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Passive/Hybrid Solar Components - An Approach to Standard Thermal Test Methods

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National Engineering Laboratory
U.S. Department of Commerce
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Washington, DC 20234

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Prepared for
U.S. Department of Energy
Office of Solar Applications for Buildings
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

As part of a continuing program to develop standard test procedures to measure thermal performance of solar heating and cooling equipment, NBS has developed a plan and methodology that will be utilized for passive/hybrid solar components. A survey of passive solar products currently available or under development enabled the development of an interim classification system consisting of ten component classifications for purposes of thermal testing. A survey of currently available thermal test procedures was performed to assess the applicability of these test methods for passive/hybrid solar components. Existing test procedures that are useful for the Direct Gain Fenestration System classification are identified and recommendations are made for evaluation of these laboratory-based procedures by comparison with field-based testing of components under controlled interior conditions. A proposed program to develop testing procedures for the Collector Storage Wall Module classification is provided. Recommendations are also made for the development of new test procedures for the Direct Gain Fenestration System and Collector Storage Wall Module passive/hybrid solar components classifications for which existing test methods are not applicable.

Key words: passive/hybrid solar components; solar energy; steady-state tests; thermal test procedures; transient thermal tests.

FOREWORD

The use of solar energy for space heating, cooling and supplying domestic hot water to buildings is receiving serious attention at present due to the mounting public awareness of the shortage of conventional fuels. It is clear that this trend is creating an on-rush of solar components of various designs, all claiming high efficiency and potentially significant fuel savings if used. The purpose of the research program presently underway at the National Bureau of Standards and whose preliminary results are described in this report, is to develop thermal performance evaluation and testing methods for passive/hybrid solar devices so that the components can be evaluated in a meaningful and consistent way.

In discussing testing procedures, certain commercial components are identified in order to provide a descriptive characterization of their features and thermal performance characteristics. Inclusion of a given component is this report in no case implies a recommendation or endorsement by the National Bureau of Standards, and the presentation should not be construed as a certification that any component would provide the indicated performance. Similarly, the omission of a component does not imply that its capabilities are less than those of the included components. The information presented was obtained primarily from the open literature. This report is intended to be informative and instructive and not an evaluation of any commercially available components.

The purpose of this report is to identify needed standard thermal performance test methods for passive/hybrid solar components. Comments concerning the classification and plan for developing standard thermal performance test methods for passive/hybrid solar components are invited and should be sent to:

Passive/Hybrid Solar Program Group Leader
National Bureau of Standards
Building 226, Room B-126
Washington, D.C. 20234

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1. INTRODUCTION

1.1 BACKGROUND

Identification and development of performance based standards for solar heating and cooling systems and components is a key objective identified in both the Department of Energy (DoE) National Program for Solar Heating and Cooling [1]* and in the National Program Plan for Passive and Hybrid Solar Heating and Cooling [2]. Performance based standards are required to establish minimum requirements for health and safety as well as acceptable minimum levels of thermal performance, durability and reliability. In anticipation of the need to plan and coordinate the development of standards for solar energy systems, subsystems, components, and materials, the American National Standards Institute (ANSI) established a Steering Committee on Solar Energy Standards and with financial support of DoE and technical assistance from the National Bureau of Standards (NBS), prepared a plan to avoid duplication within the program and to ensure that all needed standards are systematically developed [3].

Staff members in the Solar Equipment Group at NBS have been active in programs to assist in developing standard test procedures for measuring thermal performance of solar heating and cooling equipment since 1974. The objectives of these programs have been to encourage the adoption of consensus standards for thermal performance testing of a variety of solar products by performing the basic research needed to develop draft testing procedures and the validation of these procedures through laboratory and field testing of a number of solar energy components and systems. The first test procedures developed at NBS were for solar collectors and thermal storage devices. As a direct result of this effort, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) was able to adopt standard test procedures [4, 5] for both components in early 1977. Currently under way are efforts to develop standard test procedures for other products, including complete solar domestic hot water systems [6], and modular passive/hybrid solar components.

The work discussed in this report represents a status assessment of thermal test procedures for passive solar components, a summary of which was presented at a National Passive Solar Conference [7]. In addition, this report presents an input to a coordinating group comprised of staff members of the national laboratories assisting the Solar Energy Research Institute (SERI) in the development of a national plan dealing with performance evaluation of passive/hybrid solar heating and cooling systems [8].

It is evident that there is an immediate need to develop standardized test procedures for thermal performance of passive/hybrid solar components in support of research and development activities of DoE, which are currently being implemented as part of the National Program for Solar Applications. In 1980, the DoE issued two Program Opportunity Notices (PONs) intended to lead to development of marketable passive/hybrid solar components [9, 10]. In both of these PONs, engineering field testing of thermal performance is required for final

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* Numbers in brackets identify the references listed in section 6.

design development for each passive/hybrid solar component, and independent laboratory testing of final prototype designs is desired in order to achieve maximum credibility of product performance. Standard methods for testing many of these components have not been identified to date.

It is also evident that there will soon be an increased need for standardized thermal performance test procedures which can be applied to a broader range of building products varying from components to complete systems. The U.S. Congress has passed legislation requiring the development of standards for energy consumption related to the heating and cooling of new buildings [11]. These standards, when promulgated, will require more detailed information on the thermal performance of a wide variety of building products to be derived from standard test methods. This information is needed to accurately estimate the thermal performance of the entire building, in order to demonstrate that building energy consumption is in compliance with the proposed standards, and also to provide an improved basis for evaluation of alternate passive solar design concepts and for selection of specific products.

1.2 APPROACH AND CONTENT OF REPORT

A general approach for drafting standard test methods for a technology in a stage of development similar to that of passive solar components is concisely described in a recent report prepared by NBS for the Solar Energy Research Institute (SERI)[12]. That report states that the major activities in preparing standard test methods for solar energy systems should include the following:

(1) Evaluation of the proposed test procedure for: practicality and economic feasibility to perform the test, the lack of impedance to new technology development, and the avoidance of unfair discrimination of one product or technology in favor of another due to implementation of the test procedure,

(2) Preparatory work for writing and introducing a test method would include steps such as: background information search, establishing the appropriateness of the proposed method, describing the principles and assumptions, and performing error analysis,

(3) Preparation of the step-by-step procedures developed for each test method and subsequent validation of the procedure by interlaboratory comparisons.

The following sections in this report include some of the key elements identified in items (1) and (2) above, prior to the actual preparation of the draft testing method. Section 2 identifies the characteristics and classifications of passive and passive/hybrid solar components and systems, for the purpose of testing for thermal performance. Section 3 is an overview of thermal performance test procedures for materials and assemblies, such as those used in building envelope sections and active solar systems which perform one or more of the thermal functions of passive/hybrid solar components including controlling solar gain, thermal transmission and thermal storage.

The test procedures reviewed include existing consensus test procedures of technical organizations and experimental work documented in the open literature but not presently adopted as standard tests. Also reviewed in section 3 are the testing methods that have been used in research and development activities for passive/hybrid solar energy systems. Section 4 discusses the applicability of existing testing procedures and reviews the important features to be applied or developed in new standardized test procedures for two of the passive solar component classifications considered to be at the most advanced stage of development. Section 5 identifies and discusses the recommended activities to be performed in developing new test procedures for these two specific passive classifications. Also, an outline of a long-range plan is given for systematic development of new test procedures for all ten component classifications presented in the report.

2. CLASSIFICATION OF PASSIVE/HYBRID SOLAR COMPONENTS FOR THERMAL PERFORMANCE TESTING

The objective of this portion of the study was to develop a classification system for passive/hybrid solar components based on thermal performance testing requirements. Input to this study included information on specific passive/ hybrid solar products such as details of design, principles of operation and the functional role of each product in building applications. This information was obtained from manufacturers' response to a letter questionnaire, review of technical and popular literature, and technical evaluation of proposals submitted to the Government for passive and passive/hybrid solar and energy conservation products. The information derived from this study has resulted in the development of an interim classification system that contains groupings of generic passive/hybrid solar components. For each class of passive and passive/hybrid solar components, it is possible that standard test procedures for thermal performance can be developed.

2.1 CHARACTERISTICS OF PASSIVE AND PASSIVE/HYBRID SOLAR COMPONENTS

To be identified as a passive solar component, within the scope of this study, the criteria a product must satisfy is that it is: (1) capable of being mass produced for manufacturing economy; (2) fabricated in modular incremental sizes to permit ready integration into building structures; and (3) designed to utilize solar energy in conjunction with natural thermal processes such as conduction; free convection, radiation and evaporation to reduce fossil energy consumed in buildings for purposes of space heating, space cooling and/or domestic water heating.

Passive/hybrid solar components, which are similar to passive solar components but utilize small quantities of non-renewable energy to improve the transfer of solar or thermal energy or to improve the control of the natural process, are included in the scope of this study. Hereinafter in this report, the term passive component will be assumed to also include passive/hybrid solar component.

Components that do not meet the criteria listed above are excluded from consideration in this study. Excluded components are: (1) passive design elements that exhibit significant variation in thermal properties from unit to unit, such as site-built storage walls constructed with local materials, (2) products that primarily reduce solar heat gain during both the cooling and heating seasons, or (3) products that are primarily designed or utilized to reduce electrical energy consumption by displacing artificial lighting with natural daylighting.

2.2 SOURCES OF INFORMATION ON PASSIVE COMPONENTS

2.2.1 Results of Letter Survey

A letter questionnaire was sent to 169 manufacturers or distributors of passive solar products describing the NBS project to identify and classify these products for the purposes of developing standard test methods. The list of manufacturers was compiled from solar product directories that appeared in several trade magazines, and from a passive solar product directory prepared by the Northeast Solar Energy Center (NESEC) [13]. The letter questionnaires were mailed between January 1979 and April 1980 and requested information on product descriptions, recommended installation and operating procedures, and anticipated thermal performance for each passive solar product handled by the organization. Appendix A includes a sample letter and the list of firms that were contacted.

Of the 169 information requests, 74 responses were received containing information on a wide range of products, some of which were not related to passive solar applications. Of the 74 responses received, 37 passive solar products were identified which satisfied the above definitions. Product information extracted from manufacturers' response were compiled for each of the 37 products and is presented in appendix B. Included in this information are the product description data, operating procedures and thermal performance data reported by the manufacturers. No attempt was made to verify the accuracy of these data.

2.2.2 Other Sources of Data

Other sources of technical information on both commercially available products, and products currently under development included technical papers published in the journals of ASHRAE and the International Solar Energy Society, the Proceedings of the National Passive Solar Conferences, and the Proceedings of the American Section of the International Solar Energy Society. A comprehensive overview of a number of new developments in insulating window systems that was useful in developing our classification system is described in reference [14].

In addition to the technical sources of information, numerous articles published in solar energy trade magazines and consumer-oriented technical magazines were reviewed. Noteworthy compilations of product description information are included in the Lawrence Berkeley Laboratory's (LBL) publication -- Windows for Energy Efficient Building [15], William Schurcliffe's book Thermal Shutters and Shades [16], and the Northeast Solar Energy Center's recent publication - Passive Solar Products Directory [17].

NBS staff members also assisted in the technical review of proposals received by the DoE in response to the Project Opportunity Notice (PON) on "Marketable Products for Passive Solar Applications" [9]. Product testing was an important factor for this PON and applicants were required to provide details on their proposed plans for thermal performance testing, in addition to providing information on product descriptions and thermal performance.

Other than "Windows for Energy Efficient Buildings", "Thermal Shades and Shutters" and the "Passive Solar Products Directory" no systematic compilation of data for passive solar products is available. In some cases, the particular passive solar products are still in the conceptual or early laboratory stages of development, and in other cases, the information is considered to be proprietary.

2.3 INTERIM CLASSIFICATION FOR PASSIVE SOLAR COMPONENTS

2.3.1 Classification Scheme

Based on a review of the function, construction and operating principles of a substantial number of different products, the interim classification shown in table 1 was developed. Both the major subdivision by test method and the major classes of passive solar components distinguish different thermal performance test requirements.

The major subdivision by test method is determined by whether the passive solar component is provided with elements that store thermal energy. Products that provide little, if any, thermal storage can be tested using steady-state test methods, and products that provide thermal storage require transient test methods.

Functional characteristics distinguish major classes of passive solar components from one another. Space heating, space cooling, and hot water heating are different functions, each requiring different test procedures for thermal performance. Other functional characteristics which affect thermal test requirements include the location and orientation for an applications of the component. Components for use in a south wall exposed to solar radiation, require different test procedures than components either isolated from direct solar radiation or which are to be placed in ceiling, floor or interior wall sections. The heat transfer to and from a component is dependent on its location and orientation, and this must be considered in each test procedure.

2.3.2 Discussion of Passive Solar Component Classification

Figures 1-10 are conceptual illustrations of passive solar components identified in table 1. Examples of available products, corresponding to some of the passive solar component classes of table 1, are listed in appendix B. A number of passive solar components identified in table 1 but not described in appendix B correspond to components that were not commercially available at the time of the survey but which may be available in the near future.

Based on the survey and literature review, it is apparent that there are large numbers of products, either commercially available or currently under development, which provide different building functions and operate under different heat transfer principles, and which qualify as passive solar components under the terms of our definitions. Currently four groupings of passive solar components appear to be most advanced in terms of their commercial availability. These four are: (1) Direct Gain Fenestration System (DGFS), (2) Collector/Storage Wall Modules (CSWM), (3) Sunspace/Greenhouse Modules (S/GM), and (4) Domestic Hot Water Systems (DHW).

TABLE 1

INTERIM CLASSIFICATION OF PASSIVE SOLAR COMPONENTS
ACCORDING TO TEST METHODS FOR THERMAL PERFORMANCE

Passive Component Classification(1)	Thermal Test Method(2)	
	Steady State	Transient
1. Direct Gain Fenestration Systems (DGFS) ° Multiple-glazed windows ° Movable insulation - shutters, loose-fill materials between glazings ° Movable shading devices - insulating shades, blinds, louvers, draperies, curtains ° Air Flow Windows	●	
2. Collector/Storage Wall Modules (CSWM) - with sensible heat storage (water, concrete, brick) or latent heat storage (phase change materials)		●
3. Sunspace/Greenhouse Modules (S/GM)		●(3)
4. Passive Solar Water Heating Systems (PSWH) ° Discrete component thermosyphon systems ° Integrated component (Batch) system		●
5. Thermosyphon Solar Air Heating Collectors (TSC)	●	
6. Thermal Storage Units (TSU) non-integrated floor, ceiling,or wall elements or containers using sensible or latent heat storage materials		o
7. Roof Pond Modules (RPM)		o
8. Radiative Cooling Modules - (RCM) with selective radiative control finishes, coating	o	
9. Ground Coupling Modules (GCM)		o
10. Evaporative Cooling/Natural Ventilation Modules (EC/NVM)	o	

NOTES:

(1) Listed in order of judged current need for standard thermal test methods.

(2) Symbol ● = high level of confidence in identifying type of test method (e.g., steady-state or transient) to be developed.

