NAT'L INST. OF STAND & TECH
A11105 974377
REFERENCE
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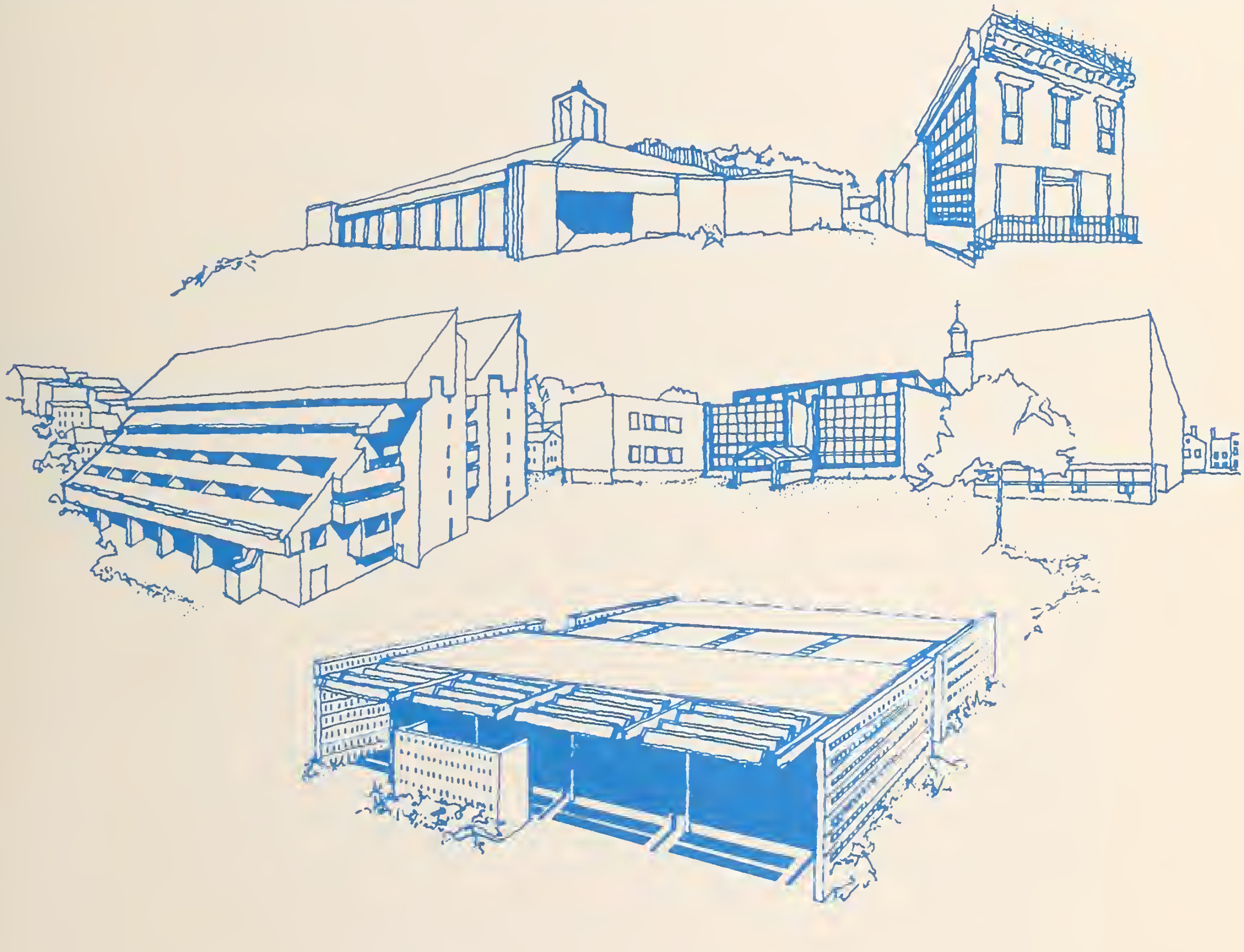
NBS TECHNICAL NOTE 1187

U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards



Performance Criteria for Solar Heating and Cooling Systems in Commercial Buildings

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No.1187
1984
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Center for Building Technology
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National Bureau of Standards
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Prepared for:
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U.S. Department of Energy
Washington, D C 20585

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Issued April 1984

National Bureau of Standards Technical Note 1187
Natl. Bur. Stand. (U.S.), Tech. Note 1187, 229 pages (Apr. 1984)
CODEN: NBTNAE

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1984

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402

ABSTRACT

This document establishes baseline criteria for the design, development, technical evaluation and procurement of solar heating and cooling systems for commercial buildings. These performance criteria were developed in accordance with Public Law 93-409 the "Solar Heating and Cooling Demonstration Act of 1975." The document is intended as a resource for use in establishing minimum acceptance levels of performance for solar heating and cooling systems. Criteria which deal with public health and safety are in compliance with general building codes and standards. The criteria on thermal and mechanical performance, durability/reliability and operation/servicing present performance requirements considered to be representative of acceptable levels for conventional space conditioning equipment. By the use of performance language in the document, it is believed that sufficient latitude has been provided to allow innovation and flexibility that is essential for the stimulation of a viable solar industry.

Key words: building; cooling; heating; hot water; performance criteria; solar energy; standards

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FOREWORD

The Solar Heating and Cooling Demonstration Act of 1974 (P.L. 93-409) authorized a 5-year program for research, demonstration, and development for solar heating and cooling systems in residential and commercial buildings. As part of the demonstration program, the Act directed the Secretary of the Department of Housing and Urban Development (HUD), utilizing the services of the Director of the National Bureau of Standards (NBS), to develop and publish Interim Performance Criteria for solar heating and cooling systems for residential buildings within 120 days of enactment and to use the criteria in the selection of solar energy systems and demonstration projects. The Interim Performance Criteria were published on January 1, 1975. The Act further directed that the services of NBS be used to develop and publish "definitive performance criteria" as soon as feasible with information gained from the demonstration program.

The initial Interim Performance Criteria for Commercial Solar Heating and Combined Heating/Cooling Systems and Facilities were published by the National Space and Aeronautics Administration (NASA) for the Energy Research and Development Administration (ERDA). The interim commercial criteria were made available in February 1975 with similar technical content and format developed for the residential criteria.

In November 1976 the interim commercial criteria were updated after the technical responsibility was transferred from NASA to NBS. The revision was issued as NBSIR 76-1187, "Interim Performance Criteria for Solar Heating and Cooling Systems in Commercial Buildings," and was used in evaluation of project proposals submitted under the Commercial Solar Demonstration Program and the Federal Solar Buildings Program. Because of advances in the state-of-the-art of solar technology, the Department of Energy (DOE) sponsored the preparation of this revision of the November 1976 document.

The document is intended to serve as a technical reference and resource for the solar industry, the building industry, Federal, State and local agencies, designers and building owners concerned with assessing the design and performance of solar energy systems in commercial buildings.

The document is intended to establish minimum levels of performance with regard to health and safety and the various aspects of technical performance. The criteria for health and safety put primary emphasis on compliance with existing codes and standards. The criteria on thermal and mechanical performance, durability/reliability,and operation/servicing, present performance requirements considered to be representative of acceptable levels relative to conventional space conditioning equipment. By the use of performance language in the document, it is believed that sufficient latitude has been provided to allow the innovation and flexibility that is essential for the stimulation of a viable solar industry at this time and in the future.

In developing these criteria, several sources have been utilized:

- Performance criteria developed by the National Bureau of Standards (NBS) for the Department of Housing and Urban Development (HUD) and the Department of Energy (DOE).

  - "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings" - January 1975.

  - "Interim Performance Criteria for Solar Heating and Cooling Systems in Commercial Buildings" - NBSIR 76-1187, November 1976.

  - "HUD Intermediate Minimum Property Standards Supplement, 1977 Edition, Solar Heating and Domestic Hot Water Systems" - 4930.2.

  - "Interim Performance Criteria for Solar Heating and Cooling Systems in Residential Buildings" - NBSIR 78-1562, November 1978.

  - "Performance Criteria for Solar Heating and Cooling Systems in Residential Buildings" (Draft for Public Comment) - NBSIR 80-2095, Revised January 1981, Federal Register, Vol. 46, No. 121, pp. 32740-32823, June 24, 1981.

  - "Performance Criteria for Solar Heating and Cooling Systems in Residential Buildings," Building Science Series 147, National Bureau of Standards, September 1982.

- Experience gained in the Federal Solar Demonstration Program (Residential/Commercial) through feedback as provided for in P.L. 93-409

- Findings from solar research activities

  - Government laboratories - National Bureau of Standards, Los Alamos National Laboratory, National Aeronautics and Space Administration, Argonne National Laboratory.

  - Sponsored research - Dubin-Bloome Associates, Planning Research Corporation Energy Analysis Company, Boeing Aerospace Company, International Business Machines, University of Wisconsin, Colorado State University, Mueller Associates, Automation Industries (Vitro Laboratory Division).

  - Special studies - Burt-Hill-Kosar-Rittelman Associates, Travis-Braun Associates, Robertson Ward, Jr., FAIA, Florida Solar Energy Center, Polytechnic Institute of New York, Mueller Associates, TPI, Inc.

  - Technical standards organizations - American Society for Testing and Materials, American Society of Heating, Refrigerating and Air-Conditioning Engineers, American Society of Mechanical Engineers,Inc., American National Standards Institute.

  - Industry organizations - Solar Energy Industries Association, Inc., Solar Energy Research and Education Foundation, Air Conditioning and Refrigeration Institute, Sheet Metal and Air Conditioning Contractors National Association, Inc.

- Professional organizations - American Institute of Architects

ACKNOWLEDGMENTS

This document was prepared by the Center for Building Technology staff of the National Bureau of Standards. Members and former members who participated in the preparation of this document, as well as previous performance criteria documents prepared for the Energy Research and Development Administration and Department of Housing and Urban Development (see Foreword) include:

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Robert D. Dikkers	Leopold F. Skoda
Thomas K. Faison	Elmer R. Streed
James R. Harris	David Waksman
John K. Holton	W. Douglas Walton (Center for Fire Research)

Acknowledgment is also made of the helpful comments and suggestions received from Carl W. Conner, Department of Energy, William Freeborne and David Moore, Department of Housing and Urban Development, and the many organizations mentioned in the Foreword.

The buildings drawn on the cover are representative of commercial buildings that were built with support from the Department of Energy. They demonstrate applications of passive and active solar heating and cooling systems. Shown are an intercultural center in Washington, D.C.; a visitors information center in Troy, NY; a showroom in Denver, Colorado; a gymnasium in Alexandria, VA; and an elementary school in Baltimore, MD.

INTRODUCTION

Background

Public Law 93-409 provided for "demonstration within a three-year period of the practical use of solar heating technology, and . . . . the development within a five-year period of the practical use of combined heating and cooling technology." Under the provisions of the Act, the Department of Energy had reponsibility for implementation of the commercial building solar demonstration program. As part of that program, the National Bureau of Standards was utilized to develop this document. This document follows earlier work by the National Bureau of Standards and the National Aeronautics and Space Administration in developing "interim" performance criteria for the National Solar Demonstration Program, References [1, 2].*

A companion document for residential application which was sponsored by the Department of Housing and Urban Development has been referenced in the Federal Register, Reference [3] and is available through the Government Printing Office as a National Bureau of Standards publication, Building Science Series 147, "Performance Criteria for Solar Heating and Cooling Systems in Residential Buildings," Reference [4].

Objectives

These criteria have the following objectives:

1. Aid consumer acceptance by the provision of validated consensus performance measures;

2. Assist industry growth through accepted uniform methods of technical performance assessment;

3. Assist the administration of Federal solar programs by the establishment of standard performance measures;

4. Assist regulatory authorities in developing and interpreting health and safety code provisions;

5. Aid financial and insurance organizations by the provision of standard performance criteria upon which to base risk assessment;

6. Assist public and private building programs through provision of a technical performance assessment base from which project construction specifications may be developed; and

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* Numbers in brackets [ ] indicate references at the end of this introduction section.

7. Guide industry, professional and educational organizations in the development of appropriate good practice manuals.

Scope

The performance criteria cover both passive and active solar heating, cooling, and domestic hot water installations or combinations thereof[1/] in individual buildings or central systems for groups of buildings both new and existing.

The criteria do not cover swimming pool heaters but they do cover pools within buildings used to moderate environmental conditions or to store heat for reuse. They do not cover photovoltaic, wind, biomass, or process heating or cooling applications. The criteria are related primarily to technical performance of components and systems and do not directly address economic considerations and energy conservation.

The criteria given in this document primarily consider aspects of planning and design that are different from conventional buildings by reason of the solar energy systems under consideration and are intended to:

1. Establish minimum levels for health and safety that are consistent with those presently established for conventional systems used in building applications;

2. Ensure that the proposed heating, cooling, and hot water systems or combinations thereof, are capable of providing levels of performance consistent with those provided by conventional systems used in building applications;

3. Verify that proposed systems and components are capable of providing their design performance levels;

4. Ascertain that the systems and components are durable, reliable, readily maintainable, and generally constructed in accordance with good practice; and

5. Provide appropriate instructions and information for the operation and servicing of the systems and components.

Many of the problems and circumstances discussed in the criteria are unique to solar installations. Several useful references drawn from the Federal Solar Demonstration Program give insight into such problems, References [5, 6, 7, 8, 9, 10, 11, 12].

Reference is also made to the American National Standard Recommended Requirements to Code Officials for Solar Heating, Cooling, and Hot Water Systems, Reference [13]. This document identifies health and safety requirements for solar systems.

[1/] Although not specifically mentioned in P.L. 93-409, it is recognized in this document that not all cooling systems are combined with heating systems.

The performance criteria are intended to be flexible in order to allow freedom of design and encourage innovation in keeping with the intent of P.L. 93-409.

Many of the criteria which explicitly address active solar systems also have implications with regard to passive systems. The majority of the criteria which are directly intended for passive systems are found in Chapters 1 and 2. Several of the other criteria, especially those dealing with health and safety concerns are applicable to passive systems, as well as active ones. Judgement must be exercised in applying the criteria to assure that passive system concerns are adequately addressed.

Organization and Format

This document is organized on the basis of performance criteria dealing with heating, cooling, and hot water systems and their integration into buildings.

Performance statement entries, with the exception of Chapter 1, are presented in the Requirement, Criterion, Evaluation and Commentary format. The Requirement is a qualitative statement giving the user need or expectation for the item being addressed. It is a general statement of what the system or its components shall be able to do. The Criterion is generally a quantitative statement giving the level of performance required to meet the application or expectation for the item being addressed. The one or more criteria associated with each requirement state those considerations that are necessary to meet the requirement. Due to limitations in the state-of-the-art, a quantitative statement is not always contained in each criterion in this document. In addition, quantitative statements have been intentionally omitted in some criteria where these values will be provided by the designer. The Evaluation sets forth the record of experience, methods of test and/or other information upon which an evaluative judgment of compliance with a criterion will be based. It states the standards, inspection methods, analyses, review procedures, historical documentation, or other methods that may be used in evaluating whether or not the system and its components as designed comply with the criterion. It is expected, in many cases, that the review of documentation of in-use performance or professional judgment will be used as evaluative tools in lieu of testing. The Commentary provides background for the reader and presents the rationale behind the selection of specific data presented in the Requirement, Criterion or Evaluation. The commentary is intended for informational purposes and in some instances, provides design guidelines. Such guidelines are only one suggestion of appropriate methods; in most instances, there will be other methods equally as effective. Including a commentary in the presentation ensures a workable process of updating these performance criteria. The commentary provides the rationale for selection of performance levels and methods of evaluation. When questions arise as to the basis for a particular criterion, the reader will have available the rationale behind the criterion. With the present state-of-the-art, there will be a need for periodic updates to adjust levels of acceptability for both systems and components.

The document is organized into chapters on the basis of the performance attributes listed below:

1. Site and Building performance statements deal with the interactions between the solar energy system and its surrounding environment, the site, and building. These performance statements provide for integrating the building and site with the system and its components without seriously degrading the environment or impairing the normal function of the building and its components. Because of their more general nature, the statements in this chapter are not organized in the Requirement/Criterion/Evaluation/Commentary format discussed previously.

2. Thermal performance statements are used to evaluate the ability of systems and their components, as designed, to operate and provide their rated output and, in some cases, to evaluate the determination of that output. The ability of the solar heating system to maintain the building at a specified temperature under a given set of outdoor conditions is an example of a thermal consideration.

3. Mechanical performance statements address the mechanical design and performance of the solar energy systems and their components. Factors such as the ability of the system to withstand normal design service conditions, e.g., pressure and temperature, are considered under this category.

4. Safety and Health deals with the mitigation of hazards that would result in personal injury or property damage. Hazards such as those due to scalding, lacerating, toxic and/or flammable materials are also considered under this category.

5. Durability/Reliability relate to the ability of systems and their components to perform designed functions for a specified interval under designated use conditions. Corrosion and thermal degradation are typical durability/reliability related items.

6. Operation and Servicing deals with the features of systems and their components that allow them to be maintained in good operating condition for extended periods of time. Manuals and instructions, routine scheduled maintenance, corrective maintenance, replacements, and repairs are considered under this category. Accessibility is an important maintainability consideration.

Appendices A and B reference conditions for and methods of testing and evaluation that can be used to prove compliance with stated requirements. As a general rule, consensus standards are to be used when applicable. The Abbreviations section offers the names of Code Groups, Associations, and Government Agencies. The SI Conversion Units section offers metric conversion factors for all quantitative units appearing in the text.

The Composite Index locates components, materials, operations, and other technical topics according to their appearance in the text.

For the purposes of this document, the various systems and components, both active and passive, treated in this document are abbreviated as follows:

(H)	Heating system
(C)	Cooling system
(HW)	Hot water system (service HW)
(H/C/HW)	is used when a requirement or criterion is applicable to the individual H, C, HW system or any combination thereof.

References

1. "Interim Performance Criteria for Commercial Solar Heating and Combined Heating/Cooling Systems and Facilities," NASA, Marshall Space Flight Center, Document No. 98M10001, February 1975.

2. "Interim Performance Criteria for Solar Heating and Cooling Systems in Commercial Buildings", NBSIR 76-1187, National Bureau of Standards, U.S. Department of Commerce, Washington, D.C. 20234, November 1976.[3/]

3. Federal Register, Vol. 46, No. 121, pp. 32740-32823, June 24, 1981.

4. "Performance Criteria for Solar Heating and Cooling Systems in Residential Buildings," Building Science Series 147, National Bureau of Standards, U.S. Department of Commerce, Washington, D.C. 20234, September 1982.[3/]

5. Proceedings of the Solar Heating and Cooling Demonstration Program Contractors' Review, Vol. 2, CONF 771229, Department of Energy, New Orleans, LA, December 5-7, 1977.[3/]

6. Proceedings of 3rd Annual Solar Heating and Cooling Research and Development Branch Contractors' Meeting, U.S. Department of Energy, Washington, D.C., September 24-27, 1978.[1/]

7. Conference Proceedings-Solar Heating and Cooling Systems Operational Results, U.S. Department of Energy, Colorado Springs, CO, November 28-December 1, 1978.[1/]

8. Standard Practice for Installation and Service of Solar Space Heating Systems for One- and Two-Family Dwellings, ASTM E683-79, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, 1979.

9. "Installation Guidelines for Solar DHW Systems in One- and Two-Family Dwellings," HUD-PDR-407, GPO 023-000-00520-4, U. S. Department of Housing and Urban Development, April 1979.[2/]

10. Weinstein, S., Architectural Concerns in Solar System Design and Installation, Solar/0801-79/01, U.S. Department of Energy, March 1979.[1/]

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12. "National Solar Heating and Cooling Demonstration Program - Project Experience Handbook," Preliminary Draft, DoE/CS-0045/0, U.S. Department of Energy, September 1978.[1/]

13. American National Standard Recommended Requirements to Code Officials for Solar Heating, Cooling and Hot Water Systems, ANSI/CABO 1.0-1981, Council of American Building Officials, 1981.

1/ Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830.

2/ Superintendent of Documents, U. S. Government Printing Office, Washington, D.C. 20402.

3/ National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

TERMINOLOGY*

Absorber: The part of the solar collector that receives the incident solar radiation and transforms it into thermal energy.

Absorptance: The ratio of the amount of radiation absorbed by a surface to the amount of radiation incident upon it.

Active solar system: A method of space conditioning or water heating that utilizes solar radiation primarily by means of mechanical equipment rather than building elements.

Air chamber: A closed section of pipe or a container filled with air entrapped at atmospheric pressure that when mounted in a water supply line absorbs the pressure surges caused by the rapid opening and closing of valves.

Air mass: The ratio of the mass of atmosphere in the actual earth-sun path to the mass that would exist if the sun were directly overhead at sea level.

Aperture: An opening in a building wall, roof, or other collection device that transmits solar radiation.

Applicable authority: The organization, office, or individual responsible for approving equipment, an installation, procedures, or performance levels. An applicable authority may range from a code official to an individual owner.

Auxiliary energy system: 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 necessary energy back up requirements during periods when the solar H, C or HW systems are inoperable. It 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 heating, cooling, and/or hot water to the building.

Backflow: The flow in pipes, ducts, and other chambers opposite to the intended direction of flow.

Backflow preventer: A device or means to prevent backflow, especially in regard to the potential for contamination of potable water supply.

Backsiphonage: A form of backflow due to a negative or subatmospheric pressure.

Chemical incompatibility: The inability of materials to remain in contact with each other without chemical interaction, such as electrolytic action or plasticizer migration.

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* The definitions given here are for use in this document only.

Closed system: An arrangement in hydronic systems where ambient air is not allowed to enter the system under normal operating conditions.

Collector array: Group of solar collectors or absorbing surfaces connected by pipes or ducts and including any pipes or ducts to the point where there is only one inlet and one outlet.

Collector array manifold: All pipes or ducts within the collector array but external to the collector panels.

Collector azimuth angle: The angle between the direction the collectors face and due south (in the northern hemisphere).

Collector efficiency (ASHRAE 93-77): The amount of energy removed by the transfer fluid per unit of gross collector area during the specified time period divided by the total solar radiation incident on the collector per unit area during the same time period, under steady state or quasi-steady state conditions.

Collector orientation: Combination of collector tilt and azimuth angles.

Collector tilt angle: The acute angle between the collector plane and horizontal.

Cooling degree days: The number of degrees that the daily mean temperature is above 65°F (18.3°C). These are totaled to give cooling degree days per month or per year.

Cooling (C) system: The complete assembly necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, for space cooling purposes. (Where cooling is required, nocturnal radiation, evaporative cooling and/or other means may be used in combination with, or in lieu of, heat actuated space cooling).

Combustible liquid: Combustible liquid shall mean any liquid having a flash point at or above 100°F (37.8°C) (See "Flammable liquid").

Combustible material: See noncombustible material.

Contaminants (hazardous): Materials which when added unintentionally (or intentionally) to the potable water supply cause it to be unfit for human consumption.

Control system: Devices and their electrical, mechanical, 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 or building.

Creep: A time-dependent deformation of material resulting from sustained loads which can be influenced by factors such as temperature and solar radiation.

Depletable energy: Energy from any source other than solar energy converted to thermal energy at the building site or from thermal energy extracted from the air, groundwater, or ground. Depletable energy sources include coal, natural or manufactured gas, oil, other petroleum products, wood, and electricity. Electricity produced offsite is considered to be depletable energy, even though the source of the electricity may be some form of solar energy such as hydropower or wind.

Depletable energy limit: Allowable depletable energy use over one year for a H/C/HW system based on predicted system performance.

Design hot water load: The rate of energy required to be added by the mechanical system to the water at design maximum hot water use rate and temperature, not including energy to offset standby water heater, recirculation and distribution losses. Normally, the design hot water load is determined by a combination of recovery rate and hot water storage capacity.

Design life: The period of time during which an H/C/HW system is expected to perform its intended function without requiring major maintenance or replacement.

Design maximum flow temperature: The maximum temperature that will be obtained in a component when the heat transfer fluid is flowing through the system.

Design maximum no-flow temperature: The maximum temperature that will be obtained in a component when the heat transfer fluid is not flowing through the system.

Design space cooling load: The instantaneous rate of energy required to be removed by the mechanical system from the space being cooled to achieve space cooling under summer design conditions.

Design space heating load: The instantaneous rate of heat required to be added by the mechanical system to the space being heated to achieve space heating under winter design conditions.

Design working pressure: The value of the pressure used in design calculations for pressure related operational and construction characteristics. This is the maximum allowable working pressure for which a specific part of a system is designed.

Dielectric fitting: An insulating fitting used to isolate electrochemically dissimilar materials.

Draindown system: An open-loop water system in which all water drains out of the collectors and exposed piping at a pre-set point above the freezing temperature.

Drainback system: A liquid solar collector system in which the collector fluid drains down to an interior storage tank when design conditions require such action (either automatic or manual).

Ease of ignition: The time elapsed between the exposure of a material to a controlled heat or flame source and the onset of flaming. The ease of ignition may be used in analyzing the relative fire hazard of the materials.

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 system: Those portions of the H/C/HW systems that convey energy from one place to another. Heat transfer from the collector to storage and from storage to the point of use is accomplished through the energy transport 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.

Flammable liquid: Any liquid having a flash point below 100°F (37.8°C) and having a vapor pressure not exceeding 40 pounds per square inch (275 KPa) absolute (2068.6 mm Hg) at 100°F (37.8°C) (NFPA 321) (see "Combustible liquid").

Flash point: The minimum temperature of a liquid at which sufficient vapor is given off to form an ignitible mixture with the air near the surface of the liquid or within the vessel used as determined by appropriate test procedures and apparatus as specified in NFPA 321.

Flow condition: The situation that exists when the heat transfer fluid is moving through the collector array under normal conditions.

Fully conditioned space: The volume within the building envelope in which a temperature of 70°F (21°C) is capable of being maintained during the 97-1/2 percent winter outdoor heating design temperature conditions.

Glazing: A membrane or sheet of transparent or translucent material (glass or plastic) used for admitting light. Glazing retards heat losses due to reradiation and convection. Examples: windows, skylights, greenhouse and collector coverings.

Gross floor area: Floor area of the building measured to the outside of exterior walls that enclose fully conditioned spaces and to the center of party walls and walls adjacent to semi-conditioned spaces.

Gross solar contribution: Total solar input of a passive solar energy system less excess energy discharge (venting) losses due to the passive solar energy system.

H/C/HW system: The mechanical space heating, space cooling, or hot water system, or any combination thereof, in which solar energy intercepted at the building site is converted to usable thermal energy to satisfy partially or fully the respective energy requirements. This includes systems having discrete collectors with thermosiphon-driven control for air- or liquid-type collectors.

Hazardous substances: See "Federal Hazardous Substances Act Regulations," Code of Federal Regulations (CFR), Title 16, Part 1500.3 (b)(4)(i). The following is an extraction of the definition: "Any substance or mixture of substances which is toxic, corrosive, an irritant, a strong sensitizer, flammable or combustible, or generates pressure through decomposition, heat or other means, if such substance or mixture of substances may cause substantial personal injury or substantial illness during or as a proximate result of any customary or reasonably foreseeable handling or use, including reasonably foreseeable ingestion by children. 'Hazardous substances' shall not apply to substances intended for use as fuels when stored in containers and used in the heating, cooling, or refrigeration system of a house."

Heating degree days: The number of degrees that the daily mean temperature is below 65°F (18.3°C). These are totaled to give heating degree days per month or per year.

Heating (H) system: The complete assembly of systems necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, for space heating purposes.

Highly toxic: See "Federal Hazardous Substances Act Regulations," Code of Federal Regulations (CFR), Title 16, Part 1500.3(b)(6)(i). The following is an extraction of the definition: "'Highly toxic' means any substance producing a lethal dose in half (LD50) of white rats, when ingested as a single dose, of 50 mg or less per kg of body weight." Part 1500.3(c)(1)(i) and (ii) also gives further specific definitions relative to inhalation and absorption. Human data when available, shall take precedence (see also "Toxic").

Hot water energy requirements: Energy required over a given period of time to heat the supply water to a designated use temperature, including energy required to offset standby water heater, recirculation and distribution losses, but not including hot water system operating energy.

Hot water (HW) system: The complete assembly of subsystems or components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, to provide hot water in the building. It may either be integrated directly into the H, C or combined H and C (H/C) system or be completely separate from them.

In-service conditions: The conditions to which a solar H/C/HW system will be exposed during its operational lifetime.

Langley: The meteorologist's unit of solar radiation intensity, equivalent to 1.0 gram calorie per square centimeter, usually used in terms of langleys per minute. 1 langley per minute = 221.2 Btu per hour per square foot = 697 watts per square meter.

Liquid heat transfer fluid: The operating or thermal storage liquid including water or other liquid base and all additives at the concentration used under operating conditions.

Load: Peak rate of energy demand on a mechanical H/C/HW system. Load is energy per unit time or power.

Maximum service temperature: The maximum temperature at which a system is designed to operate either with or without the flow of heat transfer fluid.

Mechanical system: All equipment and controls required to satisfy space heating, cooling or hot water energy requirements. The mechanical system may contain both solar and auxiliary components, including pumps, pipes, blowers, ducts, insulation, solar collectors, thermal storage, heat exchangers, valves, and electrical wiring.

Minimum service temperature: The minimum temperature at which a system is designed to experience either with or without the flow of heat transfer fluid.

Net solar contribution: Solar radiation transmitted through a portion of the building envelope and absorbed within the building during a given daily, monthly, or annual cycle, less the transmission, and ventilation (excess energy discharge) losses due to the same portion of the building envelope during the same period. This is equivalent to net solar gain.

Nocturnal cooling: The cooling of a building or heat storage device by the radiation of heat to the night sky.

"No-flow" condition: The situation that exists when the heat transfer fluid is not flowing through the collector array due to shutdown or malfunction and the collector is exposed to the amount of solar radiation that it would receive under normal operating conditions. Heat transfer fluid may or may not be in the collector but it is not flowing if present. This condition is sometimes referred to as the "stagnation" condition.

Noncombustible material: Material which does not act to aid combustion or add appreciable heat to an ambient fire when tested in accordance with ASTM E136-79, "Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C," and pass the tests set forth therein.

Normal operating condition: Condition of operation during which no applicable parameter (e.g. temperature, pressure or flow rate) is at or near an extreme or unexpected value.

Open system: An arrangement in hydronic systems where ambient air is allowed to enter the system under normal operating conditions.

Operating energy: Energy required to operate pumps, compressors, fans, blowers, valves, controls, movable shutters, or any other equipment, but not energy intended to directly satisfy a load. Operating energy, as defined here, includes energy to operate a heat pump compressor, and defrost energy for heat pumps, when these components are an integral part of the solar system.

Operative temperature: The average of the dry bulb temperature and the mean radiant temperature at a given location.

Optimum collector orientation: Collector orientation that results in the maximum annual solar energy collected and used. The optimum orientation depends on factors such as site location, system type, annual solar fraction, local weather conditions, load profile, and thermal storage size.

Outgassing: The emission of gases by materials and components usually during exposure to elevated temperature or reduced pressure.

Passive solar components: Components of a building that serve to modify the space conditioning energy requirements by means of reflecting, absorbing, transmitting, or storing solar energy. These components include fixed and movable apparatus which can be operated either manually or automatically. Examples of passive solar components are: shading devices, windows, attached greenhouses, Trombe walls, and mass placed for storage of solar energy.

Passive solar energy system: A method of space heating or cooling that utilizes solar radiation primarily by means of building elements rather than mechanical equipment. In passive systems, the energy flows are primarily by natural means (radiation, convection, conduction). For the purposes of this document, this definition includes some systems in which at least one energy flow is by natural means and at least one is by forced means, otherwise known as hybrid systems.

Physical incompatibility: The inability of materials in contact with each other to resist degradation by physical actions such as differential thermal expansion.

Pitting: The process by which localized material loss is caused in materials by erosion or chemical decomposition.

Plasticizer migration: The movement of plasticizers used in plastic materials. These plasticizers may concentrate in a narrow boundary area or migrate to another material in contact with the plastic.

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.

Potential heat: The difference between the heat of combustion of a representative specimen of material and the heat of combustion of any residue remaining after exposure to a simulated standard fire, determined by combustion calorimetric techniques.

pphm: Parts per hundred million.

Premature failure: Failure that occurs before the end of the design life.

Pyranometer: A device used to measure the total solar radiation incident upon a surface per unit time per unit area. This energy includes the direct radiation, the diffuse sky radiation, and the solar radiation reflected from the foreground.

R-value: Resistance to heat flow given in units of $ft^2 \cdot °F \cdot h/Btu$ (1 $ft^2 \cdot °F \cdot h/Btu$ is equivalent to 0.176 $m^2 \cdot °C/W$).

Radiation: The process of heat transfer by the transmission of electromagnetic waves between two or more bodies in sight of each other. These radiant waves are converted to heat only after being absorbed by matter.

Rate of heat release: A measure of the heat production of a material under a specified set of fire exposure conditions which may be used in evaluating the relative hazard of the material.

Recovery rate: The rate at which a water heater can replenish its supply of hot water, traditionally expressed in gallons per hour per 100°F (37.8°C) temperature rise.

Safety glazing materials: Glazing materials so constructed, treated, or combined with other materials as to minimize the likelihood of cutting and piercing injuries when these glazing materials are broken.

Service loads: Loads that are expected during the service life of a structure and upon which the design of the structure is based.

Shall: Where "shall" is used with a special provision, that provision is mandatory if compliance with the criterion is claimed.

Should: Term used to indicate a criterion that is not mandatory but is desirable as good practice.

Significant (deterioration, loss, etc.): Deterioration that results either in a decrease in performance greater than that allowed for in the design, or in the creation of a hazard.

Solar constant: The average intensity of solar radiation reaching the earth outside the atmosphere; amounting to 2 langleys or 1.94 calories per square centimeter, per minute equal to 430 Btu/h•ft^2 or 1353 watts/m^2.

Solar degradation: The process by which exposure to sunlight deteriorates materials.

Solar energy: Solar radiation or energy from solar radiation intercepted and converted to thermal energy at the building site.

Solar fraction: The ratio of solar energy applied to the load by the active solar energy system to the total load. Solar fraction may be calculated for any time period, for example monthly or annually. Solar energy applied to the load may include uncontrolled heat losses from the active solar energy system if these losses contribute to satisfying the load and is reduced by uncontrolled heat losses if these losses increase the load (cooling systems).

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.

Space cooling load: Rate at which heat must be removed from the conditioned space by the mechanical system to maintain indoor temperature at a constant value. Space cooling load reflects sensible and latent heat gain due to external and internal sources. However, storage capacity within the building and contents affects the relationship between heat gain and space cooling load.

Space cooling system: The mechanical system containing all equipment and controls required to satisfy the space cooling load.

Space heating load: Rate at which heat must be added to the conditioned space by the mechanical system to maintain interior temperature at a constant value.

Space heating system: The mechanical system containing all equipment and controls required to satisfy the space heating load. The space heating system may include solar collectors, thermal storage, energy transport devices, and auxiliary energy equipment. The space heating and space cooling systems may have some components in common.

Storage system: Equipment in which thermal energy is stored so that it can be used when required. Specific designs may utilize more than one heat storage temperature (e.g., dual temperature storage) and may employ either heat or cold storage in all or part of the storage subsystem.

System: The complete assembly necessary to supply heat, service hot water, or other usable form of solar energy to a structure.

Tap temperature: The temperature at which water is discharged from an outlet at the point of use.

Thermal stratification: Separation into different temperature regions. Thermal statification usually occurs vertically in liquid thermal storage containers but may also occur horizontally in rock bins.

Thermosiphon: Flow of fluid through a closed loop induced by density difference in the fluid caused by temperature difference which is in turn caused by heat transfer into and out of the loop.

Total solar input: Amount of solar radiation transmitted through the aperture of a passive solar energy system and absorbed within the building during a specified time period.

Toxic: See "Federal Hazardous Substances Act Regulations," Code of Federal Regulations (CFR), Title 16, Part 1500.3(b)(5) and (c) (2). "'Toxic' shall apply to any substance (other than a radioactive substance) which has the capacity to produce personal injury or illness to man through ingestion, inhalation, or absorption through any body surface." An extraction of the more specific definition in (c)(2) adds the following: "'Toxic' means any substance producing a lethal dose in half (LD50) of white rats when ingested as a single dose, of from 50 mg to 5 g per kg of body weight." Part 1500.3(c)(2) (i), (ii) and (iii) also give further specific definitions relative to inhalation and absorption (see also "Highly toxic").

Transmittance: The ratio of the radiant flux transmitted through and emerging from a body to the total flux incident on it.

UV: Ultraviolet radiation, that part of the terrestrial solar energy between 0.3 and 0.4 micrometers (300-400 nanometers).

Water hammer: Potentially damaging forces, exemplified by pressure surges and attendant pounding noises and vibration that develop in a pipe system when a column of liquid flowing through a pipe line is stopped abruptly.

Zero hardness: A property of softened water such that no calcium or magnesium can be found in it by ordinary analytical methods.

2-1/2 percent summer design temperaure: The outdoor air temperature will be higher than the stated value not more than 73 hours per year (2-1/2 percent of the 2,928 hours in June through September).

97-1/2 percent winter design temperature: The outdoor air temperature will be lower than the stated values for not more than 54 hours per year (2-1/2 percent of the 2,160 hours in December, January and February).

CHAPTER 1

SITE AND BUILDING

CHAPTER 1

SITE AND BUILDING

1.0

Introduction

This chapter sets forth considerations of the use of solar energy as related to broadly encompassing impacts beyond the scale of the solar energy system itself. The performance criteria for solar energy systems exist within a context of requirements that increase in scope from the building for which the system is designed, to the site, to the region and its climate, up to the scale of national energy goals. At each level, certain requirements have evolved which will influence solar installations. Policy decisions concerning energy conservation tax incentives, grant programs, reduced interest financing, fuel pricing, or sun rights are examples of issues that may have profound influence on solar energy applications.

It is critical that solar installations work in harmony with the overall conditions of climate, site, building characteristics, and use patterns of the occupants. Proper and efficient performance of the site and building will increase the probability for efficiency of the solar energy system and in turn the level of performance of components and materials as well.

1.1 Climate and regional considerations. Regional climate and resource conditions may exert a strong influence on designs. Certain construction materials have strong indigenous applications and establish constraints within which the designer or any solar building project must work.

Specific regional climatic considerations include the following and are subdivided into categories of natural, man made, and climatic factors.

Natural Factors:

(a) Sun altitude and declination - for consideration of collector aperture tilt and shading, etc.

(b) Orientation - due south vs. magnetic south - to determine orientation and building geometry

(c) Topography - for consideration of building into slopes, earth berming, and otherwise maximizing southern exposure and minimizing others, References [1,2]*

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* Numbers in brackets [ ] indicate references at the end of this chapter.

