Protective Signaling Systems

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NFPA 321 (1973) Basic Classification of Flammable and Combustible Liquids

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UL 174 (1972) Standard for Household Electric Storage-Tank Water Heaters (ANSI C33.87-1972)

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UL 296 (1974) Standard for Oil Burners

UL 573 (1972) Standard for Electric Space-Heating Equipment (ANSI C33.12-1972)

UL 726 (1973) Standard for Oil-Fired Boiler Assemblies

UL 727 (1973) Standard for Oil-Fired Central Furnaces (ANSI Z96.1-1973)

UL 730 (1974) Standard for Oil-Fired Wall Furnaces

UL 732 (1974) Standard for Oil-Fired Water Heaters

UL 900 (1971) Safety Standard for Air Filter Units (ANSI B124.1-1971)

UL 1042 (1973) Standard for Electric Baseboard Heating Equipment (ANSI C33.95-1973)

Water Quality Criteria 1972, National Academy of Science and National Academy of Engineering

APPENDIX F

ABBREVIATIONS

(Code Groups, Associations, and Gov't Agencies)

AASHO	American Association of State Highway and Transportation Officials
AGA	American Gas Association
AMCA	Air Moving and Conditioning Association, Inc.
ANSI	American National Standards Institute
ARI	Air-Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASSE	American Society of Sanitary Engineering
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association, Inc.
BMC	Basic Mechanical Code (Division of BOCA)
BOCA	Building Officials and Code Administrators International, Inc.
CISPI	Cast Iron Soil Pipe Institute
CPSC	Consumer Product Safety Commission
CS	Commercial Standard
FCCCHR	Foundation for Cross-Connection Control and Hydraulic Research
FS	Federal Specifications
HUD	Department of Housing and Urban Development
HVI	Home Ventilating Institute
IAPMO	International Association of Plumbing and Mechanical Officials
IBR	Institute of Boiler and Radiator Manufacturers (Now Hydronic Inst.)
ICBO	International Conference of Building Officials
IEC	International Electrotechnical Commission
ISO	International Standards Organization
MCA	Mechanical Contractor's Association
MSS	Manufacturer's Standardization Society of the Valve and Fitting Industry
NACE	National Association of Corrosion Engineers
NAS/NRC	National Academy of Science/National Research Council
NBS	National Bureau of Standards
NEMA	National Electrical Manufacturer's Association
NESCA	National Environmental Systems Contractors Association
NFO	National Forest Products Association
NFPA	National Fire Protection Association
NRCA	National Roofing Contractor's Association
NSF	National Sanitation Foundation Testing Laboratory, Inc.
NSPC	National Standard Plumbing Code
PL	Public Law
SAE	Society for Automotive Engineers
SBI	Steel Boiler Institute (Now Hydronic Institute)
SMACNA	Sheet Metal and Air Conditioning Contractors National Association, Inc.
SPMA	Sump Pump Manufacturer's Association
TEMA	Tubular Exchanger Manufacturer's Association, Inc.
UBC	Uniform Building Code
UPC	Uniform Plumbing Code
UMC	Unfiorm Mechanical Code
UL	Underwriter's Laboratories, Inc.

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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 report presents standards for the use of solar heating and domestic hot water systems in residential applications. The standards have been developed for application in numerous housing programs of the Department of Housing and Urban Development and are a companion document to be used in conjunction with the HUD "Minimum Property Standards for One and Two Family Dwellings," 4900, and "Minimum Property Standards for Multifamily Housing," 4910. To the greatest extent possible, these standards are based on current state-of-the-art practice and on nationally recognized standards including the MPS and the HUD "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings."

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)*
Solar buildings; solar collectors; solar domestic hot water systems; solar heating; standards; thermal storage.

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