Symbol o = lower level of confidence in identifying type of test method (e.g., steady-state or transient) to be developed due to either a lack of or a small number of commercially available components.

(3) If more components become commercially available without integral thermal storage, then these components should be classified under DGFS.

2.3.2.1 Direct Gain Fenestration Systems (DGFS)

DGFS are the most commercially available passive solar components. They are manufactured or site-assembled products, usually of modular dimensions and specific materials, and usually designed for vertical or near vertical installation in the south-facing walls of buildings. Figures 1a - 1d illustrate different DGFS components which are either multiple glazings or specific components used in conjunction with a south-facing glazing. For a space heating function, a DGFS component: 1) allows a substantial fraction of solar irradiance incident on the fenestration to be transferred into the building, and 2) is a significant resistance (higher than for a single glazing) to heat loss from the interior space to the outdoor environment, where the heat loss will vary with indoor-to-outdoor air temperature difference and outdoor wind speed. A DGFS component for space cooling purposes: 1) minimizes solar gain by reflection or opaque shading, and 2) is a significant resistance (higher than for a single glazing) to heat gain from the outdoor environment.

Since a DGFS component does not have appreciable integral thermal storage, its thermal energy transfer occurs almost instantaneously, either directly by transmission of short-wavelength solar radiation, or indirectly by absorption and re-radiation as long-wavelength infrared radiation or by convection. The convective transfer may be either free or forced. If forced convection is used, small amounts of electrical power are used to operate a fan.

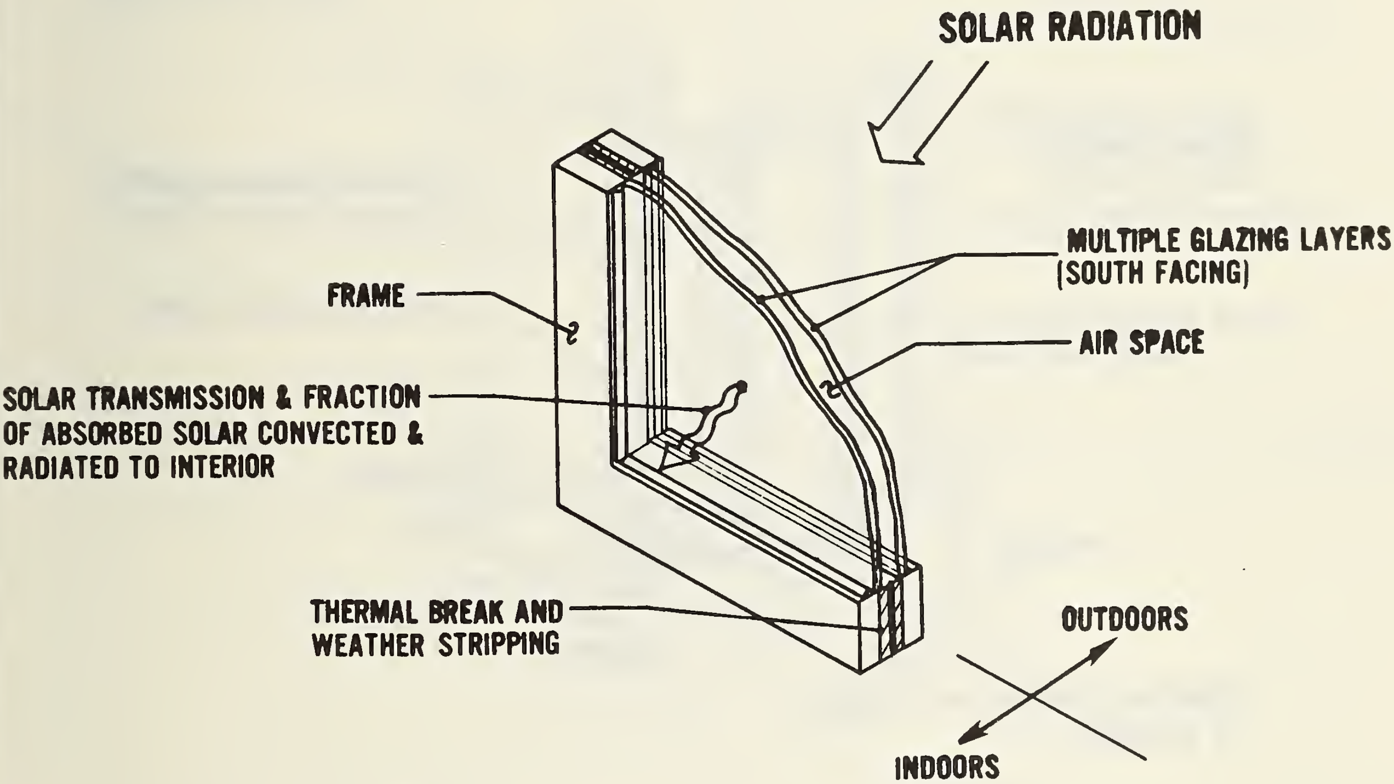
On figures 1a - 1d, the distinctive passive solar attributes are identified for each DGFS component illustrated. There is only a subtle distinction between a movable shade and movable insulation DGFS component (figures 1b and 1c). The distinction is based on the physical difference in how the component resists thermal transmission. A component is a shade if its primary resistances to thermal transmission are accomplished by reflective surfaces and dead air spaces which minimize radiation and convection heat transfer respectively. A component is called insulation if its low conductance material is the primary resistance to thermal transmission.

One concept for an air flow window is illustrated in figure 1d. A different concept utilizing a three pane aspirated window with forced convective flow for heat exchange is discussed in reference [37].

2.3.2.2 Collector/Storage Wall Modules (CSWM)

Intensive development activity has been observed for the passive solar components called Collector/Storage Wall Modules (CSWM). A CSWM includes a glazing, storage medium, movable insulation (if provided) and the means to control the energy transfer between the storage medium and the building space. Figure 2 illustrates a CSWM assembly. CSWM are manufactured or site-assembled products, usually of modular dimensions and specific materials, that are designed for vertical or near-vertical installation in the south-facing, exterior walls of buildings. The primary purpose of the CSWM is to absorb and store as thermal energy, a substantial fraction of the solar irradiance incident on exterior surface of the CSWM. At a later time the stored thermal energy is radiated and convected into the adjacent building space. A lesser

Figure 1a. Multiple-glazed window (DGFS)

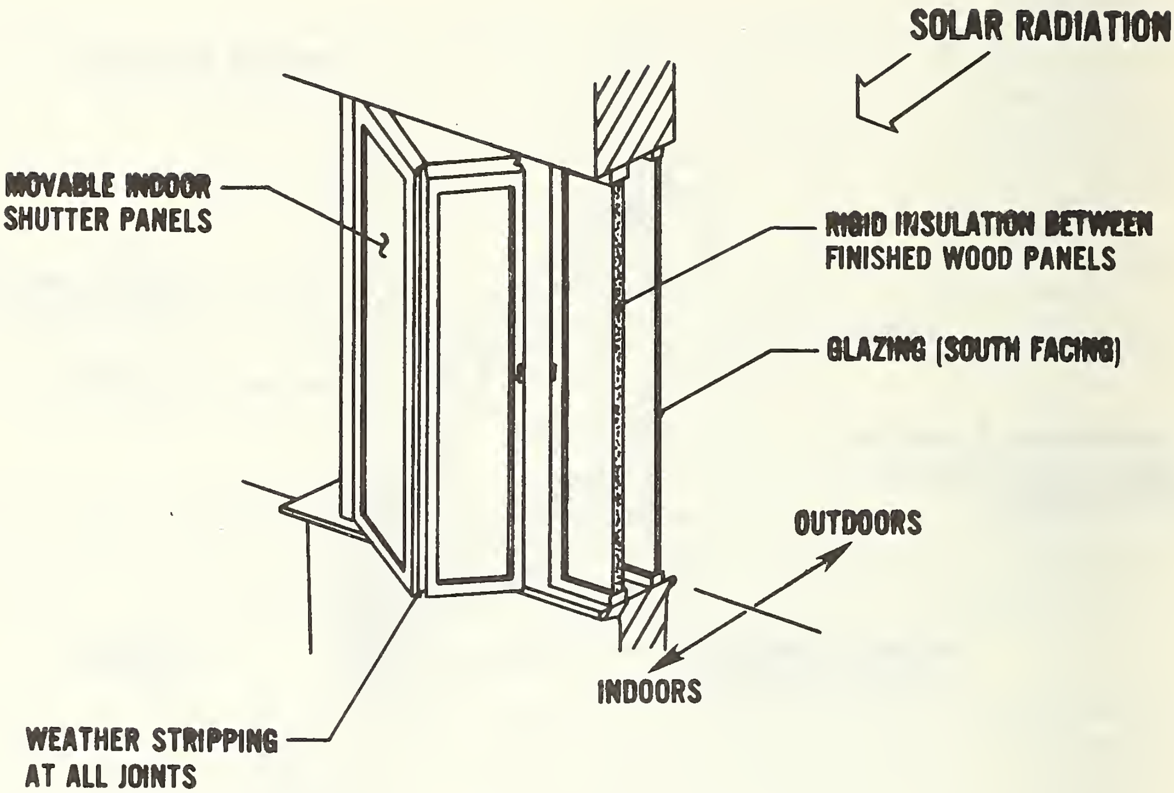


FUNCTION: Space Heating

- o Heat Gain
  - i) solar transmission
  - ii) fraction of absorbed solar is convected and radiated to interior
- o Heat Loss Resistance
  - i) sealed air space between glazings
  - ii) low conductance frame and/or thermal break, weather stripping

NOTE: Must shade during cooling season

Figure 1b. Indoor movable insulation (DGFS)



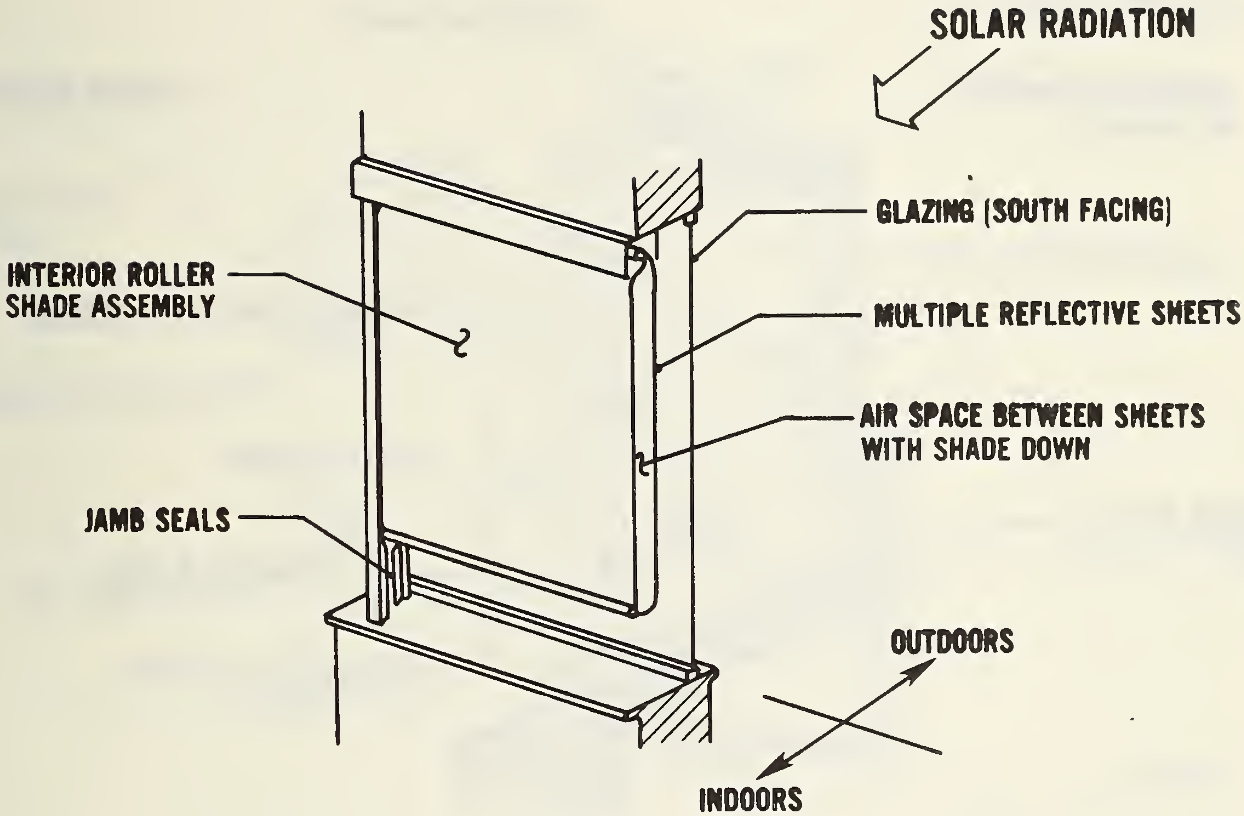
FUNCTION: Space Heating

- o Heat Gain (panels open)
  - i) solar transmission
  - ii) fraction of absorbed solar is convected and radiated to interior

- o Heat Loss Resistance (panels closed)
  - i) insulation in panels
  - ii) tight seal closure
  - iii) dead air space between glazing and closed panels

NOTE: Shutter is a DGFS component only when combined with a south-facing glazing

Figure 1c. Indoor movable shade (DGFS)