(d) Altitude - for the effects of atmospheric density

(e) Vegetation - as it affects shading, reflection and air movement, References [1, 2]

(f) Ground temperature - as it affects ground water temperature and earth exchange cooling

(g) Water table height - for considerations of excavation, burying of storage elements, earth contact housing, and wetting of insulation

(h) Water quality - its mineral content, pH, etc., when used for heat transfer fluid or thermal storage

Man Made Factors:

(a) Density and growth of development - in consideration of solar rights, shading, glare, obtrusive installations, References [2, 3, 4]

(b) Pollution of air - as it affects insolation, corrosion of exposed parts, stain and dirt deposits on collector cover plates, or glazing

(c) Building materials and architectural character - consideration of mass and geometry or prevalent building types

(d) Building codes - to the extent that they constrain solar applications, Reference [4]

Climatic Factors:

Macro-climatic factors have a direct influence on solar H/C/HW systems. Typical sources of climate data are the Climatic Atlas, Reference [5] and Comparative Climatic Data, Reference [6]. Reference [7] although specifically directed to residential application may be useful in small commercial designs and describes adaptation of building form for regional climate characteristics. Following is a tabulation of typical climate factors:

(a) Temperature (annual average, seasonal, and daily)

(b) Solar radiation (annual, monthly, daily, hourly) Note: data on a weekly basis would offer many advantages but is usually not tabulated in that form

(c) Wind or air movement (direction, velocity, frequency)

(d) Relative humidity

(e) Rainfall and snow

Micro-climatic factors are those of specific interest to an individual building, site, and immediate surroundings. Climatic characteristics become more focused at this scale and may be tempered or exaggerated by local features, creating weather characteristics unique to the site. The characteristics unique to the site may be caused by its topography, landscaping, and proximity to surrounding buildings, hills, lakes, or open plains, Reference [1]. The following characteristics should be considered at this scale:

(a) Shading - time, duration, and season of occurrence are important for heating as well as cooling

(b) Air movement (direction, velocity, frequency)

(c) Atmospheric quality (fog, haze) and direct vs. diffuse solar radiation

(d) Relative humidity

1.2 Site considerations. Site design and siting criteria for energy conserving buildings incorporating solar energy systems are similar to good practice guidelines for non-solar buildings. The difference is in the special affinity for the sun and the sun's path required for solar energy applications. The performance uncertainties at this time and marginal energy balances often experienced in the operation of solar energy systems require greater consideration of the subtleties of the building/environment relationships. In passive solar applications, the entire building is likely to be affected by these relationships and for applications at least the solar energy system will be affected. Overdesign as a means of coping with the performance uncertainties of solar energy installations is expensive and not likely to be cost effective.

Achieving an optimum orientation for the building and/or collector apertures is of primary importance. During the winter months, approximately 90 percent of the sun's energy occurs between the hours of 9:00 a.m. and 3:00 p.m. It is important that solar collection surfaces not be significantly shaded during this time. Site planning should also take into account the direction of prevailing winds.

The judicious use of vegetation and other landscaping techniques can play a significant role in solar energy efficiency as well as energy conservation in general. The use of trees and vines to provide summer shading while still permitting full exposure to solar radiation in the winter is particularly important in passive applications. Various ground cover materials can increase reflection or reduce glare as may be appropriate. Trees may be used to channel cooling breezes and evergreens can be used as effective wind breaks to moderate cold winter winds. Fences, screens, walls, and earth berms are other site design elements which would be considered to provide sun capturing spaces or as barriers to heat loss. References [1, 2, 8, 9, 10, 11] describe siting considerations and Reference [7] describes the extensive influence these have on passive designs.

1.3 Building considerations. A well designed solar energy system must include a building that is energy conserving since collector area and sizing of other solar hardware components are proportional to the building load requirements. There are several aspects that may be considered. One consideration is the exterior envelope of the building where energy can be conserved by modifying factors such as: color,thermal resistance, thermal mass, Reference, [15], orientation, shading, surface area, and weather tightness. ASHRAE Standard 90A-1980, Reference [12] sets forth requirements for the design of the exterior envelope of new buildings for effective use of energy. Insulation to levels greater than those specified in 90A-1980 is normally desirable in solar buildings to minimize heating load. In the case of passive buildings, it may be desirable to tailor the design to the optimum use of glazed areas, thermal mass, insulation, ventilation, and other appurtenances for heating, cooling, and illumination. Listed in Table B.5 of Appendix B are typical properties of selected building materials that may be beneficial to the user selecting building components and materials for solar application.

A second consideration is the mass of the building which can exert considerable influence on the building's thermal behavior. Studies have indicated the beneficial peak leveling and carryover characteristics of properly designed building mass, Reference [13].

A third consideration is space planning and coordinating space use with natural temperature variations. The planning of interior spaces and proper temperature zoning is important for energy conservation and especially important in passive buildings. Such interior planning has a significant effect on the movement of energy (natural and mechanical) in buildings for both the heating and cooling seasons and the maintaining of comfort conditions corresponding with the activity within the spaces. Spaces having minimal heating and lighting requirements may serve as an effective buffer zone when placed in the north facing portion of the building. Spaces having greater heating and lighting requirements and more frequent use, can benefit from placement adjacent to southern exposures. In some passively designed buildings, the probability of large temperature swings may also affect zoning and room placement. The protection of entrances from winter winds by the use of a double entry or vestibule can be advantageous. Reference [14] presents a number of projects which illustrate design response to these needs. The need for grouping of mechanical spaces to take advantage of shorter piping and duct runs and associated thermal losses is similar to non-solar buildings but potentially more important in solar applications. Waste heat recovery and storage in the thermal storage mass of passive solar buildings is often possible. Which combination of options is chosen and how effective the selection will be is dependent on design conditions and design goals. Recent publications give the designer and potential owner information on the integration of passive solar concepts and practices for commercial application, References [16,17,18,19,20,21].

1.4 Building/solar system interaction. The adverse effect(s) that a building or site might have on solar H/C/HW systems or components and their performance must be considered in the design. The adverse effect(s) that the solar H/C/HW systems or components have on the building or site are addressed in Chapters 2 through 6 as appropriate.

Solar components should be located where the potential for their misuse is minimized. The proximity of system components to sidewalks and playgrounds should be examined to minimize potential misuse or vandalism.

Building exhausts, plumbing vents, or other air discharge openings through roofs or exterior walls should not be located such that their emission will cause the deposition of grease, lint, condensation,or other deleterious materials on solar components, especially apertures or collector glazing. Similarly, solar components should not interfere significantly, either physically or aerodynamically, with building vents, flues, and exhausts.

Interior items such as rugs, carpets, wall hangings, and furniture which may cover passive solar components such as thermal storage, absorbers, or apertures may seriously reduce the thermal performance of these passive components.

Routine maintenance of the building should not have adverse effects on the solar components, nor should required maintenance of the solar systems have adverse effects on the building components. Maintenance of building and site and roof surfaces are specifically covered in Criteria 6.2.4 and 6.2.5.

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CHAPTER 2

THERMAL

Contents (continued)

CHAPTER 2

THERMAL

2.0 Introduction

This chapter sets forth the requirements and criteria that determine acceptable thermal performance of passive and active solar energy systems in commercial buildings. In those instances where both active or passive systems apply to the criteria, the general term "solar energy system" will be used. The definitional distinction between active and passive systems, however, can be useful where only one type is affected by the criteria. Passive solar energy systems are usually elements of the building envelope and mass which are designed to have a beneficial effect in reducing the depletable energy requirements of the building. These passive systems employ primarily natural means for accomplishing energy flows such as radiation, natural convection or conduction. Active systems, on the other hand,can be thought of as external equipment procured for the purpose of meeting the energy requirements of the building. Most systems have the ability to supply energy on demand (controllers) through the use of forced convection energy flows. Because of the interrelationship between the conventional HVAC system and the active solar system, the conventional system is considered a part of the solar system acting as backup. A more detailed discussion of the classification of active and passive systems is available in Reference [1].*

Chapter 2 is divided into nine requirements. The first three requirements; 2.1, 2.2, and 2.3, apply to the design of the solar system with respect to its ability to provide comfort at ASHRAE design conditions while not adversely affecting the energy consumption of the building. Specifically, Requirement 2.1 treats the definition of design conditions and preservation of the habitability of the building when considering the integration of a solar system. Requirement 2.2 states that the solar system shall reduce conventional energy consumption for the intended end-use without significantly increasing the other end-use energy consumptions. When comparisons of different fuel consumption are required, the energy value is that at the building envelope and does not reflect fuel costs or quality. It is assumed that design analyses will account for such factors. Requirement 2.3 specifies the sizing of the solar system with respect to design conditions and peak demand. Peak demand is included in the requirement because of the importance of

* Numbers in brackets [ ] indicate references at the end of this chapter.

building energy demands at the community level. Public law mandates that utilities maintain sufficient generating capacity to meet the maximum requirement. This results in considerable excess capacity during average conditions. If the use of solar in a considerable number of buildings within a community increased the peak demand, it may result in further power plant construction and a reduction in overall utility efficiency.

Requirements 2.4 through 2.7 present specific criteria related to the selection and design of specific components within the overall solar energy system. These requirements are primarily aimed at active solar systems. Because of the similarity between thermosyphon system components and active service hot water components, criteria from these requirements can usually be applied directly to the design of a thermosyphon system.

Requirement 2.8 deals with those problems related to the integration of components into an efficient solar energy system. Again, the material is primarily directed toward active rather than passive systems.

Requirement 2.9 is concerned with the overall effect of the solar energy system on the use of depletable energy sources. Integration of all factors is considered in this requirement including active and passive solar system contributions, effects on all end uses, and effect on equipment efficiencies. The criteria of this chapter are not intended to supplant general practice design procedures but rather to avoid unintentional deleterious effects on the overall thermal performance of the building and its equipment through the use of solar energy.

2.1
Requirement

Design conditions. The solar energy space conditioning and/or service hot water systems in combination with conventional mechanical systems, shall be capable of maintaining conditions which are suitable for normal usage of the building. The use of such systems shall not adversely affect the habitability of the building. These systems, in combination with conventional mechanical systems, shall be capable of automatically operating to protect the system components, the building and its contents against damage due to temperature extremes when the building is unattended.

Commentary

If passive solar techniques are utilized, the mechanical system for active solar must provide the means by which the space temperature, humidity, and ventilation requirements are met after the space has been tempered by the passive solar techniques. The resulting restructuring or modification of a building's energy loads due to the inclusion of passive solar techniques should be realized and quantified. The design process for modification of the buildings energy load through incorporation of passive features requires analysis of climatic conditions and an understanding of how building energy loads respond to exterior conditions. The extent to which building energy load is changed as the result of passive solar design must be known before the conventional mechanical and/or active solar system is designed. For passive solar buildings with no active solar space conditioning system, this requirement must be met entirely by the conventional system. This requirement addresses the ability of the mechanical system to meet peak design conditions, and not the amount of depletable energy used, which is covered under Requirement 2.9, System performance. The mechanical system must be adequately sized, to meet the design condition, but not oversized, to avoid the excessive use of depletable energy.

2.1.1
Criterion

Space comfort/interior design conditions. Minimum and maximum allowable dry-bulb air temperature shall be specified in the design for each interior space, and shall be suitable for its intended use. Other design parameters such as relative humidity, air movement, and temperature of interior surfaces may be specified for certain categories of spaces if required by the applicable authority.

Evaluation

The ASHRAE Handbook, Applications Volume, Reference [2] shall be used to determine the suitability of the specified interior design conditions for each conditioned space. ASHRAE Standard 55-81 shall be used to determine the suitability of specified thermal conditions for occupied spaces, Reference [3]. Broad categories of building types and representative interior design conditions are given below:

Category I Buildings (examples): Recreation facilities, hotels, motels, shopping centers, schools, assembly places (theaters, churches, convention centers), restaurants, transportation centers, and guard office spaces. Category I spaces shall be designed to satisfy the environmental conditions established in ASHRAE Standard 55-81. Human occupancy is the primary consideration in these spaces.

Category II Buildings (examples): Hospitals, laboratories (clean rooms), computer facilities, museums, and libraries. Category II spaces require tight control and generally the specific control limits are not to satisfy human comfort needs, but provide more stringent control. Because the limits are generally in response to individual space uses, the specific limits shall be supplied by the applicable authority who must establish the design limits for individual space use conditions.

Category III Buildings (examples): Warehouses, and greenhouses. Category III spaces may not require as tight control as required by the other two categories. Because of the wide range of space condition requirements that may be applicable to solar energy assisted space conditioning systems, the control limits for Category III space conditioning shall be specified by the applicable authority.

Although the three broad building categories are given as a guide, the specific use of each identifiable space and its space conditioning requirements shall be listed separately.

Commentary

The operation of many passive solar energy systems is dependent upon temperature gradients to get thermal energy into and out of storage and to transport energy from one location to another. The transfer of heat from a solid to an airstream can be a difficult process. The movement of air at speeds greater than natural convection in order to convect heat from a mass surface requires the use of parasitic fan energy. Tolerances for dimensions and airflows can be very small and must be analyzed accordingly. Moderate temperature fluctuations, approximately 6 to 8 degrees F, outside the comfort zone may be appropriate during non-use periods such as night hours.

Consideration must be given to the specific use and occupancy schedule of each identifiable space to ensure the appropriateness of the passive strategy to provide suitable comfort conditions when needed. An example of an inappropriate choice would be the use of a Trombe wall in a commercial building that needs heat only during the day. Mass walls typically have a slow morning warm-up and store heat for use at night, when in this case it is not really needed.

In addition to air temperature, the thermal comfort in interior spaces is affected by the temperature of interior surfaces, air velocity, as well as clothing characteristics of the occupants. The mean radiant temperature (MRT) is as important as air temperature in affecting heat loss and comfort. When air movement is low, the effective temperature is approximately the average of the air temperature and the MRT. The effective use of mass in a building can have a moderating effect on the MRT and, thereby, the interior comfort conditions. A thorough discussion of these factors and design guidelines appropriate for Category I buildings are given in Reference [3].

When passive techniques are employed for cooling purposes, comfort is frequently maintained by providing sufficient air movement to compensate for dry bulb temperatures which exceed the boundaries of the normal comfort zone. These considerations should be accounted for when using the ASHRAE Standard 55-81.

For Category II and III buildings, Reference [2] provides very thorough coverage of specific applications.

2.1.2
Criterion

Habitability. Solar systems used for heating, cooling, lighting, or combinations of these energy requirements shall not adversely affect the habitability or productivity of the occupants of the building.

Evaluation

For thermal evaluation, refer to Section 2.1.1 Space comfort/ interior design conditions for applicable guidelines in determining the suitability of the specified interior design conditions for each conditioned space.

For lighting evaluation, the IES Lighting Handbook, References [4] and [5], gives acceptable lighting levels and calculation procedures for both electric lighting and daylighting systems. All assumptions upon which analysis is based must be explicitly stated.

Commentary

Refer to Section 2.1.1 Space comfort/interior design conditions for appropriate commentary regarding comfort conditions and habitability.

The inclusion of passive solar in commercial buildings may influence the behavior, and, therefore, productivity of its occupants. This effect can be either beneficial or deleterious. A well-designed passive system can create a more pleasant working environment for occupants, whereas a poorly designed and/or operated passive system may diminish worker effectiveness.

The DoE Passive Commercial Buildings Program is conducting a survey of the occupants of the various buildings in the program. Although the majority of the occupants (and users of the building) have reported an increase in satisfaction with the working environment (compared to conventional alternatives), excessive temperature swings, lighting glare and accoustical problems have been reported in some cases.

Additionally, active solar systems, which are usually isolated from the occupied spaces, seldom produce these types of benefits or problems. Also, the problems associated with passive solar systems in commercial buildings are often a result of diminished tolerance and system control by occupants as compared to their residential building counterparts.

2.1.3
Criterion

Hot water design conditions. Hot water temperature and hourly recovery rate shall be specified in the design and shall be suitable for the building category, function, and specific application.

Evaluation — The temperature and recovery rate shall be compared to values given in ASHRAE Systems Handbook, Chapter 37, Service Hot Water, Reference [6], for the appropriate building category and specific use. Combinations of hot water storage and recovery rate may be specified as provided by ASHRAE.

Commentary — See Criterion 4.3.4 for provisions related to health and safety.

2.2 Requirement — Building energy requirements. Solar energy system design shall show evidence of reducing the need for depletable energy sources for each energy end-use to which the system is applied, without significantly increasing depletable energy requirements for end-uses which are not served by the solar energy system.

Commentary — Solar energy systems are typically used in combination with conventional mechanical/lighting systems to provide satisfactory space conditioning (heating and cooling), visual conditions (lighting), and service hot water systems. The solar components may be used to address one of these energy end-uses, or to address any combination of these end-uses.

In most residential solar designs (especially passive designs), the solar elements address a single energy requirement (usually heating) and augment a conventional auxiliary mechanical system of relatively simple control. However, due to thermal and cost-performance limitations, commercial scale solar designs typically include solar elements that address multiple aspects of the energy requirement (lighting, cooling, heating) and, therefore, must be integrated with the applicable mechanical/electrical systems and controlled accordingly.

Traditionally, architects and engineers have focused more on the net heating, cooling, and lighting loads which are met by the mechanical and lighting equipment rather than on the energy input to the equipment to meet these loads. Consequently, decisions are made which have a substantial effect on reducing the net load, but may be of relatively little importance in terms of energy consumption or energy cost. Designers need to understand the choice which must sometimes be made between saving units of energy (such as BTU's or kwh's) and saving the cost of that energy (dollars).

The largely intuitive approach which many designers have developed to address residential energy problems with passive strategies is of little use in the design of most commercial (nonresidential) buildings -- in fact, it may be quite misleading. Many experienced designers have erred by assuming that heating oriented passive strategies were appropriate for buildings with low surface/volume ratios, substantial internal heat generated by people and lights, and "business day" occupancy patterns. This mistaken assumption leads to overly complex strategies, which deliver heat to the building at the wrong time of day, and which may actually increase building operating costs compared to a nonsolar alternative.

Analysis of a reference building can often assist the designer in determining appropriate passive strategies for commercial buildings. In this analysis, energy loads and their costs in a conventional, nonsolar building of identical size, use, patterns of use, and site as the building to be designed, are generally determined. The result of this analysis is the identification of typical energy loads and loading schedules for heating, cooling, lighting, and hot water purposes in a building of the use type under consideration. Such information gives the designer a framework of energy use to which an effective passive solar strategy can then be addressed.

Although the criteria in this section are separated according to individual energy end uses, it should be recognized that the typical commercial building application will make use of solar energy to serve combinations of these end-uses.

2.2.1
Criterion

Space heating energy. Solar energy space heating systems shall reduce the total depletable energy requirement for heating when compared to a reference building of similar size and use, established by an owner, designer or other applicable authority, without significantly increasing other energy requirements.

Evaluation

Review drawings, specifications, and design calculations.

Analysis tools available range from hand calculation techniques, References [7] and [8] to computer analysis programs for hand-held calculators References [9, 10, 11] and mainframe computers References [12, 13, 14, 15, 16, 17, 18, 73]. Reference [19] is a brief survey of passive solar building design computer programs.

Calculations shall take into account the size of the mass, thermal conductivity, absorptance, location relative to solar gain areas, forced or natural convection of air to and from storage and presence of insulating materials such as carpets or hangings over massive floors or walls that prevent direct solar radiation.

Movable insulation may be considered to operate as designed, whether it is manually or automatically operated. Interior space temperature may vary according to occupancy schedules or nighttime setback, and should be accurately reflected in the calculation.

Active space heating systems are usually composed of components which are isolated from the habitable spaces in the building and which interface with the conventional mechanical equipment with automatic controls.

In passive systems, care should be taken to design the solar elements, including thermal storage and controls, to deliver heat to the occupied spaces at the appropriate time. In commercial buildings with high occupancy levels and artificial lighting/equipment use, the internal heat may cause a cooling load on a typical winter day.

Additional thermal mass for thermal storage is not necessarily required for all passive solar heating systems, but the need for additional mass depends on the size of the aperture relative to the size of the heated space. Storage is not needed if solar gains can be utilized directly without causing the interior design temperature to exceed the specified range.

Thermal mass not only affects heating effectiveness, but can also have a pronounced effect on space temperature fluctuations by storing excess thermal energy (either from solar gains or internal gains) until needed or exhausted.

If locating the storage so that it is exposed to direct solar radiation is not practical, it may be remotely located. For large systems this has the advantage of distributing heat to other parts of the building and enabling a very large storage. The low temperature of heat stored by this means, however, makes air-flow heat transfer back to the conditioned space very inefficient and direct thermal coupling of storage space is preferred. Remote thermal mass charged by air may be effective for attached sun spaces but are not advisable for direct gain systems because of the moderate temperatures of any available heat.

For the direct gain zone in general, massive surfaces should be relatively dark in color and low density surfaces should be relatively light. The time delay of thermal conduction should be considered in determining the thickness of passive storage mass. Thermal properties for commonly used storage materials are given in Table B.5 of the Appendix to this document as well as in Reference [20].

In direct gain designs that have a fixed quantity of thermal storage mass, distributing the mass over as large an area as possible will maximize performance and will minimize the thickness of the mass layer. Mass within 4 in. of the surface is more effective than mass at a greater depth because it is more directly coupled with the conditioned space. Floor slabs directly over dry earth, and with perimeter insulation only, will likely have a tempering effect on interior temperatures during long, cold, cloudy periods, although temperatures may drop somewhat.

2.2.2

Criterion

Space cooling energy. Solar energy space cooling systems shall reduce the total depletable energy requirement for cooling when compared to a reference building of similar size and use, established by the owner, designer or other applicable authority, without significantly increasing other energy requirements.

Evaluation

Review drawings, specifications, and design calculations.

Analysis tools available range from hand-calculation techniques, References [7] and [8] to computer analysis programs for hand-held calculators, References [9, 10, 11] and mainframe computers, References [12, 13, 14, 15, 16, 17, 18, 73]. Reference [19] is a brief survey of passive solar building design computer programs.

Commentary

Active and/or passive space cooling systems are usually designed to serve more than one building requirement, except in some buildings which are used only seasonally. Refer to Criteria 2.2.1 and 2.2.3 for additional considerations.

Passive cooling systems in commercial buildings are usually defined to include: natural or fan assisted ventilation (including economizer cycles); shading and other cooling load reduction techniques; evaporative effects; dehumidification; radiant cooling effects; and possibly earth contact. Many of these techniques rely on factors other than the control of dry bulb temperature alone to produce space comfort (see Criterion 2.1.1 and related Commentary).

The opportunity to utilize thermal mass associated with a passive system for cooling is often overlooked due to preoccupation with passive solar heating in building design. When properly designed, thermal mass for heat storage has the potential to provide both heating and cooling in certain climates.

The designer should take precautions to avoid conditions under which the solar components increase the space cooling loads. Active solar collectors, which are a part of the building envelope or connected closely to the building, may transmit heat to to the conditioned interior spaces during the cooling season, particularly if allowed to stagnate. Uncontrolled fluid flow through a heat exchange coil in the space conditioning ductwork may increase cooling energy requirements.

In passive heating systems, components such as direct gain glazing, mass walls (particularly those without seasonal exterior venting), and attached sunspaces or atriums may substantially increase cooling energy requirements, unless appropriate preventative measures are taken. Fixed or movable shading devices, deciduous vegetation, and movable insulation with reflective exterior surfaces are some of the control measures frequently used.

The building storage mass can act as a heat sink and substantially decrease cooling energy requirements. Cooling can result from daytime shading and utilizing nighttime ventilation techniques, either natural or mechanically induced. This strategy is most effective in climates with relatively low nighttime humidity levels and large day/night temperature swings during the cooling season.

2.2.3
Criterion

Lighting energy. Passive solar systems which are designed primarily for daylighting shall reduce the total depletable energy requirement for artificial lighting when compared to a reference building of similar size and use, established by an owner, designer, or other applicable authority, without significantly increasing other energy requirements.

Evaluation

Review drawings, specifications, and design calculations.

Analysis tools available range from hand calculation techniques to analysis programs for handheld calculators and mainframe computers, References [11, 18, 73].

For analysis purposes, the daylighting aperture shall be replaced by an opaque material having the same thermal properties as a typical wall or roof section used on the rest of the building. It must be demonstrated that the building with the daylighting system will use less energy than the building that relies entirely on electric lighting. Compliance need be demonstrated only for the months of January and July. If the criterion is not met for those two months, an annual energy calculation will be necessary. Depletable energy shall be calculated as delivered to the building site. Electric lighting energy savings due to the daylighting system shall be calculated relative to the energy required for standard lighting levels as required by local building codes. Automatic electric light dimming devices or manually operated devices may be assumed to operate as designed. Chapter 9 of the IES Lighting Handbook Reference Volume, Reference [4] gives acceptable lighting and daylighting systems. All assumptions upon which the analysis is based must be explicitly stated.

Commentary

In commercial buildings, lighting is often the largest energy requirement, and, due to the characteristics of the current energy pricing structure, frequently the largest single element in energy cost for a building. Many commercial building designs which use passive techniques are designed to reduce artificial lighting by the use of daylighting. Usually these designs are also intended to reduce the energy required for space heating and space cooling.

Studies of daylighting systems have included comparisons of combined lighting and space conditioning energy requirements with and without electric lighting control devices, Reference [21]. Simply turning down the lighting level in perimeter areas will save electric lighting energy equal to many times any increase in space conditioning energy requirements. Studies have shown that an economic payback period of several years was achieved for the cost of the automatic control devices.

Simulation of a double-domed acrylic skylight in three locations -- Boston, Pittsburgh, and San Diego -- resulted in net annual energy savings for each location, both with and without building mechanical space cooling, Reference [22].

Experimental studies at the National Bureau of Standards, Reference [23], have indicated that the use of daylighting can reduce the combined space conditioning and light energy requirements when proper window management is used.

A general discussion of daylighting system design is given in Reference [24]. Lighting of perimeter zones with windows, intermediate zones with lenses and reflectors, and deep zones with tracking reflectors, concentrators, and light conduits, are discussed. The IES Lighting Handbook, Reference Volume, Reference [4], includes a chapter on daylighting, and the corresponding Applications Volume, Reference [5], includes a chapter on energy management of lighting systems.

2.2.4
Criteria

Service water heating energy. The combined solar and auxiliary service hot water system shall be capable of providing service hot water at the required temperature and delivery rate. The system shall reduce the requirement for conventional energy.

Evaluation

The temperature and recovery rate shall be compared to values given in ASHRAE Systems Handbook, Chapter 37, Service Hot Water, Reference [6], for the appropriate building category and specific use. Combinations of hot water storage and recovery rate may be specified as provided by ASHRAE.

Commentary

Service hot water systems may be of the passive or active type. Thermosiphon collection loop systems are considered to be of the active type, because of the existence of mechanical components such as solar collectors, pipes, and heat exchangers. Active systems are often categorized by type of solar collection loop. For example, there are pumped or thermosiphon systems, and direct or indirect systems, depending on whether the potable water circulates through the collectors. Indirect systems usually employ an antifreeze solution as a collection fluid and one or more heat exchangers in the collection loop. On the load side, recirculation systems continuously circulate hot water to the use points so that hot water is available at all times at each use point. If the solar service hot water system is combined with a solar space conditioning system, this requirement applies to the combined system to the extent sufficient to show that the service hot water function is met.

2.3
Requirement

System design capacity. The solar energy systems,in combination with conventional HVAC and lighting systems utilizing conventional energy sources, shall be capable of maintaining space comfort conditions, lighting conditions, and service hot water at the levels required for the normal intended use of the building. The inclusion of solar energy systems shall not increase the demand rate (the instantaneous requirement for energy) of conventional energy sources above that caused by similar buildings not using solar energy.

Commentary

Electrical demand, or the instantaneous requirement for electricity which a building places on a utility, is a factor which must be considered in any design, but particularly in solar commercial buildings. It is important to the owner to know the magnitude of both consumption (kilowatt hours per month) and peak demand (maximum rate of usage in kilowatts). Frequently, demand charges are the major portion of an electrical service bill.

Passive systems installed in commercial buildings can have a more significant effect on electrical peak demand than other types of solar buildings because of the direct integration of the solar elements and the type of energy requirements which solar can displace. For example, daylighting is frequently used as a passive technique in commercial buildings, displacing some of the electrical demand for lighting. Daylight also has a higher luminous efficacy than most artificial lights (greater lumens per watt) resulting in a diminished cooling load. If the building is operated properly, the use of daylighting will reduce electrical demand by (1) lessening the requirement for electricity for artificial lighting and (2) reducing the cooling load which must be met by the mechanical system. If, however, the artificial lights are not dimmed or switched off when sufficient daylight is available, the electrical demand will probably increase since the mechanical system must meet the combined cooling load imposed by the artificial lighting and the solar gain through the glazing.

2.3.1
Criterion

Heating system design capacity. The solar energy heating system, including the auxiliary,shall have the capacity of maintaining, in conditioned spaces, the minimum interior design temperature specified under Criterion 2.1.1 at the 97-1/2 percent winter outdoor design conditions.

Evaluation

Design load calculation shall exclude instantaneous solar gains and internal heat release from occupants,lights,and appliances. A building heat loss calculation procedure comparable in detail to the method outlined by ASHRAE, References [25] or [20], Chapter 21, Infiltration and Ventilation, Chapter 22, Design Heat Transmission Coefficients, Chapter 23, Weather Data and Design Considerations, and Chapter 24, Heating Load, shall be used. For heat loss calculations, exterior thermal storage walls associated with passive solar components shall be assumed to be at room temperature. The design load may be reduced by an amount equivalent to the rate of energy released from thermal storage within the building mass if shown to be appropriate for the historical frequency of occurrence of low ambient temperature and solar radiation. (These frequency distributions must be documented by the designer.) For discussion of typical storage capability and sizing procedures see Reference [26]. At design load conditions, all movable passive solar components shall be considered to operate as designed. Reference [26] provides acceptable methods of design of conventional space heating systems that are also useful for solar energy systems.

Commentary

The intent of this criterion is to insure that the heating system is sized properly to meet winter design conditions. It is not intended that control of interior conditions to meet the specified interior design conditions be accomplished at all times.

The system performance on the basis of annual depletable energy use is covered under Requirement 2.9, System performance.

The relationship between the size of the solar energy heating system and the auxiliary heating system is not covered here. No minimum solar contribution to the heating load is required.

Solar contribution is covered indirectly under Requirement 2.9, but the issue of the size of the solar system relative to the load is an economic one, and, therefore, outside the scope of the Performance Criteria. The only concern here is that the combined solar and auxiliary heating system can meet design conditions.

Chapter XII of Reference [27] provides a comprehensive description of considerations in the design of solar space heating systems. References [28] and [29] describe some problems encountered in heating system design in the National Solar Demonstration Program.

2.3.2
Criterion

Cooling system design capacity. The solar energy cooling system, including the auxiliary, shall be capable of limiting the temperature and relative humidity in conditioned spaces to the maximum specified under Criterion 2.1.1 at design cooling conditions.

Evaluation

Design cooling conditions shall include the 2-1/2 percent summer outdoor design conditions, (Chapter 23 of Reference [20]), maximum solar heat gain, maximum design occupancy, internal heat generation,heat gain due to passive solar heating systems, and all sensible and latent load due to active solar energy equipment. A building cooling load calculation procedure comparable in detail to the method outlined in Reference [20], Chapters 21, 22, 23, and 25 or Reference [25] shall be used. The design load may be modified due to the operation of passive components such as shading devices or movable insulation and due to thermal storage within the building mass if justified by statistical analysis of weather patterns. For small single-zone buildings, the design load may be calculated using the simplified procedure described in Reference [20], Chapter 25.

Commentary

The space cooling system must maintain comfort conditions when passive solar components for space heating and/or mechanical components for water heating are operated as designed. Reference [6], Section I, provides recommended design criteria for conventional space cooling systems that are also useful for solar space cooling applications. Chapter XIII of Reference [27] provides a description of several methods that directly utilize solar energy for space cooling. Reference[28] describes some generic system problems encountered with space cooling system designs from the National Solar Demonstration Program and References [30] and [31] provide a summary of measured thermal performance of several of the instrumented space cooling systems. References [32] and [33] describe applications of cooling systems for commercial buildings.

Air conditioning equipment utilizing conventional energy, ambient air, ground sink, or stored thermal energy may be used in conjunction with the solar system in an assist or auxiliary mode. The use of evaporation, nocturnal radiation, desiccant cooling, or other passive techniques should be designed to operate in conjunction with devices that collect, store, or distribute the converted thermal energy in a controllable manner.

2.3.3 Criterion — Lighting system design capacity. The combined natural and artificial lighting systems shall be capable of providing the required lighting conditions for performance of the tasks for which the building is designed.

Evaluation — Design lighting conditions shall be selected based on the illuminance selection procedure (Appendix A of Reference [4]) developed by the IES. Using this quantity of light, the lighting system can be designed using the average luminance (or zonal cavity) calculation procedure (Chapter 9 of Reference [4]). Actual coefficient of utilization tables for proposed equipment used in this calculation procedure should be generated by an independent testing laboratory to ensure accurate and uniform data.

The artificial lighting system can be reduced to evening use requirement levels if daylighting will provide the supplemental lighting required during daylight hours. Daylighting levels should be determined for the worst case condition (i.e., 8 a.m. in December) and the occupants must realize the reduced lighting levels will occur during evening hours or worst-case conditions.

Task lighting systems shall be sized to provide the quantity of light described above; however, calculations should be done using the point calculation methods (Chapter 9 of Reference [4]). This lighting system should include both task lights and a general lighting system which provides a minimum task to surround luminance ratio 3:1.

Commentary — Historically, lighting systems have been designed using rules-of-thumb and intuition which are based on constant worst-case conditions. This design procedure has caused many spaces to be overlit and/or underlit. The average luminance calculation procedure has been selected because it relates room conditions, light level, and actual fixture efficiency to arrive at the proper quantity of fixtures and/or lamps required. (The actual fixture efficiency is very important with today's new higher efficiency fixtures.) The lighting system should be sized for a maintained level of light (i.e., including maintenance factors). Designers and owners should realize the benefits of improved maintenance procedures. Group lamp replacement, annual fixture cleaning, and higher quality equipment can reduce the required number of fixtures and, therefore, reduce depletable energy consumption.

This procedure does not account for the quality of the lighting system which can have a large effect on energy consumption. Lighting quality can be described by Equivalent Sphere Illumination (ESI) and/or Visual Comfort Probability (VCP). A system (which includes both equipment and layout) with a higher ESI and VCP may actually require less footcandles to give the same user comfort and efficiency. This higher quality system may reduce depletable energy consumption while maintaining habitability of the space.

Many analysis tools are available to determine daylighting levels in a space; however, the most accurate and most informative still remains the three dimensional, built to scale model. New weather data are being made available to determine the worst-case condition described above.

No matter how efficient the final lighting system is, additional energy can be saved through the use of manual and automatic controls. Separately switched lights can allow unneeded lights to be kept off. Photocell controls can dim or switch-off lights when daylighting is adequate. Motion detector switches can be useful in seldom used spaces such as conference rooms and private offices. Energy management systems can be used to turn off lights during unoccupied hours, or adjust the levels for cleaning and maintenance operations. Care should be taken in selecting the appropriate control for each lighting system.

Energy saving lamps and ballasts are another way to reduce energy consumption. New high efficiency lamps can give the same quantity of lumens for less watts; however, designers should be aware of possible problems such as color rendition, lamp life,and compatibility with ballasts and switching/dimming controls.

2.3.4
Criterion

Water heating system design capacity. The combined solar and auxiliary water heating system shall be capable of providing the design hot water temperature and recovery rate specified under Criterion 2.1.3.

Evaluation

Documentation shall be provided to show that the temperature and recovery rate (or combined recovery rate and storage capacity) of the auxiliary water heating system are capable of meeting the design load. Average cold water supply temperature for the month having the lowest water temperature shall be stated and used for calculation of design load. If the auxiliary water heating system is not sized to meet the design load alone, it must be shown that the combined solar and auxiliary water heating system can meet the design load at all times. In this case, the solar heat collection and storage system must be able to maintain a sufficient quantity of water at an elevated temperature (relative to that of the cold water supply)at times of design hot water usage so that the auxiliary system can meet the reduced load.

Commentary

In most systems the auxiliary system is sized to meet 100 percent of the design load. There may be applications, however, for which it is more efficient to allow a reduced-size auxiliary system. Storage of a large volume of solar-heated water and an elevated temperature during cloudy periods can result in high heat losses (see Criterion 2.5.1, Thermal energy loss and Criterion 2.8.2, Storage size).

Chapter 37 of the ASHRAE Systems Handbook, Reference [6] provides design guidance for design of water heating systems for a variety of applications.

2.4*
Requirement

Collector array. The solar collector array shall be capable of of absorbing solar radiation and converting it to useful thermal energy for providing the functions of space heating, space cooling, and/or service water heating under expected operating conditions.

Commentary

The collector array normally consists of several individual collector units connected by a manifold and positioned to receive maximum or near maximum solar radiation. The total collector array must be properly designed to assure effective energy transfer to the other parts of the active solar energy system, the storage or point of use.

2.4.1
Criterion

Collector orientation. The collector array shall be positioned to provide the maximum usable collected solar energy on an annual or seasonal basis depending upon the type of system. If special circumstances require a different orientation, the resulting reduced performance shall be determined and stated in the design documentation.

Evaluation

Solar radiation for the geographic location, orientation of the collector array type (stationary or tracking), shading (external shading and self-shading by other collectors in the

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* Note: Requirements 2.4 through 2.8 address active solar energy system components and their integration, assuming conventional active system design. Innovative or nonconventional active system components and subsystems do not have to meet specific criteria under these requirements if they are not applicable. However, it must be shown that innovative active components or subsystems do meet the intent of these requirements.

array), and building shape and orientation shall be considered in determining the optimum collector orientation. The system type (space heating and/or cooling and/or water heating) and daily profile of energy use shall also be examined. Collector orientation factors are given for converting radiation on a horizontal surface in Chapter 3 of Reference [34].

Commentary

Situations in which collectors are placed on existing buildings may result in deviation from thermally optimum orientation. Typically, annual or seasonal incident solar radiation should not be less than 80 percent of the radiation for the same period that would be received at the optimum orientation. In general, stationary collectors should face due south and have a tilt angle equal to (a) local latitude for water heating only, or for combined space heating and cooling, (b) local latitude minus 15 degrees for space cooling only, and (c) local latitude plus 15 degrees for space heating only or combined space and water heating. Single-axis tracking collectors may be oriented north-south or east-west, depending on site and and system requirements.

High-rise buildings with small roof areas or unfavorable building orientation may require special architectural integration and preclude thermally-optimum orientation of collectors, yet the solar systems may be technically and economically appropriate.

Tilt deviations of +15 degrees from the above values and azimuth deviations of 20 degrees east and 30 degrees west of true south will not likely decrease performance by more than 10 percent. Local conditions such as shading or fog, or the particular advantage of emphasizing morning or afternoon gain should be considered. It is often desirable to orient the collectors toward the east of due south when the collected solar energy can be used during the daytime.

2.4.2
Criterion

Individual collector performance. The thermal efficiency of the individual collectors as installed in the array shall not differ significantly, relative to single-collector tests, due to flow rate or fluid properties over the design operating range.