FUNCTION: Space Heating

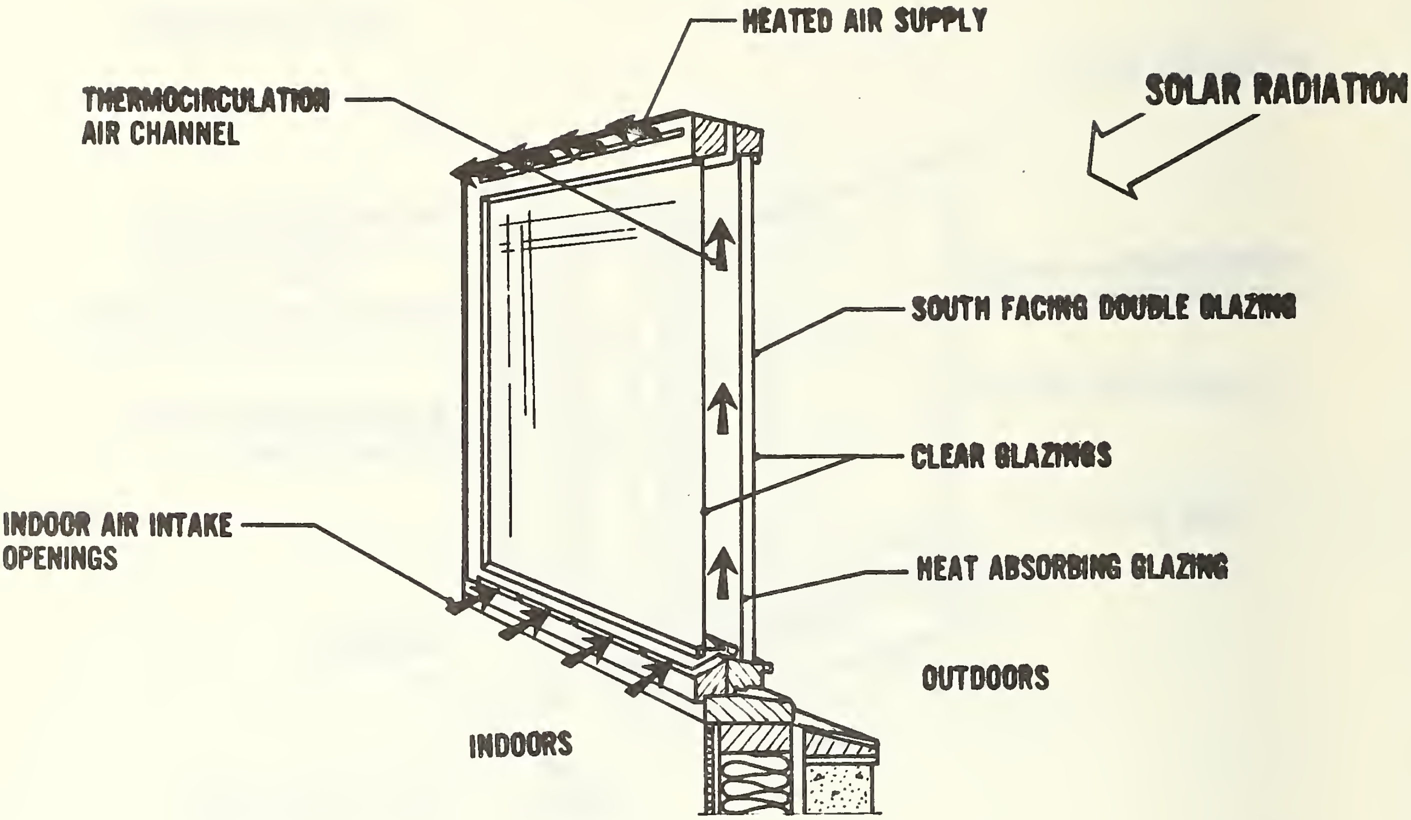
- o Heat Gain (shade rolled up)
  - i) solar transmission
  - ii) fraction of absorbed solar convected and radiated to interior

- o Heat Loss Resistance (shade rolled down)
  - i) air space between multilayer sheets
  - ii) air space between glazing & shade when there is a tight seal around shade perimeter

Space Cooling (shade rolled down)
- i) resistance to solar gain by reflective sheets
- ii) resistance to convective heat gain by air spaces between multilayer sheets

NOTE: Shade is a DGFS component only when combined with a south-facing glazing

Figure 1d. Air flow window (DGFS)

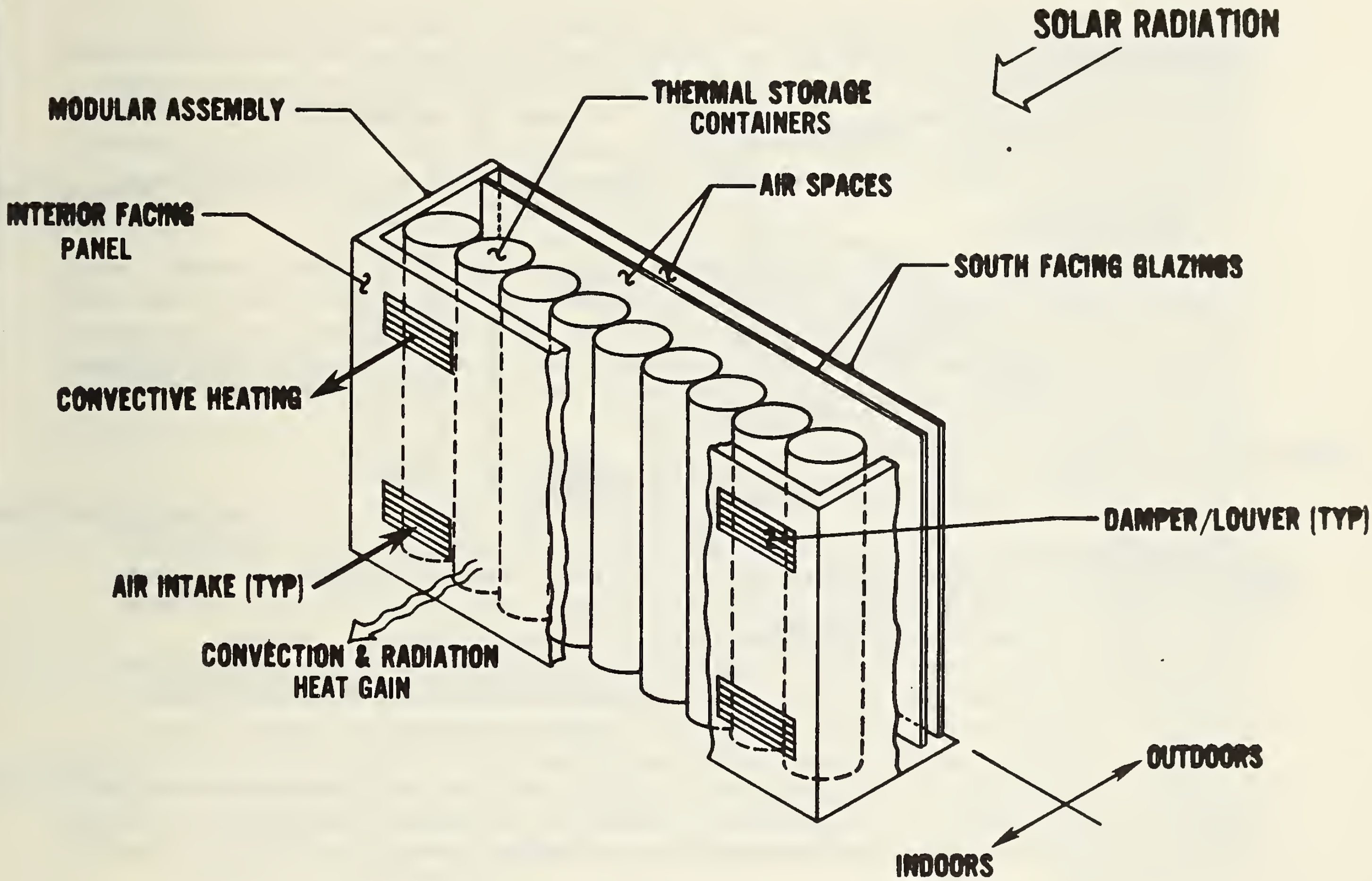


FUNCTION: Space Heating

- o Heat Gain
  - i) solar transmission
  - ii) fraction of absorbed solar, by heat absorbing glazing, that is convected to air in thermocirculation channel
- o Heat Loss Resistance
  - i) air space between outer double glazing
  - ii) low conductive frame and/or thermal break and weather stripping

NOTE: Fan makes this a passive/hybrid solar DGFS

Figure 2. Collector/storage wall module (CSWM)



FUNCTION: Space Heating

- o Heat gain - solar transmission through glazings to heat mass storage; fraction of heat stored is convected and radiated to interior

- o Heat Loss Resistance

    i) air space between storage and glazing
    ii) control of operable dampers or louvers on interior facing panel
    iii) air space between multiple glazings (if provided)

NOTE: Must shade during cooling season

fraction of the solar irradiance may be transferred immediately into the building space, either directly as transmitted solar energy through transparent sections of the storage wall, or indirectly as radiated and convected thermal energy in a similar fashion to the DGFS. Storage of thermal energy occurs within the CSWM either as sensible energy storage in materials such as masonry or water, or as latent energy storage in materials such as hydrated salts or paraffin waxes.

Other attributes of a CSWM include the conscious effort to reduce thermal energy transfer between the building space and the outside environment due to air temperature difference and due to wind. This may be accomplished either by selection of the thermal properties and configuration of the materials comprising the CSWM, or by utilizing movable insulation devices that are positioned to limit thermal and/or solar energy transfer.

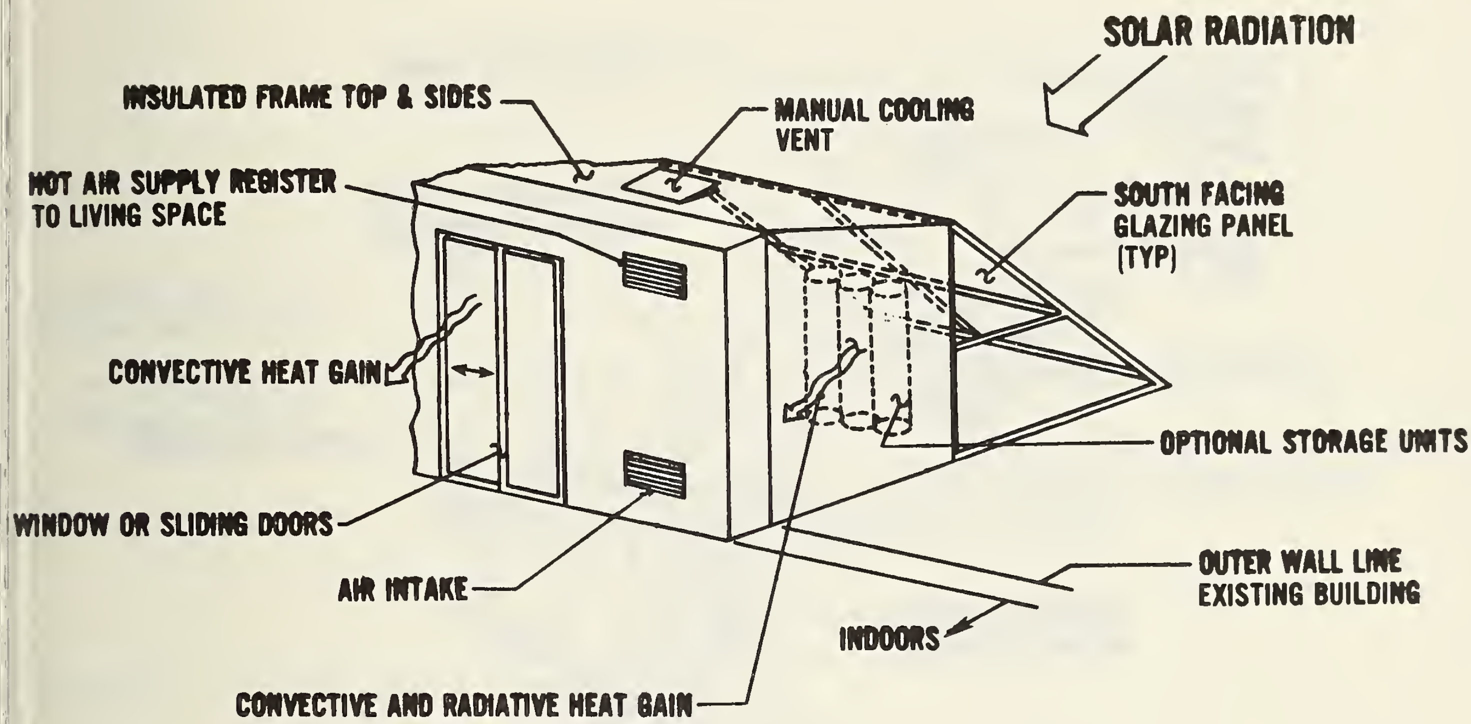
2.3.2.3 Other Passive Solar Component Categories

Sunspace/Greenhouse Modules (S/GM) are a class of passive solar components (figure 3) that perform passive solar functions similar to DGFS, but it has been assumed in the interim classification that sunspace greenhouse modules will include integral thermal storage as a standard feature. However, responses to the survey and the commercially available components identified in reference [17] do not satisfy this assumption regarding integral thermal storage. If this continues to be the way sunspace/greenhouse modules are marketed, then the appropriate thermal performance testing would be the same as for DGFS. In addition, if sunspace/greenhouse modules require extensive site assembly which results in significant variation in thermal performance from one module to another due to air leakage, then standard testing would not be useful or recommended.

Passive Solar Water Heating Systems (PSWH) distinguish another class of passive solar components. Figures 4a and 4b illustrate typical passive solar thermosyphon and batch water heating systems respectively. In the thermosyphon system, the solar collector and thermal storage container are discrete components, while in the batch system, the solar collector and thermal storage container are integrated components. Examples of commercially available systems of both types are identified in reference [17].

A number of commercially available Thermosyphon Solar Air Heating Collectors (TSC) are identified in reference [17]. The TSC illustrated in figure 5 differs from a DGFS air flow window in that there is no direct solar transmission through a TSC since its absorber plate is opaque. A TSC, also differs from an active solar collector due to: 1) the natural convective energy transport, and (2) the simpler controls associated with its operation. Although a TSC operates at a variable air flow rate through the collector, the absence of appreciable thermal mass suggests that steady-state boundary conditions may be appropriate for standard testing of TSC components.

Figure 3. Sunspace/greenhouse module (S/GM)



FUNCTION: Space Heating

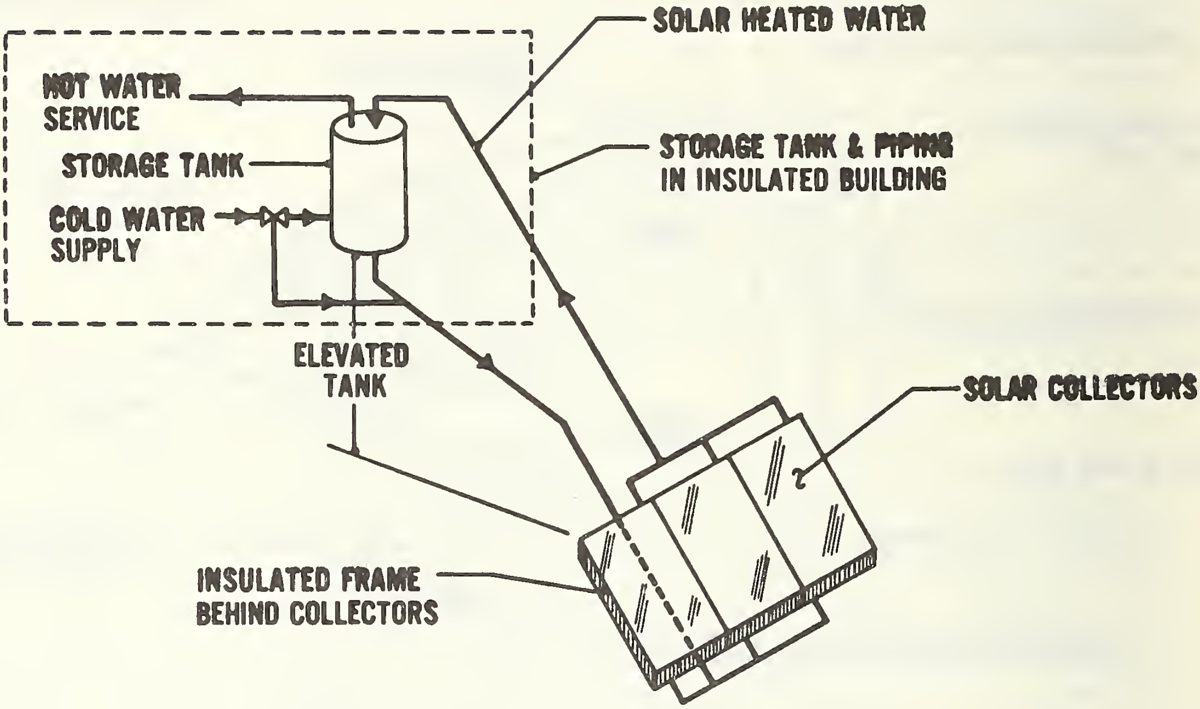
- o Heat Gain - solar transmission through sunspace glazing is utilized by:

  i) natural or fan assist convective heating into the living space, and/or
  ii) storing absorbed solar in sunspace thermal mass for later use, and/or
  iii) natural or fan assist convective heating into remote storage for later use.

- o Heat Loss Resistance - sunspace volume and enclosure increases the thermal resistance between the building south-facing wall and the outdoor environment

NOTE: Must be shaded or vented to outdoors during cooling season

Figure 4a. Passive solar water heater - discrete component thermosyphon system (PSWH-DCT)

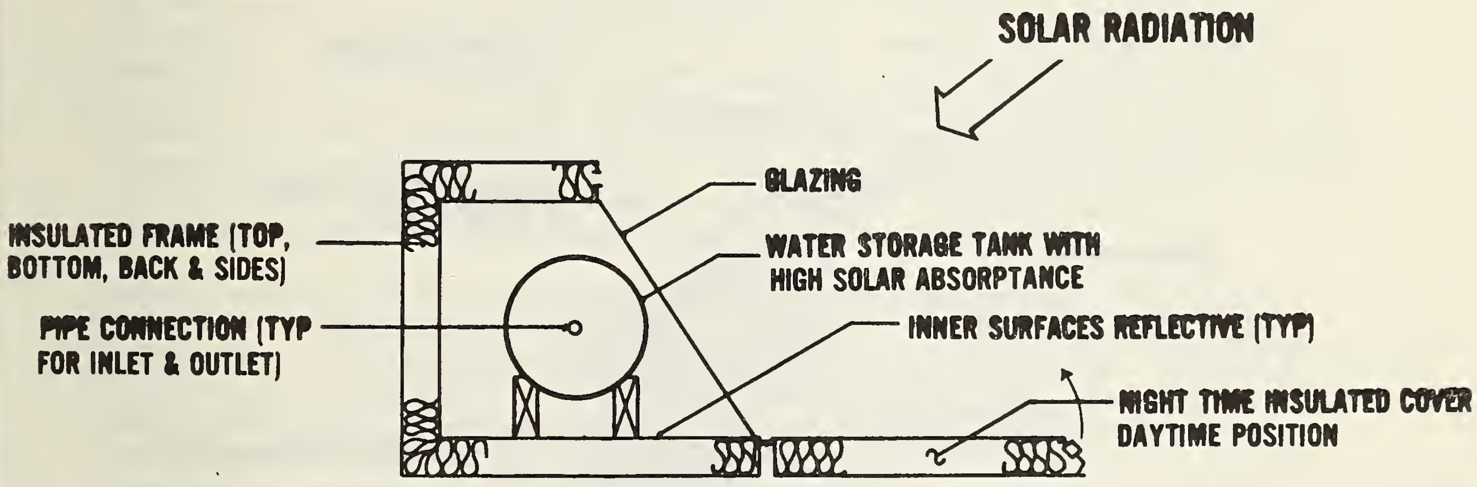


FUNCTION: Hot Water Service

- o solar heated water in collectors circulated by natural convective flow to an elevated storage tank,
- o freeze protection by drain down or auxiliary heaters

NOTE: Not shown in simple illustration are typical control sensors, vent and relief valves

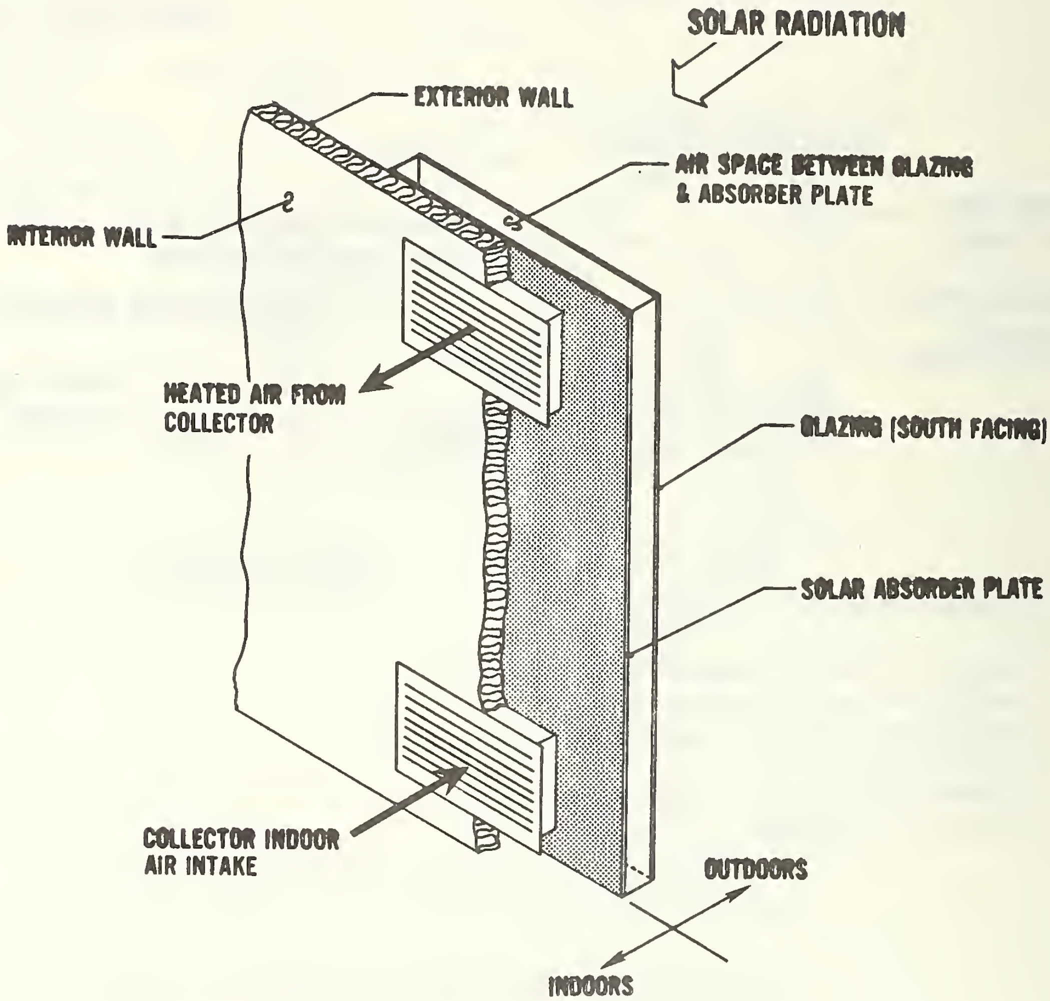
Figure 4b. Passive solar water heater - integrated batch system (PSWH-IS)



FUNCTION: Hot Water Service

- o water in tank is heated by direct and reflected solar irradiance
- o insulated cover for non-collecting conditions
- o freeze protection by drain down or auxiliary heaters

Figure 5. Thermosyphon solar collector (TSC)



FUNCTION: Space Heating

- o Heat Gain - solar transmission through glazing heats absorber panel; heated absorber plate induces convective air flow; heated air flows indoors through upper vents.

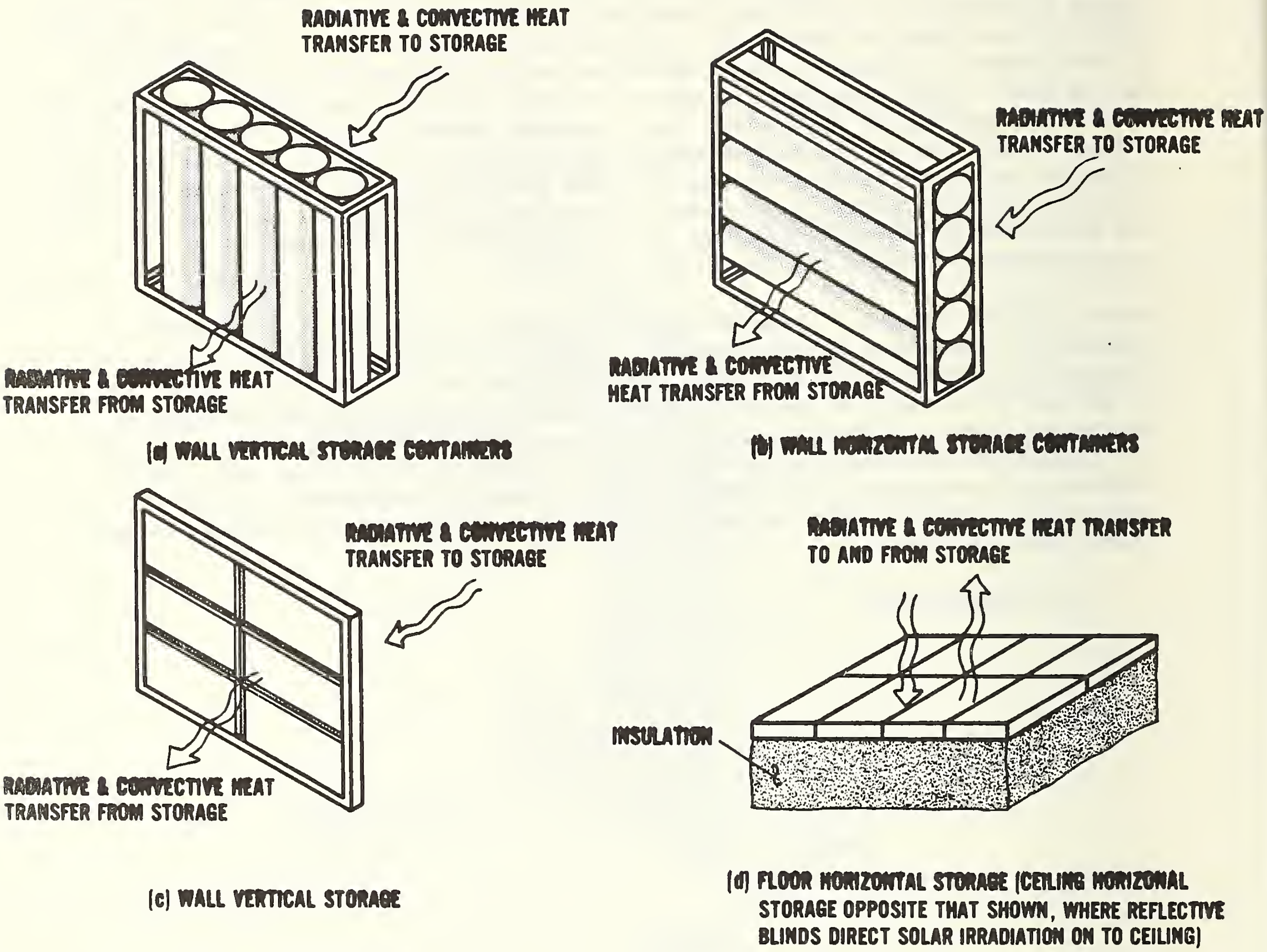
- o Heat Loss Resistance
  - i) air space between absorber and glazing
  - ii) operable dampers on vents to prevent reverse thermosyphoning at night

NOTE: During cooling season, must shade or vent assembly to outdoors

Thermal Storage Units (TSU) are a class of passive solar components that are usually elements of a larger passive solar system for space heating or cooling. Figure 6 illustrates different types and applications of TSU. These components differ from a CSWM in that: 1) a glazing is not a part of the component; and 2) the component location and orientation is not limited to a vertical south facing wall. A TSU may contain either or both sensible and latent heat storage materials, and may be used where heat transfer occurs through the component or occurs in and out of the same surface, as indicated in figure 6. The rate and direction of heat transfer in charging and discharging TSU components may significantly affect thermal performance; therefore, for standard testing, the rate and direction of thermal charging and discharging of a TSU must be representative of expected conditions.

Other interim classes of passive solar components include Roof Pond Modules (figure 7), Radiative Cooling Modules (figure 8), Ground Coupling Modules (figure 9), and Evaporative Cooling/Natural Ventilation Modules (figure 10). At present, for each of these component classes, it is not clear whether a sufficient number of components will be commercially manufactured to warrent development of standard performance tests. Evaporative cooling and natural ventilation components are combined as one class of components, since in conventional HVAC systems evaporative cooling and ventilation techniques are often used together.