Evaluation

Procedures equivalent in accuracy to ASHRAE Standard 93-77, Reference [35], shall be used to determine the efficiency curve of the single-collector test. Post-stagnation test as given in Section 10 of Appendix A (modification of test in NBSIR 78-1305A, Reference [36]), is required.

Three primary factors must be taken into consideration when calculating array performance relative to the single-collector test. First, the average flow rate through the array may differ from the test flow rate. Second, the flow rate through the lowest-flow collector in the array may be less than the average flow rate due to imbalance of flow among the collectors. Third, the heat transfer properties of the actual collection fluid may differ from the properties of the fluid used in the single-collector test. Each of these three factors shall be evaluated.

Determination of the flow rate through the lowest-flow collector in the array is difficult, and there are no readily-available, simple methods for doing this. Some collector manufacturers have empirical data for flow rate through each collector in certain array configurations. Some engineering firms and collector manufacturers have computer programs for performing the iterative calculations necessary to determine the flow rates through all collectors in the array, but agreement with measured data is not always good. The viscosity of some fluids changes with temperature in the collector operating range, and the transition between laminar and turbulent flow cannot easily be predicted for many situations.

Reference [6], pages 236-244 and 266-268, may be used to determine loss in efficiency due to flow rate and fluid property changes. Reference [37] gives the effect of flow rate on a typical air-type collector and also gives typical collector efficiency curves. A revised collector efficiency curve for an average-flow-rate collector and one for the lowest-flow-rate collector in the array shall be constructed.

Any significant decrease in performance in the design operating range shall be justified on the basis of rational system design trade-offs. Such trade-offs may include the following conditions: Use of a liquid with a lower specific heat than water may be necessary for freeze protection or for corrosion prevention. Lower average flow rate may result in significant reduction in operating power for fluid circulation (see Criterion 2.6.2). Variable-flow collection systems may be very energy efficient, although the flow rate may not equal that used for the single panel test at all times.

Commentary

The performance of the average-flow-rate panel as installed in the array will be required as an input to the system performance calculation under Requirement 2.9.

The middle collectors in parallel arrays tend to have reduced flow and therefore run hot. To alleviate this, a high ratio of pressure drop across any collector to the pressure drop across the manifold is required. The minimum flow through a collector is important, but it is not necessary to have equal flow to all collectors in the array. In large arrays, acceptable flow variations may be as great as 3 to 1 in individual collectors, while maintaining the required minimum flow in the lowest-flow collector. Reverse return arrangement of manifolds helps to balance the flow to individual collectors. Too many collectors in series tend to increase the inlet temperature of the last collectors and should be avoided. Experimental studies, Reference [38] of the influence of flow rate and fluid type in a broad class of flat plate collectors resulted in thermal performance variations of up to 10 percent. Experience in the National Solar Demonstration Program has shown cases of extremely low flow rates in central collectors in parallel arrays, resulting in hot conditions that caused permanent damage to the collectors.

In the case of site-built collectors for which no test data are available, the flow rate at each major branch in the array should be documented and balanced. The methods given in Reference [39] may be used to predict the performance of the collector array. The balance of flow to all parts of a site-built array is important whether individual collectors are used or the array is built as one unit, such as an integral part of a building roof.

2.4.3
Criterion

Manifold thermal loss. Under typical conditions during the coldest month of system operation,the rate of thermal loss from pipes or ducts within the collector array shall not exceed 10 and 15 percent of the solar energy collection rate for liquid and air systems, respectively.

Evaluation

This is an instantaneous calculation. Both the rate of thermal loss and the solar energy collection rate must be calculated for the following conditions:

1. Time of year: coldest month of system operation, usually January in most of the continental United States.

2. Solar irradiance: 70 percent of the clear sky value at noon for the coldest month.

3. Ambient temperature: normal high for the month as given in the U. S. Climatic Atlas.

4. Collector fluid inlet temperature: minimum usable storage temperature or use temperature.

Additional information to be provided by the designer includes the collector efficiency curve, the air leakage rate (for air systems), and insulation thickness and conductivity. The solar energy collection rate can be calculated as the product of the solar irradiance on the collector surface, the collector area, and the instantaneous collector efficiency (at the given fluid inlet temperature, ambient air temperature and collector orientation). The collector efficiency curve shall be based on flow rates and fluid properties as discussed under Criterion 2.4.2, Individual collector performance. Thermal loss from the manifolds shall be calculated using standard procedures such as given by ASHRAE, Reference [20].

Commentary

The collector array includes all collector panels and associated piping or ducts to the point where there is only one inlet and outlet. Thermal loss from internal manifolds and within individual collector panels is taken into consideration in the panel performance (Criterion 2.4.2) and is not included in this criterion. Typical manifold thermal loss levels that have been achieved in the National Solar Demonstration Program are less than 10 percent of the solar energy collection rate for liquid systems and 15 percent for air systems. Air leakage from ducts can significantly increase thermal energy loss (see Criterion 3.3.4 for specification of allowable air leakage). Maintaining a slightly subatmospheric pressure in the collector array, resulting in air leakage into the array, causes less decrease in thermal performance than leakage out of the array, Reference [40]. Reference [41] provides a simple analytical technique for analyzing the thermal effects of collector air leakage. A similar procedure for analyzing the effect of thermal loss from collector supply and return ducts or pipes on system performance is described in Reference [42]. Chapter 9 of Reference [43] recommends suitable insulation type and thickness for collector array manifold pipes and ducts. Reference [44] describes methods for determination of economically optimum insulation thickness. The solar irradiance value of 70 percent of the noon clear sky level represents approximately the average value over the day. (For a sinusoidal function, the average power is equal to 0.707 times the peak amplitude. Clear-sky solar irradiance follows approximately a sinusoidal function over the day.)

2.4.4
Criterion

Thermal loss during noncollection periods. During the coldest month of system operation, daily thermal loss from the collector array and all exterior pipes or ducts, when not in a heat collection or rejection mode of operation, shall not exceed 10 percent of the daily collected solar energy.

Evaluation

This is a cumulative energy calculation over a typical 24-hour day during the coldest month of system operation, which is usually January. Thermal loss from the collector panels, pipes or ducts exterior to the building, must be included. Thermal loss due to thermosiphoning, capacitance effects (cool down at night), and freeze protection shall be evaluated separately and then totaled. If the collectors are above the storage, remain filled, and the configuration permits thermosiphoning, check valves or backdraft dampers must be present to prevent reverse thermosiphoning when the collectors are colder than storage. When the collection fluid remains in the collector during operation, daily thermal loss due to capacitance effects must be calculated. Thermal loss due to capacitance effects is equal to the product of fluid mass in the collectors and exterior piping or ducts, fluid heat capacity, and the difference between the temperature of the hot fluid at the time of system shutdown and the temperature to which it cools (normal ambient low for the month). It can be assumed that the collection system will shut down once a day. Thermal loss due to freeze protection (draindown, fluid circulation, etc.) shall be calculated for an average day in the coldest month. If circulation of liquid from storage is used as the freeze protection method, thermal loss from collector and exterior piping shall be calculated for the length of time liquid is circulated. Reasonable values shall be assumed for ambient temperature, storage temperature, insulation of pipes or ducts, and the thermal loss factor of the collectors. The time of freeze control circulation shall be calculated based on control strategy, length of day, percent possible sunshine, and statistical ambient temperature data. Reference [45] gives mean number of days having minimum temperature of 32°F (0°C) and below for the month of January for various locations. Energy loss due to other methods of freeze protection such as heat tapes shall be included. Energy collected for the day shall be calculated on the basis of average conditions of solar irradiance and ambient temperature. Collection fluid inlet temperature shall be assumed to be equal to the minimum usable storage temperature.

Commentary

Some collector designs reduce the possibility of thermal loss due to reverse thermosiphoning; for example, those having inlet and outlet at the same elevation. Draining of all liquid from collectors and exterior piping to the storage tank when energy is not available (collector drain back system) eliminates thermal loss due to thermosiphoning, capacitance and freeze protection and is recommended for many applications. The effect of leakage past dampers in air type systems is discussed in Reference [46]. Leakage past dampers that serve to isolate the collector loop from the rest of the system should be limited to two to five percent. Spring-loaded check valves should be considered for preventing thermosiphoning in liquid systems. See Criteria 3.2.9 and 3.3.3. The noncollection period addressed in this criterion does not include shutdown for servicing or repairs.

This criterion is directed toward active collector systems but consideration must be given to losses from thermal mass collector/storage components, such as Trombe walls. Guidelines for such components have not yet been developed but the principles governing energy transfer during application should be addressed in estimating actual performance of such components during non-collection periods.

2.4.5
Criterion

Thermal energy dissipation. Collectors used for thermal energy dissipation shall be capable of dissipating thermal energy at the required rate.

Evaluation

Collector thermal loss rate may be estimated using the slope of the ASHRAE 93-77, Reference [35], test efficiency curve, and adjusted for the effect of the collector loop heat exhangers, if any. The slope of the collector efficiency curve, $F_R U_L$, multiplied by the collector area and the difference between ambient and fluid temperatures, will give a conservative value of the rate of thermal energy dissipation, and is satisfactory for design purposes. More accurate (and higher) values of energy dissipated may be calculated using more refined analyses that consider the effective temperature of the night sky, if thermal energy dissipation occurs at night. Compliance must be demonstrated for the time of day and time of year that represent the most demanding performance as specified in the design.

Commentary

Collectors may be used as a thermal sink for heat pumps operating in the cooling mode. They may also be used to cool the system at night to dump thermal energy that is not needed. For example, collectors in a solar heating system may be operated to collect thermal energy during summer days and reject it at night to prevent the collectors from reaching extremely high temperatures. See Criterion 2.6.5 for provisions covering non-collector thermal energy rejection equipment such as cooling towers. See Criteria 3.5.3 and 4.3.2 for provisions regarding system pressure and temperature relief controls.

Efficient solar collectors are inherently inefficient thermal rejectors, especially designs utilizing selective coated absorbing surfaces, multiple glazings or evacuated tubes. It can be difficult to reject at night the amount of thermal energy collected during a typical sunny day.

2.5
Requirement

Thermal storage. The thermal storage subsystem shall be capable of efficiently accepting thermal energy, storing it, and releasing it to partially or fully satisfy the space heating, space cooling, and/or water heating load(s).

Commentary

Refer to Section 2.8 for criteria concerning the size of thermal storage and its effect on system performance.

2.5.1

Criterion

Thermal energy loss. Thermal energy loss from thermal storage shall not exceed 15 percent of the energy input to the storage subsystem for any month in which the load exceeds the collected solar energy.

Evaluation

Conductive thermal loss or gain through insulation, losses through storage container structural supports, and losses due to air leakage shall be examined and documented. Underground storage containers must be insulated. For purposes of calculation of energy loss, the storage temperature may be assumed to be the minimum usable storage temperature.

For other than service hot water storage only and when such thermal loss does not have an adverse effect on the cooling load, thermal energy losses that can be traced directly to heated spaces and, therefore, reduce the heating load are not required to be included in the 15 percent limitation.

Commentary

Specification of allowable air leakage from thermal storage containers is given in Criterion 3.3.4. Storage containers for air systems should be sealed in accordance with Criterion 3.3.2. See also Criterion 3.1.3 for insulation requirements.

Typical measured values in the demonstration program show thermal loss as low as five percent of the energy input to storage during the heating season for liquid collection and storage systems. Reference [26], page 19,gives a simple calculation procedure for determining the required insulation to limit thermal loss to two percent in 12 hours.

It may be justifiable to keep thermal losses from storage well below the levels specified by this criterion, so that the adverse effect on the cooling load during summertime operation will be kept small.

The high temperature of active cooling system hot storage places extra emphasis on thermal energy loss. Delivery of solar energy directly to the chiller, bypassing storage, reduces storage losses and delivers higher temperatures. For cooling systems that provide a small fraction of the cooling load with solar energy, it is possible to design the system without large hot water storage tanks, using only a small buffer tank to prevent frequent cycling of the absorption chiller. For applications dominated by cooling loads, hot storage should be outside of the conditioned space. Experience in the National Solar Demonstration Program, Reference [31], shows that cold storage energy gains offset savings accrued by means of off-peak electric chiller operation.

Thermal energy transferred from space heating and hot water systems to the conditioned space during the summer months must be accounted for in the calculation of design cooling load for the mechanical cooling system (see Criterion 2.3.2, Cooling system design capacity).

2.5.2 Criterion

Thermal stratification. Means to promote thermal stratification in the hot thermal storage subsystem shall be used to increase overall system efficiency whenever practical.

Evaluation

The shape, number, and arrangement of the storage container(s) shall be examined. The location of inlets and outlets and the velocity of heat transfer fluids into and out of the container shall be designated on the drawings. The direction of fluid flow, especially through rock bins for air systems, shall be noted in the documentation for each mode of system operation. Baffles in tanks and the location of auxiliary heat input to the storage container shall be examined.

Commentary

Thermal stratification in the storage container is usually desirable in order to provide low collector inlet temperatures and to provide high temperatures to load or equipment. Consideration should be given to trade-offs between stratification and thermal losses from a second tank in the case of solar water heaters. F-CHART, Reference [34], assumes fully mixed storage; however, improved thermal performance may be achieved in practice with stratified storage.

It has been shown that the thermal performance of a well-insulated tank in the demonstration program could be greatly improved by eliminating short-circuiting from inlet to outlet by means of baffles.

In single-tank HW systems, the auxiliary heating unit should be placed at approximately the upper third of the tank to promote stratification. Short-circuiting of water flow paths between the inlet and outlet of storage should be prevented. Reference [47] describes the effect of stratification by use of mathematical models.

Gas-fired water heaters are becoming available with the heater placed midway up the tank to allow thermal stratification for use with small solar energy systems.

In existing buildings, it may not be practical to make full use of thermal stratification due to physical space restrictions. For example, a horizontal tank may be more practical than a vertical one.

It is good practice for air system rock beds to have the vertical dimension as large as practical, and supply hot air to the top as well as draw hot air from the top for heating purposes. When vertical construction is not possible, horizontal rock beds can be stratified horizontally with proper flow directions of hot and cooler air.

The dependence of collector array efficiency on thermal stratification and hence, inlet temperatures to the collector array has been indicated by a statistical analysis of storage temperatures and corresponding collector array efficiencies. Average storage temperatures in space heating systems with better than average collector array efficiency was 102°F, whereas systems with worse than average collector array efficiency had storage temperatures averaging 112°F, Reference [48].

2.5.3
Criterion

Auxiliary energy to thermal storage. Auxiliary energy added to the solar energy storage container shall not significantly reduce system performance.

Evaluation

If auxiliary energy is added to the thermal storage container, it must be shown that any reduction in collector performance will be offset by reduced thermal energy loss due to fewer numbers of storage containers, less surface area for energy loss, or the ability of the collectors to provide thermal energy to reduce standby losses that would otherwise have been made up using auxiliary energy. Stratification must be maintained in the storage container to prevent auxiliary/heated fluid from being transferred directly to the collector inlet.

Commentary

The addition of auxiliary energy to thermal storage containers can severely decrease collection efficiency by increasing collector inlet temperature.

It is advisable to keep the solar and auxiliary systems separate, and in parallel, if possible. Auxiliary energy may be added to thermal storage if thermal stratification is preserved.

See Criterion 2.5.2 for discussion of stratification.

2.6
Requirement

Energy transport. The energy transport system shall be capable of efficient transfer of thermal energy among the various components and subsystems.

Commentary

The energy transport system typically consists of insulated pipes or ducts, pumps or blowers, heat exchangers, and a working fluid such as water or air.

Efficient energy transfer requires low thermal losses (or gains), low operating power to move fluids, and proper sizing of heat exchangers.

2.6.1 Criterion

Thermal energy loss. During normal operation, the rate of thermal energy loss from any energy transport subsystem shall not exceed 15 percent of the rate of energy input to that subsystem.

Evaluation

The energy loss from the energy transport subsystem shall be calculated and documented to be less than or equal to the allowable limit established in the above criterion. Energy input to the collector-storage loop, for example, can be calculated by multiplying the temperature difference between the inlet and outlet to the heat exchanger on the storage side by the mass flow rate and specific heat of the fluid. Fluid temperature shall be assumed to be the highest (lowest for cold fluids) that would occur during normal operating conditions. Ambient temperature to which thermal energy is lost shall be assumed to be average room temperature if in a conditioned space, average expected temperature if in a semiconditioned space, and average monthly outdoor temperature for the coldest month if outside. This is an instantaneous calculation similar to Criterion 2.4.3, not a cumulative energy calculation as for Criterion 2.4.4.

For other than service hot water systems and when such thermal loss does not have adverse effects on the cooling load, thermal energy losses that can be traced directly to heated spaces and, therefore, reduce the heating load, are not required to be included in the 15 percent limitation. Specification of allowable air leakage from the primary solar duct system is given in Criterion 3.3.4.

Commentary

It has been found in air systems that there may be approximately a one-to-one correspondence between the percent of air leakage and the loss of thermal efficiency of the system, based on computer modeling of a typical residential air-collection heating system, Reference [40]. In other words, a 10 percent rate of air leakage could increase the energy use of the solar energy system by about 10 percent relative to a zero-leakage system. This may apply to small commercial buildings with similar solar energy system designs.

This criterion does not apply to the air distribution system within the conditioned space (see Reference [49], Sections 5.10 and 5.11 for pipe and duct insulation guidelines). Typically, thermal loss should be less than 5 percent of the energy transferred for liquid systems, and 10 percent for air systems under normal operating conditions. Collector-to-storage losses for systems in the Federal Demonstration Program are as low as 3 percent of the collected solar energy. Reference [50] discusses the effect of energy transport losses on the thermal performance of solar energy systems. Chapter 9 of Reference [43] indicates insulation thickness for pipes and and ducts for residential applications, which may be applicable to commercial buildings.

There is concern that thermal loss from the energy transport system, especially by means of air leakage, could significantly degrade the control of energy flow.

If thermal losses from the energy transport system are maintained at the levels specified by this criterion, the adverse effects upon the system to meet the cooling load during any summertime operation should be acceptably low.

2.6.2

Criterion

Operating power. During normal operation, operating power for circulating the solar collector heat transfer fluid shall not exceed 10 percent of the rate of solar energy collected.

Evaluation

Steady state heat transfer calculations are required to document that the operating power limit is not exceeded. This is an instantaneous calculation (as in Criteria 2.4.3 and 2.6.1), not a cumulative energy calculation (as in Criteria 2.4.4 and 2.5.1). Power is energy per unit time. Pump or blower electric input power is a function of the volumetric fluid flow rate, the differential pressure across the pump or blower, the pump or blower efficiency, and the electric motor efficiency. Typical pump or blower efficiencies are about 50 to 70 percent, and motor efficiencies are from 80 to 95 percent. Alternatively, the pump or blower manufacturer's power curve can be consulted at the proper flow rate and differental pressure.

For example,to evaluate operating power for the solar collector subsystem, the rate of collection of solar energy is calculated based on the following conditions:

1. Time of year: coldest month of normal system operation, usually January.

2. Solar irradiance: 70 percent of clear-sky irradiance at solar noon.

3. Ambient outdoor temperature: normal daily high for the month.

4. Collector inlet temperature: minimum usable storage or use temperature.

Additional information to be provided by the designer includes the collector efficiency curve, the air leakage rate (for air systems), and insulation thickness and conductivity. The solar energy collection rate can be calculated as the product of the solar irradiance on the collector surface, the collector area, and the collector efficiency (at the given fluid inlet temperature and ambient air temperature). The collector efficiency curve shall be based on actual flow rates and fluid properties as discussed under Criterion 2.4.2, Individual collector performance. The rate of solar energy collection is a power quantity.

Commentary

Under normal operating conditions, operating power should not exceed 5 percent of the rate of energy collection for liquid systems or 10 percent for air systems. Reference [51] includes values for operating power in thermal performance analysis of selected projects in the National Solar Demonstration Program.

The use of thermosiphon loops can be very effective in reducing operating power where feasible.

Typically near the end of the day, just prior to collection system shutdown, there may be a very small temperature differential between collector array inlet and outlet, and the rate of collection of solar energy may be only slightly greater than the collection loop operating power. This is in accordance with proper design practice, and is not intended to be prevented by this criterion. This criterion only applies to the specific conditions specified under the evaluation above.

2.6.3
Criterion

Collector loop energy transfer. If a heat exchanger is used in the solar collection loop, the energy transfer surface area shall be compatible with the energy to be collected and allow the collectors to operate in an effective manner.

Evaluation

The heat exchanger effectiveness shall be reviewed under average operating conditions and peak design conditions. Factors such as the heat transfer fluid flow rate, fluid properties, average and peak solar irradiance on the collection surface, collector area, collector efficiency curve, and storage or use temperature shall be considered as these variables influence overall performance, Reference [52]. For thermosiphon or drain-down systems, fluid flow rates shall be estimated considering the piping size, height of storage above the collectors, and the collector hydraulic characteristics.

Commentary

Reduced collector loop energy transfer rate will result in high collector temperature, and hence reduced collection efficiency. The approach temperature difference for the heat exchanger should be as low as practical, 5°F-15°F (3°C-8°C), as recommended in Reference [53].

The presence of a heat exchanger between storage or load and the collectors effectively increases the temperature of the fluid entering the collectors, and therefore reduces collection efficiency. The effect can be particularly significant in the case of air-to-liquid heat exchangers. Air-type collectors should only be used when air can be supplied to the load or storage, as for space heating systems. Preheating of make-up air directly is a very efficient strategy because no heat exchanger is required.

2.6.4

Criterion — Energy transfer to load. If a heat exchanger is used between storage or collector array and the load, the heat transfer surface area and rates of fluid flow shall be adequate for effective operation of the storage and/or collectors and for transfer of energy at a rate to satisfy the design load.

Evaluation — Heat transfer surface area, fluid flow rates, and design load shall be reviewed. Design loads as determined under Criteria 2.3.1, 2.3.2, and 2.3.4 shall be used in the calculations.

Commentary — Liquid-to-air heat exchanger coils in space heating ducts must be sized large enough to adequately transfer heat at typical collector or storage outlet temperatures.

It is important that hot water heating coils be large enough to avoid unnecessary use of auxiliary energy. Information is readily available from manufacturers on heat exchanger performance parameters. Typically, the temperature ranges will be somewhat lower for solar applications and should be reflected in the calculations and documentation.

2.6.5

Criterion — Thermal energy rejection. Thermal energy rejection equipment shall be capable of rejecting thermal energy at the required rate.

Evaluation — Compliance must be demonstrated for the time of day and time of year that represents the most demanding thermal energy rejection requirement as specified in the design of the system. It shall be shown that under these conditions the equipment will operate within the range specified by the manufacturer.

Commentary — This criterion covers non-collector thermal energy rejection equipment such as cooling towers. See Criterion 2.4.5 for provisions regarding the use of solar collectors as thermal energy rejectors. Thermal energy rejection equipment may be located within the collector array or external to it. One of the main purposes of this type of equipment in solar energy systems is to protect the solar collectors from overheating when they are not designed to stagnate. When storage is at its maximum allowable temperature, any thermal energy collected must be able to be rejected by the thermal energy rejection equipment. Therefore, this equipment should be capable of dissipating thermal energy at the maximum solar energy collection rate, and for the maximum allowable temperature conditions (storage, collectors, or specific equipment limitations).

2.7
Requirement

Controls. The control subsystem shall be capable of proper and efficient regulation of other components of the system to fulfill the space heating, space cooling and/or water heating system requirements.

Commentary

Simpler control subsystems have been found to be as efficient as complicated ones and are often less prone to malfunctions. Extensive coverage of control system design is presented in Reference [54]. For commercial buildings with cooling capability the complexity of the control system will generally increase.

2.7.1
Criterion

Sensor location. Control sensors shall be located and installed so that they will accurately measure the desired variable for correct system operation.

Evaluation

Examine the placement of sensors and their installation details. The presence or absence of flow past the sensor location should be checked and noted. Check for backflow or thermosiphon effects during non-operation periods and determine the precision of sensors.

Commentary

Sensor location should not increase depletable energy use of the system. Normally the temperature differential between the sensor and the point of desired measurement should not exceed the precision range of the sensor. The sensed condition at all times should be considered when determining sensor placement. Thermosiphon or backflow in an idle loop can cause sensors to give erroneous indications of system operating conditions. Proper placement or insulation from external conditions, or the use of check valves or backdraft dampers will reduce sensor susceptibility to the influence or detrimental, extraneous or uncontrolled heat flows. Reference [55] discusses the implications of sensor location on system performance.

2.7.2
Criterion

Collector circulation set points. Collection loop set points shall be selected so that the collection fluid will only circulate when the rate of collection of solar energy exceeds the operating power required for fluid transport thermal energy, except when circulation is required for freeze protection or thermal energy dissipation.

Evaluation

Since normally the turn-on set point is greater than the turn-off set point for a typical differential controller, it is important to check the turn-off set point of the controller to ensure that the temperature differential allows a solar energy collection rate at least equal to the pump or blower power. See Criterion 2.6.2 for procedures for calculation of pump or blower power. For variable-flow systems,the pump or blower power requirement at the time of collection loop shutdown shall be computed. The rate of solar energy collection at the time of system shut-down can be calculated by multiplying the turn-off set point temperature differential by the collection fluid mass flow rate and heat capacity.

Commentary

Collector pump or blower cycling can be reduced by proper deadband in on/off controllers or use of time delays. Studies, References [54, 56], have shown that proportional controllers are not substantially more effective than on/off controllers. Typical set points for a liquid collection system are 10°F (6°C) between storage and collector temperature for start-up and 3°F (2°C) for shut-down. Higher temperature differentials should be used for air collector systems. References [54] and [56] provide useful information for the determination of set points.

2.7.3
Criterion

Leakage past valves and dampers. Leakage past control valves and dampers shall not significantly degrade the thermal performance of the system.

Evaluation

Control logic, operation of control dampers and valves, and potential flow paths and temperature of leaking fluids shall be examined. Manufacturers' specifications for leakage rate of valves and dampers shall be examined. Low-leakage dampers shall be specified.

Commentary

As described in Reference [46], it is important that dampers in the air collection loop close tightly. Large thermal losses can occur because of thermosiphoning from storage to collectors at night if valves or dampers do not close tightly. This can also cause freezing of liquids in air-to-liquid and liquid-to-liquid heat exchangers.

Valves that open to allow flow of thermal energy rejection devices (such as cooling towers) must close tightly. Particular attention should be directed toward valves that, for safety reasons, are normally open to the thermal energy rejection device, and are held closed during system operation by the control circuit. Leakage past these valves can cause considerable thermal losses and decrease system performance significantly.

See Criterion 3.3.3 for specification of allowable damper leakage.

The effect of leakage on the temperature of the conditioned space should be considered. Leakage past valves or dampers must not cause the temperature in conditioned spaces to exceed the limits specified under Requirement 2.1, Design conditions.

2.7.4
Criterion

Priority of energy use. Only when sufficient solar energy is not available to meet the load shall the control system allow auxiliary energy to be used.

Evaluation

Control logic, system configuration, sensor locations and type, and operation of thermostats shall be examined.

Commentary

The intent of this criterion is to use solar energy whenever possible to reduce storage losses and enhance collection efficiency. It is good practice to keep the solar and auxiliary subsystems separate, with for example, the solar coil first in the air stream and the auxiliary coil second. Two-stage thermostats are recommended so that the auxiliary energy system is applied after the solar energy, if the solar energy system cannot maintain the temperature in the desired range. In this way, the control system prioritizes the use of energy such that solar energy is first applied toward meeting the load, if possible, then auxiliary thermal energy is used, if necessary, to supply the balance.

This criterion is not intended to prevent the simultaneous use of solar and auxiliary energy. The most important consideration is to conserve depletable energy resources.

2.8
Requirement

Component/system integration. All components in the system shall be selected and integrated into the system for proper and efficient function of the system as a whole.

2.8.1
Criterion

Collector selection. The solar collector shall be selected based on efficient operation in the desired operating temperature range of the equipment to which the collected solar energy is delivered.

Evaluation

Post-stagnation test data, References [35, 36] shall be reviewed for the collector used. Temperature requirements of equipment, heat exchanger approach temperature difference, solar radiation intensity, ambient temperature, wind and diffuse/beam solar radiation data shall be reviewed.

Commentary

High-temperature applications, for example, cooling systems, may utilize low-loss collectors. Low temperature applications (space and water heating) can use collectors with a higher loss coefficient depending on ambient temperature and solar radiation intensity. Heat exchangers with high approach temperature differences require that the collectors work at a high inlet temperature. See commentary in Criterion 2.6.3. Degradation of collectors and the effect on selection is discussed in Chapter 5. Direct/diffuse radiation data are discussed in Chapter 3 of Reference [39].

Although cost is not within the scope of these criteria, a number of collector characteristics will affect operation efficiency and cost effectiveness. These characteristics might include:

number and material of cover plate(s)

heat transfer medium (air, liquid) and flow rate

freeze protection technique

absorber coating type

absorber plate and conduit material, gauge and integrating technique

insulation material effectiveness

Reference [53] gives useful information and discussion.

2.8.2
Criterion

Storage size. The minimum storage size shall be that which, when starting from a discharged state, will provide storage for the thermal energy from the collector which exceeds operational requirements for a clear-sky day of full system operation during the peak-load month.

Evaluation

The peak-load month shall be determined and a typical day of operation defined. Solar energy shall be collected and the load shall be calculated on an hourly basis throughout the 24-hour day. Clear-sky conditions shall be assumed. The collector inlet temperature may be assumed to be the average storage temperature, and the ambient outdoor temperature may be assumed to be equal to the normal daily high throughout the day. The minimum size storage needed to allow storage of excess collected solar energy for the day shall be calculated as follows. Assume the storage is fully discharged in the morning. At some time during the day the rate of solar energy collection may exceed the load. (If it does not, storage may not be needed.) Add the surplus solar energy for each hour in which the collected solar energy exceeds the load. The daily total stored energy will be equal to the capacity of the minimum storage size. The design storage size shall not be smaller than the calculated size. More detailed calculations may be provided by the designer.

Commentary

Storage need not be provided (see Requirement 2.5). Storage size affects collection efficiency, temperature stability of the subsystem, and cycling of equipment, especially absorption chillers. Too small storage can result in inefficient use of solar collectors. Too large storage can result in unacceptably high losses (see Criterion 2.5.1) or too low temperatures to offset the load. Proper size storage depends on the magnitude of the load and collectable solar energy, and the time relationship between the two. If all collectable solar energy can be used immediately, for all, or most times during the year when a load exists, storage is not required. This may be the case for cooling systems that operate seven days a week. For systems in which the load is out of phase with the solar energy system input, such as a space heating system, storage is almost always required. However, if solar energy is used only to preheat outside ventilation air during occupied daytime hours, then storage may not be needed except perhaps to reduce maximum supply temperatures.

The minimum allowable storage should be selected on the basis of minimum acceptable thermal performance, that is, full utilization of collectable solar energy during the month of peak load. The intent of this criterion is not to optimize the storage size, but to specify the smallest recommended size.

The largest reasonable storage size would be that which can store the collected solar energy for two consecutive clear-sky days when there is no load. This may be desired, for example, so that collectable solar energy is not wasted during a two-day weekend when there is little or no space conditioning load for a commercial office building or school. Results from a comparative analysis of National Solar Demonstration Program space cooling systems indicate that cold storage does not improve system efficiency relative to having hot storage only, Reference [31]. However, Reference [57] includes the following conclusions:

> "Cooling storage is more important for residential applications simply because the cooling load and solar availability are not coexistent as they are for commercial buildings. Of all of the storage options investigated, cold-side latent storage appears most promising for commercial absorption and Rankine systems, and residential absorption system in cooling dominated climates."

2.8.3

Criterion — Fluid flow rates. The flow rates through all components in each circuit shall be compatible and shall be within the ranges specified by the equipment manufacturer.

Evaluation — Documentation shall be provided to show that the flow rates of the design and the manufacturers' specified range or operation limits are compatible. Heat exchanger performance must meet design specifications for the flow rate specified. Each fluid flow loop or circuit shall be evaluated separately. Pumps and fans shall be selected to operate at or near their best efficiency point. Variable-flow systems must meet this criterion at all flow rates. Equipment configuration shall incorporate provisions for balancing the flow to all components on the same circuit. (See Criterion 2.4.2 for balance of flow through collector panels.)

Commentary — Overall system efficiency can suffer due to specification of equipment requiring different flow rates in the same loop. Equipment sizes and arrangements (in series or parallel) should be chosen considering compatibility of flows and heat transfer rates. Heat transfer capability of heat exchangers varies considerably with flow rate. See Criteria 3.2.1 and 3.3.1 for provisions regarding fluid velocities in pipes and ducts.

2.8.4

Criterion — Auxiliary equipment selection. Auxiliary energy equipment shall be selected and integrated into the system to minimize the use of depletable energy on an annual basis.

Evaluation — The auxiliary energy source, equipment location, equipment efficiency ratings, suitability of the equipment to the local climatic area, and controls and operating procedures shall be evaluated.

Commentary — Parallel solar/auxiliary heat pumps may not be efficient in cold climates. In this arrangement, the heat pump uses outside air as an energy source when the solar portion of the system cannot supply the load. Since the heat pump coefficient of performance and capacity are reduced at low source temperatures, this arrangement is not always advantageous.

The effect of a large number of solar conditioned buildings on central power facilities could be substantial and must be considered in the selection of auxiliary energy sources, and design of the system and controls for times of peak auxiliary energy use. Energy sources that can be stored on-site such as oil or gas are preferred to those that cannot be stored such as electricity direct from a utility. Conversion of electricity to a storable form of energy is acceptable provided energy losses from storage are not high.

In the case of solar-powered absorption chillers, auxiliary electric chillers may aggravate loads on electric utilities during peak cooling power requirements. Auxiliary energy used to heat water for operation of the absorption chiller may result in reduced solar collector efficiency and not provide back up cooling in case of failure of the absorption chiller. Careful design trade-offs must be made, such as dual storage tanks, auxiliary energy input location, physical size of system components, etc.

Experience gained from the National Solar Demonstration Program indicates that loading and operating procedures are more important to overall absorption chiller performance than the hot water inlet temperature. Frequent cycling of the chillers should be avoided (see Criterion 2.8.2).

2.9
Requirement

System performance. The total building system, including passive and active solar components, the mechanical system, and lighting, shall be designed to conserve depletable energy.

Commentary

In addition to meeting peak load conditions and having well-designed and properly integrated components, the solar energy system must have adequate overall performance. The purpose of this requirement is to provide a means to describe and verify overall system performance. This requirement applies only to those space heating, cooling or water heating systems that utilize solar radiation received at the building site as an energy source. The system performance indicator is "depletable energy use." Other indicators such as solar fraction, solar savings fraction, solar contribution, or energy savings, should not be used. Depletable energy can be calculated equally for passive or active systems, and for standard or innovative systems, and can be used as a basis for deciding among various alternative building or system designs. No maximum level of depletable energy use is required. To set such a level would be beyond the scope of these criteria, since that is primarily an economic issue, not a thermal one. Only the accurate statement and verification of system performance is required. For solar space conditioning systems, lighting energy is included in the energy calculation to promote the use of sunlight to offset the high electrical energy requirements and thermal output associated with artificial lighting systems.

2.9.1
Criterion

Depletable energy use. The annual depletable energy use for lighting, space conditioning,and/or water heating systems shall be determined and shall not exceed the limit established by the owner, designer, or local jurisdiction as applicable.

Evaluation

The calculation of annual depletable energy use shall be based on analytical predictions or correlations derived from simulations using hourly values of solar radiation, ambient temperature and system load for at least one day a month including operating energy requirements and thermal losses, and H/C/HW system and component performance characteristics. Otherwise, it shall be based on experimental data for similar solar energy systems in similar buildings in the same climatic area.

The energy use calculation shall be based on operating conditions provided by the applicable authority including occupancy schedule, temperature set points for day/night and summer/winter, and ventilation schedule. Emergency Building Temperature Restrictions, Reference [58], is one example of legislated operating conditions. Energy records of comparable buildings may be used to substantiate calculated energy use.

The annual depletable energy use for space conditioning systems shall specifically include energy for lighting purposes.

Depletable energy includes coal, oil, natural and manufactured gas, other petroleum products, electricity, and wood. Depletable energy does not include solar energy converted to thermal energy or electricity at the building site or thermal energy extracted from the groundwater, or ground at the site. Electricity produced off-site from any source including hydropower or wind, is considered to be depletable energy. The end result of the calculation shall be the total annual energy use for each depletable energy type (oil, electricity, etc.) as delivered to the building site.

Commentary

Examples of applicable authorities responsible for determining the depletable energy use limit may include building codes, Reference [59], states, local or regional jurisdictions, legislative action (such as the proposed BEPS, Reference [60]), or the building owner.

For active systems, collector output should be based on actual fluid flow rate and fluid properties as installed in the array (see Criterion 2.4.2). The prediction of system performance shall take into consideration, where information is available, expected normal degradation of components resulting from environmental deterioration or system wear. Fouling factors of heat exchangers and post-stagnation collector efficiency data are examples of system performance degradation.

Experimental verification of complete system performance or actual usage data from similar projects may not be available; therefore, analytical simulation methods employing empirical subsystem or component performance can be used to calculate the performance over the full range of operating conditions.

All systems that provide the functions of heating and/or cooling require a building thermal load analysis to determine the energy demand on the mechanical equipment. This analysis can vary from simplified methods such as described in Chapter 43 of the ASHRAE Systems Handbook, Reference [6], and based on the modified degree-day method for heating and the equivalent full-load hour method for cooling, to sophisticated computer programs such as NBSLD, Reference [61], which perform dynamic simulation of hourly thermal loads for each building zone for an entire year. Reference [62] provides a summary of computer programs available for heating and cooling thermal load determination. Refinements to the simplified energy calculation procedures, Reference [63], are currently being developed to include elements deemed essential to the accuracy of the calculation procedure. The choice of a particular method used to calculate building thermal load depends on the specific application. Buildings containing two or less zones and not utilizing passive solar components can usually be evaluated using the simplified procedures; however, larger, multiple-zoned buildings and buildings having passive solar components should utilize the more comprehensive methods.

The annual thermal performance of all heating, cooling, lighting, and hot water systems can be evaluated using a variety of methods after the respective energy demands are determined.

Simplified methods, such as the f-Chart method, Reference [34], varying from handbook calculation procedures to interactive computer programs, Reference [64], are suitable for many smaller active solar energy systems. The f-Chart method is based on a correlation of detailed simulation of liquid and air active solar systems for space heating and hot water, hot water only, and space heating only. The f-Chart method is not suitable for use with:

passive components

tracking collectors

space cooling systems

heat pumps

multi-zone heating systems

Anticipated advances in the interactive computer version, f-Chart, are expected to increase the list of system types that can be modeled. Operating energy for pumps, blowers, and controls is not calculated by the method and must be estimated separately.

SOLCOST, Reference [65], is another simplified method of calculating system thermal performance. In addition to the systems that can be modeled by the f-Chart method, SOLCOST is also applicable to heat pump systems, both solar-assisted and solar augmented, and for single and double axis tracking collectors. Like f-Chart, SOLCOST does not calculate operating energies for pumps, blowers, and controls.