Figure 6. Thermal storage units (TSU)



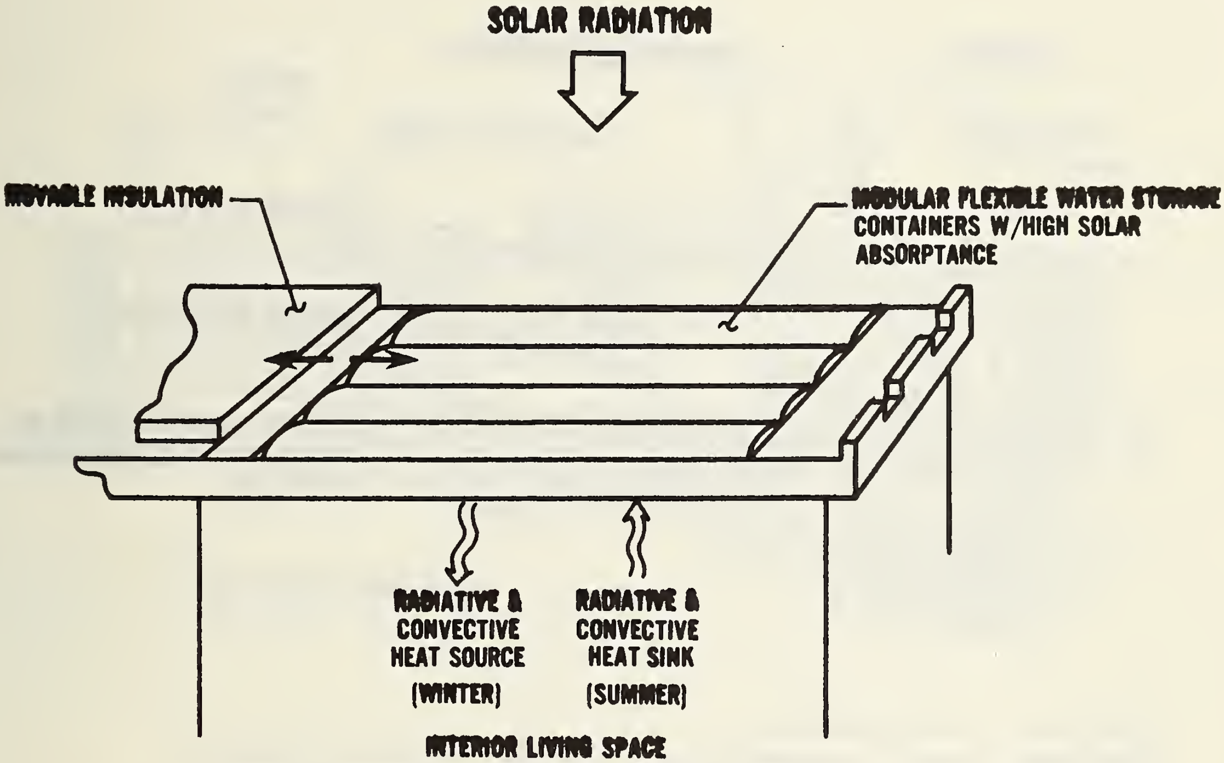
FUNCTION: Space Heating or Cooling

- o containers with sensible or latent thermal storage materials absorb thermal energy from solar or infrared radiation or convective sources and release thermal energy by convection, and infrared radiation

- o heat flow direction typically is:

  i) through the storage units for wall applications, and
  ii) into and out of the same surface of storage for ceiling or floor applications

Figure 7. Roof pond module (RPM)



FUNCTION: Space Heating

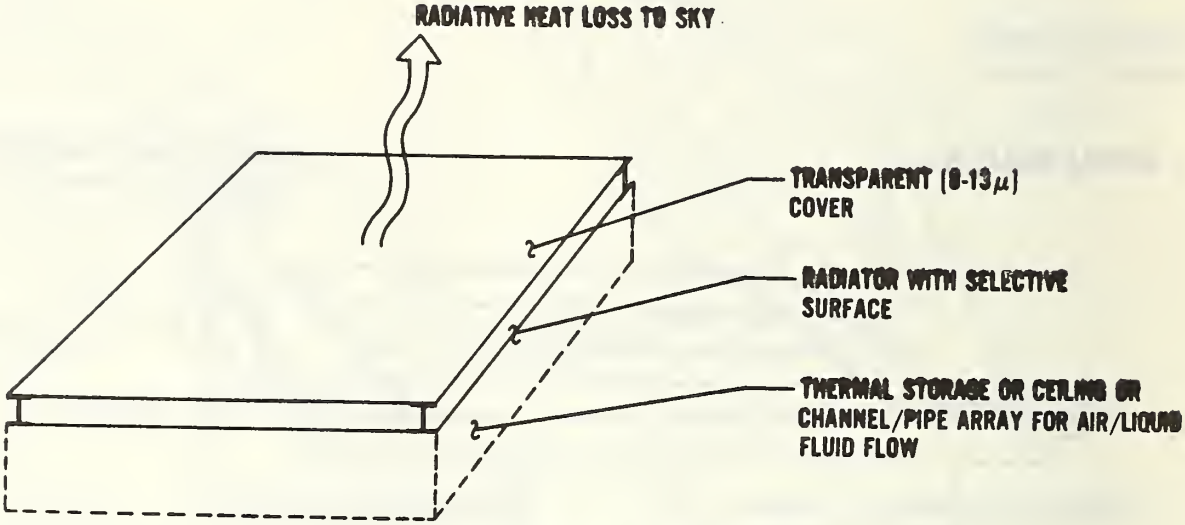
- o Heat Gain - modular storage units absorb solar irradiance; fraction of absorbed solar in the ceiling is convected and radiated to the living space below

- o Heat Loss Resistance - movable insulation on the roof

Space Cooling

- o Heat Rejection - modular storage units absorb heat convected and radiated from the living space during the day (storage insulated from solar radiation); movable insulation removed at night and storage units radiate to cool night sky

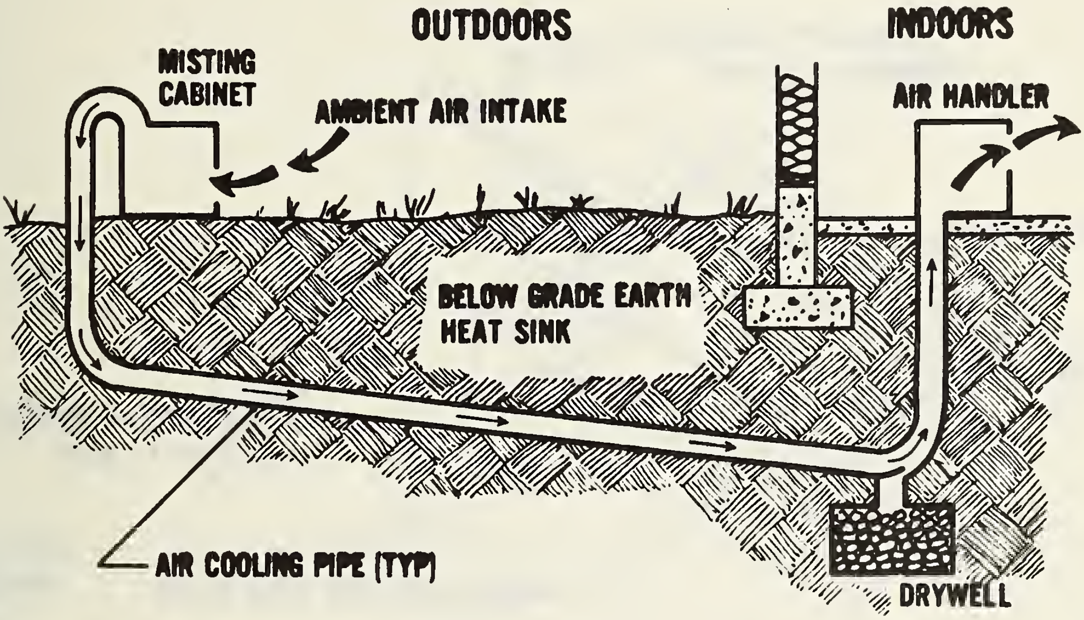
Figure 8. Radiative cooling module (RCM)



FUNCTION: Space Cooling
LOCATION: Roof - horizontal or tilted for northern exposure
OPERATION: RCM absorbs heat from storage units or heat exchanger below; heat absorbed by RCM radiated to atmosphere (particularly cool night sky); transparent cover minimizes convective heating of RCM radiator surface.

NOTES:
1] Direction of heat flow is through the module.
2] Shaded from solar irradiance during the day.

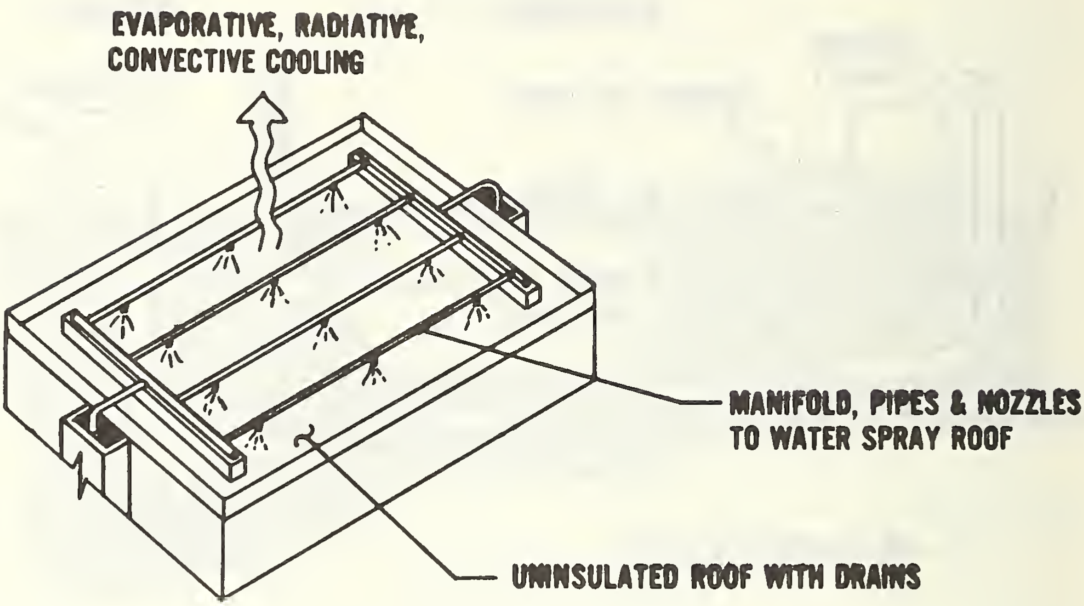
Figure 9. Ground coupling modular system (GCM)



FUNCTION: Space Cooling - below grade earth is a heat sink for air drawn from outdoors through pipes; misting cabinet enhances air cooling heat exchange; pipes pitched toward drywell to remove condensate.

NOTES:
1] Illustration from reference [38]
2] Fan assist air handler makes this a passive/hybrid system

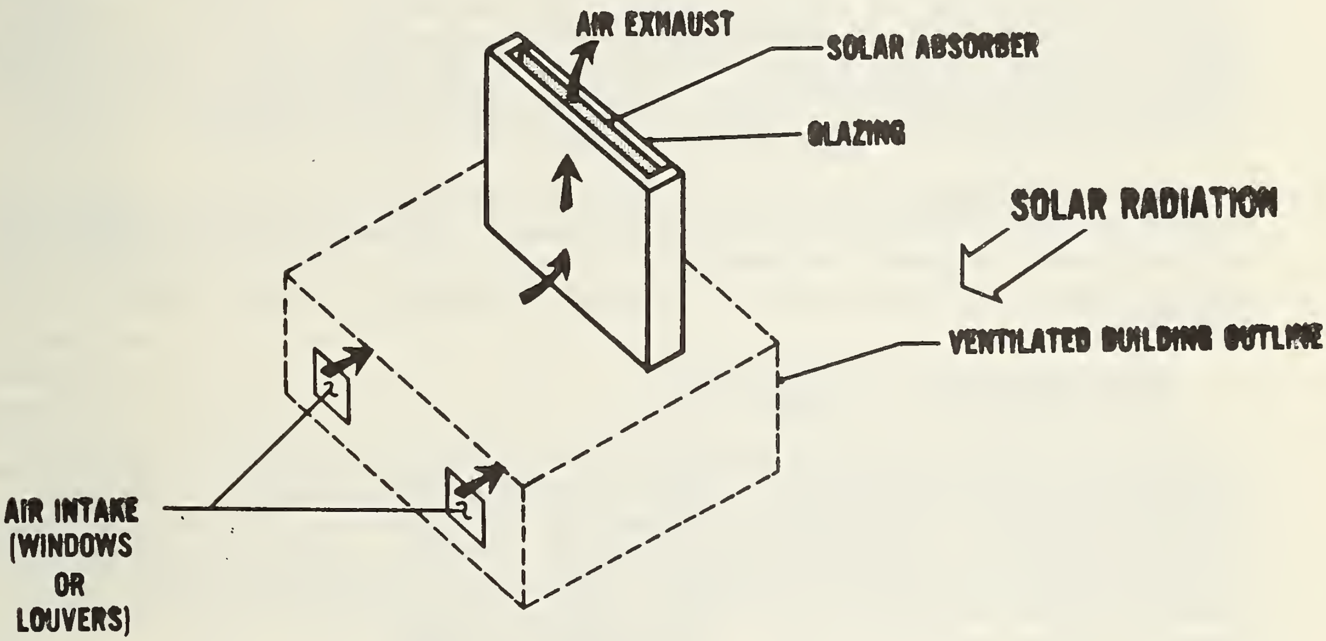
Figure 10a. Evaporative cooling module (EC/NVM)



FUNCTION: Space Cooling - water spray evaporatively cools roof; cooled roof absorbs heat from below by radiation, convection and/or a heat exchanger

NOTE: Pump and controls make this a passive/hybrid system

Figure 10b. Natural ventilation module (EC/NVM)



FUNCTION: Space Cooling - solar irradiance absorbed by chimney induces natural convective air flow through the building

NOTE: Concept illustration from information in reference [39]

3. REVIEW OF EXISTING THERMAL PERFORMANCE TEST PROCEDURES FOR APPLICABILITY IN TESTING PASSIVE SOLAR COMPONENTS

The purpose of this section is to provide an overview of existing standard and non-standard laboratory and field thermal performance test procedures for their potential application in testing passive solar components. Section 3.1 describes related consensus test procedures developed by technical organizations including ASHRAE and ASTM, voluntary test procedures of trade associations, new test procedures currently under development and experimental work documented in the technical literature but not presently adopted as test standards.

Section 3.2 provides a brief discussion of recent activities in the field testing of passive solar systems in test rooms in connection with the research and development programs for passive solar applications and describes the potential application of these efforts for standard testing of passive solar components.

3.1 LABORATORY-BASED TEST PROCEDURES

A review of existing laboratory-based test procedures for passive solar applications has been made for a range of product characterizations varying from measurement of thermophysical properties of materials to the determination of overall thermal performance of systems and components such as building envelope assemblies, solar collectors, solar domestic hot water systems and thermal storage assemblies. The ASTM consensus standard test procedures were identified from the Annual Book of ASTM Standards [18].

Table 2 includes a brief description of the applicable test article and the thermal characteristics measured in each test procedure. The symbols used to identify the thermal results in table 2 are described in table 3. Information for identifying commercial testing laboratories that perform the thermal performance tests listed in table 2, is presented in Appendix C of this report.

Examination of the existing procedures suggested that for reporting purposes, each test procedure could be distinguished according to test article description and according to thermal property or result obtained. In general, the thermal properties or results in the categories of heat and mass transfer and radiative transfer are obtained from steady-state test conditions, while those in the category of thermal storage are obtained from transient test conditions.

For each group of test articles listed in table 2, existing test procedures are assessed below for their applicability as standard thermal performance tests of passive solar components. The following considerations were included in the assessment:

(1) importance of the test result as a performance characteristic of a passive solar component,

(2) similarity between component installation in a test apparatus with a typical installation for an application of the component, and

(3) adequacy of the test conditions for characterizing thermal performance of a passive component over a representative range of operation.

3.1.1 Materials Thermal Properties Measurements

The numerous test procedures in table 2 for materials heat and mass transfer characteristics are distinguished by variations that must be considered for (1) physical configuration differences of material assemblies, (2) influence of the test sample orientation and installation on thermal performance (3) magnitude of the thermal result (i.e. thermal conductivity ranging from insulators to conductors), and (4) objectives of the test (absolute or comparative results). These considerations also apply for developing new test procedures for passive solar components.

Most of the materials thermophysical property test procedures listed in table 2 for heat and mass transfer and thermal storage characteristics, are not directly applicable for testing passive solar components. The passive solar components identified in section 2 are often non-homogeneous assemblies that either have configurations significantly different from the materials test specimens or if installed in the test apparatus as required by these procedures might not yield results representative of typical field installations of the passive solar components. However, property measurements for materials are useful to obtain necessary data for thermal modeling of passive solar components, especially if thermophysical property data are not available in handbooks or the available data show significant variation.

The test procedures listed in table 2 for materials under the category of radiative transfer properties, such as ASHRAE 74-73 and ASTM E 424-Method B, which measures solar-optical properties, and the UF-ASHRAE solar calorimeter which measures shading coefficient, are judged to be potentially useful as the basis for testing DGFS passive solar components. These tests, performed in the field under natural sunlight, will be discussed further in section 4 of this report.

3.1.2 Building Envelope Sections

The DGFS classification of passive solar components closely resembles the test articles applicable for the test procedures listed in table 2 under building envelope section test samples. All the procedures listed under this group of test samples for both laboratory testing for heat and mass transfer characteristics and field testing for radiative thermal characteristics will be discussed in section 4 for their applicability in testing DGFS passive components. Note that in table 2 for these test samples there are no procedures listed under thermal storage characteristics because interest in the past has focused on steady-state test results for test articles without significant integral thermal storage.

3.1.3 Solar Collectors

The ASHRAE 93-77 and German Bundesverband Solarenergie (BSE) test procedures, listed in table 2, have been developed for measuring solar collector efficiency under steady-state conditions with constant-rate, forced-convection fluid flow. However, it is apparent that these procedures could be used as the basis for developing test procedures for solar collectors in passive solar applications under steady-state boundary conditions with a thermosyphon (free convection) variable rate fluid flow through the collector. One difference between these procedures and the others previously identified in table 2, is that the tests for solar collector efficiency provide a standard methodology to measure more than one type of thermal characteristic such as heat loss (F_RU_L or Q_L) and solar-optical characteristics ($F_R(\tau\alpha)_e$ or η_o). In the ASHRAE 93-77 procedure, tests for heat loss and solar optical characteristics are performed outdoors under natural environmental conditions, while in the BSE procedure heat loss is measured indoors and solar optical efficiency is measured outdoors. Reference [19] discusses a comparison of test results using both of these procedures. It is possible that future refinement in solar collector test procedures will result in increased testing indoors.

3.1.4 Solar Domestic Hot Water Systems

The ASHRAE Standard 95P is the procedure for indoor thermal performance testing of solar domestic water heating systems, and includes conditions for testing passive solar thermosyphon hot water systems. The requirements for testing a passive solar thermosyphon hot water system include the use of a solar simulator to irradiate the solar collector and implementation of a time-dependent water draw-rate from storage. It is judged that if any refinements are needed for testing passive solar thermosyphon hot water systems, or if specific procedures are needed for testing passive solar batch hot water systems, these procedures could be incorporated as revisions to ASHRAE Standard 95.

3.1.5 Thermal Storage Assemblies

The ASHRAE 94-77 test procedure has been developed for testing non-solar irradiated storage assemblies of water tanks, pebble beds and phase-change materials under conditions of forced convection flow of the heat transfer fluid. This test procedure is judged suitable for performance testing of underslab thermal storage in passive solar applications provided the storage container is thermally isolated from the building and ground. However, because many passive solar components such as solar storage walls and combined solar fenestration-storage assemblies receive thermal energy by direct solar irradiation, and discharge stored thermal energy by free convection and radiation, the ASHRAE 94-77 test procedure is deemed unsuitable for measurement of thermal performance of these passive solar storage components.

3.2 FIELD TEST METHODS FOR PASSIVE SOLAR SYSTEMS

As part of the research and development activities for passive solar heating systems, extensive field-based testing programs have been conducted at several national laboratories and at a number of universities. The majority of these system tests have been performed with the interior temperature essentially uncontrolled. The passive test room program initiated at the Los Alamos Scientific Laboratory (LASL) [20], exemplifies much of the thermal testing performed for passive solar systems to date. In these testing procedures, a number of passive solar heating system configurations are tested in small outdoor test rooms or cells using the naturally occurring outdoor weather conditions and with the test room air temperature allowed to vary to an equilibrium level such that the net thermal energy gain from the passive system to the room air is equal to the net thermal energy loss from the room air through the walls of the test cell.

These testing programs have yielded significant information on the operating principles and the relative thermal performance of alternative system configurations in side-by-side testing arrangements. Frequently, the results of the test room data for the more promising passive solar system configurations have been generalized by developing analytical models or thermal networks for the configuration and demonstrating that the thermal models predict the same test room air temperatures as measured in test. Computer simulations are then performed, using the validated thermal models for other climatic regions and operating modes, to predict long-term thermal performance for larger passive systems than those of the test rooms.

However, utilization of such test rooms with uncontrolled indoor air temperature is not recommended for standard testing of passive solar components, because of the high degree of thermal interaction that can occur between the test room and passive test component. In the uncontrolled test rooms, the room air temperature is sensitive to such test room characteristics as insulation thickness, surface area and thermal mass. Uncontrolled air temperature in the test room tends to modify temperature-dependent heat transfer mechanisms such as free convection or infrared radiative transfer that normally occur. It appears that the more appropriate thermal boundary condition for standard testing of passive solar components would be to establish fixed conditions of indoor air temperature and room surface temperature, and to accurately measure the rate of heat transfer that occurs between the outside and the inside, through the passive solar component. Although this procedure represents an idealization of the actual thermal boundary conditions occurring in a building, the measured heat transfer rates are supportive of energy calculations because the thermal energy transfer through a passive solar component would displace an equal amount of fossil energy, provided the building load is capable of using that energy. Thermal energy transfer rate is judged to be a better measure of thermal performance than air temperature in a test cell.

Recommendations in the remaining sections of this report reflect the philosophy that calorimetric testing of passive solar components in controlled laboratory conditions is the most appropriate method for testing these products. However, significant efforts are required to develop the specific testing procedures and facilities, and most important, the interpretation and the application of the test results.

TABLE 2

EXISTING TEST PROCEDURES FOR THERMAL CHARACTERISTICS OF MATERIALS, COMPONENTS, AND SYSTEMS

	MEASURED THERMAL PROPERTIES								
	A. Heat and Mass Transfer			B. Radiative Transfer			C. Thermal Storage		
Test Article	Procedure	Property[5]	Test Specimen	Procedure	Property[5]	Test Specimen	Procedure	Property[5]	Test Specimen
1. Materials ° insulation ° brick ° plastics, rubber & elastomers ° conductors ° liquids ° glazings ° absorbing surfaces	ASTM C177	k, R	homogeneous insulation & plastics, rubber, elastomers	ASHRAE 74-73	$\tau_s(\Theta)$, $\alpha_s(\Theta)$	a) glazing - rigid, semi-rigid or film b) reflector or absorber minimum size 24" x 24"	ASTM C351	C_p	insulation
							ASTM D2766	C_p	liquids, solids
							ASTM E457	q_c	solids (large samples)
	ASTM C182	k	insulating firebrick	ASTM E424 Method A Method B	 τ_s, ρ_s τ_s	size dependent on instrument rigid, semi-rigid or film, minimum size 24" x 24"			
	ASTM C201	k	refractories	ASTM E434	ϵ_{th}, α_s/ϵ_{th}	rigid disk			
	ASTM C202	k	refractory brick	ASTM E408	ϵ_{tn}	coatings, finishes			
	ASTM C335	k, R	pipe insulation	ASTM E445	ϵ_{tn}	coatings, finishes			
	ASTM C408	k	ceramics & metals	UF-ASHRAE[1] Solar Calorimeter	SC	translucent fenestration materials			
	ASTM C518	k, R	insulation & plastics, rubber, elastomers						
	ASTM C653	R	insulation batts & blankets						
	ASTM C687	R	loose fill insulation						
	ASTM C691	R, U_o	non-homogeneous pipe insulation						
	ASTM C745	q_o	evacuated multi-layer insulations						
	ASTM C855	R	roof insulation						
	ASTM D1518	U_o	fabrics, battings						
	ASTM C2717	k	liquids						

TABLE 2 (Continued)

EXISTING TEST PROCEDURES FOR THERMAL CHARACTERIZATION OF MATERIALS, COMPONENTS, AND SYSTEMS

	MEASURED THERMAL PROPERTIES								
	A. Heat and Mass Transfer			B. Radiative Transfer			C. Thermal Storage		
Test Samples	Procedure	Property[5]	Test Specimen	Procedure	Property[5]	Test Specimen	Procedure	Property[5]	Test Specimen
2. Building Envelope Sections	ASTM C236[2]	R, U_o	walls, windows, etc.	ASHRAE 74-73	$\tau_s(\Theta)$, $\alpha_s(\Theta)$	translucent assembly			
° walls ° windows ° shading devices	ASTM Calibrated[3] Hot Box	R, U_o	walls, windows, etc.	ASTM E424 Method B	τ_s	translucent assembly			
	AAMA 1502.6	U_o	windows, sliding glass doors	UF-ASHRAE[1] Solar Calorimeter	SC				
	ASTM E283	Q	windows						
3. Solar Collectors (forced flow)	ASHRAE 93-77[4]	$F_R U_L$	solar collectors	ASHRAE 93-77	$F_R(\tau\alpha)_e$[4]	solar collectors			
	BSE	Q_L	solar collectors	BSE	η_o	solar collectors			
4. Solar Domestic Hot Water Systems (forced flow & thermosyphon)	ASHRAE 95 P	Q_L	solar water heating system	(From ASHRAE 93-77)			ASHRAE 95 P	Q_s, e_s	solar water heating system
5. Thermal Storage Assemblies (forced flows, no solar irradiance on the assemblies	ASHRAE 94-77	L	rock bed assembly, phase change assembly, water tank				ASHRAE 94-77	C_c, C_d	rock bed assembly, phase change assembly, water tank

Note: 1 experimental apparatus at Univ. of Florida not presently incorporated into a consensus standard.

2 a future revision will include a procedure to measure U_o in the presence of simulated wind.

3 presently being drafted by committee

4 determined from ASHRAE 93-77 efficiency curve procedure

5 see table 3 for nomenclature.

TABLE 3

NOMENCLATURE

C_c	performance coefficient for heat storage determined in accordance with ASHRAE Standard 94-77
C_d	performance coefficient for heat removal determined in accordance with ASHRAE Standard 94-77
C_p	specific heat ($J\ kg^{-1}\ K^{-1}$)
e_s	fractional energy savings determined in accordance with ASHRAE Standard 95P
$F_R U_L$	slope of solar collector efficiency curve determined in accordance with ASHRAE Standard 93-77
$F_R(\tau\alpha)_e$	intercept of the solar collector efficiency curve determined in accordance with ASHRAE Standard 93-77
k	thermal conductivity, a property of a homogeneous material ($Wm^{-1}\ K^{-1}$)
L	heat loss rate determined in accordance with ASHRAE Standard 94-77 ($W°C^{-1}$)
Q	air leakage rate determined in accordance with ASTM Standard E 283 ($m^3 s^{-1}$)
Q_L	daily system hot water load determined in accordance with ASHRAE Standard 95P (kJ)
Q_s	daily net energy output from solar collector and storage elements of the hot water system determined in accordance with ASHRAE Standard 95P (kJ)
q_c	heat transfer rate imposed on test sample determined in accordance with ASTM Standard E 457 (W)
q_o	heat flux through evacuated insulations determined in accordance with ASTM Standard C 745 (Wm^{-2})
R	thermal resistance of a test article based on surface-to-surface temperature difference across the sample ($K\ m^2\ W^{-1}$)
SC	shading coefficient for a fenestration component, determined in accordance with the procedures in reference [28], the ratio of the sum of the solar transmission and fraction of absorbed solar irradiance convected and radiated indoors to the sum for a double strength 1/8" thick single glazing (dimensionless)

TABLE 3 (Continued)

NOMENCLATURE

U_o	overall heat transmission coefficient of a test article based on air-to-air temperature difference across the sample (Wm^{-2} K^{-1})
α_s	solar absorptance
$\alpha_s/\varepsilon_{th}$	ratio of solar absorptance to total hemispherical emmittance determined in accordance with ASTM Standard E 434
ρ_s	solar reflectance
τ_s	solar transmittance
Θ	angle of incidence between the direct solar beam and the normal to test article surface
ε_{tn}	total normal emittance
η_o	solar optical efficiency determined in accordance with the BSE procedure described in reference [19]

4. THERMAL PERFORMANCE TESTING PROCEDURES FOR SELECTED PASSIVE SOLAR COMPONENTS

This section discusses the application of existing test methods and the features of revised or new methods for thermal performance testing of two of the passive solar components judged to be in the most advanced stages of development. Section 4.1 discusses steady-state testing concepts recommended for Direct Gain Fenestration Systems (DGFS), including windows, and window insulating and shading devices. Transient testing concepts are discussed in section 4.2 for Collector/Storage Wall Module (CSWM) types of passive components having integral thermal storage used in conjunction with glazed fenestrations.

4.1 STEADY STATE TESTING FOR DIRECT GAIN FENESTRATION SYSTEMS

A comprehensive evaluation of the transfer of thermal energy through a DGFS would consider the simultaneous effects of radiative transfer due to solar irradiation of the exterior surface, heat transfer due to inside-to-outside air temperature difference, and mass transfer (air leakage) due to inside-to-outside pressure difference. Moisture transfer due to water vapor pressure differential is not considered to be a significant thermal energy transfer mechanism in DGFS products and will not be considered.[1] Current evaluation procedures assume that radiative, heat, and mass transfer processes are parallel mechanisms, and that each process can be considered separately and the results added. A primary area of needed research is to determine the extent of interaction between the thermal energy transfer mechanisms as they occur in passive solar applications and to determine whether results from synergistic effects correspond to results obtained from current evaluation procedures.

According to ASHRAE [21], the rate at which solar and thermal energy are transferred in a DGFS consists of three distinct contributions: (1) the directly transmitted fraction of the external solar irradiance, (2) the inward-flowing fraction of thermal energy resulting from absorption of solar energy in each glazing layer, and (3) the thermal energy transfer due to air temperature difference. The first two heat transfer contributions are due to solar irradiation, and they are usually combined into a single characteristic called the Shading Coefficient (SC).[2] The third heat flow term, based on indoor-to-outdoor air temperature difference, is a characteristic called the Overall Heat Transfer Coefficient (U_o), which is known also as the Overall Thermal Transmittance or the Overall Conductance.

The transfer of mass through a DGFS occurs primarily due to pressure difference caused by wind, which results in movement of air through the unsealed cracks

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1 The effects of moisture condensation on the long-term durability and the potential degradation in thermal performance of DGFS are recognized but not considered within the scope of this report.

2 ASHRAE defines Shading Coefficient to be the ratio of the solar heat gain through the fenestration system to the solar heat gain through a reference fenestration system, which is taken to be a single sheet of double-strength clear plate glass.

in the product, although experiments show that temperature difference also has an effect on the air leakage rate. Based on the assumption that the heat and mass transfer characteristics are essentially independent, the thermal performance of a DGFS can be measured using current available standard test procedures to measure (1) the overall heat transfer coefficient (U_o), (2) the Shading Coefficient (SC) and (3) the infiltration coefficient (Q). The validity of such an assumption is addressed in the proposed research activities described in section 5. A brief description of existing test procedures and test facilities is presented in the following section, followed by a discussion of the application of these test procedures for DGFS products.