Detailed simulation methods such as TRNSYS, Reference [14], are warranted for mechanical systems installed in large complex buildings or for systems not covered by the simplified procedures. A listing of computer programs for solar system thermal performance is available from the Conservation and Renewable Energy Inquiry and Referral Service, Reference [66], and a more comprehensive summary of calculation procedures is described in Reference [67].

Although the thermal performance of buildings containing passive solar components such as direct-gain buildings can usually be calculated using the previously described building thermal load techniques, thermal network analysis techniques may be required for buildings having indirect-gain features such as Trombe walls. General purpose analyzers such as SINDA, Reference [68], or specialized programs such as PASOLE, Reference [13], are available for these types of buildings. Hand calculation procedures such as the Solar/Load Ratio, Reference [69], method are also available. Reference [19] is a brief but comprehensive survey of passive solar building design computer programs. The choice of a calculation procedure for estimating solar energy system thermal performance depends on the application.

In recent experiments on solar HW systems at the National Bureau of Standards, Reference [70], the predicted long-term thermal performance using the f-Chart, SOLCOST and TRNSYS programs were all within 8 percent of the measured results. Similar efforts have been made to compare space heating system measured performance with f-Chart predictions using instrumented data from the National Demonstration Program, References [71,72].

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CHAPTER 3

MECHANICAL

CHAPTER 3 - (Continued)

MECHANICAL

CHAPTER 3

MECHANICAL

3.0 Introduction

This chapter presents performance criteria for the mechanical aspects of solar energy systems. The mechanical requirements are directly related to active systems. For passive systems, many of the design features can be considered structural, as well as mechanical. Where appropriate, these criteria have been included. For simplicity, both are considered in this chapter. Criteria that pertain to passive systems are incorporated into sections throughout the chapter under applicable topics (for example, sealing of air systems) and are not limited to Requirement 3.4.

3.1 Requirement

System design conditions. The H/C/HW system and components shall be capable of being operated over the flow rate, pressure and temperature ranges, and under structural conditions anticipated in actual service without significant impairment and shall conform to applicable local and nationally recognized codes and standards.

Commentary

It is desirable that the design consist of components that are covered by recognized standards,where available, and are specified by the manufacturer to be suitable for the pressure, temperature, and flow application. Available codes and standards are listed by ASHRAE, Reference [1]*. Underwriters' Laboratories currently has under development a set of standards for solar collectors that may be applicable (U.L.1279-PROPOSED).

Heat transfer through the system may use a number of different transfer approaches such as gravity (or thermosiphon) circulation, combined forced and gravity circulation, or forced circulation. Systems or applications that do not lend themselves to engineering analysis may require prototype tests or documented performance under in-use conditions. A standard practice for installation and service of solar heating systems (H), Reference [2] and installation guidelines for solar hot water systems (HW), Reference [3] have been prepared. Although specific to residential application, they may be of assistance for commercial use.

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* Numbers in brackets [ ] indicate references at the end of this chapter.

3.1.1 Criteria — Solar collectors. The solar collectors shall be designed to accommodate the specified pressure drops and to resist stagnation and thermal stress conditions. Criteria involving thermal performance are covered in Requirement 2.4.

Evaluation — Review drawings, specifications, manufacturer's literature, test data, and design calculations. Provisional tests described in test methods 7.2 (no-flow 30-day degradation) and 7.6 (thermal cycling) of NBSIR 78-1305A, Reference [4] are one means of assessing the effects of several of these conditions on collectors. ASHRAE 93-77, Reference [5] provides coverage of collector pressure drop.

Commentary — Collectors must often withstand considerable thermal cycling and weathering conditions. Thermal performance may be reduced by the degradation of glazings, seals, and absorber materials.

3.1.2 Criterion — System balancing. The energy transport system shall be designed with provisions for measuring and balancing of all specified design flows and shall be balanced after installation to ensure that specified flow rates are achieved.

Evaluation — Flow rates shall be adjusted to meet the requirements of Criteria 2.4.2, 2.6.3, 2.6.4, and 2.8.3. Two methods for balancing are Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems, NEBB, Reference [6] and National Standards for Field Measurement and Instrumentation, Total System Balance, AABC, Reference [7]. These methods are cited as examples of currently used air balancing test methods. Review of drawings, specifications, historical performance, previous test data, and design calculations or testing can provide the basis for judging compliance.

Commentary — Flow rates can vary widely or even short circuit areas within collector arrays, storage assemblies, and energy transport systems resulting in reduced performance.

Typically, liquid flow is about 0.02 gal/min·ft^2 (0.014 L/s·m^2) of collector (range 0.01 to 0.03 gal/min·ft^2, typical). Reverse return piping configurations are self-balancing within certain limits. Balancing devices must be provided on each parallel leg of a direct return system. For air collectors, a flow rate of 2 ft^3/min·ft^2 (0.01 m^3/s·m^2) of collector is typical (range 1-4 ft^3/min-ft^2, typical).

Balancing dampers placed in ducts having excessive air flow rates is a common means of balancing air systems. Means should be provided to mark and/or lock the flow set point indicators. Flow rates and velocities for thermosiphon systems will vary dynamically and will not necessarily fall within stated ranges.

3.1.3 Criterion

Insulation. Insulation of collectors, piping, ducts, thermal storage containers and heat exchangers shall be of a type satisfactory for its intended purpose and installed in accordance with recognized standards and practices.

Evaluation

Review drawings and specifications. Insulation design and installation shall be in accordance with ASHRAE, Reference [8], Chapter 20. Factory manufactured insulated ducts shall satisfy the requirements of UL 181, Reference [9]. Fibrous glass ducts shall satisfy SMACNA requirements, Reference [10].

Commentary

Protection of exterior pipe and duct and storage container insulation is of great importance in preventing thermal losses. Joints in waterproof coverings may allow moisture intrusion into the insulation resulting in decreased R-value. Requirements for resistance to weathering exposure are contained in Criteria 5.1.1, 5.1.2, and 5.1.3, for thermal stability in 5.2.1, and for fire resistance in 4.4.3 and 4.4.4.

Insulation should be protected against compressive loads from pipe and duct supports and storage tanks. Some insulating materials such as cellular glass foam have high compressive strength and may be suitable for insulating both around and under earth supported storage containers. Most insulation materials do not have adequate compressive strength and may require additional supporting devices, when used beneath storage containers or other heavy components. Care should be taken that thermal shorts through supports and fittings are minimized. Insulation on underground and unsheltered above ground components must be well waterproofed. Provisions for subsurface drainage are highly recommended. Construction in high water-table areas may be impractical. Concrete or other storage mass on grade should have perimeter insulation either vertically along the foundation wall or horizontally under the storage mass, from the perimeter inward for a distance of 1 to 2 ft (.3-.6 m). Such insulation may be placed outside the foundation wall to increase the volume of the insulated thermal mass, but only if well protected from physical damage and weathering, and be impervious to moisture absorption. ASHRAE, Reference [8], and Reference [11] contain guidance.

3.1.4 Criterion

Structural deflection. Under the effect of deflections caused by the loads defined in Criterion 4.6.1, in addition to the anticipated creep deflections, the system as a whole or any component, connection or support thereof, shall not suffer permanent damage which would require replacement or repair, or which would impair its intended function during its service life.

Evaluation
Review documentation of data for design, tests, and installations. Evaluate and/or test components and elements where deemed essential. Determine compliance with generally accepted standards, and engineering and trade practices, where applicable.

The criterion is deemed satisfied if it can be demonstrated that deflections caused by the specified loads can be accommodated by suitable details or adequate flexibility.

Commentary
The intent of this criterion is to provide for the proper functioning of the system under service loading conditions without breakdown or permanent impairment beyond levels comparable to conventional heating and cooling systems.

Loads lower than required ultimate loads should not cause large, irrecoverable deformations. The deflection of conventional elements supporting the system elements should not exceed the limits of conventional engineering standards for the appropriate materials and for nonconventional elements the deflection should not exceed the limitations specified in Section 13.2.4 of Reference [13].

Reference [14] gives a range of limits on deflection depending on circumstances that may be used for guidance in assessing compatibility. Safety concerns such as broken glazing and hazardous fluid leaks that may be caused by excessive deflections are covered in Criteria 4.6.1, and 4.3.3.

3.2
Requirement
Liquid systems. The subsystems and components of liquid systems shall be designed for flow rates, temperatures, pressures, mechanical stresses, material properties, and heat transfer liquid characteristics to provide proper and efficient performance.

Commentary
In liquid systems, maximum pressure and temperature are primarily a function of fluid properties and relief valve settings, along with the properties of the materials that comprise system components. Fluid compatibility is an important consideration and is covered in Requirement 5.3. See 6.2 and 6.3 for requirements for system maintenance, servicing, and monitoring. Illustrations of recommended design practices are contained in References [1, 2, 3, 12].

3.2.1
Criterion
Piping design. Pipe sizing shall be in accordance with accepted design practice or recognized methods and velocities

shall not exceed the values listed in Tables 5.3 and 5.4. Anchorage shall be provided where necessary. Support shall be provided to prevent piping from deflecting beyond acceptable limits and to maintain a slope for positive drainage.

Evaluation

Review drawings, specifications, and design calculations for compliance with applicable local and national codes and standards.

Commentary

Since the size and energy requirements of pumps are a function of the system flow resistance, pressure drops should be kept as low as practical. Fittings such as bends, tees, globe valves, reducers, or other obstructions to flow should be minimized or simplified by careful arrangement of piping runs. For long runs, smooth turns with soft temper pipe or large radius elbows should be considered. Accepted practices for plumbing design are discussed in standard plumbing guides, References [15, 16]. Velocity limits to prevent erosive wear are given for selected materials in Tables 5.3 and 5.4 of Chapter 5.

A thermosiphon water heating system is an example where pipe sizing is essential as hot water circulation results from the change in density of the fluid with temperature. Movement of a heat transfer fluid by natural convection is achieved by relatively low pressure differentials and low pressure drops are essential. Design considerations and equipment performance data are available in References [17, 18, 19, 20].

Adequate anchorage and support are necessary in order to prevent damage to the piping, insulation, or building surfaces from sagging, vibration, and thermal cycling. Support and anchorage systems are illustrated in Reference [21]. Supports for horizontal runs should be eight foot (2.4 m) for drawn copper tubes, six foot (1.8 m) for annealed copper tube, twelve foot (3.7 m) intervals for threaded pipe, one to two foot (.3-.6 m) intervals for rigid plastic pipe, and six foot (1.3 m) for aluminum tubing. For larger size piping, greater than 2 inches (5.08 cm), it is recommended that the manufacturers recommendations be obtained for spacing of anchors and allowances for thermal expansion.

See also Chapter 5, especially 5.1, 5.2, and 5.3 for additional concerns including non-metallic piping and coupling hoses.

3.2.2
Criterion

<u>Leak testing</u>. The portions of installed H/C/HW systems that contain pressurized liquid heat transfer fluids shall not leak when exposed to designated pressures.

Evaluation

Review specifications and testing. The portions of the H/C/HW systems that contain pressurized liquid heat transfer fluids and are not directly connected to the potable water supply shall be leak tested at pressures not less than 1-1/2 times their design working pressure for a minimum of 15 minutes, when filled with a recommended testing fluid. Those portions of the system designed to operate at, or close to, atmospheric pressure shall be filled with a recommended testing fluid and tested for a minimum of 30 minutes. Those portions of installed H/C/HW systems that are directly connected to the potable water supply system shall be tested in accordance with applicable local and nationally recognized codes and standards. Pipes and tanks shall be leak tested before enclosing, backfilling or insulating. The test pressure shall be applied for the period of time necessary to inspect for leakage. The temperature of the liquid shall be within 5°F (3°C) of the initial ambient conditions. Provisional tests for evaluating the leakage and pressure resistance of solar collectors are described in test method 7.12 of NBSIR 78-1305A, Reference [4].

Commentary

In most applications, the leak testing should be done with the specified heat transfer fluid. Glycol mixtures and oils have lower surface tensions than water and can leak through normally watertight connections. In addition, use of water in systems later filled with oils or other immiscible liquids could lead to fluid deterioration or corrosion due to residual water. If the fluid temperature is significantly lower than that of the ambient conditions, sweating may result and proper examination will be difficult. In addition, the use of hot liquids can result in the swelling of packings and joint materials, thus, concealing leaks.

Provisions should be made at the highest point or points in the system to permit venting of all air in the piping during the filling operation. See also Criterion 3.2.6. In applying the pressure, caution should be exercised so that excess pressure is not applied to the system. Protection of certain components such as expansion tank(s), air vent(s) and pressure gauge(s) and capping of pressure relief devices should be considered to avoid damage of these components during pressure testing.

3.2.3
Criterion

Liquid quality. The systems shall have strainers, filters, or other means to collect particulate matter that could impair heat transfer or the flow of the heat transfer fluid and result either in a reduction of system efficiency or deterioration of system components beyond acceptable limits.

Evaluation

Review drawings and specifications.

Commentary

The piping in some solar collectors and 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. The buildup of sludge may be the result of decomposition of the heat transfer liquid, reactions with additives within the liquid itself, or reactions of the heat transfer fluid with piping materials or extraneous impurities such as pipe dope, solder flux, cutting oils, or general system dirt. A strainer with a brass, stainless steel, or monel screen should be installed ahead of the pumps and control valves to remove foreign matter that might damage the pump, clog collector or heat exchanger passages, cause galvanic corrosion in the system, or cause valve malfunction. The change in pH of some heat transfer fluids due to their decomposition at elevated temperatures is of great concern. See Criteria 5.2.1, 5.3.1, and 6.2.1.

To aid in preventing sludge, the system piping should be thoroughly cleaned and flushed prior to the introduction of the heat transfer fluid. Problems can develop when liquids such as "hard" water are used. See also Criteria 6.1.5 and 6.2.1.

3.2.4
Criterion — Thermal expansion of fluids. Adequate provisions for the thermal expansion of heat transfer fluids and thermal storage fluids that can occur over the service temperature range shall be incorporated into the system design.

Evaluation — Review drawings, specifications, and design calculations. Expansion tanks shall be sized in accordance with ASHRAE Handbook/Systems, Reference [16].

Commentary — Water expands about 4 percent in volume when heated from 40°F to 200°F (4°C to 93°C). Other heat transfer fluids will have different coefficients of volumetric expansion.

Means should be provided in the system design to contain this additional fluid volume without exceeding the relief pressure of the system. Provisions for expansion of fluids should be located in all loops in which thermal energy may be added to or removed from the fluid and that may be isolated by valves.

3.2.5
Criterion — Draining and filling. Fill and drain devices shall be provided for the flushing, filling and periodic recharging of the system, and to facilitate maintenance and repair of liquid systems. In systems employing toxic or combustible fluids, such devices shall be in compliance with Criteria 4.2.2 and 4.2.4.

Evaluation — Review drawings, specifications, and maintenance instructions.

Commentary — In systems using toxic or combustible liquids, it may be desirable to design fill and drain devices so that only skilled maintenance personnel can service the system. See Criteria

6.2.1 and 3.2.3 for further discussion of maintaining the quality of heat transfer liquids.

Water wall units,barrels, columns, and other collector/storage assemblies may require draining and filling provisions for the individual liquid containers.

3.2.6

Criterion — Entrapped air. When liquid heat transfer fluids are used, the system shall provide suitable means for air or gas removal from the piping and liquid containment system.

Evaluation — Review drawings and specifications.

Commentary — Entrapped air in piping and collectors can impede the flow of liquids through piping, reduce heat transfer effectiveness, and otherwise reduce overall system efficiency. The freezing of exterior uninsulated air vents has been known to occur and create trapped air conditions in solar piping systems. Air vents are typically installed in the high points of the system and above the air eliminator. Automatic float vents must be mounted and operated as directed by the manufacturer.

3.2.7

Criterion — Vacuum relief. Closed storage tanks, expansion tanks, and piping located at elevations above the system served shall be protected against collapsing when subjected to vacuum. Such components shall be designed to withstand negative pressures or have vacuum relief protection.

Evaluation — Review drawings and specifications.

Commentary — Possible collapse of tanks and piping from being subjected to negative pressure is an important design consideration, Reference [22]. If vacuum relief valves are used, it is important to protect them from freezing. See also Criterion 3.6.2. (These valves are also used in drain down systems to permit drainage by admitting air at atmospheric pressure.)

3.2.8

Criterion — Thermal expansion of materials. The system components and assemblies shall be designed to allow for the thermal expansion and contraction and the flexing of plumbing or other fittings that will occur over the service temperature range.

Evaluation — Review drawings, specifications, and calculations.

Commentary — Piping, solar collectors, and other components may experience changes in dimensions as a result of temperature changes. Such changes can result in excessive stresses within the piping, piping supports and anchorages, structural elements, pumps, and solar collectors if means are not incorporated in the system design to allow for the thermal movement. These problems are especially severe in long pipe runs and pipes with lateral connecting lines. Movement due to thermal changes can also result in inadvertent dissimilar metals contact with other components or building elements, leading to possible corrosion problems. See also Criterion 3.2.1.

Expansion coefficients for commonly used materials are given in Tables B.2 and B.5 of Appendix B.

3.2.9

Criterion — Valves. Valves shall be specified and located to provide proper and efficient system performance and be in accordance with applicable local and nationally recognized codes and standards. Valves shall be specified and set to avoid system or component damage.

Evaluation — Review drawings and specifications for proper design application and code compliance.

Commentary — Improper application or installation, malfunction, and failure of valves has caused significant problems in solar energy demonstration projects.

Valves may be either manual or motor operated. Motor operated valves that control the draindown cycle of a draindown type solar energy system are covered in 3.6.2. Motor operated valve installations should be designed for fail-safe operation in the event of power failure. Solenoid valves may also present problems due to incomplete closure. Globe valves should not be used as isolation (shut-off) valves because of the restriction they introduce. Gate or ball valves are preferable for shut-off. Square head cocks, ball or globe valves are commonly used as balancing valves. Gate valves are unsuited for balancing. Temperature and pressure relief valves and vented backflow preventors should be set to avoid system damage and should not be located in such a way that they can discharge near personnel, electrical components, and other vulnerable items. See also Criterion 4.3.1. Because of the low flows generated in thermosiphoning, check valves used to prevent such thermosiphoning should be mounted carefully to ensure closure. The use of control valves with visual position indicating devices is encouraged.

3.2.10

Criterion — Pumps. Pumps shall be specified to provide proper and efficient performance. Selection and installation shall be in accordance with the requirements of the Hydraulic Institute, Reference[23] and local and nationally recognized codes and standards where applicable.

Evaluation — Review drawings, manufacturer's literature, and specifications for compliance with Hydraulic Institute Standards, referenced above.

Commentary — Pump selection in accordance with the heat transfer fluid is important with respect to viscosity, specific heat, and specific gravity. Sizing of pumps should consider additional static head during filling or start-up operations. The energy consumption of pumps must be considered in satisfying Criterion 2.6.2 which establishes the limit for operating energy.

Bronze or stainless steel pumps should be used in open systems to prevent corrosion. Cast iron pumps can be used with glycol/water heat transfer fluids in closed systems. It is important that the fluid corrosion inhibitors be maintained. Galvanized pumps should not be used with glycol solutions. As a general rule, dissimilar metals should be avoided where possible. Specific coverage of materials/heat transfer fluid degradation is given in Criterion 5.3.1.

In draindown systems, the pump must be a certain distance below the minimum water level in the receptor tank to retain prime and provide adequate positive suction head. Running air-bound for short periods of time may damage the pump.

3.3

Requirement — Air systems. The subsystems and components of air systems shall be designed for capacity, temperatures, mechanical stresses, materials properties, and flow rates to provide proper and efficient performance.

Commentary — For active systems, see 6.2 and 6.3 for requirements for system maintenance, servicing, and monitoring. Illustrations of recommended design practices are contained in References [1, 2, 3]. For passive systems, particularly those with separate air distribution systems, care should be taken to meet the intent of this requirement.

3.3.1

Criterion — Duct design. The sizing and specification of ducts, duct joints, dampers, air movers, and other air handling components shall be in accordance with recognized standards. Installation shall comply with National Fire Protection Association (NFPA) Standards: 90B, Reference [24]; 31, Reference [47]; and 54, Reference [48]. Velocities shall not exceed 900 ft/min (4.6 m/s).

Evaluation — Review plans and specifications. Design of all heating and cooling duct systems shall be in accordance with recommendations as applicable in ASHRAE Fundamentals, Reference [8], the Air Conditioning Contractors of America (ACCA), Reference [25] and/or the Sheet Metal and Air Conditioning Contractors National Association (SMACNA), Reference [19]. See Criterion 4.4.3.

Commentary

Ducts should be designed for the shortest practical run and elbows should be kept to a minimum. Constrictions should be avoided whenever possible. The use of turning vanes should be considered at duct bends to reduce pressure losses. Recommended air velocities for main trunk ducts, air collector manifold ducts, and air collector riser ducts fall in the range of 700-900 ft/min (3.6-4.6 m/s), References [19, 26]. Lower velocities may be desired if quieter operation is required. The gauge pressure of the air in the collectors should be slightly negative and as close to atmospheric as possible to minimize leakage. This usually requires the collectors to be on the suction side of the air mover.

Air flow through ducts, filters, heat exchangers, collectors, and other flow restrictions will establish the total pressure loss, which should be kept to a minimum in order to reduce blower operating cost. Blowers sized near the center of their performance curves and the use of variable speed or belt-driven fans will allow for "tuning" flexibility in air flow; however, sizing should also consider efficiency of operation. Standards for design, sizing, construction, and installation of ducts used with solar energy systems are covered in Reference [19].

3.3.2
Criterion

Sealing of air systems. The following sealing requirements shall be used for the various components of air systems. Restrictions on the percentage of air leakage for various components are given in Criterion 3.3.4. Requirements for sealing according to high pressure duct standards does not imply that these components will function at high pressures.

(a) Primary solar duct system (PSDS) (duct system between the collectors and thermal storage and the ducts making connection to the space distribution system;this does not include the manifold-to-collector connection): The PSDS shall be sealed in accordance with Seal Class A of SMACNA High Pressure Duct Construction Standards, Reference [27] or otherwise constructed in such a manner to provide equivalent air tightness. Fibrous glass ducts shall be sealed in accordance with SMACNA Fibrous Glass Duct Construction Standards, Reference [26] and any applicable conditions of listing for Class 1, UL 181 ducts, Reference [9].

(b) Space distribution duct system (SDSS) shall be sealed in accordance with Seal Class B, C, or D of SMACNA Low Pressure Duct Construction Standards, Reference [28] for the appropriate pressures where losses may be considered non-detrimental. This occurs where losses are to heated space and the components are not used to transport heat during the cooling season. In cases where leakage is detrimental or to unheated spaces, the SDDS shall be sealed in accordance with Seal Class A. In either case, construction that will provide equivalent airtightness shall be allowed in lieu of the sealing requirement.

(c) Thermal storage shall be constructed of or lined with low permeability materials and sealed or otherwise fabricated to limit air leakage. This is not intended to apply to storage which is directly coupled to heated spaces as is commonly done in passive applications. Sealing shall include joints in thermal storage, duct, and access openings.

(d) Collector arrays and other manufactured components such as air handling units, heat exchangers, and filters shall be assembled and sealed in accordance with manufacturers' instructions. Sealing shall include all joints between manufactured components and ducts. Equivalent airtightness shall be provided for site-built collector arrays.

(e) Passive air transport assemblies exposed to the outdoors or semi-conditioned spaces shall be tightly constructed in accordance with energy conservation guidelines to control air infiltration and leakage, References [29, 30, 31, 32, 33].

Evaluation

Review drawings and specifications. Airtightness of equivalent construction shall be demonstrated by documentation of satisfactory long-term performance under in-use conditions or testing in accordance with Criterion 3.3.4.

Commentary

These requirements may appear to be excessive, however, the prevalence of air leakage in many demonstration projects and evidence of detrimental effect on thermal performance dictate these sealing levels for all air solar systems. The principles described in the SMACNA Standards, References [10, 27, 28] should be utilized in deciding upon techniques and materials to be used in providing equivalent air tightness.

(a) PSDS: Sealing to Class A levels should limit PSDS leakage to one percent of system operating air flow. All metal ducts should be examined to gain an indication of airtightness. Application of such ducts in a solar system may require extensive sealing of seams and joints. Flexible canvas connections will probably have too much leakage to be satisfactory in the PSDS. Checking for leakage and sealing leaks are best accomplished during the process of field assembly before the installation is covered by other construction. Sealing as required above includes connections to all ancilliary units such as storage and blowers, but does not include manifold-to-collector connections.

(b) SDDS: Sealing of SDDS to the recommended levels should limit air leakage to 5 percent of system operating air flow for Class B, C, or D sealing and to one percent for Class A.

(c) Thermal Storage: Thermal storage using metal as the airtight barrier may be sealed in accordance with Seal Class A and should achieve air leakage rates of one percent or less of system operating air flow. Thermal storage using plastic may be appropriate for similar treatment. Construction involving wood, masonry, or other porous materials may call for other methods, but techniques which would make the container airtight while simultaneously being able to withstand all service temperatures would seem appropriate. The objective of such sealing should be to limit leakage to one to five percent of system operating air flow.

Concrete should be considered potentially porous and may require lining and sealing to bring air leakage within acceptable limits. Problems associated with shrinking, warping, and cracking should be considered when detailing storage containers made of wood.

(d) Collector arrays and other components: In designing collectors, air handling units, heat exchangers, etc., for solar applications, designers should pay particular attention to details of construction and field installations that will minimize air leakage. Airtightness of manufactured as well as site-built units may be addressed through numerous techniques including basic product configuration and materials selection as well as factory installed gaskets, felts, mastics, etc. Careful attention to the collector-to-manifold connection detail will result in decreased leakage. Reference [34] discusses the effect of air leakage on system performance.

(e) Passive air transport assemblies: Since air pressures in passive systems are essentially those generated by natural buoyancy, good construction practices used for the control of infiltration should provide acceptable airtightness. Attention to the quality of construction for leakage control is very important because the surface areas involved in passive air transporting assemblies are sometimes very large and contain many sources for air leakage.

3.3.3

Criterion — Damper leakage. Control dampers and back draft dampers in the PSDS shall comply with SMACNA Solar Installation Standards, Reference [19] and shall have resilient blade edges, such as felt, or shall be otherwise constructed to ensure tight cutoff of the air stream.

Evaluation — Review drawings and specifications to determine that correct damper type is specified.

Commentary — Damper leakage has a major effect on the performance of the system. Analysis of some operating systems has shown a 40 percent system performance loss due to leaky dampers, Reference [35]. Leaking back draft dampers have allowed cold night air to circulate over service HW coils and cause freezing. Leakage should be limited to two to five percent on critical dampers, particularly those which serve to isolate the collector loop from the rest of the system. Carefully designed, constructed, and installed dampers should be capable of meeting this level of performance. Details of damper design are as important in ensuring tight cutoff over an extended service life as the materials used. Adequate sealing can be achieved using felt, vinyl, foamed plastic, and other materials. Specifically designed "low leakage" dampers may be required. Many seal materials are especially prone to deterioration after a period of use. Access ports should be provided for inspection and periodic maintenance.

See Criterion 6.2.2 for access requirements. Lightweight back-draft dampers used in passive applications, i.e., Trombe walls, are discussed in Criterion 3.4.1.

3.3.4

Criterion — Air leak testing. Specification for installations with more than 1500 ft^2 (139 m^2) of total active collector gross area shall contain provisions for testing in accordance with Chapter 10 of SMACNA High Pressure Duct Construction Standards, Reference [27]. A minimum of 25 percent of each of the following portions of the system for each category (unheated or non-detrimental loss) shall be randomly selected and tested. Leaks shall be corrected to restrict leakage to the percentages of total system design air flow rate, as indicated below. If losses from ducts and storage are into the heated space and these portions of the system are not used during the cooling season, the losses shall be considered non-detrimental.

Evaluation — For active systems, leak testing shall be performed in accordance with SMACNA High Pressure Duct Construction Systems, Reference [27] as applicable.

The following threshold leakage limits are based on the achievable levels noted in Criterion 3.3.2 for each portion of the system.

	Unheated spaces	Non-detrimental losses
Primary Solar Duct System	2%	2%
Space Distribution Duct System*	2%	10%
Thermal Storage**	2-10%	10%
Collector Array	15%	N/A

There are no criteria yet established for air leakage in passive systems. See Commentary following for subjective evaluation of passive system leakage using inspection and the more quantitative techniques of pressurized and the trace gas testing for determining building/system performance.

Commentary

Higher leakage rates for the PSDS in non-detrimental loss situations are not allowed because control of energy flows in the solar system is of critical importance. Uncontrolled leakage, even to heated spaces, may result in inefficient utilization of thermal storage and thus, higher auxiliary energy use.

In order to perform leakage tests, it may be necessary to make provisions for blanking dampers at various locations in the system.

In small installations, not governed by this requirement, it may be desirable to conduct simple leak tests by operating the system (with outlets appropriately covered over) and feeling or listening for points of leakage or introducing smoke from a smoke bomb or other chemical source and making a visual inspection.

Correct duct design can significantly impact air leakage (see Criterion 3.3.2). References [34, 36] discuss certain aspects of air leakage in air systems.

For passive systems, a method of checking for gross leakage is to conduct a careful visual inspection of the building exterior at night with strong light sources inside the building. Leakage paths will be revealed by the presence of visible openings.

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* Systems exempt from this requirement are defined in Criterion 3.3.2b.

** Varies according to material of construction. See Criterion 3.3.2c (Commentary).

Another technique that may be useful for determining building tightness is the fan pressurization or depressurization procedure, Reference [37]. Tracer gas decay and air bag techniques might also be useful. Section 301.4 of Reference [30] gives quantitative information for air leakage rates for some building components and includes a standard test method for air leakage.

Differences between the above values for loss rates and those in the commentary of 3.3.2 reflect the difference between what is achievable (1%, 5%) and what may be considered a reasonable minimum (2%, 10%).

3.3.5

Criterion — Air quality. Adequate means shall be provided to prevent the accumulation of dust, dirt, water, or gases that could result either in a reduction of system efficiency, deterioration of system components, or discomfort of building occupants.

Evaluation — Review drawings and specifications.

Commentary — The material used for rock bed storage with air systems should be selected for size and freedom from dirt and dust. The use of smooth and washed material and of filtered air is desirable. Health requirements for air quality are given in Criterion 4.1.4.

ASTM C33-81, "Standard Specification for Concrete Aggregate," Reference [49], gives some guidelines that are helpful for quality control of gravel.

To facilitate rock bed washing, to remove drain water that may have leaked into the storage container, or to remove condensed moisture, it may be desirable to construct rock storage containers with water resistant interior surfaces and drainage provisions. Drains should not be the normal water trap type because the water will probably be evaporated by the heat from storage, thereby destroying the trap and allowing sewer gases to enter rock bed storage. Better arrangements might simply employ a removable plug or valve in the bottom of the rock bed.

In some air collectors, performance reduction due to accumulation of dirt from the system on the coverplate may be a significant problem. In collectors where air flow is in contact with glazing, normal dirt build up from air drawn from occupied spaces could cause a deterioration of heat transfer ability and spectral properties of the absorber. High temperatures could bake on such deposits. Filtering of such air flow is very desirable.

A similar situation may exist in passive systems with air circulation (Trombe walls, air thermosiphons, etc.) where dirt deposits may occur on absorber or glazed surfaces. Because of the low air velocities involved with passive systems,filtration may be impractical and access for cleaning should be considered.

3.4 Requirement — Building solar (passive) components. Proper and reliable techniques and devices shall be provided to collect, store, distribute, control,and prevent the loss of passively collected solar energy.

Commentary — References [38, 39, 40] provide a full discussion of the technical aspects of passive solar design.

3.4.1 Criterion — Energy transport and distribution. Mechanical devices, when used in conjunction with passive solar components for energy transport and distribution shall provide proper and reliable performance.

Evaluation — Review drawings and specifications.

Commentary — Inadequate or inefficient energy distribution systems have been reported as one of the most common design faults in passive projects in the Federal solar heating and cooling demonstration program.

Passive systems rely primarily upon natural means of energy flow. However, some designs work more effectively when supplemented by devices that enhance and/or control such energy movement. Location, sizing, and details of devices should be of concern when designing means of distributing thermal energy to achieve desired temperature levels and for exhausting excessive heat.

Thermocirculation control vents should avoid undue restriction to air flows and provide airtight closure against backdraft. Lightweight (1 to 1.5 mil), (.0254 mm to .0381 mm) plastic film one-way dampers have demonstrated adequate performance in Trombe wall applications. The vent opening with which they operate must also be well constructed to assure a tight fit. A backing of wire mesh or other means may be required in larger vent openings or when strong drafts are anticipated to prevent suction of the film into the openings. Typically the size of these vents are approximately one percent of the Trombe wall area (this percentage being for the lower vents with upper vents of equal size). Reference [38] provides a full discussion of the effects of vent size on thermal performance.

A number of areas of potential inadequacy of such devices should be noted:

(a) Lightweight backdraft dampers may be fragile and of limited reliability. Such components should be accessible for inspection and repair.

(b) Overheat vents may be located in remote positions and be operated only on a periodic basis. Such vents should be accessible for inspection and cleaning to assure effective opening and closure.

(c) Thermally activated operators such as freon cylinders and liquid pistons should be selected for reliable service and installed in a manner which will allow periodic inspections.

(d) Installations of heat pipes and thermic diode assemblies should be done with a recognition of the need for future inspection and possible removal for testing or recharging.

3.4.2

Criterion

Movable insulation. Manual or automatic movable insulation shall be designed and installed for proper perimeter sealing and reliable manipulation, operation, and storage.

Evaluation

Review drawings and specifications, especially for details of fit and closure of insulation at the perimeter of glazed openings.

Commentary

There are three general categories of movable insulation applications; manual, thermally driven, and motor driven. Some applications combine movable insulation with shading and/or reflection devices. To be effective, surface mounted insulation must make a tight and well-sealed cover for the aperture to prevent drafts behind the insulation panel which will reduce its ineffectiveness. Night insulation is likely to improve performance more than double glazing if a tight seal is achieved. The higher the R-value of the insulation, the tighter the air seals it should have. Unless the edges are well sealed, an R-factor greater than five is questionable, Reference [39]. Some of the techniques used to provide effective seals include channels or slots in jambs and sills, magnets, weights, and friction fit.

Of particular concern is the potential for binding,racking, and inadequate closure of large area coverage devices. Also, there have been problems with blowers and suction equipment in some applications utilizing pelletized or granular movable insulation materials. Condensation between tight fitting insulation and glazing has been a problem. See Criterion 4.4.3 for fire hazards of insulation.

For further discussion including guidelines and assessment methods, see References [38, 39].

3.5
Requirement

Control system. The control system shall be designed to operate the solar and auxiliary H/C/HW system in a proper and efficient manner.

Commentary

See Criteria 2.7.1 through 2.7.4. Control systems have been found to be a major source of operational difficulties in Federal demonstration programs as described in the National Solar Data Network, Reference [41]. Reference [42] also gives guidelines for control systems and components.

3.5.1
Criterion

Inhabited space temperature control. Each space conditioning system or zone shall be capable of providing occupied space temperature regulation by at least one adjustable control capable of adjustment within a minimum range from 55°F to 75°F (13°C to 23°C) where used to control heating only and 70°F to 85°F(20°C to 30°C) where used to control cooling only and 55°F to 85°F (13°C to 30°C) where used to control both heating and cooling.

Evaluation

Review drawings and specifications.

Commentary

Controls may be automatic or manual. This is intended to include manual adjustment of devices such as wood stoves used as auxiliary or back-up. Localized controls for building heating and cooling are discussed in Reference [1]. See also Criterion 2.3.1 for requirements for auxiliary heating systems size.

3.5.2
Criterion

Service hot water temperature. The temperature control for the combined solar and auxiliary energy source shall be capable of adjustment over the range of temperatures acceptable for the intended use.

Evaluation

Review drawings and specifications. Review mechanical design for compliance with Criterion 4.3.4.

Commentary

Service hot water tanks are typically equipped with a thermostat capable of controlling heating in the temperature range of 120°F to 160°F (49°C to 66°C). Temperature control devices used with solar energy systems must be compatible with safety requirements and may require the capability to cool the discharged water as does a tempering valve. Controls and valves should fail-safe to a position that would prevent scalding of a hot water user (see Criterion 4.3.4).

3.5.3

Criterion — System temperature and pressure limit control. Controls shall maintain the H/C/HW system within the temperature and pressure operating limits of the equipment specified in the design. See also 2.3.1 and 4.3.4.

Evaluation — Review drawings and specifications.

Commentary — Control provisions may be required for the dumping of heat when temperatures approach unacceptable levels. Should the temperature or pressure exceed specified limits, deterioration of components may occur and/or system function may be impaired due to such factors as boiling, vapor locks, cavitation, degradation of insulation and seals, and unacceptable expansion of fluids or materials. Bleeding in of cold water to replace hot water in storage is one means of achieving this control. For safety in use provisions, see Requirement 4.3.

In systems that are not capable of withstanding thermal shock created by filling hot collectors with cool fluids, control subsystems may be required to protect the system from cold filling. Such controls would limit filling to non-insolation periods.

Thermal shock and cycling stresses can be severe over the life of many system components. Mechanical components and system control functions should be designed to optionally minimize the effects of such stresses. Some collector types such as evacuated glass tubular collectors may be especially sensitive to these stresses, and appropriate means of protection should be provided. Provisions for thermal shock resistance of components and materials are given in Criterion 5.2.3.

3.5.4

Criterion — Temperature sensor installation. Temperature control sensors shall be specified to be installed in a manner as to provide proper system control. See Criterion 2.7.1.

Evaluation — Review drawings, specifications, and system diagrams.

Commentary — Problems of sensors giving erroneous readings of system operating conditions have been experienced because of heating or cooling in the immediate vicinity of the sensors due to extraneous heat flows and improper physical placement of the sensors. Degraded performance, incorrect indication of system performance, or system failure by freeze-up can result from such erroneous readings. Problems have occurred with sensor installations for storage containers as well as collector components.

The sensor should be in direct contact with the measured object or substance. Heat transfer pastes may be used to increase thermal contact. Sensors for sensing fluid temperatures should be immersed directly in fluids or in direct contact with the containment device or pipe. Insulation of sensors from extraneous heat flows can increase the accuracy of the readings obtained from them. Location of sensors based on their influence on system thermal performance is specified in Criterion 2.7.1. Reference [43] gives guidance in the correct installation of sensors and probes.

3.5.5

Criterion — Auxiliary system control. Provisions shall be made in the control system to allow separate operation of the auxiliary system.

Evaluation — Review drawings, specifications, and control system.

Commentary — Installations with integrated solar and auxiliary control systems have caused the auxiliary heating system to become inoperative when the control failed on the solar side. Such failure leaves the building without any heat. Separate control provisions are also desirable with integrated solar cooling control systems but failure of such controls will not result in a level of hazard comparable to failure of the heating system. In most systems, it is desirable that controls be designed so that the solar components and auxiliary components will operate both jointly and independently.

3.5.6

Criterion — Tracking collector controls. Control devices and drive mechanisms of tracking collectors shall be capable of maintaining the focus of collectors on the daily path (or reflection) of the sun within design limits. For tracking collectors that cannot tolerate stagnation, control devices shall be capable of moving the collectors off-focus during no-flow periods or other protective measures shall be provided.

Control devices shall be specified to automatically stow the collectors if the wind velocity exceeds the specified limits; otherwise, the collectors shall be designed to withstand maximum design wind speeds at that location.

Evaluation — Review past performance data, drawings, and specifications.

Commentary — Malfunction of sensors and associated circuitry, elongation and slippage of cables, shearing of gears,and binding of rotational elements have resulted in improper tracking and reduced performance of the collector array.

3.5.7
Criterion — Control wiring. Control wiring designed for exterior use shall be suitable for weather exposure or protected from weathering. Control wiring shall be selected and installation specified to prevent damage and breakage of wiring.

Evaluation — Review drawings and specifications.

Commentary — Control wiring should be in general compliance with Section 725 of the National Electric Code, Reference [44]. All wires and cables should be supported along runs and electric cable should be securely anchored to junction boxes. Some control devices may require shielded control wires to prevent electromagnetic interference. Wire runs should be soldered (using rosin flux) or properly crimped to obtain the most accurate signal transmission. Some devices may require protection from soldering temperatures.

3.6
Requirement — Freeze protection. System components shall be protected from or tolerant of damage by freezing of heat transfer liquids at the lowest ambient temperatures that will be encountered in actual use.

Commentary — Various methods of freeze protection are available including the use of freeze-inhibited fluids such as glycol solutions and oils, warm water circulation, and draindown. Antifreeze solutions and oils are incompatible with many standard seal materials. Studies of freeze associated problems are detailed in Reference [45].

3.6.1
Criterion — Antifreeze concentration. Systems using antifreeze solutions shall have an adequate concentration of antifreeze to prevent freezing at the coldest ambient temperatures expected to occur in the geographic location for which they are installed.

Evaluation — Review specifications and weather data.

Commentary — At the approach of cool weather, the antifreeze content should be checked for proper concentration. System leaks and improper solution make-up may result in inadequate concentrations. For this reason, the use of automatic water-only make-up techniques are not recommended. See Criteria 6.1.5 and 6.2.1 and Requirements 4.1 and 4.2. Reference [45] provides detailed recommendations for antifreeze systems.

3.6.2
Criterion — Draindown, drainback systems. Systems using automatic draindown for freeze protection shall provide for complete and timely drainage of components exposed to freezing condi-

tions by the proper combination of sensing and control mechanisms, valves, vents, pipe slopes, flow and pressure control.

Evaluation

Review drawings and specifications.

Commentary

References [20, 45] provide detailed recommendations for draindown systems. Draindown systems require control provisions to provide venting for draining and refill (see Criterion 3.2.7) and may require special provisions to prevent corrosion of system components during these operations. For this reason, pumps for open systems using water as the heat transfer liquid should be either bronze or stainless steel. Pumps in closed systems may be cast iron. See Criterion 3.2.10.

Automatic air vents, vacuum relief valves, and draindown valves should be insulated to protect them from freezing. The rate of draindown should be such that ice blockages do not form in the process of draindown. It is important that draindown systems be designed and installed so that all lines are pitched to drain a minimum of 1/4 inch per foot (21 mm/meter) since roof deflection can counter this by as much as 1/10 inch per foot (8 mm/meter). It is also important that lines are adequately supported and joints are leaktight. In air-assisted draindown systems, moisture-laden warm air may be drawn from storage into exterior components. If this is not prevented, the moist air can freeze a control valve or create blockage in the exposed collector loop resulting in severe freeze problems.

Fail-safe freeze protection methods are desirable since, in the event of power failure, freeze protection methods involving pumps, heaters, and valves that require electric power will be inoperative.

Draindown systems are frequently designed to drain at an outdoor temperature of about 38°F (3°C) and to refill at about 42°F (6°C). Such set points may be used but with the penalty of not collecting useful energy when solar radiation is available at the time of cold ambient temperatures. This problem can generally be avoided by initiating draindown based on the collector absorber plate temperature. The temperature sensor initiating draindown should be located on the component having the smallest thermal time constant. Collector panel time constants are available from the ASHRAE test, Reference [5]. However, the water pipe time constant would have to be calculated based on its heat capacity and insulation R-value. It is important that pipes passing through unheated spaces be considered as potential freeze problems. Such locations could be well below freezing and create problems even though the control sensor may not indicate the need for draindown.

The hardness or mineral content of the water used in draindown systems should be evaluated for the potential build-up of scaling products in piping, valves, or collector passages. See Criterion 3.2.3.

The collector loop holding tank or the expansion tank should be properly located with respect to the system pumps and should be placed in a warm space. Water level indication should be marked on the storage tank, clearly distinguishing between the appropriate water level during normal operation and level at drainback to allow adequate capacity for drainage. The control valves should be properly located, be air and water tight, and fail safe in a manner that assures system drainage.

3.6.3

Criterion

Power operated protection. Systems using the circulation of warm water or other methods that use electrical power for freeze protection shall have provisions for back-up protection of the system in the event of power failure. The method and degree of automation of back-up protection shall be related to the probability of concurrence of power failure with freezing conditions and the presence of operating personnel.

Evaluation

Review drawings and specifications.

Commentary

Continuous circulation of heat transfer fluid should not be used for freeze protection due to the excessive energy loss this causes. Pulse or intermittent warm water circulation or heat tapes may be justified in very mild climates where freezing temperatures are infrequent.

Backup protection methods should be selected for the level of potential risk that is projected. If, for example, records indicate freezing will occur once every 20 years, the probability of this happening concurrently with a power failure and with no one present to manually drain the system is probably acceptably low and reliance on simple manual drain method would be justified. For small HW systems, manual methods might be considered acceptable for somewhat more frequent freezing recurrence intervals. Judgment must be exercised as experience has shown the simultaneous occurrence of freezing conditions and power outage, or exceedingly high power demand to be reasonably high. Larger systems would probably warrant consideration of more automated backup provisions such as automatic draindown or possibly even stand-by electrical generation. Backup standby power is probably most feasible where it is being considered for other back-up reasons as well.

Reference [46] contains a detailed discussion of freeze protection for warm climates.

3.6.4

Criterion — Freeze tolerant designs. Components that will experience freezing conditions (based upon 20 year extreme weather data) and are not provided with specific freeze protection techniques shall be capable of withstanding freezing conditions and perform reliably after exposure to such conditions.

Evaluation — Review drawings and specifications. Freeze tolerance of collectors shall be tested in accordance with test method 7.6 of NBSIR 78-1305A, Reference [4].

Commentary — Stresses in collector assemblies caused by differential thermal expansion and contraction and by freezing of heat transfer fluids, if any, can cause permanent damage: distortions, dislocations, and bursting of collector components. Care is necessary to ensure that all components exposed to freezing conditions, not just collectors, be freeze tolerant. Also, differential controllers should not allow pumps to start when ice in the upper part of the collector warms and melts while the lower part is still blocked with ice. Water wall units, drums, etc., normally thought to be protected may be exposed to freezing conditions during extreme conditions, i.e., when the building is shutdown in the winter. Under ordinary operating conditions, these water walls would be protected by auxiliary backup.

Designs which utilize vacuum insulation for protection can freeze if this vacuum is lost due to leakage or for other reasons. Freeze tolerant designs should be tested for reliability.

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CHAPTER 4

SAFETY AND HEALTH

CHAPTER 4 - (Continued)

SAFETY AND HEALTH

CHAPTER 4

SAFETY AND HEALTH

4.1
Requirement

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

4.1.1
Criterion

Protection of potable water. Potable water shall not come in contact with materials that affect the taste, odor, or physical quality and appearance of the water in an undesirable manner.

Evaluation

Review of plans and specifications. The quality of the water shall be in compliance with the National Interim Primary Drinking Water Regulation, Reference [1].*

Commentary

This criterion is not intended to preclude using dyes suitable for ingestion as a means for the detection and warning of leaks in the system.

4.1.2
Criterion

Separation of circulation loops. Potable water systems shall be separated from circulation loops of systems utilizing non-potable heat transfer or thermal storage fluids by a minimum of two physically separated walls or interfaces between the potable water supply and the non-potable liquid or shall be protected in such a manner that equivalent safety is provided. Alternative protection shall be provided in a manner acceptable to the applicable authority(ies) having jurisdiction.

Evaluation

Review drawings and specifications. Alternate levels of protection shall be directly related to the toxicity potential of the heat transfer fluid used. For example, a suggested guideline for levels of protection is currently being examined by ASME.1/

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* Numbers in brackets [ ] indicate references at end of this chapter.

1/ A preliminary draft standard prepared by the ASME Solar Energy Standards Committee in June 1980, contains guidelines for liquid-to-liquid heat exchangers which relate the toxicity of the fluid to the extent of protection provided.

Commentary

It is very difficult for the system designer to assess the safety of the heat transfer fluids that are currently on the market. It is also very difficult for the designer to determine the safeguards that must be taken to ensure safe system operation. Data are available in the literature that rank various heat transfer liquids on the basis of their relative toxicity.[1/] These data do not indicate the cut-off points at which various degrees of protection must be taken; however, consensus standards (in development)[2/] may consider these relationships for solar applications. This problem is compounded by factors such as: (1) the use of additives to modify fluid properties; (2) the possible formation of harmful decomposition products, e.g., by thermal degradation; (3) dilution of the heat transfer fluid in the potable water stream, should failure occur, will help to reduce the level of toxicity hazard; (4) the fact that liquids are generally available in varying grades of chemical purity; (5) the possibility that the system will be refilled in the future with a hazardous liquid; and (6) the possibility that the circulation in a closed loop system for prolonged periods of time will even result in the contamination of potable liquids, e.g. by metal ion buildup. Thus, one must consider the attributes of the actual fluid as used in the system.

4.1.3
Criterion

Backflow prevention. Backflow of non-potable fluids into the potable water system shall be prevented in a manner approved by the applicable authority.

Evaluation

Review drawings and specificiations. Inspect assembled systems.

Commentary

Pollution of the potable water supply can occur by way of backflow caused by back pressure and/or backsiphonage within an inadvertent cross connection between the potable supply and non-potable fluid in the system.

Piping arrangements, backflow prevention and/or air gaps are commonly used to prevent contamination of potable water

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1/ Toxicity ratings of commercial substances from two widely acknowledged sources, Gosselin, Reference [2] and Durham, Reference [3] are available. These have been summarized and tabulated in a convenient manner for many materials commonly used in solar systems in Reference [4].

2/ A preliminary draft standard prepared by the ASME Solar Energy Standards Committee in June 1980, contains guidelines for liquid-to-liquid heat exchangers which relate the toxicity of the fluid to the extent of protection provided.

systems. A check valve is not a substitute for an approved backflow preventor and should not be used in its place.

Reference [5] provides discussion as well as evaluation of some of the many backflow prevention devices available. However, without proper routine maintenance, any backflow prevention device can fail. The false sense of security imparted by an expensive, yet failed, backflow preventer may permit nonpotable or even lethal quantities of fluid to be ingested.

4.1.4

Criterion — Contamination of air. Materials which come in contact with air shall not affect the odor or biological quality of the air in an occupied space in an undesirable manner.

Evaluation — Review drawings and specifications.

Commentary — Special consideration should be given to the presence of fungus, mold, or mildew in air handling systems since such microorganisms are often allergenic. Filtering of air streams to reduce dust which may carry such microorganisms is desirable. Such provisions in passive systems with low air velocities may be impractical. Rock containing asbestos should not be used due to the potential carcinogenic hazard. Cleanliness of the rock storage medium is further covered in Criterion 3.3.5.

There is growing concern over the possible occurrence of harmful air pollutants in tightly sealed buildings, Reference [46]. Release of radioactive radon gas in particular has been associated with some masonry and concrete products such as those that may be used in large quantities in passive solar components or in rock storage bins, References [6, 7, 8]. Release of formaldehyde gas from the resins used in urea formaldehyde foam insulation, adhesives, and binders could present a problem when associated with air carrying components such as storage units or collectors.

Protection from contamination of the air supplied to occupied spaces may be accomplished by the use of suitable, noncorrosive heat exchangers. The use of heat exchangers will penalize the thermal performance of the system to some degree.

4.1.5

Criterion — Growth of fungi. Components and materials used in the H/C/HW systems that come in contact with air being supplied to a conditioned space or with potable water and that operate under conditions that promote the growth of fungi, mold, or mildew shall not support such growth.

Evaluation — The materials shall be capable of withstanding exposure to fungus as defined by either Method 10 of UL 181, Reference [9] or Appendix D, Section E, of the MPS 4900.1 and 4910.1, References [10, 11]. Review environmental and design operation conditions.

Commentary — Fungi can feed on some organic materials and generally thrive in warm, moist environments. The potential for fungus growth in a rock storage container which becomes damp due to the failure of waterproofing membrane around underground or exterior containers or other causes could be a substantial problem requiring periodic maintenance. Use of a fungicide in such maintenance could introduce another potential airborne hazard and, therefore, other methods may be preferable.

The formation of condensation is a related problem that is also a concern. Condensation may occur on materials when used for cooling storage in air systems as well as on aperture glazing and between glazing and movable insulation.

4.2
Requirement — Control of hazardous substances. The use of hazardous substances within the solar energy system shall be controlled in such a manner to prevent any unreasonable risk or danger to the occupants, building, or surrounding area.

Commentary — See the Terminology section for the definition of "hazardous substances" and the indicated reference providing guidelines to regulations regarding such substances.

4.2.1
Criterion — Toxic fluids. The use of toxic fluids shall comply with the Federal Hazardous Substances Act, Reference [12] and the requirements of the applicable authority. (See definition of "toxic" in Terminology section.)

Evaluation — Review specifications.

Commentary — Toxic fluids are those having the capacity to produce personal injury or illness to man through ingestion, inhalation or absorption through any body surface, Reference [12]. A compilation of the toxicity characteristics of materials used in solar systems has been prepared, Reference [4]. When evaluating the toxicological properties of fluids, special consideration should be given to the effect of a system failure on the occupants. The evaluation should include the effects from contacting both the liquid directly and the vapor given off by the liquid.

The toxicological effects of the fluid should be evaluated at the elevated temperatures expected during system operation as well as at ambient temperatures. Characteristics of the complete fluid mixture must be considered in determining toxicity. For example, the addition of inhibitors and/or buffers to antifreeze/water mixtures or to water may affect toxicity characteristics.

4.2.2
Criterion

Identification of hazardous fluids. Systems using heat transfer fluids or thermal storage fluids that are designated as toxic or flammable by the supplier or the applicable authority shall be identifiable, and drains and other designated fluid discharge or fill points in the solar system should be labeled with: a warning identifying and summarizing the hazardous properties of the fluid, instructions concerning the safe handling of the fluid, safe means of disposal, and emergency first aid procedures.

Evaluation

Review drawings, specifications, and labeling (size, color, etc.) for compliance with the Federal Hazardous Substances Act, Reference [12].

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.

4.2.3
Criterion

Detection of hazardous fluids. Means shall be provided to indicate a failure of the fluid transfer system (e.g., leakage, pump failure, or activation of relief valves) and the provision of warning when leaks occur if heat transfer fluids or thermal storage fluids that require special handling are used. The extent of warning (i.e. whether solely maintenance personnel or all of the occupants of a building) shall be determined on the basis of the degree of hazard presented by the fluid used and the type of occupancy.

Evaluation

Review drawings and specifications. Test detection and warning system(s), i.e., visibility of a dye or operation of warning device.

Commentary

It is common practice to relate toxicity and flammability ratings to the level of hazard created at ambient temperatures. Heat transfer fluids which do not present a hazard at ambient temperatures may be hazardous at the temperatures developed in the system. 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.

4.2.4
Criterion

Disposal of hazardous fluids. Systems utilizing toxic, corrosive, combustible, or explosive heat transfer fluids or thermal storage fluid shall provide for the catchment and/or harmless removal and disposal of these fluids from drains, recharge points, vents, or points of probable leakage (i.e., leakage from components that would not normally be expected to last the life of the system) as approved by applicable authority.

Evaluation

Review drawings and specifications and local disposal regulations.

Commentary

The discharge of toxic, corrosive, combustible, or explosive fluids into sewers can create serious health and safety hazards both within the community and at a considerable distance along watercourses into which the sewers discharge. Safe disposal of these fluids requires, among other things, the consideration of the fluid composition, its concentration and frequency of discharge, and the nature of the sewage treatment and disposal system available to the site. In some instances, catchment of this discharge and removal to the specialized treatment facilities may be the only acceptable disposal method. Under such conditions, adequately sized and protected catch basins must be provided.

The leakage of toxic fluids into the ground could contaminate ground water. In addition, leakage of some heat transfer fluids can damage roofing, sealants, and other building materials. The leakage of combustible fluids may pose a fire hazard when exposed to external ignition.

4.3
Requirement

Protection from physical hazards. The H/C/HW systems shall not create a hazard to people greater than those found in conventional buildings where solar energy equipment or design concepts are not used.

4.3.1
Criterion

Pressure and/or temperature relief devices. Pressure and/or temperature relief devices shall be provided in each portion of the system where excessive pressure and temperatures can develop and shall be set to open at not more than the maximum pressure and temperature for which the system is designed.

Evaluation

Review drawings and specifications and/or determine that methods, devices, and materials to be used are approved by a recognized testing and evaluation agency as being suitable for the proposed use.

Commentary

Care should be taken in the design and layout of the fluid transport system to prevent conditions in which locally excessive pressures or temperatures are developed as a result of flow restrictions or air locks. Large pressure or temperature changes due to flow of vapors or boiling fluids should be considered in the selection and location of relief devices. Relief devices must be protected from freezing as conditions can occur when relief is needed and the relief valves are inoperable because they are frozen. General requirements for use and installation of pressure relief devices are given in Reference [45].

4.3.2
Criterion

System failure prevention. 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 system, the temperatures and/or pressures developed in the H/C/HW systems will not present a danger to the occupants or damage any of the components of the system or the building.

Evaluation

Review drawings, specifications, and design calculations.

Commentary

Excessive pressure and temperatures that can build up within or on collectors under "no-flow" conditions are an important consideration. Consideration should be given to the thermal shock which could occur when cool heat transfer fluids are introduced into collectors which have been exposed to solar radiation under "no-flow" conditions. Due to the possibility of large hydrostatic head pressures on tanks that may be greatly in excess of pressures elsewhere in the system, care should be taken in the selection of the location of safety devices. In systems which are designed for maximum temperatures less than the maximum no-flow temperature (see Appendix A, Section 1) it is essential that some means of protection such as energy dumping be provided. System protection for failure at low temperature conditions is covered in Requirement 3.6, Freeze Protection.

4.3.3
Criterion

Glazing materials. Glazed solar components with slopes less than 45° from the horizontal and which are lower than 8 feet (2.4 m) above a walking surface for unrestricted traffic adjacent to the component shall be safety glazed or otherwise protected against impact of persons falling against the glazing. Application of glazing materials in solar components that otherwise might present a risk of injury to persons because of falling or blowing of broken pieces or shards shall consist of safety glazing or be protected against breakage or restrained from falling.

Evaluation

Review plans and specifications for glazing locations and characteristics. Review compliance certification documents or test in accordance with procedures specified in "Federal Mandatory Standard for Architectural Glazing Materials", Reference [13] and "Performance Specification and Method of Test for Safety Glazing Materials Use in Buildings", Reference [14].

Commentary

This criterion and references cited in the Evaluation are intended to reduce the risk of injuries to people from accidental contact with solar glazing materials. It is intended that they be applied to glazing materials in solar systems only in those areas where there is a likelihood that people might accidentally come in contact with the glazing, such as installations on which children might climb or against which a passerby might fall or which is overhead and susceptable to breakage.

An additional concern is for glazing materials presenting a risk of injury to persons because of broken, sharp pieces or sheets that could fall from their mounting or be picked up and driven by wind.

Glazing considered by this criterion include those used as covers for flat plate solar collectors, as tubes in solar collectors, as solar reflectors, as roof or wall panels in passive installations, and as storage containers which are routinely accessible.

Traditionally, greenhouse type structures have been considered to provide adequate protection against the hazard of persons falling against them. It is not the intent of this criterion to impose new requirements on greenhouses of conventional design when used for solar applications.

For tubular type collectors, safety glazing may be inappropriate and should be considered on the basis of their particular design. In such cases other means of protection such as screening, etc., may be required where installations fall under this criteria.

Where large expanses of glazing are used, as in passive installations, the Federal safety standard for architectural glazing materials, Reference [13] should be reviewed for its applicability with respect to physical location and arrangement of the glazing and exposure risk of persons nearby.

Potential safety hazards should be considered in areas exposed to frequent hail storms, falling limbs or other projectiles with regard to installation of skylights, clerestory windows, and collector arrays. Where safety glazing is not employed, consideration should be given to provisions to restrain or deflect broken glass which may slide off elevated solar system components over entrances and locations of pedestrian and vehicular traffic ways. It is not the intent of this criterion to completely prevent punching or local cracking of nonstructural elements such as cover plates of collector panels under hail impact, but rather to control damage by keeping it at a level which would not create hazards by excessive shattering of glazed elements.

Film-type glazing materials for the outermost cover plates, if unsupported, may be unacceptable if they undergo large deflection under load, e.g., a flexible type glazing could deflect to the extent that a person's hand could touch the hot absorber surface, resulting in personal injury. See Criterion 4.3.5.

4.3.4
Criterion

Scalding. Hot water systems shall limit the temperature of the hot water for personal use at the tap to 140° + 5°F (60°C + 3°C) except where other limits are established by applicable authority. See Criterion 2.1.3.

Evaluation

Review drawings and specifications.

Commentary

This may be accomplished, for example, by the use of tempering or mixing valves or by the use of controls such as a high temperature cutoff on the solar energy storage device (which may result in wasteful energy loss). If other than the mixing valves or high temperature cutoff are used, it should be demonstrated that the required safe temperature limit will not be exceeded. This should be done by calculation of the temperatures in the system as a function of time throughout three successive clear sunny days in mid-July with the ambient temperature assumed at design conditions. The calculations should include the effect of water draw rate, tank heat losses, and typical collector efficiency values.

The major concern is not only for dangerously high temperatures but also for the sudden rise to such temperatures. It is generally suggested that mixing or tempering valves are the most cost effective means for providing for protection from scalding. The +5°F (+3°C) margin is given to allow a reasonable margin of error for the design temperature capability that must be provided (see Criterion 2.1.3) and the temperature limitations of this section.

4.3.5

Criterion — Surface temperature. Components of the H/C/HW systems that are accessible, located in areas normally subjected to public traffic and which are operated at elevated temperatures shall either be insulated to maintain the exposed surface temperatures at or below 140°F (60°C) at all times during their operation or be suitably isolated. Any other exposed areas that are operated at hazardous temperatures shall be insulated or identified with appropriate warnings.

Evaluation — Review drawings and specifications.

Commentary — The maximum allowable temperature commonly accepted for general use hot water installations without special protection is 140°F (60°C). In addition to the physical safety aspect, hot surfaces should be insulated to conserve energy or to prevent unwanted heat exchange with the space.

4.3.6

Criterion — Water storage hazards. Water storage containers larger than 200 gal. (755 L or .755 m^3) and located in or immediately adjacent to occupied spaces shall be adequately protected from damage and structurally restrained in such a manner to prevent rupture or collapse into the occupied spaces.

Evaluation — Review drawings and specifications.

Commentary — Large volumes of stored water are a potential hazard whether heated or not. The flood of water that may result from ruptured tanks as well as the mass of the water-filled containers are of concern. These containers, individually or collectively, may fail due to impact, faulty fabrication or possibly corrosion. The safety hazard is greatly increased if the water is heated. See Criterion 4.6.1 for structural design considerations.

4.3.7

Criterion — Snow and ice. Provision shall be made over entrances and locations of pedestrian and vehicular ways to restrain or deflect accumulated snow and ice masses which may slide off elevated solar system components.

Evaluation — Review drawings and specifications.

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 routes located away from the building) should be considered. This criterion is not intended to apply to areas where snow and freezing conditions do not normally occur.

4.3.8
Criterion

Lightning. As applicable, lightning protection shall be provided in accordance with the NFPA No.78 Lightning Protection Code, Reference [15].

Evaluation

Review of calculations, drawings, and specifications.

Commentary

Damage to control components and the potential of fire are major concerns for lightning protection.

If solar system piping is used as grounding for lightning protection, there must be a continuous electrical path to ground. Care must be taken that this does not short circuit dielectric isolation and thus result in corrosion problems if dissimilar metals are used in the system.

4.4
Requirement

Fire safety. The design and installation of the H/C/HW systems and their components shall provide a level of fire safety consistent with applicable codes and standards.

Evaluation

Review of drawings and specifications for conformance with the local and nationally recognized codes and standards for fire safety including but not limited to applicable sections of:

NFPA 89M, Reference [16]
NFPA 90A, Reference [17] and 90B, Reference [18]
NFPA 211, Reference [19]
NFPA 54, Reference [20]
NFPA 30, Reference [21]
NFPA 31, Reference [22]
NFPA 256, Reference [23]
The National Electrical Code, Reference [24]
ASTM E84, Reference [25]

In cases where sufficient engineering information is not available, testing to show compliance may be required. Potential heat, rate of heat release, ease of ignition, and smoke generation will be considered in assessing the potential fire hazards.

Commentary

It is the intent of the criteria of this requirement to (1) assure that the use of materials, equipment, and fluids will present no greater fire hazard than that allowed for conventional systems; (2) provide proper clearance and venting of heat build-up for those system components that operate at elevated temperatures; and (3) give consideration to the combustibility of materials adjacent to high temperature components in determining the clearance and/or insulation required. Special consideration should be given to the fire safety features of innovative system designs, particularly those utilizing insulation in a way which may present a greater hazard than with conventional designs, such as passive system thermal control elements. Special consideration should also be given to the use of combustible glazing materials, particularly when those materials are used in large quantities and/or exposed to the building interior either directly or through air passages.

4.4.1
Criterion

Liquid flash point. The flash point of a liquid heat transfer fluid shall equal or exceed the higher temperature determined from a and b below:

a. A temperature of 50°F (28°C) above the design maximum flow temperature of the fluid in the solar system;

b. The design maximum no-flow temperature of the fluid. Exception: When the collector manifold assembly is located outside of the building and exposed to the weather and provided that the relief valves located adjacent to the collector or collector manifold do not discharge directly or indirectly into the building, and such discharge is directed away from flames and ignition sources, only A above applies.

A "liquid heat transfer fluid" is defined as the operating or thermal storage liquid including water or other liquid base and all additives at the concentration used under operating conditions. The flash point shall be determined by the methods described in NFPA No. 321, "Basic Classification of Flammable and Combustible Liquids," Reference [26]. Flammable liquids shall not be used, and in systems using a gaseous heat transfer fluid, a flammable gas shall not be used. The design maximum flow temperature of the fluid is defined as the maximum fluid temperature that will be obtained when the heat transfer fluid is flowing through the system. Generally, this temperature will occur in the collector when it is receiving its maximum level of solar radiation at maximum ambient temperature.

Evaluation

Review drawings, specifications, design calculations, and test data for flash point and collector stagnation and operating temperatures. An acceptable way of determining the design maximum flow temperature is to limit temperatures of control devices or relief valves, or through theoretical or test analysis of the system. A method of determining the maximum no-flow temperature is by measuring the fluid temperature under stagnation conditions. The no-flow, 30 day test is presented in Section 10 of Appendix A. The design maximum no-flow temperature of the fluid is equal to the plate temperature at stagnation.

It should be noted that this method is not valid for collectors with very low loss coefficients.

Commentary

Flash point values listed in manufacturer's literature are frequently typical values and may be determined by an open cup flash point test. Flash point values used should be based on actual measurement or certified minimum values determined by the required closed cup flash point test method, Reference [26].

The flash point of aqueous solutions of organic materials depends on the percentage of water in the mixture. In the case of ethylene glycol, a flash point does not exist for certain percentages of ethylene glycol with water. When these mixtures are boiled and vapors allowed to escape, the flash point of the mixture usually will be reduced, ultimately approaching that of the pure substance. Care should be taken that the flash point of the solution is based on the anticipated percentage of water during actual use of the liquid in the system and not necessarily on the percentage as installed. A study of solar heat transfer fluid flash points and flash point criteria is presented in Reference [27].

4.4.2
Criterion

Combustible liquids. The storage, piping, and handling of combustible liquids shall be in accordance with the Flammable and Combustible Liquids Code NFPA No. 30, Reference [21].

Evaluation

Review specifications or code compliance.

Commentary

This criterion applies to those liquids which have met Criterion 4.4.1 for flash point. See also Criteria 4.2.2, 4.2.3, and 4.2.4.

4.4.3
Criterion

Flame spread classification of insulation. The flame spread classification index for all insulation materials except those installed underground and outside the structure shall not exceed the following values:

Plastic foam 75
Other insulation materials . 150*

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* The Consumer Product Safety Commission "Interim Safety Standard for Cellulose Insulation," Federal Register, Volume 43, No. 153, P. 35240, became effective on September 8, 1978 and supersedes these requirements for cellulose insulation where applicable. Modifications to this standard are under consideration by CPSC.

Insulation materials used for duct liners or air passage ways shall meet the requirements of either NFPA 90A, Reference [17] or 90B, Reference [18], whichever is applicable.

Evaluation

The ASTM E84, Reference [25] flame spread test method shall be the basis for evaluating the surface burning characteristics of the insulation materials. Where materials with facings are to be used, the surface burning characteristics of the faced materials 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 by ASTM E84. The requirement of flame spread classification of 75 maximum for plastic foams will provide as much safety assurance as is possible with current test methods. Such a classification shall not be construed as the equivalent of "non-combustible." 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.

4.4.4
Criterion

Areas of application of insulation. Materials used for thermal insulation shall be in accordance with Criterion 4.4.3 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 having a finish rating of not less than 15 minutes as determined by NFPA 251, Reference [28]. 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 pipes or pumps containing hot fluids, motors, fans, blowers, and heaters, unless the insulation and/or the heat producing appliances are specifically designed and rated for that purpose.

Evaluation

Review drawings and specifications.

Commentary

Although a degree of material combustibility is allowed, the intent is to allow thermal 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. Electric fixtures and circuit wires which are surrounded by substantial thermal insulation may be subject to overheating especially for circuits loaded at or beyond their rated capacity. In areas where occupants are likely to be engaged in normal activities, or in spaces in contact with the air stream, the insulation should perform its intended function without the increased risk of ignition, rapid flame spread, and heat and smoke generation. Attention should be given to the requirements as they pertain to innovative insulation systems such as movable and fixed insulation installed as part of passive systems. Insulation in concealed spaces may be a particular fire problem due to its susceptibility to smouldering and its inaccessibility for firefighting.

4.4.5

Criterion — Fire resistance requirements. The presence of solar components and their installation (penetration, etc.) shall not reduce the fire resistance of building elements (walls partitions, roofs, floors, etc.) required by the applicable authority.

Evaluation — Review drawings and specifications. Testing to show compliance in accordance with NFPA 251, Reference [28] and applicable standards.

Commentary — Solar components may form the load bearing elements of walls, roofs, etc. In addition, the presence of solar components (collectors, storage, etc.) and the passage of system components through fire-rated assemblies may adversely affect the fire endurance rating of the assembly in terms of fire penetration or premature collapse of structural elements. Large expanses of combustible glazing or other components used in wall and roof elements may significantly reduce the fire resistance of these components.

4.4.6

Criterion — Roof covering fire performance. The presence of roof mounted solar collectors or other components shall not reduce the required fire rating of the roof covering materials below that required by the applicable authority.

Evaluation — Review drawings and specifications. Testing when necessary to show compliance shall be in accordance with NFPA 256, Reference [23] with the collectors mounted as intended to use.

Commentary — Special consideration should also be given to the use of combustible glazing materials, particularly when those materials are used in large quantities and/or exposed to the building interior either directly or through air passages.

The type of testing that should be performed to evaluate the influence of solar collectors on the fire resistance of roof assemblies is described in test method 7.13 of NBSIR 78-1305A, Reference [29]. Testing using these procedures has shown that when collectors are mounted parallel to the roof, with a space greater than 1 1/2 inches between the collector and the roof, the fire resistance of the roof covering is generally reduced, Reference [44].

4.4.7
Criterion

Self-ignition of combustibles. Combustible solids used in solar equipment and adjacent combustible solids shall not be exposed to elevated temperatures which may cause ignition.

Clearance between combustible solids and system components having elevated temperatures shall be maintained in accordance with the following:

Installation Clearances

Maximum Surface Temperature (°F)	Required Clearance (inches)
less than 200	0
200 to 250	1
250 to 500	6
over 500	not allowed*

Evaluation

Review calculations, drawings, and specifications. Test to show compliance where necessary.

Commentary

Exposure of wood and/or other fibrous materials as well as other combustible materials over an extended period of time may result in the material reaching and surpassing its self-ignition temperature, Reference [49]. Such conditions may exist, for example, within active collectors framed in wood or inside attic collectors. The most commonly accepted ignition temperature of wood is on the order of 392°F (200°C). However, studies have indicated that wood may ignite when exposed to a temperature of 212°F (100°C) for prolonged periods of time. The ignition temperatures of plastics may be above or below those of wood or fibrous materials. Clearances for HVAC equipment, ducting and piping are discussed in NFPA No. 89M, Reference [16] and 90B, Reference [18]. Where applicable, clearances

* Combustible solids shall not be exposed to temperatures above 500°F unless the components are so listed and the clearances to combustible materials as specified in the component listing and marking shall be maintained for such elevated temperatures.

specified by a nationally recognized testing laboratory may be used.

4.5
Requirement

Installation arrangement. The location of solar components shall not increase the accident/hazards potential to a greater extent than would be expected for a conventional non-solar building.

Commentary

Some examples can be given of how the presence of solar components might increase accident potential: (1) reflected rays from the collector could be distracting to drivers on adjacent highways or annoying to the occupants of nearby buildings, and (2) the ground around a storage unit might settle, creating a hazard because of the uneven ground.

4.5.1
Criterion

Identification and location of controls. Main shutoff valves and switches should be conspicuously marked and placed in locations that are readily accessible to those personnel who would normally be expected to operate them in the event of an emergency. These valves and switches shall be located in the same manner as specified in 250.24 of NFPA 70, Reference [24] for electrical panels.

Evaluation

Review drawings and specifications.

Commentary

In large buildings, accessibility would normally be limited to qualified personnel; however, in small buildings, accessibility for the tenants should be provided.

In addition, controls which should only be adjusted by skilled personnel should not be located in areas subjected to normal occupant access.

4.5.2
Criterion

Emergency egress and access. The design and installation of the H/C/HW systems shall not impair the emergency movement of occupants of the building or emergency personnel to an extent greater than that allowed by NFPA 101, Reference [30] and applicable codes and standards.

Evaluation

Review drawings and specifications. Evaluate alternative means for provision of equal safety protection.

Commentary

If operable windows or exterior doors, required by many codes for sleeping areas, are eliminated for increased thermal control, such rooms and adjacent corridors should have listed smoke detectors which are interconnected and a door opening directly into a corridor that has access to two remote exits in opposite directions.

The location of solar equipment on a roof could reduce the usability of that roof for firefighting or egress. Solar system components located outside the building but near a means of egress could block the means of egress if a fire occurs.

4.5.3
Criterion

Electrical wiring. Electric wiring shall be installed in accordance to the requirements of the National Electrical Code, Reference [24] or the applicable authority. Particular attention must be given to the routing of wire and placement of electrical equipment in or near spaces which have higher than normal temperatures as a result of the operation of solar components.

Evaluation

Review of specifications and building drawings. The National Electrical Code, Reference [24], Chapter 3, states the requirements for temperature limits and derating factors for wiring exposed to elevated temperatures.

Commentary

Experience from the Solar Demonstration program has shown that spaces adjacent to solar collectors can become heated to higher than normal temperatures. The installation of branch circuit wiring in spaces that will experience elevated temperatures that may require a special type wire be used, or the type generally used wire, having a thermal limit of 140°F (60°C) be derated. Recent studies, References [47, 48] have shown that the 140°F (60°C) limit can be reached when branch circuits are located in attic spaces and normal loading is assumed. Thus special precautions should be used when locating electrical equipment and wiring either in or near collectors, or other components which might cause the wire to exceed its rated temperature limit.

4.6
Requirement

Structural safety. The H/C/HW system shall provide a level of structural safety consistent with applicable codes and standards.

Commentary

This requirement deals with the ability of systems and elements to maintain their structural integrity under in-service and extreme conditions. Factors such as wind, snow, operating, seismic, and thermal restraint loads are considered. Typical failures that are to be avoided might include: the collapse of a frame supporting solar collectors due to wind, snow, or earthquake; collapse of the thermal storage vessel or its supporting structure; the blowing off or fracture of a glass cover plate due to wind or thermal stresses.

Note that this applies to all elements of a solar system, not just those with a function of providing support for some other element. In this regard, there is an important distinction made between conventional elements, those elements for which design and construction procedures are contained in existing building regulatory documents, and non-conventional elements, those elements for which such procedures are not available. Elements made of materials documented in existing building regulatory documents, such as structural steel, aluminum, timber, glass, masonry, and concrete, that will be exposed to service conditions that are normally considered in such documents are examples of conventional elements. Newer materials such as a new alloy of aluminum, or conventional materials exposed to an unusual environment such as welded steel subjected to unusually high or low temperatures, or plastics subject to high and low temperatures are examples of non-conventional elements. Elements with a structural support function will generally be conventional.

4.6.1
Criterion

Structural resistance of H/C/HW systems. The elements and connections of the H/C/HW systems shall safely support all loads expected during the design life of the system without failure.

The structural resistance of conventional elements shall be determined in accordance with generally accepted engineering practices for the appropriate material, References [31, 32, 33, 34].

When common building materials cannot be judged by conventional criteria because they are exposed to unusual service conditions such as high temperatures, or where new materials are used structurally, the guide performance criteria in section 13.2.4 of Reference [35] should be used to determine structural resistance.

The design load shall include the following loads and shall be taken from and combined in accordance with ANSI Standard A58.1, Reference [36] and as noted:

1. Dead loads. Include the weight of heat transfer fluid contained in the component except when using dead load to resist uplift or overturning.

2. Live loads. Include all static and dynamic loads caused by the operation of the solar energy system and all appropriate maintenance loads. Surfaces that must support maintenance personnel shall resist a single concentrated load of 250 lbs (113 kg) distributed over a 4 square inch (2580 mm^2) area at the most critical locations. Also include vehicular loads as stipulated by AASHTO, Reference [37] on elements at or below grade subjected to traffic.

3. Soil and water pressures on buried elements.

4. Wind loads. Account for any unusual shape or exposure factors in accordance with accepted engineering practice. Reference [38] includes information on wind loads on solar collectors.

5. Snow and ice loads. Include any unusual loads due to drifting or slide-off. Solar components shall resist the appropriate surcharges, as defined in Reference [36]. Reference [39] provides information on ice loads on slender elements.