4.1.1 Measurement of Overall Heat Transfer Coefficient U_o

Several test procedures are available for measurement of the overall heat transfer coefficient U_o, each differing primarily in the construction of the test apparatus and in the provisions for simulating wind at the outside surface of the test article. Figures 11, 12 and 13, respectively, illustrate the test apparatus configurations for the ASTM C236 Guarded Hot Box procedure [22], the ASTM Calibrated Hot Box procedure[1], and the AAMA 1502.6 procedure [23]. In each of these procedures, the test sample is installed in an opening in the wall between hot and cold environment chambers, each of which is maintained at constant temperatures, and the steady-state rate of heat transfer through the test sample is measured. The overall heat transfer coefficient U_o is calculated as the ratio of the measured heat transfer rate per unit area to the temperature difference between the air space on each side of the test sample.

A distinguishing feature between the guarded-hot-box and the calibrated-hot-box procedures is the control of heat flow from the metering volume. In the guarded-hot-box apparatus (figure 11), a temperature-controlled chamber surrounds five sides of the metering chamber to minimize heat transfer between the metering volume and the external environment. In a calibrated-hot-box apparatus (figures 12 and 13), a substantial thickness of insulation is used to minimize this heat flow path, and the rate at which heat transfer occurs is measured by calibration.

The air flow adjacent to the test article is another distinguishing feature of these test procedures. In the ASTM C236 procedure, air is circulated at a low velocity on each side of the test article only to ensure uniform temperatures in each chamber but not to promote forced convective heat transfer at the test article surfaces. In the revision being considered for the ASTM Calibrated Hot box procedure, forced convection heat transfer at the exterior surfaces is an optional feature that is implemented by using a fan to provide wind air motion parallel to the test sample. The AAMA 1502.6 test procedure takes a different approach in defining the outdoor conditions for testing aluminum frame windows and sliding glass doors, and is based on the rationale described in reference [24]. In this procedure, the simulated wind is directed perpendicular to the sample exterior surface, and the air velocity for testing is determined in a calbration test on a flat glass panel to produce exterior surface heat transfer coefficients equivalent to the ASHRAE winter design value for a 6.7 m/s (15 mph) wind.

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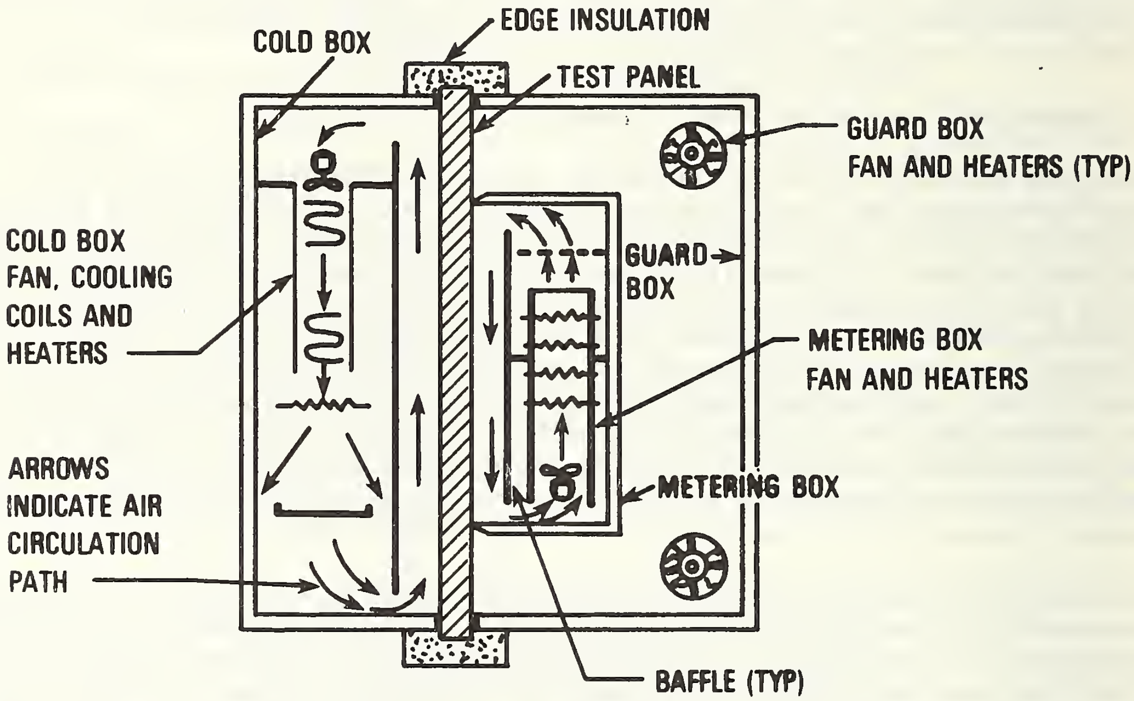
[1] New procedure in draft form

Figure 11. General arrangement of equipment in guarded hot box apparatus for the ASTM C236 standard thermal transmission test procedure of building envelope assemblies [22]



Elevation View

Figure 12. Conceptual general arrangement of equipment in a calibrated hot box apparatus from a draft of a proposed ASTM standard thermal transmission test procedure for building envelope assemblies

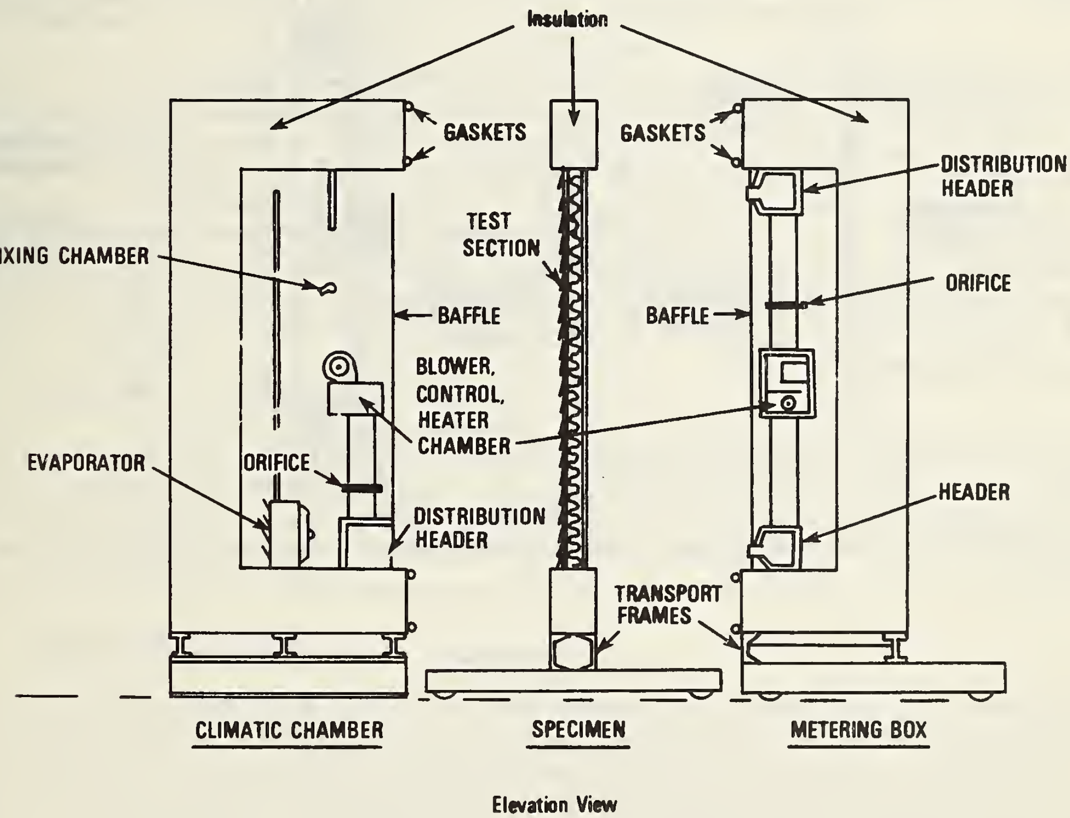
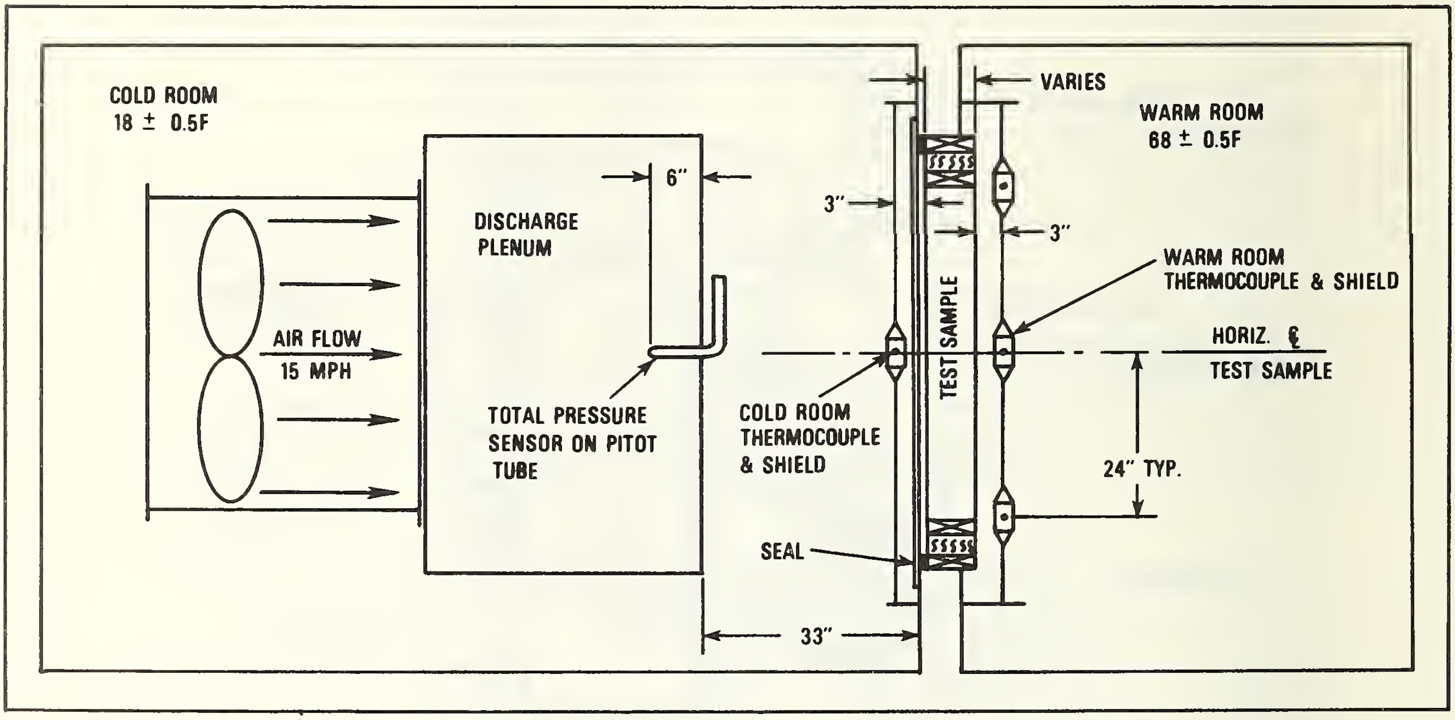


Figure 13. General arrangement of equipment in calibrated thermal chamber for AAMA 1502.6 thermal performance tests of insulating windows and sliding glass doors [23]



Elevation View

Although the current ASTM C236 procedure is essentially a test to measure surface-to-surface thermal conductance, the proposed modifications to ASTM C236 and the new ASTM Calibrated Hot Box procedures being developed will provide measurements of air-to-air thermal conductance. However, because some window assemblies are not uniformly flat, reference [24] suggests the parallel air flow over a window in the ASTM procedures could possibly affect the heat flow measurements in a non-reproducible manner. Because of this, reference [24] states that the measured U_o in the test may not be representative of what exists in actual service. Therefore, air flow perpendicular to the window being tested is preferred by advocates of the AAMA 1502.6 procedure, who believe this is a more uniform and realistic influence on the window thermal transmission, as well as a means of establishing a consistent exterior surface boundary conditions.

On the other hand, earlier experimental work [25] suggested that for all practical purposes, surface coefficients obtained for air flow parallel to a flat surface might be used without any correction for direction of wind. Because of the differences identified above for the measurement of overall heat transfer coefficient in DGFS products, it is recommended that experimental efforts be undertaken to obtain a clearer understanding of the significance of the differences in these tests and to identify the appropriate test procedures for specific DGFS products. Discussion of the research and evaluation tasks proposed for U_o measurements on DGFS projects is described in section 5.

4.1.2 Measurement of Shading Coefficient

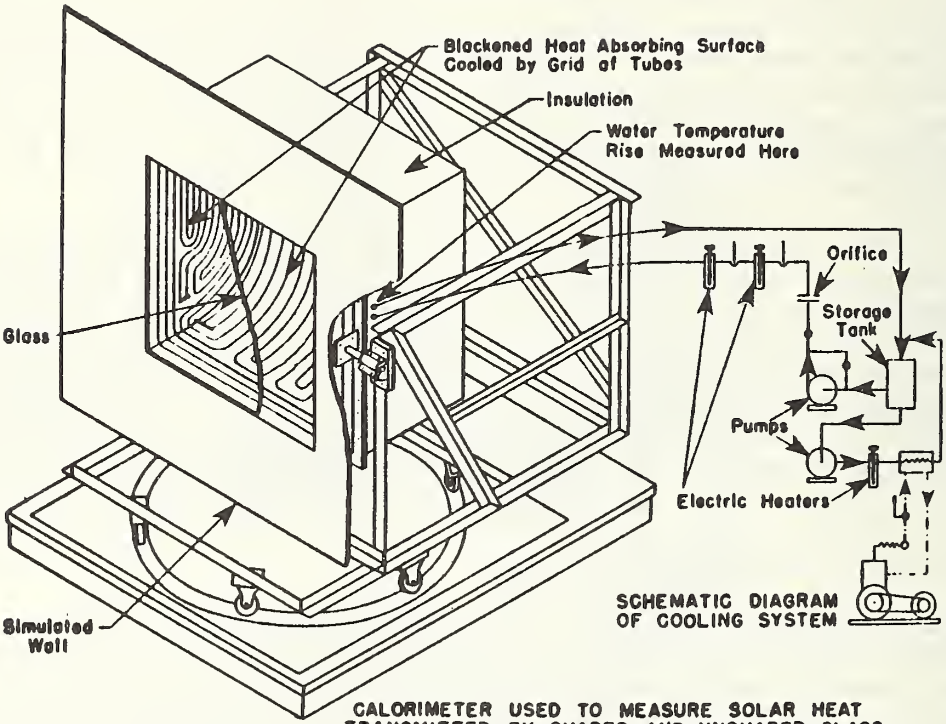
Two alternate techniques to evaluate Shading Coefficient for a DGFS are possible: the direct measurement method using a calorimeter; and the indirect calculation method using measured solar optical properties for each glazing material along with the calculation procedures described in the ASHRAE Handbook of Fundamentals [26].