6. Earthquake loads. For components and connections which cannot be evaluated within the scope of the referenced provisions, the value of "Cp" (horizontal force factor) shall be taken as 1.0. Reference [38] includes information on earthquake loads.

7. Constraint loads. Those loads caused by temperature changes, shrinkage, moisture changes, normal functioning of the system, time-dependent changes within the materials of the system and by differential movement of the supporting structure and foundation settlement shall be taken as the most severe likely to be encountered during the service life.

8. The load from ponding of water on large horizontal surfaces shall be considered.

Evaluation — Review drawings, specifications, calculations, and testing.

Commentary — It is expected that most aspects of structural design for solar installations will fall within the domain of conventional engineering practice and that existing codes and standards may be applied to such. The intent of this criterion is that conventional elements and systems continue to be designed in accordance with applicable building code documents. The performance criteria in Section 13.2.4 of Reference [35] are specified for use in those situations in which accepted engineering standards are not applicable. Considerable care is required in determining the structural resistance in such situations. For structural testing of flat plate collectors, a test method has been proposed in Reference [29] for the following tests: positive live loads, negative and combination wind loads, and longitudinal loads.

It is recognized that some elements will be designed using the ultimate resistance and factored loads while others will be designed using an allowable resistance and unfactored loads.

The loads presented are those expected to occur in the projected lifetime of the installation. Particular attention should be given to the load caused by the thermal cycling of the system, both under normal conditions and "no-flow" conditions.

The following paragraphs of commentary address the loads listed under the criterion:

(1) The design dead load of mass storage materials (water tubes, drum walls, etc.) may in some instances need to be considered on other portions of the structure (floors, partitions, etc.). These loads can be quite important, particularly in retrofit application.

(2) The design live loads for roofs constitute minimum loading requirements needed primarily for human safety while the building is undergoing maintenance. Resistance to these loads need not be required for collector panels that are mounted on roofs without forming 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 should be required, because the roof will need to be repaired from time to time and must support the workman making the repairs.

(3) Wind load pressure coefficients for flat plate collectors are presented in Reference [40] and a tabulation of extreme wind speeds is contained in Reference [41].

    Wind loads due to the presence of solar systems may be more severe than those normally acting on buildings and require special attention especially in retrofitting an existing building.

(4) Rows of solar collectors protruding from a roof are similar to a snow fence and may significantly increase the amount of snow retained on the roof, requiring special attention especially in retrofitting an existing building. Reference [38] provides design guidelines.

(5) The value of "Cp" for seismic design supplied for elements that are not specified by the referenced provisions is consistent with conservative values for elements appended to structures.

(6) The possibility of stresses being imposed by thermal expansion or contraction, wind movement, seismic loads, vibratory loads, or foundation settlement need to be considered. Thermal expansion and contraction effects should

be evaluated for the extreme operating temperature range; note particularly, pipe thrusts at anchors and elbows. Solar components vary in their ability to withstand the effects on their performance of differential settlement. For example, a rock storage bin can probably settle a great deal without affecting its performance; however, a plumbing connection may be able to withstand very little differential settlement. Time dependent changes within materials or the system should include consideration of materials degradation. Of particular concern may be deterioration of plastics and organic materials, corrosion and electrolytic action between dissimilar metals such as between a collector and its support. Materials degradation is further discussed in Chapter 5.

In some circumstances, such as collectors framed in wood or attic collectors, wood and other fibrous materials may be subject to sustained or cyclic elevated temperatures for extended periods of time (years). Under such conditions, strength reduction of structural members may be very significant and should be considered, References [42, 43]. Uneven heating of such structural members may cause racking or twisting during the normal course of the day. This should be accounted for in the design of the structure.

(7) Ponding is defined as the retention of water due to the deflection of horizontal surfaces. Measures to resist ponding include providing sufficient stiffness to prevent excessive deflections, providing slope to carry excess water away, providing drains to remove water or providing overflow locations to limit the depth of water.

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CHAPTER 5

DURABILITY/RELIABILITY

CHAPTER 5

DURABILITY/RELIABILITY

5.0 Introduction

The performance requirements and criteria in this chapter deal with the ability of components and materials to maintain satisfactory long-term performance under in-service and extreme conditions. Factors such as the effect of external environment, temperature, chemical compatibility and wear or fatigue are addressed.

The intent in developing the requirements of Chapter 5 on durability/reliability is to assure that the components and materials designed to work as a system in the application of solar energy have a reasonable level of reliability. Much of the evaluative testing needed to assess performance should already have been carried out as part of the materials manufacturer's product development process, thus much of the requested information should be relatively easy to supply. There may be cases where a proposed design or application creates a unique condition of exposure, and additional testing will be needed to demonstrate compliance with the intent of the criteria. When testing of components or assembly of components is necessary, the performance of the assembly should indicate whether or not more detailed materials evaluation may be required. For instance, water leakage into a component would indicate that either the material must be resistant to moisture damage or the component must be redesigned to prevent water penetration. If the material is to resist degradation from moisture, evidence must be made available to show that the proposed materials possess the required characteristics to resist exposure to moisture.

As an aid to the user, a guide has been prepared which lists requirements and criteria for various components and materials, and the corresponding need for evaluative testing and analysis. A general guide for the consideration of each requirement and criterion for the various components and materials is contained in Tables 5.1a, 5.1b, 5.1c and 5.1d. The subsystems covered by these tables include the collector, the energy transport, the storage and the control subsystems and their components. These tables delineate the types of environmental conditions to which solar components and their materials could be exposed in actual service.

Tables 5.2a, 5.2b and 5.2c on collector, energy transport and storage components, respectively, are provided as an aid to identifying the need for assessing properties of materials. These tables do not relate directly to specific criteria, but guide the evaluator in determining which materials properties are critical for various subsystem components. The designated critical properties, when evaluation is required, should be measured before and after exposure to the environmental conditions or aging procedures presented in Chapter 5. Table B.1 (see Appendix B) presents standard practices which are available for determining physical properties of materials.

Appendix A provides test methods for evaluating components and materials to estimate if satisfactory performance can be achieved. The test methods listed in Appendix A are to be used when standard practices, such as ASTM standards, are not available. If standard practices are available, and satisfactorily address the issues of conditioning exposure and measurement of performance, such standards are preferred over the test method presented in Appendix A. Appendix B contains several tables intended to assist evaluators and designers with durability/reliability issues when materials are considered for solar application. In addition to Table B.1, which lists available ASTM standards useful in materials property measurement, tables of materials properties and characteristics are presented. Tables B.2, B.3, B.4 and B.5, which were derived from literature sources, provide the evaluator/designers with baseline information on properties of: cover plates, absorptive coatings, heat transfer liquids, and selected building materials.

5.1
Requirement

Effect of external environment. The H/C/HW systems and their various components shall not be affected by external environmental factors to an extent that will significantly impair their function during their design lives.

5.1.1
Criterion

Solar degradation. Solar components or materials shall not be adversely affected by exposure to sunlight in service to an extent that will significantly impair their function during their design lives.

When components or materials are exposed to ultraviolet radiation, there shall be no signs of excessive deterioration of optical, physical, or mechanical properties, or any other changes that would significantly affect the performance of the components in the system.

Evaluation

Compliance may be documented with data on satisfactory long-term performance under in-service conditions or engineering analysis. Where adequate information is unavailable, evaluation shall, where applicable, be carried out using the following standard practices which include solar degradation provisions: for cover plate materials, ASTM E765-80, "Standard Practice for Evaluation of Cover Materials for Flat Plate

Solar Collectors", Reference [1]*; and ASTM E782-81, "Standard Practice for Exposure of Cover Materials for Solar Collectors to Natural Weathering Under Conditions Simulating Operational Mode", Reference [2]. For absorptive coatings ASTM E744-80, "Standard Practice for Evaluating Solar Absorptive Materials for Thermal Applications", Reference [3], and/or as appropriate ASTM E781-81,"Standard Practice for Evaluating Absorptive Solar Receiver Materials When Exposed to Conditions Simulating Stagnation in Solar Collectors with Cover Plates", Reference [4]. If the test methodology described in these standards is not appropriate for the component or material in question or for the environmental conditions expected in service, the methodology outlined in Section 3 of Appendix A or other methods,shall be used to demonstrate that the intent of the criterion is met.

Commentary

Organic materials may be particularly susceptible to degradation resulting from prolonged exposure to solar radiation. Ultimate failure of these materials is frequently caused by physical impact, wind flutter, etc. Components of particular concern include cover plates, coatings, sealants, gaskets, absorber surfaces, collector heat traps,exposed coupling hoses, coatings or coverings of exposed insulation, devices for controlling entrance of sunlight(shutters, shades, drapes, blinds, etc.), reflectors, and collector casing assemblies. Combinations of materials (e.g., dissimilar metals) may give rise to corrosion problems that are not obvious from testing individual materials.

5.1.2
Criterion

Moisture penetration/degradation. Solar components or materials shall not be adversely affected by exposure to moisture in service to an extent that will significantly impair their function during their design lives.

Evaluation

When components, materials, or combinations thereof are exposed to moisture, there shall be no signs of excessive material degradation or reduction in insulation effectiveness that would significantly affect the performance of the components or the system.

Compliance with the above criterion may be documented with data on satisfactory long-term performance under in-use conditions or engineering analysis. If evaluative testing is required, the complete collector assembly shall be assessed for water leakage according to tests in Section 10 of Appendix A; or Section 7.5 of NBSIR 78-1305A, Reference [5] for thermal shock/water spray penetration and rain penetration. Consideration of water vapor stability of materials can be determined by the method described in ASTM

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* Numbers in brackets [ ] indicate references at the end of this chapter.

D2247-68 (1973), "Standard Method for Testing Coated Metal Specimens at 100 Percent Relative Humidity", Reference [6] or ASTM E744-80, "Standard Practice for Evaluating Solar Absorptive Materials for Thermal Applications", Reference [3]. The effect of moisture upon the weathering of cover plate materials can be evaluated using ASTM E765-80, "Standard Practice for Evaluation of Cover Materials for Flat Plate Solar Collectors", Reference [1]. ASTM E765-80 describes both natural and artificial weathering accompanied by water spray cycles. For determining the effect of moisture and water upon thermal insulation used in solar collectors, ASTM E861-82, "Standard Practice for Evaluating Thermal Insulation Materials for Use in Solar Collectors", Reference [7] can be used. Where other tests are available, that meet the intent of evaluating resistance to moisture penetration/degradation, such tests may be used.

Commentary

Moisture can exhibit itself in several forms, e.g., rainfall, melting snow and ice, condensation or vapor. The intent of this criterion is to ensure adequate performance of components or materials that are exposed to condensation in the collector interior. Some components, such as collector insulation, are usually intended to be used in low moisture environments; however, it is still possible for them to be periodically exposed to moisture from condensation. Such components would not usually be expected to meet the intent of this criterion if moisture exposure could not occur, e.g., in collectors that are hermetically sealed. Guidance for the waterproofing of exposed insulation both above and below ground is given in the HUD MPS Section 607-2, Reference [8], and also the ASHRAE Handbook of Fundamentals Chapter 17, Reference [9]. Salts extracted by moisture from some types of insulation or from organic components may cause corrosion of other system components in close proximity. Chlorides or sulfates that may be leached are a particular concern in regard to metallic corrosion. This criterion is not intended to address the effect that water in heat transfer fluid can have on system components which contact the fluid.

Efflorescence on the absorber surface of masonry walls such as greenhouse and Trombe walls can cause the deterioration of the absorber coating. Efflorescence occurs when water-soluble salts are absorbed by water passing through a cementitious surface. The salts crystallize on the surface coating causing a chalky deposit provided that the coating is permeable. If the coating is not permeable, the salts seep out beneath the coating, thus causing it to lose adhesion. If there is no water passage, efflorescence can be avoided.

5.1.3
Criterion

Pollutant degradation. Solar components and materials that are exposed to regionally prevalent air pollutants such as photochemical oxidents (ozone), sulphur dioxide, nitrogen oxides, or salt spray shall not be adversely affected to the extent that will significantly impair their function during their design lives.

Evaluation

Compliance may be documented with data on satisfactory long-term performance under in-use conditions or engineering analysis. Several standard specifications have been developed for solar energy system components that address the problem of pollutant degradation. The procedures cited in the specifications which address pollutant degradation shall be used as appropriate. Specifications related to rubber seals and hoses are: ASTM D3667-78, "Standard Specifications for Rubber Seals Used in Flat Plate Solar Collectors", Reference [10]; ASTM D3771-79 "Standard Specification for Rubber Seals Used in Concentrating Solar Collectors", Reference [11]; ASTM D3832-79, "Standard Specification for Rubber Seals Contacting Liquid in Solar Energy Systems", Reference [12]; ASTM D3903-80, "Standard Specification for Rubber Seals Used in Air-Heat Transport of Solar Energy Systems", Reference [13]; and ASTM D3952-80, "Standard Specification for Rubber Hose Used in Solar Energy Systems", Reference [14]. For other components or materials where adequate information regarding resistance to degradation from pollutants is unavailable, testing using either the methodology outlined in Section 4 of Appendix A or other methods which can be shown to meet the intent of the criterion shall be used.

The maximum pollutant levels in the geographic areas where the system will be installed shall be used to determine the pollutant levels required for testing. The pollutant levels shall be obtained from the most recent edition of "Air Quality Data - Annual Statistics Including Summaries with References to Standards", Reference [15]. If components are to be used in areas where they are exposed to very low pollutant concentrations, then the degradation test(s) for pollutants need not be conducted.

When components or materials are tested in accordance with the procedure outlined in Section 4 of Appendix A, there shall be no signs of excessive deterioration of optical, physical, or mechanical properties, or any other changes that would significantly affect the performance of the components of the system.

Commentary

The effects of solar radiation in combination with air pollutants may also be an important consideration in the dry as well as wet conditions. Factors of concern include surface erosion and consequent transmission loss of cover plates, deterioration of coupling hoses, exposed seals, and corrosion of metallic elements.

A potential problem with collectors in industrial atmospheres is that pollutants can go into solution in moisture and cause permanent etching of the cover plates and absorber surfaces and other metallic components over a period of time. Such etching can permanently reduce optical properties and may cause deterioration of mechanical properties. When this possible condition exists, design consideration must be given to avoid the problem.

5.2
Requirement

Effect of temperature. Solar components or materials and building elements with which they interact shall be capable of performing their intended function for their design lives when exposed to temperatures that can develop in the system.*

5.2.1
Criterion

Thermal degradation. When exposed to maximum service temperatures, solar components or materials shall not degrade to the extent that will significantly impair their function during their design lives.

Evaluation

Compliance may be documented with data on satisfactory long-term performance under in-use conditions or engineering analysis. Evaluation may occur at the collector, component and/or material level. There are several recently developed standard practices and standard specifications which address thermal degradation problems. When assessing the assembled collector for resistance to thermal degradation, ASTM E823-81 "Standard Practice for Nonoperational Exposure and Inspection of a Solar Collector", Reference [16], Section 5 of Appendix A, or Section 10 of Appendix A, as appropriate, shall be used. Test methods for thermal degradation of cover plates are addressed in ASTM E765-80, "Standard Practice for Evaluation of Cover Materials for Flat Plate Solar Collectors", Reference [1], and ASTM E782-81, "Standard Practice for Exposure of Cover Materials for Solar Collectors to Natural Weathering Under Conditions Simulating Operational Mode", Reference [2]. Absorptive coatings shall be evaluated using ASTM E744-80,"Standard Practice for Evaluating Solar Absorptive Materials for Thermal Applications", Reference [3] and ASTM E781-81, "Standard Practice for Evaluating Absorptive Solar Receiver Materials when Exposed to Conditions Simulating Stagnation in Solar Collectors with Cover Plates", Reference [4]. For sealants and gaskets the following ASTM specifications address the problem of thermal degradation and shall be used as appropriate: ASTM D3667-78, "Standard Specification for Rubber Seals Used in Flat Plate Solar Collectors", Reference[10]; ASTM D3771-79,"Standard Specification for Rubber

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* Maximum and minimum service temperatures are defined in Section 1 of Appendix A.

Seals Used in Concentrating Solar Collectors", Reference [11]; ASTM D3903-80 "Standard Specification for Rubber Seals Used in Air-Heat Transport of Solar Energy Systems", Reference [13]; and ASTM 3952-80, "Standard Specification for Rubber Hose used in Solar Energy Systems", Reference [14]. Thermal degradation is also covered in the recently developed insulation standard ASTM E861-82, "Standard Practice for Evaluating Thermal Insulation Materials Used in Solar Collectors", Reference [7] and ASTM E862-82; "Standard Practice for Screening Polymeric Containment Materials for the Effects of Heat and Heat-Transfer Fluids in Solar Heating and Cooling Systems", Reference [19].

When information is not available on performance regarding outgassing of materials,the thermal stability of components or materials and the long-term performance of heat-transfer fluid under in use conditions, testing using either the methdology outlined in Section 5 of Appendix A or other methods which can be shown to meet the intent of the criterion shall be used. When components or materials are tested in accordance with the procedures outlined in Section 5 of Appendix A, there shall be no signs of excessive deterioration of optical, physical, or mechanical properties or any other changes that would significantly affect the performance of the components or the system.

Commentary

Organic components in the system may be particularly susceptible to thermal degradation under prolonged exposure. Organic collector components of particular concern include glazing, absorbers, absorptive coatings, heat traps, insulation, sealants, gaskets, and collector casing assemblies. Storage containers, piping, ducts, storage liners,and coatings composed of organic materials may also be affected. Organic materials may change shape or dimensions and may lose strength or become more brittle.

Outgassing of condensible volatiles from components inside the collector could lead to deposits on the underside of the collector glazing reducing glazing transmissivity or other changes in the optical properties of collector components. Materials that have been observed to outgas in operational systems are gaskets and sealants, absorptive coatings, and insulation.

Of major concern is the breakdown of some heat transfer fluids at elevated temperatures resulting in corrosive by-products and formations which create scale and sludge within the system. Because of this concern, it is recommended that a maintenance program be developed and implemented to monitor and correct corrosion and scaling problems in order to achieve the desired lifetime of the system.

If not considered in the design, viscosity changes in heat transfer fluids may lead to pumping problems, such as excessive pumping power requirements or overheating due to heat transfer fluid thickening.

5.2.2
Criterion

Thermal cycling degradation. The H/C/HW systems, their various components, and building elements with which they interact shall be capable of withstanding the stresses induced by thermal cycling for their respective design lives.

Evaluation

Compliance may be documented with data on satisfactory long-term performance under in-use conditions or engineering analysis. Evaluation may occur at the collector, component, and/or material level.

When adequate information is unavailable to assess the effects of thermal cycling upon absorber materials, ASTM E744-80, "Standard Practice for Evaluating Solar Absorptive Materials for Thermal Applications", Reference [3] may be used.

For other materials and components which require assessment of the effects of thermal cycling, testing procedures outlined in Section 6 of Appendix A or other methods which meet the intent of the criterion shall be used.

After components or materials have been exposed to thermal cycling between their maximum and minimum service temperatures, there shall be no signs of excessive deterioration of optical, physical, chemical or mechanical properties or any other changes that would significantly affect the performance of the components or the system.

Commentary

This criterion is intended to identify potential problems that may occur as a result of differential thermal movement. Physical restraints (including support conditions) that will be imposed on the system in actual use shall be considered when testing is required. Permanent dimensional changes caused by expansion or contraction can result from thermal cycling.

If thermal expansion or contraction is cumulative in system or subsystem design, the test must be designed to reflect this condition. Areas of concern include cover plate/frame, collector/support, collector/collector, collector/piping, reflective surface/substrate, piping, solder joints, coupling hoses, sensors, the bond of tubing or coatings to absorber plates, and warping or shrinkage of cover plate or absorber.

Standardized methods to evaluate the durability of phase change thermal storage materials due to temperature cycling have not been developed. Evidence of the ability of a phase change material to remain stable through a number of cycles representative of a specified portion of its design life would be useful.

5.2.3
Criterion

<u>Thermal shock degradation</u>. Solar components and materials shall be capable of withstanding the stresses induced by thermal shock for their respective design lives.

Evaluation

Compliance may be documented with data on satisfactory long-term performance under in-use conditions, by engineering analysis, or by review of plans and specifications. When adequate information regarding thermal shock resistance of collectors is unavailable, Section 7.4 (cold fill) of NBSIR 78-1305A, Reference [5] shall be used. Other tests which can be shown to meet the intent of this criterion may also be used.

After the thermal shock test, there shall be no signs of excessive deterioration of physical or mechanical properties or any other changes that would significantly affect the performance of components, collectors, or materials.

Commentary

The intent of the criterion is to determine the ability of the solar collector to withstand thermal shock caused by heavy rains falling on heated collectors and also to ensure the reliability of solar collectors to withstand thermal shock induced through filling the hot collector with relatively cool heat transfer fluid during daytime start-up. It has been reported that cover plates have failed due to the thermal differential created in the glass by the rapid sliding off of snow cover, exposing cold collectors to the heat of solar radiation.

For collectors not capable of withstanding cold fill under stagnation conditions, this provision may be waived, if the collector is protected with means of preventing circulation of cold fluid in the hot collector.

5.3
Requirement

<u>Effect of chemical compatibility of components</u>. Materials used in the solar energy system, its various components and the building elements with which they interact shall have sufficient chemical compatibility to prevent corrosion, deterioration, or wear that would significantly shorten their intended service lives under in-use conditions.

5.3.1
Criterion

<u>Materials/transfer fluid degradation</u>. Materials designed to be used in contact with heat transfer fluids or the fluid itself shall not be deteriorated or otherwise adversely affected by such contact to the extent that their function will be sign-

ificantly impaired under in-use conditions during their design life.

Evaluation

Compliance may be documented with data or satisfactory long-term performance under in-use conditions, engineering analysis, or testing.

Where adequate information is unavailable regarding the performance of containment materials in contact with heat transfer fluids, evaluative testing will be required. For rubber materials several ASTM standard specifications are available, ASTM D3832-79, "Standard Specification for Rubber Seals Contacting Liquids in Solar Energy Systems",Reference [12] and ASTM D3952-80, "Standard Specification for Rubber Hose Used in Solar Energy Systems", Reference [14] can be used as applicable.

For metallic containment materials, ASTM E712-80, "Standard Practice for Laboratory Screening of Metallic Containment Materials for Use with Liquids in Solar Heating and Cooling Systems", Reference [17] and ASTM E745-80, "Standard Practices for Simulated Service Testing for Corrosion of Metallic Containment Materials for Use with Heat-Transfer Fluids in Solar Heating and Cooling Systems", Reference [18] as appropriate shall be used.

For the evaluation of polymeric containment materials in contact with heat transfer fluids, ASTM E862-82,"Standard Practice for Screening Polymeric Containment Materials for the Effects of Heat and Heat-Transfer Fluids in Solar Heating and Cooling Systems", Reference [19] shall be used.

For the evaluation of containment materials not addressed by the above specifications and standard practices, testing shall be conducted using the methodology outlined in Section 7 of Appendix A or other methods which can be shown to meet the intent of the criterion.

Commentary

This criterion is intended to address the compatibility of the heat transfer fluid and the materials and components in the energy transport system, i.e., collectors, piping, tanks, connectors, pumps, valves, heat exchangers, and their related seals and gaskets. Metals and plastics are used in these applications. The heat transfer fluid may be water, aqueous-organic liquid solutions, or organic fluids. All may contain various additives. Metals may be susceptible to corrosion in systems with aqueous or organic heat transfer fluids. See also discussion of problems created by the thermal degradation of heat transfer liquids in 5.2.1. Some plastic materials are sensitive to exposure to either aqueous or organic fluids. Corrosion of metals by heat transfer fluids could be a serious problem in solar energy systems. SAE Standard J447a (1964), Reference

[20] provides guidance in preventing corrosion. Experience indicates that tight closed-loop systems help to minimize metallic corrosion by reducing the oxygen content of the transfer fluid.

Any use of inhibitors in heat transfer fluids should be keyed to the characteristics of all elements of the solar energy system which come in contact with the fluid including collectors, piping, connectors, tanks, pumps, valves, heat exchangers, and their related seals and gaskets. Inhibitors used with non-toxic heat transfer fluids should be selected to comply with the fluid safety requirements of Requirement 4.1. Further discussion is included in Reference [21].

Although boiling can be prevented by pressurization, excessive temperatures can break down some constituents of the fluid to form organic acids. Buffers can be used to maintain a suitable pH balance but buffering will eventually be exhausted. Changes in pH indicate the loss in buffering capacity and the transfer fluid, or at least the buffers, must be renewed. However, simply adding a buffer is not adequate unless it can also be determined that the corrosion inhibitors have not been depleted. In addition, the concentration of corrosion inhibitors present in the system should be checked periodically.

Thermal cycling may cause precipitation to occur which may lead to a build up of solids in pump seals and valve seats which may lead to malfunction.

When heat transfer fluids are used as absorbers, a bleaching of the fluid may significantly reduce system performance. See also Criterion 5.1.1.

Tables 5.3 and 5.4 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 show significant variation in resistance to corrosion. Small concentration changes in a number of chemical elements may significantly change the corrosion behavior of a material at a specific temperature. A complete description of this behavior is not possible in this document. Generally unacceptable use conditions as stated should be avoided unless it has been demonstrated that the metal or alloy perform suitably in the anticipated use condition. Adequate performance is anticipated for normal operation in generally acceptable use conditions if these general guidelines are followed.

Since plastics are generally nonconductors, galvanic and electrochemical corrosion encountered with metals are nonexistent in plastic components. However, crevice corrosion cells may be set up at plastic/metal fittings. The physical and mechanical properties of some plastics can be affected significantly by heat transfer fluids. These effects are usually more pronounced at the elevated temperatures which accompany the heat transfer fluid in an operating solar system. Incompatibility can cause plastics to swell, delaminate, soften, crack, become brittle, lose strength, etc. The specific response is dependent upon the combination of polymer and heat transfer fluid. The Uni-Bell Plastic Pipe Association has developed a Handbook of PVC Pipe Design and Construction, Reference [22] which provides tables of the resistance of PVC pipe and elastomeric seals to reaction with or attack by the chemical agents. The information in it should be used as a guide only. Due to the complexity of some organic chemical reactions, additional long-term testing should be performed to determine performance of plastic components with fluids at elevated temperatures.

5.3.2
Criterion

Dissimilar metals degradation. Non-isolated dissimilar metals shall not be degraded to the extent that their function will be significantly impaired under in-use conditions during their design lives.

Evaluation

Compliance may be documented with data on satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate information is unavailable, testing using either the methodology outlined in Section 8 of Appendix A or other methods which can be shown to meet the intent of the criterion shall be used. Dissimilar metals used in contact with heat transfer or other fluids shall be tested to reflect this condition.Where protective finishes are normally provided, they shall be used on the specimens tested.

Commentary

The use of dielectric fittings that electrically isolate dissimilar metals is desirable. When using an electrically conductive heat transfer fluid, dielectric isolation of dissimilar metal connections should occur whenever there is a galvanic couple. The use of dielectric fittings may conflict with electrical grounding or lightning protection requirements, but the problem can be alleviated by alternate grounding system.

Attention should be paid to all elements of a solar energy system when considering compatibility of dissimilar metals. This should include energy transport system, structural support and connections, and fabricated parts.

There is need to examine materials compatibility beyond the component level to assure that the total system is engineered with regard to reasonable life expectancy. The design life must take into account the long term materials compatibility, maintenance and operation, along with the desired thermal performance.

5.3.3
Criterion

Compatibility of adjacent organic materials. Organic solids in contact with other organic solids or inorganic materials shall not be degraded to the extent that their function will be significantly impaired during their design lives.

Evaluation

Compliance may be documented with data on satisfactory long-term performance under in-use conditions or engineering analysis. For compatability of collector components and thermal insulation used in the collector, ASTM E861-82, "Standard Practice for Evaluating Thermal Insulation Materials for Use in Solar Collectors", Reference [7] shall be used, as applicable, to demonstrate satisfactory performance, if testing is required. If adequate information is unavailable for other materials or components, testing using either the methodology outlined in Section 9 of Appendix A or other methods which can be shown to meet the intent of the criterion shall be used.

Commentary

Incompatibility can occur between organic materials and between organic materials and inorganic materials such as metals or phase change salts. Some sealants and gaskets are incompatible with plastic glazing materials. Plasticizer migration can result in discoloration, softening, and other types of deterioration.

Inorganic phase change salts have been stored in plastic containers. Leakage in the containers can result from deterioration of the material caused by either mechanical (e.g., thermal expansion) or chemical incompatibility of the salt and plastic.

This criterion is not intended to address the compatibility of organic transfer fluids with adjacent materials covered in Criterion 5.3.1.

5.4
Requirement

Effect of wear. Components that involve moving parts shall, with normal maintenance, be capable of performing their intended function without excessive wear or deterioration for their design lives.

5.4.1
Criterion

Degradation by wear. Dampers, check valves, pressure regulators, pumps, control devices, collector tracking mechanisms, insulation movement mechanisms and assemblies, and similar components shall be capable of operating under in-use conditions without exhibiting wear or fatigue that would significantly impair their ability to perform their intended function over their design lives.

Evaluation — Compliance may be documented with data on satisfactory long-term performance under in-use conditions, engineering analysis, or testing using an experimental verification procedure which can be shown to meet the intent of the criterion.

Commentary — Inclusion of the heat transfer fluid during tests of components with moving parts is necessary to meet the intent of this criterion. Many of the components described in this criterion involve the use of conventional components in unusual applications. A record of satisfactory performance in conventional applications may not be sufficient to adequately predict performance in solar applications and careful evaluation is desirable. Components containing moving parts whose use rarely occurs, except for safety reasons such as pressure relief devices, vacuum breakers, etc., are of particular concern.

Table 5.1a[1/]

Guide for Durability/Reliability Evaluation of Collector Subsystems, Components, and Materials

Requirements	Section 5.1 Effect of External Environment			Section 5.2 Effect of Temperature			Section 5.3 Effect of Chemical Compatibility			Section 5.4 Effect of Wear
Criteria (Section)	Solar (5.1.1)	Moisture (5.1.2)	Pollutant (5.1.3)	Thermal (5.2.1)	Cycling (5.2.2)	Shock (5.2.3)	Materials/ Transfer Fluid (5.3.1)	Dissimilar Metals (5.3.2)	Compatibility of Adjacent Organic Materials (5.3.3)	Wear (5.4.1)
COLLECTORS										
Cover Plates										
Glass	R	N.A.	0	R	R	R	N.A.	N.A.	N.A.	N.A.
Plastic	R	R	0	R	R	R	0	N.A.	0	N.A.
Absorber										
Metal	N.A.	R	0	R	R	R	R	0	0	N.A.
Plastic	R	R	0	R	R	R	R	N.A.	R	N.A.
Absorber Coating	R	R	0	R	R	R	0	N.A.	N.A.	N.A.
Gaskets	0	R	0	R	R	R	R	N.A.	R	N.A.
Sealants	0	R	0	R	R	R	R	N.A.	R	N.A.
Coupling Hoses	0	R	0	R	R	R	R	R	R	N.A.
Insulation	0	R	0	R	R	0	N.A.	N.A.	R	N.A.
Case Assembly (i.e. box)	R[2/]	R	0	0	R	R	N.A.	R	0	N.A.
Reflectors	R	R	0	0	R	0	N.A.	N.A.	N.A.	N.A.

KEY: R = Required to satisfy the above criterion

0 = Optional, i.e., required only if material or component is subjected to conditions addressed by the above criterion

N.A. = Not applicable

1/ This table is a general guide for the consideration of each requirement and criterion included in Chapter 5 for the various materials used in a collector subsystem. Where applicable standards, such as ASTM standards are available, such test methods are to be used.

2/ Organic case assembly materials only.

Table 5.1b[1]

Guide for Durability/Reliability Evaluation of Energy Transport Subsystems, Components, and Materials

Requirements	Section 5.2 Effect of External Environment			Section 5.2 Effect of Temperature			Section 5.3 Effect of Chemical Compatibility			Section 5.4 Effect of Wear
Criteria (Section)	Solar (5.1.1)	Moisture (5.1.2)	Pollutant (5.1.3)	Thermal (5.2.1)	Cycling (5.2.2)	Shock (5.2.3)	Materials/ Transfer Fluid (5.3.1)	Dissimilar Metals (5.3.2)	Compatibility of Adjacent Organic Materials (5.3.3)	Wear (5.4.1)
ENERGY TRANSPORT										
Pipes										
Metals	N.A.	R	O	N.A.	O	O	R	R	N.A.	N.A.
Plastic	O	R	O	R	R	O	R	N.A.	R	N.A.
Ducts/Plenums										
Metals	N.A.	O	O	N.A.	O	O	N.A.	O	N.A.	N.A.
Plastic	O	N.A.	O	R	R	O	N.A.	N.A.	O	N.A.
Heat Transfer Fluid	O	N.A.	N.A.	R	N.A.	N.A.	R	R	R	N.A.
Pumps	N.A.	N.A.	N.A.	R	N.A.	N.A.	R	R	O	R
Blowers	N.A.	N.A.	O	R	N.A.	N.A.	N.A.	N.A.	N.A.	R
Filters	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	O	O	O	N.A.
Insulation & Coating	O	R	O	R	R	O	N.A.	N.A.	R	N.A.
Expansion Tank	R[2]	N.A.	O[2]	O[2]	O[2]	O[2]	R	N.A.	R[2]	N.A.

KEY: R = Required to satisfy the above criterion
O = Optional, i.e., required only if material or component is subjected to conditions addressed by the above criterion
N.A. = Not applicable

[1] This table is a general guide for the consideration of each requirement and criterion included in Chapter 5 for the various materials used in an energy transport subsystem. Where applicable standards, such as ASTM standards are available, such test methods are to be used.

[2] For organic expansion tanks only.

Table 5.1c[1/]

Guide for Durability/Reliability Evaluation of Storage Subsystems, Components, and Materials

Requirements	Section 5.1 Effect of External Environment			Section 5.2 Effect of Temperature			Section 5.3 Effect of Chemical Compatibility			Section 5.4 Effect of Wear
Criteria (Section)	Solar (5.1.1)	Moisture (5.1.2)	Pollutant (5.1.3)	Thermal (5.2.1)	Cycling (5.2.2)	Shock (5.2.3)	Materials/ Transfer Fluid (5.3.1)	Dissimilar Metals (5.3.2)	Compatibility of Adjacent Organic Materials (5.3.3)	Wear (5.4.1)
STORAGE										
Containers Units										
Inorganic	N.A.	R	0	N.A.	R	R	R	R	N.A.	N.A.
Organic	0	R	0	R	R	R	R	N.A.	0	N.A.
Liners	N.A.	0	N.A.	R	R	N.A.	R	R	R	N.A.
Insulation	0	R	0	R	R	R	N.A.	N.A.	0	N.A.
Gaskets & Sealants	0	0	0	R	R	R	R	N.A.	R	N.A.
Storage Medium										
Liquid	N.A.	N.A.	N.A.	R	R	N.A.	N.A.	R	R	N.A.
Solid	N.A.	R	0	N.A.	R	N.A.	N.A.	R	R	N.A.
Phase Change Material	0	N.A.	N.A.	N.A.	R	R	N.A.	N.A.	R	N.A.
Heat Exchangers	N.A.	N.A.	N.A.	R	R	R	R	R	N.A.	N.A.

KEY:
R = Required to satisfy the above criterion
0 = Optional, i.e., required only if material or component is subjected to conditions addressed by the above criterion
N.A. = Not applicable

1/ This table is a general guide for the consideration of each requirement and criterion included in Chapter 5 for the various materials used in a storage subsystem. Where applicable standards, such as ASTM standards are available, such test methods are to be used.

Table 5.1d[1]

Guide for Durability/Reliability Evaluation of Control Subsystems, Components, and Materials

Requirements	Section 5.1 Effect of External Environment			Section 5.2 Effect of Temperature			Section 5.3 Effect of Chemical Compatibility			Section 5.4 Effect of Wear
Criteria (Section)	Solar (5.1.1)	Moisture (5.1.2)	Pollutant (5.1.3)	Thermal (5.2.1)	Cycling (5.2.2)	Shock (5.2.3)	Materials/ Transfer Fluid (5.3.1)	Dissimilar Metals (5.3.2)	Compatibility of Adjacent Organic Materials (5.3.3)	Wear (5.4.1)
CONTROLS										
Control Units	N.A.	N.A.	N.A.	R	R	R	N.A.	N.A.	N.A.	R
Sensors	0	0	0	R	R	R	0	N.A.	N.A.	N.A.
Regulators	N.A.	N.A.	N.A.	R	R	R	N.A.	N.A.	N.A.	R
Valves	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	R	R	0	R
Dampers	N.A.	N.A.	0	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	R
Tracking Devices	N.A.	0	0	R	R	R	N.A.	0	0	R
Movable Insulation	0	0	0	0	0	0	N.A.	N.A.	0	R

KEY:

R = Required to satisfy the above criterion
0 = Optional, i.e., required only if material or component is subjected to conditions addressed by the above criterion
N.A. = Not applicable

1/ This table is a general guide for the consideration of each requirement and criterion included in Chapter 5 for the various components used in a control subsystem. Where applicable standards, such as ASTM standards are available, such test methods are to be used.

Table 5.2a - Property Assessment of Materials -- Collector Components[1]

	Glazing Glass	Glazing Plastic	Absorber Metal	Absorber Plastic[2]	Absorber Coating	Gaskets and Sealants	Coupling Hoses	Insulation	Case Assembly (i.e. box)	Reflector
Visual Inspection	X	X	X	X	X	X	X	X	X	X
Optical Properties										
Solar Transmittance	X	X								
Solar Reflectance		X		X	X					X
Emittance				X	X					X
Mechanical Properties										
Tensile		X		X		X	X			
Flexure							X			
Impact	X	X								
Fatigue				X						
Burst or Rupture				X		X	X			
Physical Properties										
Dimensional Stability		X	X	X		X	X	X	X	
Hardness						X	X			
Chemical Properties						X	X	X		

1/ This table is a general guide for use in the assessment of material properties of collector components which have been exposed to test conditions established in Chapter 5.

2/ In general, plastic absorber plates contain an absorber material as an inherent part of the plate assembly. This material performs as the absorber coating.

Table 5.2b - Property Assessment of Materials -- Energy Transport Components[1/]

	Pipes		Ducts/Plenums		Heat Transfer					Expansion Tank	
	Metal	Plastic	Metal	Plastic	Fluid	Pumps	Blowers	Filters	Insulation & Coating	Metal	Plastic
Visual Inspection	X	X	X	X	X	X	X	X	X	X	X
Optical Properties											
Solar Transmittance											
Solar Reflectance											
Emittance											
Mechanical Properties											
Tensile		X									X
Flexure		X									X
Impact											
Fatigue		X									
Physical Properties											
Dimensional Stability	X	X		X							X
Viscosity					X						
Chemical Properties											
pH					X						
IR Spectra					X						

1/ This table is a general guide for use in the assessment of material properties of energy transport components which have been exposed to test conditions established in Chapter 5.

Table 5.2c - Proposed Assessment of Materials — Storage Components[1/]

	Container Metal	Container Plastic	Liners	Insulation	Gaskets & Sealants[2/]	Liquid	Solid	Phase Change Material[3/]	Heat Exchangers
Visual Inspection	X	X	X	X	X	X	X		X
Optical Properties									
Solar Transmittance									
Solar Reflectance									
Emittance									
Mechanical Properties									
Tensile		X							
Flexure									
Impact									
Fatigue		X							
Physical Properties									
Dimensional Stability	X	X				X			
Viscosity									
Chemical Properties									
pH						X			
IR spectra									

1/ This table is a general guide for the use in assessment of material properties-storage components which have been exposed to test conditions established in Chapter 5.

2/ See evaluation methods in Table B.1 of Appendix B.

3/ Methods to be developed

Table 5.3 - Open System Parameters: Generally Acceptable and Unacceptable Use Conditions for Metals in Direct Contact with Heat Transfer Fluids

Generally Unacceptable Use Conditions	Generally Acceptable Use Conditions[1]
Aluminum	
1. When in direct contact with untreated, uninhibited 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 halide ions or less electro positive metals ions, such as copper or iron.	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/s (1.22 m/s).	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 contain 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/s (1.22 m/s).[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 carbonaceous 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 <8 or >12.	1. When in direct contact with distilled, deionized, or low salt content water which contains appropriate corrosion inhibitors, with pH >8 and <12.

[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 shall 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 5.3 - (Continued)

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/s (1.83 m/s).[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 <8 or >12.	2. When in contact with stable anhydrous organic liquids.
3. When in direct contact with aqueous liquid with a temperature >131°F (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 percent and greater, these alloys become increasingly susceptible to stress corrosion. Selection of brass with a zinc content below 15 percent 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.

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[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 shall 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 5.4 - Closed System Parameters: Generally Acceptable and Unacceptable Use Conditions for Metals in Direct Contact with Heat Transfer Liquids

Generally Unacceptable Use Conditions	Generally Acceptable Use Conditions[1]
Aluminum	
1. When in direct contact with untreated, uninhibited 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 uninhibited aqueous 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 liquid shall not exceed 4 ft/s (1.22 m/s).	
Copper	
1. When in direct contact with an aqueous liquid having a velocity greater than 4 ft/s (1.22 m/s).[2]	1. When in direct contact with untreated tap, distilled, or deionized water.
2. When in contact with a chemical that can form copper complexes such as ammonium compounds.	2. When in direct contact with stable anhydrous organic liquids.
	3. When indirect contact with aqueous liquids which do not form complexes with copper.
Steel	
1. When in direct contact with untreated tap, distilled, or deionized water with pH <8 or >12.	1. When in direct contact with untreated tap, distilled, or deionized water with pH >8 or <12.
2. When in direct contact with liquid having a velocity greater than 6 ft/s (1.83 m/s).[2]	2. When in direct contact with stable anhydrous organic liquids.
	3. When in direct contact with aqueous liquids of pH >8 or <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.

[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 shall 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 5.4 - (Continued)

Generally Unacceptable Use Conditions	Generally Acceptable Use Conditions[1/]
Galvanized Steel	
1. When in direct contact with water of pH <8 or >12.	1. When in contact with water of pH >8 but <12.
2. When in direct contact with an aqueous liquid with a temperature >131°F (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 shall resist dezincification in the operating conditions anticipated. At zinc contents of 15 percent and greater, these alloys become increasingly susceptible to stress corrosion. Selection of brass with a zinc content below 15 percent 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 shall not promote corrosion.

Chapter 5 References

1. Standard Practice for Evaluation of Cover Materials for Flat Plate Solar Collectors, ASTM E765-80.[1/]

2. Standard Practice for Exposure of Cover Materials for Solar Collectors to Natural Weathering Under Conditions Simulating Operational Mode, ASTM E782-81.[1/]

3. Standard Practice for Evaluating Solar Absorptive Materials for Thermal Applications, ASTM E744-80.[1/]

4. Standard Practice for Evaluating Absorptive Solar Receiver Materials When Exposed to Conditions Simulating Stagnation in Solar Collectors with Cover Plates, ASTM E781-81.[1/]

5. "Provisional Flat Plate Solar Collector Testing Procedures," First Revision, NBSIR 78-1305A, National Bureau of Standards, U.S. Department of Commerce, Washington, DC, June 1978, PB 283-721.[2/]

6. Standard Method for Testing Coated Metal Specimens at 100 Percent Relative Humidity, ASTM D2247-68 (1973).[1/]

7. Standard Practice for Evaluating Thermal Insulation Material for Use in Solar Collectors, ASTM E861-82.[1/]

8. HUD Minimum Property Standards, One-and Two-Family Dwellings, No. 4900.1, U.S. Department of Housing and Urban Development, Washington DC, 1973.[3/]

9. ASHRAE Handbook of Fundamentals - 1981.[4/]

10. Standard Specification for Rubber Seals Used in Flat Plate Solar Collectors, ASTM D3667-78.[1/]

11. Standard Specification for Rubber Seals Used in Concentrating Solar Collectors, ASTM D3771-79.[1/]

12. Standard Specification for Rubber Seals Contacting Liquid in Solar Energy Systems, ASTM D3832-79.[1/]

13. Standard Specification for Rubber Seals Used in Air-Heat Transport of Solar Energy Systems, ASTM D3903-80.[1/]

14. Standard Specification for Rubber Hose Used in Solar Energy Systems, ASTM D3952-80.[1/]

15. "Air Quality Data - Annual Statistics Including Summaries with Reference Standards," EPA-450-2-78-040.[5/]

16. Standard Practice for Nonoperational Exposure and Inspection of a Solar Collector, ASTM E823-81.1/

17. Standard Practice for Laboratory Screening of Metallic Containment Materials for Use with Liquids in Solar Heating and Cooling Systems, ASTM E712-80.1/

18. Standard Practices for Simulated Service Testing for Corrosion of Metallic Containment Materials for Use with Heat-Transfer Fluids in Solar Heating and Cooling Systems, ASTM E745-80.1/

19. Standard Practice for Screening Polymeric Containment Materials for the Effects of Heat and Heat-Transfer Fluids in Solar Heating and Cooling Systems, ASTM E862-82.1/

20. Prevention of Corrosion of Metals, Society of Automotive Engineers, Standard J447a, 1964.6/

21. Metz, F. E. and Orloski, M. J., " State-of-the-Art Study of Heat Exchangers Used with Solar Assisted Domestic Hot Water Systems," NBSIR 78-1542, National Bureau of Standards, U.S. Department of Commerce, Washington, DC, June 1978, PB287-410.2/

22. Handbook of PVC Pipe Design and Construction.7/

1/ American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

2/ National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

3/ Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

4/ American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329.

5/ U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Monitoring and Data Analysis Division, Research Triangle Park, NC 27711.

6/ Society of Automotive Engineers, Inc., Two Pennsylvania Plaza, New York, NY 10001.

7/ Uni-Bell Plastic Pipe Association, 2655 Villa Creek Drive, Suite 164, Dallas, TX 75234.

CHAPTER 6

OPERATION AND SERVICING

CHAPTER 6

OPERATION AND SERVICING

6.0
Introduction

The installation, operation and servicing phases are most critical to the performance of solar energy systems. There has been consistent evidence that faulty actions during these phases are a primary cause of poor performance, accelerated deterioration, and system damage. The difficulties of mandating performance criteria for installation, operation, and maintenance is acknowledged; however, it is essential that owners and installers be provided with appropriate instructions for their systems and that good practice methods are followed.

This chapter complements and extends certain provisions in Chapter 3 such as: system balancing, 3.1.2; liquid quality, 3.2.3; draining and filling, 3.2.5; and freeze protection in general, 3.6. An initial checkout must verify that the system is installed correctly and that it functions properly in all modes of operation including proper flow rates. It is important that adequate information and access be provided for monitoring of the system to assure a high level of performance and to anticipate problems.

6.1

Requirement

Manuals and instructions. A manual shall be provided containing instructions for the installation, operation and maintenance of the H/C/HW systems and components. The extent of detail of the manuals shall be consistent with the need for descriptive information to properly operate and maintain the system.

Commentary

This manual may consist in whole or in part of a series of instruction sheets provided by the various system or component manufacturers. It may be a single manual, or installation instructions may be separate from operation and maintenance. Complex installations should be provided with comprehensive manuals. A packaged hot water system conversely may require only a simple manual. The simplest passive system may warrant no more than an attached informative label or tag.

6.1.1
Criterion

Installation instructions. Instructions shall be provided which describe the installation and removal (when required) of each solar energy system component in step-by-step fashion with appropriate detail.

These instructions shall describe the interconnection requirements of the various systems and components and their interface requirements with the building and site. The instructions shall be available at the installation site or from normally accessible sources.

Evaluation — Review installation instructions.

Commentary — It is not the intent of this criterion to require the provision of complete, detailed system installation specifications. For active systems, such specifications would normally be project-specific and part of the procurement process. Construction drawings and specifications may be required for passive and other site-built systems.

Reference [1]* provides guidelines for installing, operating, and servicing solar HW systems. Reference [2] provides standard practice for installation and service of solar space heating systems (H) for one- and two-family dwellings. Although these guidelines were developed for residential application, they should provide assistance in working with small commercial systems.

6.1.2
Criterion — Operation and maintenance instructions. Operation instructions shall be provided which describe operation in all modes, including start-up and shutdown under normal and emergency conditions. Description of important temperature, flow, and pressure information for checkpoints throughout the system shall be given. The maintenance manual shall provide a system schematic diagram and describe required periodic maintenance and detailed information for selected repair procedures such as removal and replacement of cover plates.

Evaluation — Review maintenance and operating instructions.

Commentary — For most active systems, flow diagrams and wiring diagrams should be included. In any system where performance requirements are dependent upon specific maintenance procedures, these should be tabulated. For example, the manual should specify acceptable methods of cleaning glazed surfaces.

6.1.3
Criterion — Maintenance plan. The manual shall include a comprehensive plan for maintaining the specified performance of the H/C/HW systems for their design service lives.

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* Numbers in brackets [ ] indicate references at the end of this chapter.

Evaluation Review of maintenance plan.

Commentary This criterion is applicable to both active and passive systems in new as well as existing buildings. The plan should include all the necessary ordinary maintenance, preventive maintenance and minor repair work, and projections for equipment replacement and maintenance of heat transfer fluid quality as appropriate. Periodic changing or cleaning of strainers and filters is one example of ordinary maintenance. Cleaning, repairing, or replacing of cover plate materials should also be included.

6.1.4
Criterion Maintenance hazards. The manual shall provide prominently displayed warning against hazards that could arise in the maintenance of the system and shall fully describe the precautions that should be taken to avoid these hazards.

Evaluation Review the maintenance instructions.

Commentary Some systems contain toxic and/or combustible materials that could result in ill effects to maintenance personnel or result in fires, explosions, or toxic fumes when repairs involving soldering or welding are undertaken. See Criterion 4.2.4 for handling and disposal of toxic fluids.

Hot pipes or valves and discharge points should be identified in the manual.

6.1.5
Criterion Flushing of liquid system. The manual shall provide instructions for initial flushing as required and periodic flushing (cleaning), if required, of the liquid passages.

Evaluation Review drawings, specifications, and operation manual.

Commentary Metal filings, flux, solder, silt, and other contaminants should be flushed out of the system prior to operation. Water should not be used to flush systems that use hydrocarbon or silicone heat transfer fluids. Systems using oil as the heat transfer fluid should be flushed with a cleaner which is soluble with the solder flux used and then thoroughly dried before filling with the oil.

Flux within the system may be caught in crevices. At this point, with elevated temperature, any moisture would rapidly oxidize the adjacent metal. See also Criterion 3.2.2.

6.1.6
Criterion Protection. The instructions shall provide information for protection of the system during installation and maintenance.

Evaluation — Review installation and maintenance instructions.

Commentary — Collectors, controls, and other components may require special protective measures during installation and shutdown for maintenance such as covering of collectors to prevent breakage of glazings and to prevent stagnation. The instructions should indicate where caution should be exercised in the selection and use of temporary coverings to avoid permanent damage of glazing such as etching and staining, and adhesive materials which may become difficult to remove.

6.1.7
Criterion — Normal operation by occupant. Instructions shall be written to inform the occupant of the minimum actions required for the normal operation of the solar energy system including the probable heat gains or losses dependent on occupant actions.

Evaluation — Review operation instructions.

Commentary — Required occupant activity such as operating movable insulation, shades, or controls may be critical, especially for some passive installations. Required manual operations should be minimized and the occupant should be advised of the consequences of energy gained or lost and potential system or building damage (e.g., water freezing) for actions taken on a daily and seasonal basis including times of building vacancy.

6.2
Requirement — Maintenance and servicing. The H/C/HW systems shall be designed, constructed, and installed to provide sufficient access and appurtenances for general maintenance and convenient servicing.

6.2.1
Criterion — Heat transfer liquid quality. Provisions shall be made to maintain the quality of the heat transfer liquid at a level that does not significantly impair its heat transfer function, reduce its compatibility with adjacent materials, or reduce freeze protection.

Evaluation — Review specifications and monitoring of the heat transfer liquid for pH, buffering capacity, viscosity,and concentration of heat transfer fluid components.

Commentary — Experience from demonstration programs indicates the importance of heat transfer liquids and their quality in preventing freeze-ups and corrosion, and for general system performance. When make-up water is of such a quality that excessive corrosion is known to exist, a suitable water treatment system as recommended by the Water Quality Association Industry Standards S-100-75 and S-200-73 should be provided, Reference [3].

The chemical composition of the heat transfer liquid should be maintained (perhaps by periodic replenishment of additives) at levels adequate to prevent unacceptable deposits on the heat transfer surfaces, corrosion of the surfaces with which the heat transfer liquid comes in contact, or loss of freeze resistance. Antifreeze solutions may lose their freeze protection capability over time due to deterioration or the addition of "make-up" water. Provisions for sampling the heat transfer liquid should be available. See Criteria 3.2.3 and 3.2.5 for maintenance related devices and Reference [4] for the influence of heat transfer fluid properties on thermal performance.

Heat transfer liquids should be tested and replaced at intervals suggested by the manufacturer. Some sources recommend checking water/glycol mixtures twice a year. See also Criterion 6.1.3. Water in unprotected steel drums or other metal containers in water storage walls should be deionized or distilled and buffered to reduce corrosion (pH>8 and <12 for steel).

6.2.2
Criterion

<u>Access for system maintenance</u>. All individual items of equipment and components of the H/C/HW systems which may require periodic examination, adjusting, servicing and/or maintenance shall be accessible for inspection, service, repair, removal, or replacement without dismantling of an adjoining major component or building element.

Evaluation

Review drawings and specifications.

Commentary

Accessibility as a function of component life is an important consideration. Individual collectors in an array should be replaceable or repairable without disturbing nonadjacent collectors in the array or other access provisions should be made. Cover plates and roof glazing, especially those susceptable to degradation by environmental exposure and hazards such as damage by falling hail, limbs, etc., should be readily accessible for repair or replacement without special skills or tools and with readily available materials. Provisions for recoating of Trombe walls and cleaning of glazing and space between glazing and wall should be considered. Access to collector glazings which require periodic recoating may be necessary.

Access to storage units may be necessary. Rock storage and liquid storage in both active and passive systems may require access for cleaning or replacement. Isolation valves may be necessary for the repair or replacement of system components. Dampers require access for maintenance, monitoring, adjusting, and balancing. Information on access provisions is provided in Reference [5].

6.2.3

Criterion — Servicing of H/C/HW systems. The H/C/HW systems shall be capable of being serviced with a minimum amount of special equipment by the appropriate existing trades (HVAC, plumbing, etc.) using a service manual.

Evaluation — Review drawings, specifications, and service instruction manuals.

Commentary — The complexity and design of certain components may require their removal and replacement to accomplish repair of the system. Routine servicing of systems should not require special personnel and equipment.

6.2.4

Criterion — Maintainability of building and site. The H/C/HW system shall not impair accessibility for or add significantly to the practical maintainability of the building or site.

Evaluation — Review maintenance plans, site plans, and building and solar system drawings.

Commentary — Building materials adjacent to solar equipment should not be exposed to elevated temperatures that result in adverse physical, chemical, mechanical, or thermal changes causing additional maintenance problems or such materials should be selected to withstand these effects.

6.2.5

Criterion — Maintainability of roof surfaces. The installation of collectors and other solar energy components on the building roof should not reduce the ability of the roof covering to restrict the entrance of moisture and water, nor reduce its resistance to weather and deterioration.

Evaluation — Review drawings and specifications.

Commentary — Damage to the roof covering or the roof assembly can occur during installation of the solar energy system or during servicing. Measures to protect the roof from damage and the entry of water during installation and servicing should be taken,Reference[6]. The presence of solar equipment on roofs may lead to numerous potential problems:

a. Reroofing in future years may be complicated by collectors mounted close to the surface, by supports, and by pipe and wiring penetrations.

b. Numerous penetrations of roof coverings mean greater maintenance problems and potential leakage. It is important that collector supports be flashed properly.

c. Some heat transfer fluids will attack certain roofing materials, and leakage from the solar system may present problems of roof degradation and deterioration.

d. The growth of fungi (mold and mildew) is possible when collectors are applied to a roof surface. If the collectors are in contact with the roof covering or held away from the covering to allow for drainage, the shaded area can support the growth of a fungus leading to roofing deterioration. Special design considerations should be included to avoid this problem.

e. Hot collector surfaces and other heated components closely adjacent to the roof surface can cause softening of the roofing materials leading to damage and deterioration.

f. The presence of solar equipment, its position relative to the roof and the various supports and penetrations, may increase the collection of debris such as branches and leaves, and thus require additional maintenance.

g. The installation of solar collectors and components should not affect the capacity of the roof to drain water completely.

h. The ice and melt water that may occur in the winter due to the presence of solar equipment requires attention to the adequacy of roof moisture barriers. Improper installation and roof details may promote the accumulation of large quantities of ice, or may cause damage to the roof by the weight or expansive action of ice.

i. The foot traffic generated by solar system maintenance personnel may cause deterioration of the roof system. Roof inspections should be performed at regular intervals and repairs made to the roofing system as soon as they are needed. For existing roofing systems, its condition should be determined prior to the installation of the solar system. Solar system components should only be installed on roofs which are assessed to be in good condition and are expected to provide satisfactory performance for their design lives.

6.3
Requirement

System monitoring. Provision shall be made for system monitoring in accordance with the specifications of the operation and maintenance manual.

6.3.1
Criterion

Checkout. On completion of installation, the system operation shall be checked for adequate performance of all components as well as the system as a whole.

Evaluation — Inspection and testing shall be performed on the installation to verify that the system and components are capable of operating as specified in the design, the manuals and instructions defined in Requirement 6.1.

Commentary — Monitoring means may involve sensors and indicators or may be as simple as inspection.

Controls should be checked in operation to determine that components operate at the proper set points, that pumps and fans start and stop properly, and that fail safe devices work. Failure or improper operation of sensors and controls have caused many problems. It is recommended that means be provided during installation to allow temperatures and flow rates to be checked during operation of the system. Poor design and improper installation of components is a major cause of system malfunction. A large proportion of mechanical failures become apparent within a short period of operation. Incorrectly wired controls, improper control set points, improper component location, reversed components, improper sensor installation, etc., are examples of faulty design and/or installation.

It is important to check distribution systems to assure that all spaces intended to receive heating and cooling in the design, receive it in the actual installation. This is particularly important with passive systems.

6.3.2 Criterion — Minimum operating information. Provisions shall be made to indicate to the user when the collector loop and/or the auxiliary energy system is operating.

Evaluation — Review drawings, specifications, and operation instructions.

Commentary — A minimum level of information is essential to the user to assure that the solar system is functioning as intended. Monitoring means may involve sensors and indicators or may be as simple as observation and awareness of appropriate radiant temperatures and air movement.

6.3.3 Criterion — Access for system monitoring. Appropriate access shall be provided for checking essential system parameters.

Evaluation — Review drawings and specifications for the placement of fittings and indicators of essential system parameters.

Commentary — Adequately located test fittings and indicators will permit system monitoring and expedite the maintenance and repair of equipment. Access for sensors and other techniques for monitoring parameters such as temperature, pressure, and critical voltages are of concern in this provision. Access for the monitoring of flow, either liquid or air, should be considered and the access point should be located so that upstream disturbances do not affect the measurements. Ports should be available for monitoring the quality of the heat transfer fluid. Charging ports are probably adequate for this purpose if located in an active portion of the transport network. Corrosion monitoring may be important for particular systems and provisions for installation of coupons, probes, and/or corrosion fuses should be considered in the layout of the system.

Chapter 6 References

1. "Installation Guidelines for Solar DHW Systems in One-and Two-Family Dwellings," HUD-PDR-407, GPO 023-000-00520-4, U.S. Department of Housing and Urban Development, Washington, DC, April 1979.[1/]

2. Standard Practice for Installation and Service of Solar Space Heating Systems for One-and Two-Family Dwellings, ASTM/ANSI E683-79, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, 1979.

3. Industry Standard for Household, Commercial and Portable Exchanger Water Softeners, S-100-75 and Recommended Industry Standards for Household and Commercial Water Filters, S-200-73, Water Quality Association, 447 East Butterfield Road, Lombard, IL 60148, 1974.

4. Chang, C., Singh, H., Chopra, P., "Influence of Solar-Fluid Properties on Thermal Performance Based on Nominal and Measured Values," ANL/SDP-TM-79-6, SOLAR/0904-79/70.[1/]

5. Uniform Mechanical Code, International Conference of Building Officials, 5360 South Workman Mill Road, Whittier, CA 90601, 1982.

6. Mathey, Robert G. and Rossiter, Walter J. Jr., "Guidelines for the Installation of Solar Components on Low-Sloped Roofs," NBS Technical Note 1134, National Bureau of Standards, U.S. Department of Commerce, Washington, DC, 1980.[2/]

[1/] Technical Information Center, P.O., Box 62, Oak Ridge, TN 37830.

[2/] Superintendent of Documentrs, Government Printing Office, Washington, DC 20402

APPENDIX A

INTRODUCTION

Appendix A references conditions for and methods of testing and evaluation of system components and materials. These conditions and methods can be used to prove compliance with stated requirements.

The testing and evaluation methods contained in this Appendix primarily concern corrosion and thermal degradation, and can be used to satisfy many of the durability/reliability requirements stated in Chapter 5.

Specific criteria from Chapter 5 are listed with the test methodologies which can be used to prove their compliance.

Conditions for and methods of testing and evaluation found in Appendix A are cross-referenced in Chapter 5 as well as throughout the text of this document where their use is potentially appropriate.

Section 1 <u>Temperature Conditions</u>. Many of the criteria given in Chapter 5 and this Appendix contain references to the maximum or minimum service temperatures in specifying the temperature at which testing should be performed. The <u>maximum service temperature</u> is the maximum temperature at which a system and its components are designed to operate, either with or without the flow of heat transfer fluid. The <u>minimum service temperature</u> refers to the minimum temperature at which a system and its components are designed to operate, with or without the flow of heat transfer fluid.

The minimum service temperature to which a component in the system will be exposed will generally occur when (1) the collector is not exposed to solar radiation, (2) the heat transfer fluid is not flowing through the system, and (3) the ambient temperature is at its lowest level. The no-flow condition mentioned above assumes the flow of the heat transfer fluid will be stopped when no useful energy can be removed from the collector to avoid pumping out heat energy. However, if the flow of fluid is not stopped at night, the minimum service temperature of some components may occur as nocturnal radiation and/or evaporative cooling takes place.

The maximum service temperature to which the collector and components that are in intimate contact with it will be exposed, will generally occur when the collector is receiving its maximum level of solar radiation at maximum ambient temperature and the heat transfer fluid is not flowing through the collector (design maximum no-flow temperature). Other components, such as those in the storage system will generally reach their maximum temperature when the collector is receiving its maximum level of solar radiation at maximum ambient temperature and the heat transfer fluid is flowing through the system (design maximum flow temperature). This temperature may be determined by limiting the temperature of control devices or relief valves or through theoretical or test analysis of the system. The design maximum no-flow temperature that will occur at various locations in the collector can be calculated by use of an analytical model and appropriate environmental conditions. Many analytical models rest on the implicit assumption that heat transfer fluid is flowing through the collector; these models cannot be used directly to calculate no-flow temperatures. An acceptable alternative for most collector designs is to calculate the collector temperatures under stagnation conditions. (A solar collector is said to be in stagnation when heat transfer fluid is flowing through the collector but because of the elevated collector temperatures the efficiency is zero.) This calculation has been performed for ten typical flat plate collector designs to provide assistance in establishing the maximum service temperatures of critical collector components. The absorber and cover plate temperatures calculated for two such flat plate collectors in stagnation are plotted as a function of ambient temperature in figure A.1. The results for all ten collectors are given in table A.1, which contains the mean plate temperature for the absorber along with the corresponding temperature for the cover plate(s) at two ambient temperatures. These data were generated using the analytical model developed by Thomas, Reference [1].* The fixed and varied parameters used in the model calculations are listed in tables A.2-A.5. Some of the key fixed parameters established for the modeling are: zero wind speed; a low fluid flow rate (0.01 kg $m^{-2}s^{-1}$); beam radiation normal to the collector surface; 45° collector tilt; a constant irradiance value of 1070 Wm^{-2}. Collector cover plate and absorber temperatures, under conditions of stagnation can be determined for other ambient temperatures within the range of temperatures indicated in table A.1 by linear interpolation.

It should be noted that the exposure conditions represent typical maximum conditions and that a higher solar radiation flux can be experienced under some atmospheric conditions or by the use of external reflectors. In addition, unconventional collector designs that include heat pipes, stagnation prevention devices and the like may not be amenable to this kind of modeling analysis. It is recommended that the temperature of critical components be experimentally established for a particular collector design whenever possible.

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* Numbers in brackets [ ] indicate references at the end of this appendix.

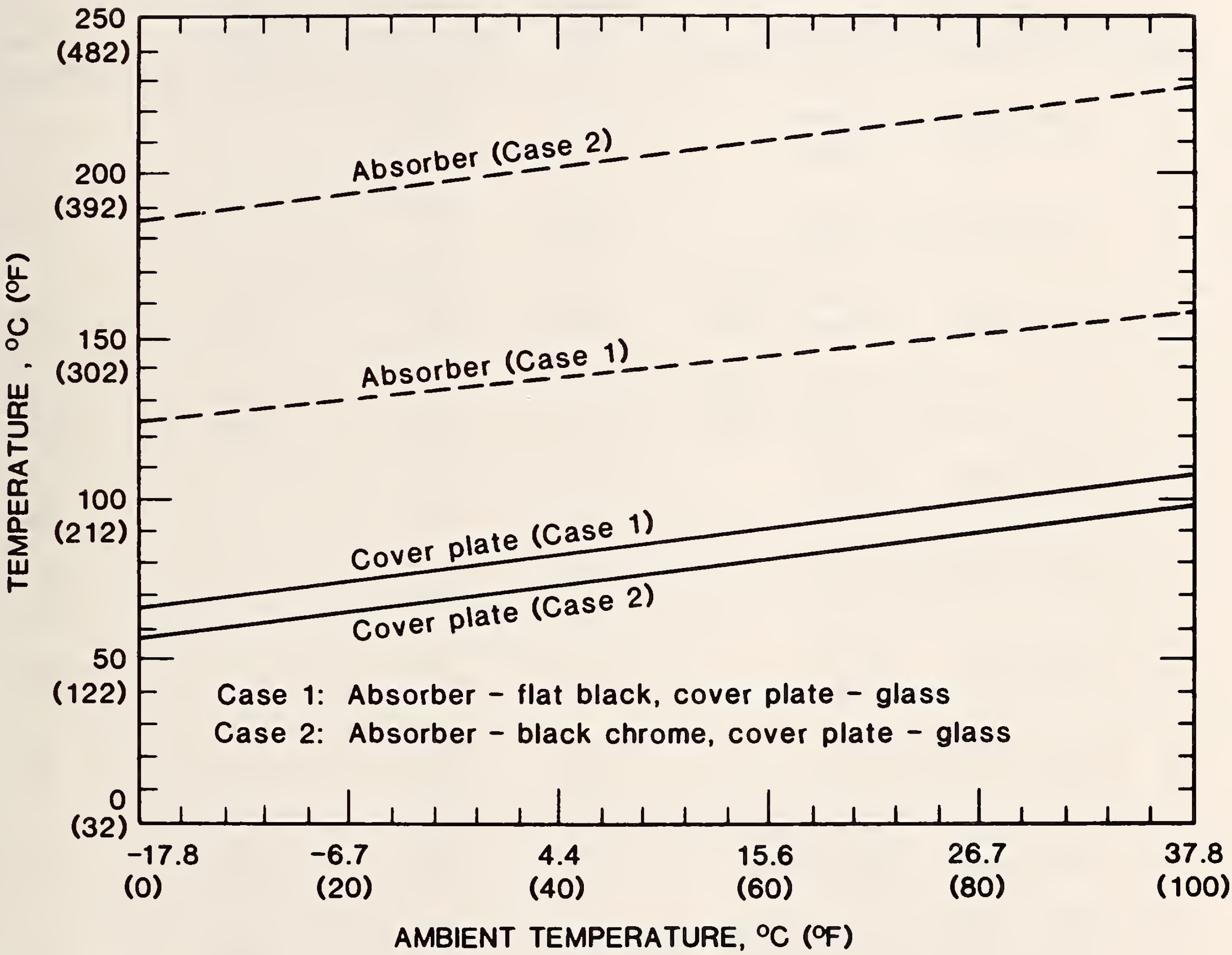

Figure A.1. Calculated surface temperatures of absorber and collector cover plate(s) under conditions of stagnation. Fixed meteorological, operational and optical parameters are given in tables A.2 through A.5. The surface temperatures for the absorber and cover plates are also presented in table A.1 at ambient temperatures of -17.8 and 37.8°C.

TABLE A.1

CALCULATED ABSORBER AND COVER PLATE TEMPERATURES FOR FLAT-PLATE SOLAR COLLECTORS UNDER STAGNATION CONDITIONS [1]a

Collector Identification			Ambient Temp. (°C)	Absorber Mean Plate Temp. (°C)	Inner Cover Temp. (°C)	Outer Cover Temp. (°C)
Case	Absorber	Cover Plate[b]				
1	Flat Black	Glass	-17.8	125	f	67
1	Flat Black	Glass	37.8	157	f	106
2	Black Chrome	Glass	-17.8	185	f	57
2	Black Chrome	Glass	37.8	226	f	98
3	Flat Black	Glass, Glass	-17.8	154	114	59
3	Flat Black	Glass, Glass	37.8	185	149	101
4	Black Chrome	Glass, Glass	-17.8	208	100	49
4	Black Chrome	Glass, Glass	37.8	245	136	93
5	Flat Black	FRP[c]	-17.8	112	f	59
5	Flat Black	FRP	37.8	146	f	100
6	Black Chrome	FRP	-17.8	171	f	52
6	Black Chrome	FRP	37.8	214	f	94
7	Flat Black	PVF[d]	-17.8	102	f	49
7	Flat Black	PVF	37.8	136	f	91
8	Black Chrome	PVF	-17.8	179	f	53
8	Black Chrome	PVF	37.8	220	f	94
9	Flat Black	FEP[e], PVF	-17.8	114	76	42
9	Flat Black	FEP, PVF	37.8	146	114	86
10	Black Chrome	FEP, PVF	-17.8	195	85	34
10	Black Chrome	FEP, PVF	37.8	233	122	79

Notes: (a) See Tables A.2 through A.5 for parameters used in the referenced model calculations.
(b) For double glazed collectors, the inner cover plate material is listed first.
(c) FRP - Fiber reinforced plastic
(d) PVF - Poly(vinyl)fluoride
(e) FEP - Fluorinated (ethylene propylene)
(f) Single glazed collector

TABLE A.2

FIXED METEOROLOGICAL CONDITIONS AND OPERATIONAL PARAMETERS

Irradiance	1070 Wm^{-2} (340 $Btu/hr^{-1}\ ft^{-2}$)
Diffuse Fraction	0.15
Angle of Incidence	0°
Collector Tilt	45°
Wind Speed	0 ms^{-1}
Fluid Flow Rate	0.01 $kgm^{-2}s^{-1}$

Table A.3. Dimensions and Heat Transfer Properties for Flat Plate Collector[a] Used in Stagnation Temperature Calculations

Absorber		
Effective Length		1.72 m
Effective Width		0.81 m
Thickness		0.9 mm
Thermal Conductivity		45.0 $Wm^{-2}°C^{-1}$
Flow Configuration		Parallel
Flow Tubes:	Number	10
	O.D.	8.1 mm
	Hydraulic Diameter	4.9 mm
	Wetted Perimeter	15.4 mm
Emittance		See Table A.4
Solar Absorptance		See Table A.4
Cover Assembly		
Number of Covers		1 or 2
Air Space between first cover and absorber		37 mm
Air space between first and second cover, if two covers		25 mm
Thickness		See Table A.5
Infrared Emittance		See Table A.5
Infrared Transmittance		See Table A.5
Index of Refraction		See Table A.5
Extinction Coefficient		See Table A.5
Insulation		
Thickness:	Back	89.0 mm
	Edge	25.4 mm
Conductivity:	Back	0.040 $Wm^{-1}°C^{-1}$
	Edge	0.040 $Wm^{-1}°C^{-1}$
Area		
Aperture		1.39 m^2
Gross		1.67 m^2

[a] Representative of collector "D" in the NBS Durability and Reliability Program [3], [4].

TABLE A.4

ABSORBER PLATE PROPERTIES

Material	Absorptance	Emittance
Flat Black Paint[a]	0.98	0.92
Black Chrome[b]	0.97	0.07

Notes: (a) Collector "C" as described in reference [2].
(b) Collector "D" as described in reference [2].

TABLE A.5

COVER PLATE PROPERTIES

Factor	Low Iron Etched Glass [3,4][a]	Fiber Reinforced Plastic FRP [3,4][b]	Fluorinated (Ethylene Proplyene) FEP [3,4][c]	Poly(Vinyl) Fluoride PVF [5]
Infrared Emittance	0.88	0.84	0.33	0.57
Infrared Transmittance	0.00	0.07	0.60	0.35
Index of Refraction	1.30	1.54	1.33	1.46
Extinction Coefficient (mm^{-1})	0.0095	0.0565	0.0658	0.078
Thickness of Cover Plate (mm)	3.175	0.965	0.0254	0.102

Notes: (a) Collector "D" (Outer Cover) as described in references [3,4]
(b) Collector "E" as described in references [3,4]
(c) Collector "H" (Inner Cover) as described in references [3,4]

Section 2 Evaluation Methods. The evaluations given in Chapter 5 and Sections 3 through 9 of this Appendix are intended to provide a means of measuring the deterioration of materials which would occur during use. Deterioration of materials is a measure of their durability. Deterioration is a result of exposure of the material to an environment which causes changes in its properties. To screen materials and to assess durability, properties must be measured before and after exposure to an environmental aging procedure. Assessment of properties should include: visual inspection of surfaces plus measurement of appropriate optical, physical, mechanical or chemical properties. Important properties will depend upon the application and the type of material. Tables 5.2a, 5.2b, and 5.2c identify the properties which must be measured before and after aging for various materials and components. Methods to perform typical property tests are listed in Table B.1 of Appendix B. Other test methods may also be used, if necessary, to document performance. Recommended aging procedures and property assessment methods are included in Sections 3 through 9.

Section 3 Test Methodology: Criterion 5.1.1 Solar Degradation. Components or materials shall be tested using at least one aging procedure and appropriate property assessment methods (Table 5.2a of Chapter 5).

Aging Procedure 1 (Simulated Laboratory Exposure)

Acceptable exposure procedures include ASTM G26-77, Operating Light Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Non-Metallic Metals, Reference [6] or ASTM D2565-79, Operating Xenon Arc-Type (Water Cooled) Light and Water Exposure Apparatus for Exposure of Plastics, Reference [7].

Expose components or materials to simulated solar radiation. With the Type A or AH apparatus, the exposure periods shall be 1400 hours. With the Type B or BH apparatus, the exposure periods shall be 1900 hours. The exterior surfaces of components which are exposed to rainfall in service shall be subjected to a water spray. The exposure cycle should be 90 minutes of light only, followed by 30 minutes of light with water spray. For components not exposed to moisture under normal operating conditions, the water spray shall not be included in the procedure.

Aging Procedure 2 (Outdoor Exposure Using Concentrated Natural Radiation)

Using ASTM E838-81, Standard Practice for Performing Accelerated Outdoor Weathering Using Concentrated Natural Sunlight, Reference [8] expose components or materials to concentrated natural solar radiation until they have received a total incident radiant exposure of 5.4×10^5 Btu/ft^2 (6.0 GJ/m^2). Exterior surfaces exposed to moisture in service shall be subjected to water spray for a period of 8 minutes during each 60 minutes of sunlight exposure. The water spray should be at a rate of 1.75×10^{-2} gal/min. ft^2 (1.18×10^{-2} L/s.m^2) +20 percent. For components not exposed to rainfall under normal operating conditions, the water spray shall not be included in the procedure.

Test specimen mounting and temperature control shall be in accordance with the procedures described in ASTM E838-81, Reference [8].

Aging Procedure 3 (Natural Weathering)

Expose components and materials to 12 months of solar radiation outdoors by the most appropriate aging procedure listed below. The average daily flux of the solar radiation, as obtained by averaging the daily fluxes over the 12 month period of outdoor exposure, shall be at least 1200 Btu/ft^2 (14.8 Mj/m^2).

Cover Materials (Flat Plate Collectors)	ASTM E782-81	Standard Practice for Exposure of Cover Material for Solar Collectors to Natural Weathering Under Conditions Simulating Operational Mode
Absorber Coatings	ASTM E781-81	Standard Practice for Evaluating Absorptive Solar Receiver Materials When Exposed to Conditions Simulating Stagnation in Solar Collectors with Cover Plate(s)
Exterior Paints (Not Absorber Coatings)	ASTM D1006-73	Standard Recommended Practice for Conducting Exterior Exposure Tests of Paints on Wood
Exterior Paints (Not Absorber Coatings)	ASTM D1014-66 (Reapproved 1973)	Standard Method of Conducting Exterior Exposure Tests of Paints on Steel
Adhesive Joints	ASTM D1828-70 (Reapproved 1976)	Standard Recommended Practice for Atmospheric Exposure of Adhesive Bonded Joints and Structures
Plastics	ASTM D1435-75 (Reapproved 1979)	Standard Recommended Practice for Outdoor Weathering of Plastics

Non-Metallic Materials	ASTM G7-77a	Standard Practice for Atmospheric Environmental Exposure Testing of Non-Metallic Materials
Pipeline Coatings	ASTM G11-79	Standard Test Method for Effects of Outdoor Weathering on Pipeline Coatings
Any material	ASTM G24-73 (Reapproved 1980)	Standard Recommended Practice for Conducting Natural Light Exposures Under Glass

Property Assessment

Properties listed in Tables 5.2a,5.2b, and 5.2c shall be measured to determine the effect of aging procedures on visual appearance and important optical, physical, or mechanical properties of the components or materials. Other properties may be used for assessment as appropriate. Properties must be measured for both aged and unaged specimens to establish a basis of comparison.

Commentary

The tests are intended to permit estimations to be made of the effect of solar radiation in degrading collector components and in reducing the collector efficiency. The exposure period for the aging procedure is considered to provide approximately the same total energy below 400 nm as would be received in 12 months of actual solar exposure in in Phoenix, Arizona.

Section 4 Test Methodology: Criterion 5.1.3 Pollutant Degradation

Aging Procedure 1 (Resistance to Ozone)

Coupon specimens of components shall be exposed for 21 days to an ozone atmosphere of 50 + 5 pphm/volume in a test chamber of 73.4 + 3.6°F (23 + 2°C). An ozone test chamber is described in ASTM D1149-78a, "Rubber Deterioration Surface Ozone Cracking in a Chamber (Flat Specimens)", Reference [9]. Specimens should be stressed to simulate service conditions.

Aging Procedure 2 (Resistance to Salt Spray)

Coupon specimens of components shall be exposed for 21 days in accordance with ASTM Method B117-73 (1979), Salt Spray (Fog), Reference [10].

Aging Procedure 3 (Resistance to SO_2 and NO_x)

Coupon specimens of components shall be supported vertically in a closed chamber having openings for gas inlet and outlet and maintained at a temperature of 73.4 + 3.6°F (23 + 2°C) for a period of 21 days. An amount of (SO_2 or NO_x) equivalent to 1 percent of the volume of the test chamber shall be introduced into the chamber each working day. A small amount of water is to be maintained at the bottom of the chamber.

Property Assessment Properties listed in Tables 5.2a, 5.2b, and 5.2c shall be measured to determine the effect of the aging procedures on important optical, physical, mechanical, or chemical properties. In addition, the surfaces of the test specimens shall be visually examined for signs of deterioration such as cracking, blistering, or dimensional changes using a microscope with an eyepiece micrometer at 20X magnification. Other properties may be used for assessment, as appropriate. Properties must be measured for both aged and unaged specimens to establish a basis for comparison.

Commentary These tests are intended to determine the resistance of components to airborne pollutants.

Section 5 <u>Test Methodology: Criterion 5.2.1 Thermal Degradation</u>. Heat transfer fluids shall be tested using aging procedures 1 and 3. Other components and materials shall be tested using aging procedure 2. Property assessment methods listed in Tables 5.2a, 5.2b, and 5.2c shall be performed before and after aging. Supplemental aging procedures are listed below and may be added where applicable. Section 1 of this Appendix may be useful in determining the maximum service temperature.

Sealants	ASTM C792-75 (Reapproved 1980)	Standard Method of Test for Effects of Heat Aging on Weight Loss, Cracking and Chalking of Elastomeric Sealants
Rubber	ASTM D454-81	Standard Test Method for Rubber Deterioration by Heat and Air Pressure
Plastic	ANSI/ASTM D794-68 (Reapproved 1977)	Standard Recommended Practice for Determining Permanent Effect of of Heat on Plastics
Plastic	ANSI/ASTM D1042-51 (Reapproved 1978)	Standard Test Method for Linear Dimensional Changes of Plastics Under Accelerated Service Conditions

Plastic	ANSI/ASTM D1204-78	Standard Test Method for Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperatures
Plastic	ANSI/ASTM D1299-55 (Reapproved 1979)	Standard Test Method for Shrinkage of Molded and Laminated Thermosetting Plastics at Elevated Temperatures
Plastic	ANSI/ASTM D1203-67 (Reapproved 1974)	Standard Test Method for Loss of Plasticizer from Plastics (Activated Carbon Methods)

Aging Procedure 1

(Resistance of Fluids to Maximum Service Temperature) Expose the heat transfer fluids to their maximum service temperature for a period of 21 days. In some cases, this may require the use of an autoclave. The fluids shall contain turnings of the metal to be used in service in quantities of 10 g of metal turnings to 100 cc of fluid. Aeration shall be provided in fluids to be used in "open" systems. Fluid aeration need not be included for "closed" system usage. The test must be repeated separately for all metal materials that are present in the system.

Aging Procedure 2

(Resistance of Components and Materials to Maximum Service Temperature)

Components or coupon test specimens shall be subjected to heat aging for a period of 21 days at the maximum service temperature. Components and materials stressed in normal use should be stressed during the exposure.

Aging Procedure 3

(Resistance of Fluids to Minimum Service Temperature)

Expose the heat transfer fluids to their minimum service temperature for a period of 24 hours and remove and immediately examine for freezing.

Property Assessment

Properties listed in Tables 5.2a, 5.2b, and 5.2c shall be measured to determine the effect of the aging procedures on visual appearance and important optical, physical, chemical, and mechanical properties of the components or materials. At the completion of aging procedure 1, the fluids shall be visually inspected for signs of undesired changes such as excessive precipitation or boiling. Other properties may be used for assessment as appropriate. Properties must be measured for both aged and unaged specimens to establish a basis for comparison.

Commentary — The tests are intended to permit estimations to be made of the effect of heat in degrading collector components and in reducing the system efficiency. Aging procedure 3 is intended to evaluate freezing of transfer fluids at the minimum service temperature. (See Criterion 3.6.1.)

Section 6 — Test Methodology: Criterion 5.2.2 Thermal Cycling Degradation. Materials and components shall be subjected to the aging procedure and appropriate property assessment methods (Tables 5.2a, 5.2b, and 5.2c).

Aging Procedure 1 — (Resistance of Components and Materials to Thermal Cycling)

Complete components or material test specimens shall be subjected to thermal cycling between the maximum service temperature and minimum service temperature for a total of 30 cycles. Each cycle shall consist of: 7.5 hours at the maximum service temperature; 0.5 hours at room temperature; 15.5 hours at the minimum service temperature; and 0.5 hours at room temperature.

Property Assessment — Properties listed in Tables 5.2a, 5.2b,and 5.2c shall be measured to determine the effect of thermal cycling on visual appearance and on important physical, mechanical, and chemical properties of the components or materials. Other properties may be used for assessment as appropriate. Properties must be measured for aged and unaged specimens to establish a basis for comparison.

Commentary — These tests are intended to permit estimations to be made of the effect of thermal cycling in degrading collector components and materials.

Section 7 — Test Methodology: Criterion 5.3.1 Materials/Transfer Fluid Degradation. Metallic containment materials used with nonaqueous liquids shall be tested using aging procedure 1 and plastic containment materials shall be tested using aging procedure 2. After aging, appropriate property assessment methods (Tables 5.2a, 5.2b, and 5.2c) shall be performed.

Aging Procedure 1 — (Resistance of Metallic Containment Materials to Nonaqueous Liquids)

The apparatus for this test consists of heating tape with appropriate power and control systems, and a variable flow pump with a reservoir for the heat transfer fluid.

The primary sample typically consists of a 36 in. (914 mm) length of tubing bent around an 8 in. (203 mm) diameter mandrel so that each leg of the U-bend is of approximately equal length. Other specimen designs are permitted if they more closely approximate conditions of application. Care should be taken in making the U-bend so that fluid flow through the tube is not significantly restricted. The tubing sample is mounted with an inclination of the plane of the U-bend at about 45 degrees to horizontal during testing. Secondary samples of similar or dissimilar metal tubing may be introduced in the loop. The test shall be carried out for a minimum period of 30 days. During the test, the temperature shall be maintained at the maximum service temperature.

Appropriate modifications including flow rate, degree of fluid aeration, and surface area ratios of the dissimilar metals shall be included in the test. Protective coatings shall form a part of the test specimen if they are used in the actual system. Testing shall be followed by visual inspection. With appropriate modification, Standard TM-01-71, "Autoclave Corrosion Testing of Metal in High Temperature Water", Reference [11] of the National Association of Corrosion Engineers for materials used in pressurized systems or ASTM D1384-80, "Corrosion Test for Engine Coolants in Glassware", Reference [12] for materials used in systems at atmospheric pressure, may be used in the evaluation of metal coupons.

Aging Procedure 2 (Resistance of Plastic Containment Materials to Liquids)

Plastic containment materials shall be tested for 7 days at maximum service temperature in accordance with ASTM D543-67 (1978),Reference [13] or ASTM D1239-55(1971),Reference [14]. The heat transfer fluid specified by the solar system manufacturer should be used. For organic based heat transfer fluids commonly used in aqueous solutions, the test reagents should include the concentrated heat transfer fluid and dilute solutions at concentrations similar to actual use.

Property Assessment Following the test, the test specimens shall not show signs of pitting, crevices, erosion, or exhibit other signs of general corrosive deterioration with the exception of discoloration.

Properties listed in Tables 5.2a, 5.2b, and 5.2c shall be measured to determine the effect of the aging procedures on visual appearance and on important chemical, physical, or mechanical properties. Other properties may be used for assessment as appropriate. Properties must be measured for both aged and unaged specimens to establish a basis of comparison.

Commentary These tests are intended to permit estimations to be made of the effect of chemical imcompatibility of the heat transfer fluids and materials in the energy transport system. Data derived from these aging procedures and property assessment methods may be used as guidelines. Assurance of chemical compatibility of critical components may require additional long-term testing under conditions (temperature, pressure, and flow rates) simulating actual use.

Section 8 Test Methodology: Criterion 5.3.2 Dissimilar Metals Degradation. Adjoining dissimilar metals used in contact with the transfer fluid should be tested using aging procedure 1. Adjoining dissimilar metals not used in contact with the transfer fluid should be tested using aging procedure 2. After aging, appropriate property assessment methods (Tables 5.2a, 5.2b, and 5.2c) shall be performed.

Aging Procedure 1 (Resistance of Metallic Containment Materials to Liquids)

Test specimens consisting of dissimilar metals in direct contact with one another shall be subject to the test as described in aging procedure 1 of Section 7.

Aging Procedure 2 (Resistance to SO_2 and NO_x)

Test specimens consisting of dissimilar materials in direct contact with one another shall be subject to the test as described in aging procedure 3 of Section 4.

Property Assessment Properties listed in Tables 5.2a, 5.2b, and 5.2c shall be measured to determine the effect of the aging procedures on visual appearance and on important chemical, physical, or mechanical properties. Other properties may be used as appropriate. Properties must be measured for both aged and unaged specimens to establish a basis for comparison.

Commentary These tests are intended to permit estimations to be made of the effect of corrosion on non-isolated dissimilar metals.

Section 9 Test Methodology: Criterion 5.3.3 Compatibility of Adjacent Organic Materials

Aging Procedure 1 (Compatibility of Adjacent Organic Materials)

Test specimens consisting of the dissimilar organic materials in direct contact with one another shall be exposed to the maximum service temperature for a period of 120 hours.

Property Assessment Properties listed in Tables 5.2a, 5.2b, and 5.2c shall be measured to determine the effect of the aging procedure on visual appearance and on important chemical, physical, or mechanical properties. Other properties may be used as appropriate. Properties must be measured for both aged and unaged specimens to establish a basis of comparison.

Section 10 No-Flow 30-Day Degradation

Testing Procedure

Evaluation of changes in collector materials or performance due to environmental conditioning shall be determined in accordance with the test procedure described in ASHRAE Standard 93, Reference [15], either before and after or only 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 collector duct opening shall be sealed to prevent cooling by convective air flow and the entry of dirt or precipitation. The collector shall be vented to prevent build-up of pressure.

2. Liquid collectors intended for use in all systems (with or without draindown) shall be completely filled with distilled water[1/] following which the inlet shall be sealed and the outlet provided with a pressure relief valve set to a value between 0 percent and +10 percent over 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 distilled water[1/] following which the fluid shall be allowed to gravity drain for 15 minutes with the collector mounted at a 45° tilt angle. The collector inlet

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1/ Manufacturer's/designer's recommended fluid shall be used in those instances when they specifically prohibit the use of distilled water.

shall then be protected to prevent entry of dirt or precipitation. The collector shall also be vented to prevent buildup of pressure.

C. Exposure Conditions:

1. Exposure conditions shall consist of 30 days of cumulative exposure to a minimum daily incident solar radiation flux of 1500 $Btu/ft^2 \cdot day$ (17,000 $kJ/m^2 \cdot day$) as measured in the plane of the collector aperture.[1/]

2. The exposure conditions shall include at least one consecutive 4-hour period or two 2-1/2 hour periods with a minimum instantaneous flux of 300 $Btu/ft^2 \cdot h$ (946 W/m^2). The exposure test is only concluded after the requirements summarized in the table of paragraph D.4. have been met.

   a. Collector orientation changes to maximize the solar radiation or supplementary reflectors may be necessary to obtain the 300 $Btu/ft^2 \cdot h$ (946 W/m^2) insolation level at certain locations. However, the maximum peak flux shall not exceed 370 $Btu/ft^2 \cdot h$ (1165 W/m^2) under normal sun-sky or simulator exposure conditions.

   b. A reflector may be used if it has sufficient width and height to uniformly irradiate the collector aperture during the 300 $Btu/ft^2 \cdot h$ exposure period. Solar irradiance measurements shall be performed in the plane of the collector to verify that the irradiance does not vary by more than 10 percent over the collector aperture and that the minimum instantaneous flux requirement is met.

   c. A transparent enclosure may be used to raise the ambient temperature around the collector. The

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1/ For collectors governed by paragraph B.2., the filled collector shall be exposed to at least one day with a minimum daily incident solar radiation of 1500 $Btu/ft^2 \cdot day$. If freezing conditions are anticipated, the collector may be drained after the day of exposure. The pressure relief valve and inlet seal shall be removed when the collector is drained of all fluid. The collector inlet shall then be protected to prevent entry of dirt or precipitation and shall be vented to prevent pressure buildup. The collector shall be exposed for a total of thirty cumulative 1500 $Btu/ft^2 \cdot days$ (either filled or unfilled) as described above. The filled exposure day(s) may occur at any time during the 30-day exposure if so desired.

enclosure material shall have a total solar transmittance of at least 0.85 and a spectral transmittance of at least 0.80 in the wavelength band from 0.3 to 0.4 μm. If used, the pyranometer shall be mounted within the enclosure and within the plane of the collector for measurement of the solar irradiance.

D. Thermal Shock/Water Spray Penetration: This test is intended to induce the thermal stresses that would occur when rain impinges on a heated collector to determine the penetration of rain into the collector and the effect of such penetration or moisture condensation, if any, on collector performance.

1. Period of test: The test shall be performed three times during the 30-day exposure period; once during the first 10 days of the exposure period as defined in paragraph C.1. and once each during the second and third 10 days of the exposure period.

2. Pre-test exposure: The spray test shall be conducted after at least one hour of radiant exposure with a minimum solar irradiance of 270 $Btu/ft^2 \cdot h$ (850 W/m^2) measured in the plane of the collector.

3. Apparatus: The test apparatus consists of three or more spray heads in a water supply rack. The water pressure for all tests is maintained at a minimum of 5 psi (34.47 kPa) at each spray head and is equivalent to simulating a rain of about 12 inches per hour or a water flow rate of 50 gallons per hour per nozzle. The supply water temperature shall not exceed 86°F (30°C). A complete description of the apparatus and procedure is presented in NBSIR 78-1305A, Reference [16].

4. Test requirements and options: Specific test requirements for exposure conditions and options are summarized in the following table.

Summary of Specific Test Requirements and Options

Test Requirement	Solar Radiation (min.)	Ambient Temperature	Time	Other
30-days at	1500 Btu/ft^2·day	-	24-h period	Liquid collectors shall be exposed filled for at least one of these days.
4-hour period or two 2-1/2 hour periods	300 Btu/ft^2·h or 300 Btu/ft^2·h with 1 h minimum of 225 Btu/ft^2·h preceding each 2-1/2 h period	80°F or minimum of 70°F if the solar irradiance is greater than 300 Btu/ft^2·h (see NBSIR 78-1305A for options).	Continuous irradiance for either 4 hours or two 2-1/2 hour periods. Exposure to occur after collector has boiled dry or been drained.	Reflector and/or enclosure may be used to reach required irradiance or temperature.
Water spray	One h minimum of 270 Btu/ft^2·h to preceed each application	Above freezing	Each application for 15 minutes continous period.	Supply water temperature of 86°F or less

E. Data Requirements

1. The exposure conditions including hourly irradiation, ambient temperature, wind velocity, and daily precipitation shall be recorded to enable determination of the average daily values. Irradiance and the ambient temperature values shall be recorded every 30 minutes during the 4-hour 300 $Btu/ft^2 \cdot h$ (946 W/m^2) minimum flux exposure period.

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

3. The results of the pre-test and post-test thermal performance shall be plotted on the same graph for comparison purposes. A written description of observed changes in the physical or optical appearance of the collector shall be reported and substantiated with photographs where appropriate.

4. For collectors receiving only a post-test thermal performance measurement, the collector shall be completely disassembled and inspected for any evidence of functional impairment or material deterioration which could result in an abnormally short collector life when operated under normal service conditions. Evidence of material degradation will require documented experimental test data indicating the ability of the material to withstand and continue to function under the conditions commensurate with the application and design lifetime.

Commentary

The purpose of this test is to identify, in a relatively short time, potential problems with collector materials or construction resulting from prolonged exposure to natural environments.

Recognizing that elevated temperature is one of the most damaging environments, solar irradiance and ambient temperature levels have been selected which represent typical summer conditions in most U.S. climatic regions. These conditions will produce the temperatures that the various materials used in solar collectors (cover plates, absorptive coatings, sealants, etc.) will experience in use. Until adequate laboratory test procedures are adapted to ensure the ability to select reliable materials and designs, an assembly level test is considered to be necessary for evaluating collector reliability.

A 4-hour or two 2-1/2 hour exposure periods with a minimum flux of 300 $Btu/ft^2 \cdot h$ (946 W/m^2) is specified in the test method. During this exposure period, it is intended that the collector be exposed to the normal peak profile that it would see on a fixed mount facing south.

The test procedure does not include provisions for evaluating tracking concentrating collectors or collectors designed for use with external reflectors to enhance solar radiation. Modifications to the exposure apparatus may be necessary to accommodate these collectors.

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2. Streed, E. and Waksman, D., "NBS Solar Collector Durability/Reliability Test Program Plan," NBS Technical Note 1136, National Bureau of Standards, U.S. Department of Commerce, Washington, D.C., 1980.[1/]

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4. Dawson, A.G. III and Thomas, W.C., "Stagnation Temperature Methods for Determining Solar Collector Thermal Performance Degradation," Interim Report (DOC NBS Grant NBS 79NADA0022) Virginia Polytechnic Institute and State University, 1981.

5. Clark, E.J., Roberts, W.E., Grimes, J.W., and Embree, E.J., "Solar Energy Systems - Standards for Cover Plates for Flat-Plate Solar Collectors," NBS Technical Note 1132, National Bureau of Standards, U.S. Department of Commerce, Washington, D.C., 1980.[1/]

6. Standard Recommended Practice for Operating Light-Exposure Apparatus (Xenon Arc Type) With and Without Water for Exposure of Nonmetallic Materials, ANSI/ASTM G26-77.[2/5/]

7. Operating Xenon-Arc Type (Water Cooled) Light- and Water- Exposure Apparatus for Exposure of Plastics, ANSI/ASTM D2565-79.[2/]

8. Standard Practice for Performing Accelerated Outdoor Weathering Using Concentrated Natural Sunlight, ASTM E838-81.[2/]

9. Standard Test Method for Rubber Deterioration - Surface Ozone Cracking in a Chamber (Flat Specimens), ANSI/ASTM D1149-78a.[2/5/]

10. Standard Method of Salt Spray (Fog) Testing, ASTM B117-73 (1979).[2/]

11. Autoclave Corrosion Testing of Metal in High Temperature Water, NACE TM-01-71.[3/]

12. Standard Method for Corrosion Test for Engine Coolants in Glassware, ANSI/ASTM D1384-80.[2/5/]

13. Standard Test Method for Resistance of Plastics to Chemical Reagents, ANSI/ASTM D543-67 (1978).[2/5/]

14. Standard Test Method for Resistance of Plastic Films to Extraction by Chemicals, ANSI/ASTM D1239-55 (1971).[2/][5/]

15. Methods of Testing to Determine the Thermal Performance of Solar Collectors, Standard 93-77, ASHRAE 1977.[4/]

16. Provisional Flat Plate Solar Collectors Testing Procedures, First Revision, NBSIR 78-1305A, National Bureau of Standards, U.S. Department of Commerce, Washington, D.C., June 1978, PB 283-721.[1/]

1/ National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

2/ American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103

3/ National Association of Corrosion Engineers, Box 1499, Houston, TX 77001.

4/ American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329.

5/ American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.

APPENDIX B

INTRODUCTION

Appendix B contains tables which have been compiled to provide the user with resources related to properties of materials used in solar application. Standards are listed in Table B.1 which could be of assistance in making physical property determination of materials. Typical physical properties and characteristics of materials have been tabulated to provide baseline values of a selected number of materials. These tables provide guidelines for selection and use of components and materials and may be useful in proving compliance with stated requirements.

Table B.1 List of Test Properties, Test Method Designations and Titles

Property	Test Method Designation Number	Title
	VISUAL OBSERVATION	
Chalking	ASTM D659-80	Standard Method of Evaluating Degree of Chalking of Exterior Paints
Checking	ASTM D660-44 (Reapproved 1976)	Standard Method of Evaluating Degree of Checking of Exterior Paints
Cracking	ASTM D661-44 (Reapproved 1975)	Standard Method of Evaluating Degree of Cracking of Exterior Paints
Blistering	ASTM D714-56 (Reapproved 1974)	Standard Method of Evaluating Degree of Blistering Paints
	OPTICAL PROPERTIES	
Solar Transmittance	ASTM E424-71 ANSI Z138.7-1973	Standard Test Method for Solar Transmittance and Reflectance (Terrestrial) of Sheet Materials
Solar Reflectance	ASTM E424-71 ANSI Z138.7-1973	Standard Test Method for Solar Transmittance and Reflectance (Terrestrial) of Sheet Materials
Emittance	ASTM E408-71 (Reapproved 1980)	Standard Test Method for Total Normal Emittance on Surfaces Using Inspection-Meter Techniques
	ASTM E434-71 (Reapproved 1980)	Standard Test Method for Calorimetric Determination of Hemispherical Emittance and the Ratio of Solar Absorptance to Hemispherical Emittance Using Solar Simulation
	PHYSICAL PROPERTIES	
Hardness	ANSI/ASTM D785-65 (Reapproved 1976)	Standard Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials

Table B.1 (Continued)

Property	Test Method Designation Number	Title
Hardness	ANSI/ASTM D2583-75	Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor
Dimensional Stability	ANSI/ASTM D2122-76	Standard Method of Determining Dimensions of Thermoplastic Pipe and Fittings
	MECHANICAL PROPERTIES	
Tensile Strength	ANSI/ASTM D638-80	Standard Test Method for Tensile Properties of Plastics
Tensile Strength	ANSI/ASTM D882-80a	Standard Test Method for Tensile Properties of Thin Plastic Sheeting
Tensile Strength	ASTM C297-61 (Reapproved 1980)	Standard Method of Tension Test of Flat Sandwich Constructions in Flatwise Plane
Tensile Strength	ANSI/ASTM D897-78	Standard Test Method for Tensile Properties of Adhesive Bonds
Tensile Strength	ANSI/ASTM D412-80	Standard Test Method for Rubber Properties in Tension
Loading or Compression Strength	ANSI/ASTM D695-80	Standard Test Method for Compressive Properties of Rigid Plastics
Loading or Compression	ANSI/ASTM D2412-77	Standard Test Method for External Loading Properties of Plastic Pipe by Parallel-Plate Loading
Flexure Strength	ANSI/ASTM C158-80	Standard Method for Flexure Testing of Glass (Determination of Modulus of Rupture)
Flexure Strength	ASTM C393-62 (Reapproved 1980)	Standard Method of Flexure Test of Flat Sandwich Constructions
Flexure Strength	ANSI/ASTM D790-80	Standard Test Method for Flexure Properties of Plastics and Electrical Insulating Materials

Table B.1 (Continued)

Property	Test Method Designation Number	Title
Fatigue	ANSI/ASTM D671-71 (Reapproved 1978)	Standard Test Method for Flexural Fatigue of Plastics by Constant Amplitude of Force
Burst or Rupture	ANSI/ASTM D1598-76	Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
Burst or Rupture	ANSI/ASTM D1599-74 (Reapproved 1980)	Standard Test Method for Short-Time Rupture Strength of Plastic Pipe, Tubing and Fittings
Burst or Rupture	ANSI/ASTM D2143-69 (Reapproved 1976)	Standard Test Method for Cyclic Pressure Strength of Reinforced Thermosetting Plastic Pipe

Table B.2 - Properties of Typical Cover Plate Materials[1/]

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 (°C)	227 (108)	220 (104)	230-270 (110-132)	200 (93)	180-190 (82-88)	410 (210)	400 (204)	400 (204)	400 (204)
Tensile Strength psi (kN/m^2)	13000 (90,000)	24000 (170,000)	9500 (65,000)	15000-17000 (100,000-120,000)	10500 (72,000)	2700-3100 (19,000-21,000)	4000 (28000) annealed 10000 (69,000) tempered	4000 (28000) annealed 10000 (69,000) tempered	4000 (28000) annealed 10000 (69,000) tempered
Thermal Expansion Coefficient in/in/°F$\times10^{-6}$ (cm/cm/°C$\times10^{-6}$)	24 (43)	15 (27)	37.5 (67.5)	18-22 (32-40)	41.0 (73.8)	8.3-10.5 (14.9-18.9)	4.8 (8.6)	5.0 (9.0)	4.7-8.6 (8.5-15.5)
Elastic Modulus psi$\times10^6$ ($N/m^2\times10^9$)	.26 (1.8)	.55 (3.8)	.345 (2.38)	1.1 (7.6)	.45 (3.1)	.5 (3)	10.5 (72.4)	10.5 (72.4)	10.5 (72.4)
Thickness in (mm)	0.004 (0.1)	0.001 (0.03)	0.125 (3.17)	0.040 (1.0)	0.125 (3.17)	0.002 (0.05)	0.125 (3.17)	0.125 (3.17)	0.125 (3.17)
Weight lb/ft^2 (kg/m^2) For above thickness	0.028 (0.14)	0.007 (0.03)	0.77 (3.8)	0.30 (1.5)	0.75 (3.7)	0.002 (0.01)	1.63 (7.96)	1.63 (7.96)	1.65 (8.06)
Refractive Index	1.45	1.64	1.59	-	1.49	1.34	1.52	1.52	1.52

1/ 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 Application, LA-UR-75-1952, paper presented at SAMPE Meeting, October 14-16, 1975, Hilton Inn, Albuquerque, NM.

Kobayashi, T., Sargent, I., "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 Plastic Encyclopedia, 1975-1976, McGraw-Hill Publishing Company.

Toenjes, R. B., "Integrated Solar Energy Collector Final Summary Report", LA-6143-MS, Los Alamos National Laboratory, Los Alamos, New Mexico, November, 1975.

Table B.3 Characteristics of Absorptive Coatings[1]

Property / Material	Absorptance[2] α	Emittance ε	α/ε	Breakdown Temperature °F (°C)	Comments
Anodic Aluminum	.94-.96	.3-.8	1.2-3		May be influenced by moisture
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-Zin-S over Nickel	.96	.97	14	536 (280)	
Black Iron over Steel	.90	.10	9		

1/ These values were obtained from the following references:

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 Used in Solar Heating Applications", LA-UR-75-1952, paper presented at SAMPE Meeting, October 14-16, 1975, Hilton Inn, Albuquerque, MN.

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.

2/ Dependent on thickness and vehicle to binder ratio.

Table B.4 Examples of Typical Heat Transfer Liquid Properties[1/]

Property	Water	Glycols		Silicone Fluid	Hydrocarbons		Glycerine ("Glycerol")
		50% Ethylene Glycol/Water	50% Proplyene Glycol/Water		Aromatics	Paraffinic oil	60% Glycerine/Water
Freezing point °F (°C)	32 (0)	-33 (-36)	-28 (-33)	----	-80 to 15 (-62 to -9)	15 (9)	-31 (-35)
Boiling point °F (°C) (at atm. pressure)	212 (100)	230 (110) [387(197) 100% glycol]	225 (106) [370(180) 100% glycol]	None	358-640 (181-337)	700 (371)	230 (110)
Flush Stability	Requires pH or inhibitor monitoring	Requires pH or inhibitor monitoring	Requires pH or inhibitor monitoring	Good	Good to Fair	Good to Fair	
Flash Point[2/] °F (°C)	None	None[3/] [232(111) 100% glycol]	None [210 (99) 100% glycol]	450-600 (232-315)	132-405 (56-207)	300-455 (149-235)	None [350(177) 99% glycerol]
Specific Heat Btu/(lb·°F)@73°F (J/kg·°K)@23°C	1.0 (4200)	0.80 (3300)	0.85 (3600)	0.34-0.48 (1400-2000)	0.36-0.50 (1500-2100)	0.43-0.63 (1800-2600)	0.80 (3300)
Thermal Conductivity Btu/(h·ft^2·°F/ft) @100°F (W/m^2·k/m)@38°C	.363@32°F (6.76@0°C)	.23 (4.3)	0.225 (4.19)	0.083 (1.6)	0.07 (1.3)	0.07 (1.3)	0.27 (5.0)
Viscosity csk@77°F (m^2/mx10^{-6})@25°C	0.9 (0.9)	3.4 (3.4)	5 (5)	20-50 (20-50)	8-50 (8-50)	1-60 (1-60)	7 (7)
Toxicity	Depends on inhibitor used	Moderate to high depends on inhibitor used	Slight depends on inhibitor used	No unequivocal toxic effects are recognized	Moderate	Low	Slight
Lifetime Estimates	Depends on inhibitor used	Less than 2 years	Less than 2 years	More than 5 years	Ranges 1-20 years	On order of 10 years	More than 5 years

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.

3/ One manufacturer of an inhibited ethylene glycol mixture (50/50 - 60/40 ethylene glycol/water) gives the following data: "Flash point COC ---- NONE After 50% of initial volume evaporated ---- 290°F"

Table B.5 Typical Properties of Selected Building Materiels for Soler Applicetion*

Property / Materiel	Absorptance α	Emittence ε	Specific Heet Ambient Btu/(lb)(°F) [J/(Kg·K)]	Density lb/ft³ [Kg/m³]	Thermal Conductivity Btu in/h·ft²·°F [W/(m²·K)]	Expension Coefficient in/in/°Fx10⁻⁶ [cm/cm/°Cx10⁻⁶]
MASONRY						
Brick*** (Glazed, white to cream)	0.26 to 0.35	0.92	0.22 [921]	130 [2080]	1.3 to 3.8 [0.19 to 0.55] 5 to 9 [0.72 to 1.30]	3.6 to 8.5 [6.5 to 15.3]
Brick*** (Common, light red to red)	0.52 to 0.68	0.93	0.22 [921]	120 [1920]	Same	Same
Brick*** (Malted purple to blue)	0.77 to 0.89		0.22 [921]	130 [2080]	Seme	Same
Concrete, stone aggregate (Smooth, light)	0.60 to 0.65	0.88	0.20 [834]	120 to 140 [1920 to 2440]	0.9 to 12.0 [0.13 to 1.73]	5.5 [9.9]
Concrete, stone eggregete (Rough, light)	0.60 to 0.85	0.94	0.20 [834]	120 to 140 [1920 to 2240]	Same	Same
Concrete, stone eggregete (Pigmentel, derk)	0.85 to 0.91	0.97	0.20 [834]	120 to 140 [1920 to 2240]	Same	Same
Stone (Light color)	0.35 to 0.54	0.36	0.21 to 0.25 [880 to 1050]	117 to 187 [1870 to 3000]	11 to 20 [1.59 to 2.88]	3.6 to 22 [6.5 to 39.6]
Stone (Dark color)	0.50 to 0.73	0.90	0.21 to 0.25 [880 to 1050]	117 to 187 [1870 to 3000]	Same	Same
Clay Floor Tile (Light color)	0.20 to 0.50		0.19 [800]		12 to 20 [1.73 to 2.88]	
Clay Floor Tile (Dark color)	0.50 to 0.80		0.19 [800]		Same	
METALS						
Aluminum (Polished)	0.10 to 0.40	0.03	0.21 [880]	171 [2740]	1404 [202.5]	13.9 [25.0]
Aluminum (Dull)	0.40 to 0.65	0.09	0.21 [880]	171 [2740]	1404 [202.5]	13.9 [25.0]
Copper (Bright)	0.18 to 0.40	0.07	0.09 [380]	556 [8910]	2688 [387.7]	9.2 [16.6]
Copper (Tarnished)	0.40 to 0.64	0.20	0.09 [380]	556 [8910]	2688 [387.7]	9.2 [16.6]
Iron (Oxidized)	0.80 to 0.92	0.94	0.12 [500] (212°F)	450 [7210]	384 [55.4]	6.7 [12.1]
Steel	-	-	0.12 [500]	489 [7830]	314 [45.3]	9.6 [17.3]
WOOD						
Hardwood		0.90	0.06 [2510]	23 to 70 [370 to 1120]	0.8 to 1.8 [0.12 to 2.6]	1.1 to 5.3 [2.0 to 9.6]
Softwood	0.60		0.06 to 0.7 [2510 to 2930]	22 to 46 [350 to 740]	0.7 to 1.1 [0.10 to 0.16]	Same
WATER						
Clear	**		1.00 [4.19]	62.4 [1.00]	4.1	Varies (Water expands about 4% in volume from 40 to 200°F)
Black (1/2 percent carbon suspension)	1.00		1.00 [4.19]	62.4 [1.00]	4.1	

* These velues were taken from different sources, es referenced below, end are meant to serve es a guide only.

1/ "Handbook of Air Conditioning, Heating end Ventileting", Clifford Strock and Richard L. Korel, Industriel Press, Inc., New York, NY, Second Edition, 1965.

2/ "Handbook of Fundamentals", Americen Society of Heeting, Refrigerating and Air Conditioning Engineers, 1791 Tullie Circle, Atlanta GA 30329, ASHRAE 1977.

3/ "Building Construction Handbook", Chepter 2, McGraw-Hill Book Compeny, Third Edition.

4/ "Journal of Reseerch of the Netionel Bureeu of Stenderds", Volume 6, pege 1003.

5/ "Concrete Manual", Bureeu of Reclamation, U.S. Depertment of Interior

** May vary with the weter conteinment device.

*** For additional information on the properties of brick, see Technical Notes on Brick Construction, 43 D Sept/Oct 1980. "Brick Pessive Solar Heating Systems - Materiel Properties - Part N". Brick Institute of Americe, McLeen, Virginia.

ABBREVIATIONS (Code Groups, Associations and Gov't. Agencies)

AABC	Associated Air Balance Council
AASHTO	American Association of State Highway and Transportation Officials
ACCA	Air-Conditioning Contractors of America
AIA	American Institute of Architects
AIAA	American Industrial Arts Association
ANL	Argonne National Laboratory
ANSI	American National Standards Institute, Inc.
ARI	Air-Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
ASME	American Society of Mechanical Engineers, Inc.
ASPO	American Society of Planning Officials
ASSE	American Society of Sanitary Engineers
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
BOCA	Building Officials and Code Administrators International, Inc.
CABO	Council of American Building Officials
CDA	Copper Development Association
CPSC	Consumer Product Safety Commission
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FHA	Federal Housing Administration
FSEC	Florida Solar Energy Center
HUD	U.S. Department of Housing and Urban Development
IAPMO	International Association of Plumbing and Mechanical Officials
ICBO	International Conference of Building Officials
ISES	International Solar Energy Society
LANL	Los Alamos National Laboratory
NACE	National Association of Corrosion Engineers
NAHB	National Association of Home Builders
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
NCSBCS	National Conference of States on Building Codes and Standards, Inc.
NEBB	National Environmental Balancing Bureau
NFPA	National Fire Protection Association
NOAA	National Oceanographic and Atmospheric Agency
NWTI	National Wood Tank Institute (ceased operations, standards available)
ORNL	Oak Ridge National Laboratory
SAE	Society of Automotive Engineers, Inc.
SAMPE	Society for the Advancement of Material and Process Engineering
SBCC	Southern Building Code Congress International, Inc.
SEIA	Solar Energy Industries Association, Inc.
SERI	Solar Energy Research Institute
SEREF	Solar Energy Research and Education Foundation
SMACNA	Sheet Metal and Air-Conditioning Contractors' National Association, Inc.
UL	Underwriters Laboratories, Inc.

SI CONVERSION UNITS

Length

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

Area

1 in^2 = 6.45 x 10^{-4} $meter^2$

1 ft^2 = 0.09290 $meter^2$

Volume

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

Mass

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

Pressure or Stress (Force/Area)

1 inch of mercury (60°F) = 3.377 x 10^3 pascal
1 pound-force/$inch^2$(psi) = 6.895 x 10^3 pascal

Energy

1 foot-pound-force (ft/lbf) = 1.356 joule
1 Btu (International Table) = 1.055 x 10^3 joule
1 Kilowatt-hour = 3.600 x 10^6 joule = 3.412 x 10^3 Btu

Power

1 watt = 1 x 10^7 erg/second
1 Btu/h = 0.2929 watt

Temperature

t°C = 5/9 (t°F - 32)

Heat

1 Btu·in/h·ft^2·°F = 1.442 x 10^{-1} W/m·K (thermal conductivity)
1 Btu/lb·°F = 4.194 x 10^3 J/kg·K (specific heat)
1 langley = 4.184 x 10^4 J/m^2 = 1 cal/cm^2 = 3.69 Btu/ft^2

COMPOSITE INDEX

☆U.S. GOVERNMENT PRINTING OFFICE: 1984 420 997 96

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO.	2. Performing Organ. Report No.	3. Publication Date
	NBS TN 1187		April 1984

4. TITLE AND SUBTITLE

Performance Criteria for Solar Heating and Cooling Systems in Commercial Buildings

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Center for Building Technology Staff

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NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

DE-AI01-76PR06010

8. Type of Report & Period Covered

Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

Active Heating and Cooling Division
Office of Solar Heat Technologies
U.S. Department of Energy
Washington, DC 20585

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. 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 document establishes baseline criteria for the design, development, technical evaluation and procurement of solar heating and cooling systems for commercial buildings. These performance criteria were developed in accordance with Public Law 93-409 the "Solar Heating and Cooling Demonstration Act of 1975." The document is intended as a resource for use in establishing minimum acceptance levels of performance for solar heating and cooling systems. Criteria which deal with public health and safety are in compliance with general building codes and standards. The criteria on thermal and mechanical performance, durability/reliability and operation/servicing present performance requirements considered to be representative of acceptable levels for conventional space conditioning equipment. By the use of performance language in the document, it is believed that sufficient latitude has been provided to allow innovation and flexibility that is essential for the stimulation of a viable solar industry.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

building; cooling; heating; hot water; performance criteria; solar energy; standards

13. AVAILABILITY

☒ Unlimited
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14. NO. OF PRINTED PAGES

229

15. Price

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