4.1.2.1 Calorimetric Method

Extensive experimental work under the sponsorship of ASHRAE and its predecessor society was performed using an outdoor solar calorimeter to directly measure Shading Coefficient for various fenestration systems including: single and multiple glazings with both clear and heat-absorbing glass, glazings with interior roller shades or draperies, and glazing with either exterior, interior or between-glass shading devices [26-28]. The primary objective of these experiments was to provide data on maximum solar heat gains through each fenestration at the summer design condition in order to calculate the required capacity of the mechanical cooling system for the building.

The principal apparatus developed for direct measurement of Shading Coefficient is the University of Florida (UF)-ASHRAE outdoor solar calorimeter [27] illustrated in figure 14. The window frame for this apparatus can accommodate glazings, glass block and interior shading devices. The apparatus can be rotated and tilted to measure directional effects of solar irradiation on solar gain through a test fenestration. The geometry and coating on the interior surfaces of the calorimeter have been designed to absorb most of the solar energy transmitted through the glazing, and thereby minimize reflected energy.

Figure 14. UF-ASHRAE solar calorimeter [27]



Batt and blanket insulation covers the calorimeter shell to limit heat loss. A water or water-glycol cooling loop with a freon-cooled heat exchanger and electric heaters are used to control the air temperature within the calorimeter. The heat gain or loss from in the calorimeter as determined from the temperature rise of the water or water-glycol liquid and the liquid flow rate is a direct measure of the rate of solar energy transfer through the fenestration. An externally mounted pyrheliometer is used to measure incident solar radiation.

Although the UF-ASHRAE Calorimeter appears to be suited for measurement of Shading Coefficient for DGFS products, sample size limitations, uncertainties in the transferability of measurements performed in Florida to other climatic regions and the availability of this research apparatus for testing commercial products, indicate that the calorimetric measurement of Shading Coefficient may not be suitable for the anticipated testing needs of passive solar products. Alternative procedures would be to measure the solar-optical properties of each glazing layer and to use the theoretical equations of reference [26] to perform a calculation of Shading Coefficient.

4.1.2.2 Solar-Optical Property Method

Standard testing procedures for measurement of the solar-optical properties of each layer of fenestration are currently available as ASTM E424 [29] or ASHRAE 74-73 [30]. Shading Coefficient can be calculated using the technique described by ASHRAE [26] for simple DGFS products consisting of multiple, homogeneous layers of glass or plastic film, when the solar optical properties of each layer are known and when the combined convective and radiative heat transfer coefficient can be estimated at each surface. The ASTM E424-Method B and the ASHRAE 74-73 procedures measure the solar-optical properties of translucent and transparent sheets and composite assemblies using natural solar radiation as a source and a pyranometer or other solar sensor as a detector. The ASTM E424-Method A procedure is a laboratory test method on small disk or sheet samples for solar optical properties. A spectrophotometer and integrating sphere produce spectral data which is integrated over the solar spectrum to obtain the desired solar-optical properties. The ASHRAE 74-73 test procedure describes the measurement of solar transmittance and reflectance at various incident angles and the measurement of the solar optical properties related to the diffuse component of solar irradiation. The ASTM E424-Method B test procedure describes the measurement of solar transmittance at near normal incidence angles. For testing some passive product assemblies, the additional data from the ASHRAE 74-73 procedure may be required to characterize product performance variation with solar irradiance level and direction.

For testing DGFS products having non-uniform transparent surfaces, revisions to the existing solar optical properties test procedures are required. For example, applications of these test procedures to passive solar components having non-uniform surfaces would require movement of the solar sensor or the installation of several sensors in order to obtain average values for the solar-optical properties.

Because of the variations in the procedures to measure or calculate shading coefficient, it is obvious that choice of a procedure to use for any DGFS product depends on the specific design of the particular product. Discussion of several research and evaluation tasks to clarify shading coefficient testing procedures for passive solar applications are described in section 5.

4.1.3 Measurement of Infiltration Coefficient Q

A number of different test procedures are currently available for field measurement of infiltration in buildings; however, the currently available standard test procedure for laboratory measurement of air infiltration through windows and doors is ASTM E 283 [31]. Figure 15 illustrates the test apparatus used to measure the rate of infiltration. In this test procedure, the test specimen is subjected to a prescribed pressure difference and the volumetric rate of air leakage is measured and corrected to standard conditions of pressure, temperature and density. The air leakage Q is reported to be the volume of air flowing per unit time through a closed and locked specimen either per unit of specimen area or per unit of crack length.

A recent study of field-measured infiltration for windows showed that significantly greater leakage rates were measured in field installations than for manufacturer-certified ratings based on laboratory measurements [32]. This was apparently due to specific installation practices observed.

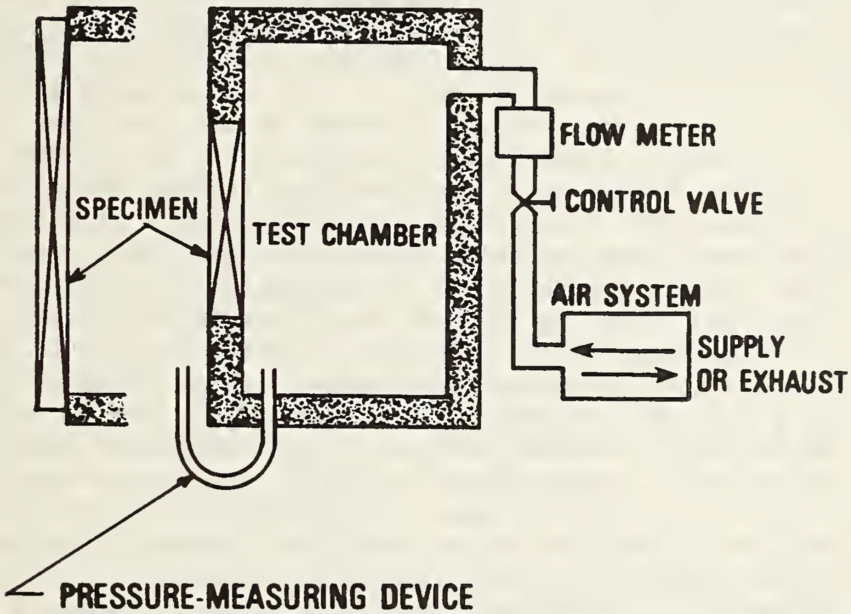
Because of this lack of correlation of results between laboratory and field measurements using ASTM E283, results from the laboratory tests may not be useful for characterizing infiltration heat gain or heat loss performance of DGFS components. However, the ASTM E283 procedure is recommended as a test procedure applicable to DGFS that contain glazings because ASTM E283: (1) can be performed in both a laboratory and in the field, which is desirable for studying installation quality, component durability, etc., and (2) can be used as a quality control test based on allowable air leakage rates.

The ASTM E283 procedure might be extended or used as the basis for a new procedure for testing DGFS movable insulation components. A special glazing assembly with known air leakage rate would be tested with the movable insulation component in place to determine the affect of the component on reducing the air leakage. However, before this approach can be considered as a viable one, careful consideration must be given on how and where to introduce the specified air leakage through the glazing assembly since this could have a strong influence on how effective a movable insulation component will be in reducing air leakage. If such a procedure could be developed it would be only useful as a qualitative one.

4.1.4 Recommended Interim Testing Program for DGFS Products

As described previously, a number of thermal performance test procedures currently exist that can be applied to testing DGFS types of passive solar components. Based on the variations that exist in these test procedures, and the lack of thermal data obtained from carefully controlled field measurement programs that correlate with thermal data from laboratory based test procedures, definitive recommendations are not possible. If the primary objective of testing passive solar components is to obtain performance data useful for

Figure 15. General arrangement of apparatus for ASTM E283 standard air leakage test through exterior windows, curtain walls and doors [31]



calculation of building thermal load and for evaluation of seasonal energy consumption, it is possible that separate measurements of overall heat transfer coefficient U_o at the winter-night design condition, infiltration rate Q at a single prescribed pressure-difference condition, and shading coefficient at the summer design condition, may not be sufficient for passive solar buildings having large surface areas of DGFS type products installed in their south facade.

Despite these reservations, application of the current testing procedures to DGFS products will provide useful information for product selection, for preliminary system sizing and for future correlation with field measurements; therefore, on an interim basis, the recommended type of thermal testing procedures for DGFS products is shown in table 4. The recommended test conditions for application of wind in the testing is based on the fact that U_o for single-glazed windows is extremely sensitive to variations in the outdoor surface conductance. Computer modelling of heat transfer through a high performance multiple-glazed window with a heat-mirror film revealed a sensitivity in thermal performance to the variations in outdoor surface conductance resulting from variations in wind speed. Therefore it is recommended that U_o measurements be performed (if possible) using one of the newer testing procedures in which wind is imposed as an outdoor boundary condition. Furthermore, it is recommended that data be obtained for both winter and summer design conditions and for each relevant operating mode of the DGFS product. When the passive solar product is a movable insulating or shading device, it is recommended that the product be tested in tandem with a single sheet of fixed, double-strength, clear glazing, either glass or acrylic. In such cases, infiltration testing will not produce meaningful results and therefore is not required. However, manufacturers of these devices might consider separate infiltration testing of their products installed in tandem with conventional movable windows, to measure the potential reduction in air infiltration rate with the product installed.

4.2 TRANSIENT TESTING FOR STORAGE WALL MODULES

Based on the review of existing test procedures, it is concluded that there are currently no acceptable methods of test directly suitable for thermal performance evaluation of passive solar components having integral thermal storage. The primary reason for this is that most of the standard test methods for thermal performance require the existence of steady-state conditions. Due to the dynamic variation in solar irradiance and ambient temperature, thermal energy storage within a passive solar product will have a major effect on its thermal performance. Thus, dynamic climatic boundary conditions are deemed essential for evaluating the thermal performance of such products. Due to the need for such boundary conditions and the type of storage components to be tested, the ASHRAE 94-77 test procedure [7] does not apply. An effort is under way in ASTM Committee C16.30 to develop laboratory-based dynamic test cycles in environmental chambers useful for characterizing the effects of "thermal mass" in building envelopes. However, these procedures are being developed primarily to measure thermal energy transfer in opaque building envelope systems due to dynamic temperature, humidity and wind conditions; therefore, these procedures will not be appropriate for testing most passive solar components. The reason for this is that in conventional building envelopes, absorption of solar irradiation occurs at the outside surface of the envelope system and this effect

TABLE 4

INTERIM RECOMMENDED THERMAL TESTING FOR DGFS PRODUCTS

	Thermal Characteristic		
DGFS Product Type	Overall Conductance[2]	Shading Coefficient[3]	Infiltration Rate
Multiple Glazed Windows	●	●	●
Movable Insulation Devices[1]			
- Winter Day	●	●	●[4]
- Winter Night	●		●[4]
Movable Shading Devices[1]			
- Winter Day	●	●	●[4]
- Winter Night	●		●[4]
- Summer Day	●	●	
Air Windows[5]	●	●	●[4]

[1] Product installed in tandem with fixed single sheet of double-strength glass or acrylic glazing.

[2] U_o test with simulated wind condition 15 mph for winter, 7.5 mph for summer condition.

[3] Based on air-mass 1.5 average winter or summer condition.

[4] Considered optional, if installed with fixed glazing.

[5] Testing recommended for each distinct operating mode at maximum air flow rate.

can be evaluated by a "sol-air temperature" test condition. However, "sol-air temperature" cycling in a hot box will not reproduce the thermal boundary conditions that passive solar components with a transparent exterior surface experience in use, since solar energy absorption occurs at interior surfaces in these components.

At present it is not clear what thermal test result can be obtained from a practical test procedure that best quantifies the thermal characteristics of a passive component with integral thermal storage. Such results might be expressed as time constants, response coefficients, efficiency characteristics, etc. In an effort to resolve this issue, three alternatives for testing passive components with integral thermal storage such as storage wall modules are discussed below.

4.2.1 Solar Simulation in an Environmental Chamber

A potential method of testing passive solar components having integral thermal storage would be to use an array of lamps for solar simulation in an environmental test chamber. A concept for testing passive solar storage walls using solar simulation in a cyclic test procedure was previously reported [33]. However, for full-scale testing of passive products, only a few test facilities have the capability to simulate the spectrum, irradiance levels and beam dimensions of the sun, and the capability to dynamically vary the solar irradiance level and ambient temperature [34] in a diurnal and seasonal fashion. Although solar simulation testing in an environmental chamber would provide the maximum capability for performance testing of passive solar components in standard test procedures, this method needs more development to support current Department of Energy passive solar programs and the solar industry.

Important features of a solar simulator and environmental chambers for testing passive solar components with integral thermal storage would include the simulation of typical and extreme diurnal cycles of ambient temperatures and solar irradiance for both winter and summer conditions; and the ability to orient the test article as normally installed, such as in a vertical, horizontal or tilted position, to assure that any free-convection processes that occur are simulated in the laboratory test.

4.2.2 Thin-Film Resistance Heaters in an Environmental Chamber

A practical near-term alternative to dynamic solar simulation testing in an environmental chamber would involve the use of thin-film electric resistance heaters to simulate the absorbed solar flux. Resistance heating techniques have been used in the aerospace industry for many years for thermal testing of satellites in vacuum chambers [35], and the technology appears to be readily transferable to passive solar testing applications. In this concept, a transient solar-optical analysis is performed to estimate hourly values of solar flux absorbed by each solar energy-absorbing surface. Thin-film heaters having appropriate values of emittance are bonded to those surfaces, and the heaters are energized in tests at power levels to match the diurnal absorbed solar flux. Ambient temperature in the ambient chamber can be varied to match the selected diurnal air temperature cycle. The air temperature in the calibrated or guarded indoor metering box is set at room conditions and the net thermal energy transferred into or out of the metering box is measured. A number of different diurnal cycles of solar irradiance and ambient temperature are needed to characterize the required testing conditions for the heating season in each specific climate considered for marketing. Figure 16 is a conceptual illustration of a passive component in an environmental test facility for such a test.

4.2.3 Outdoor Testing with a Calorimeter Metering Box

A third alternative to thermal performance testing involves installing the test article in an insulating frame and exposing the interior surface to a constant temperature metering chamber (calorimeter), while the exterior surface is exposed to the natural outdoor environment of sun, wind and ambient temperature. An important distinction is made between this procedure and other test methods in which a passive solar system is installed in an a test room and the interior temperature allowed to "float" [20]. Thermal test results obtained from these procedures, while quite useful for validating thermal models or for a comparative rating of alternate products or design applications, may not provide all the information for product evaluation necessary for commercialization, because the resulting inside test temperatures are not representative of the inside temperatures which occur in actual use.

The basic difficulties with outdoor testing in a calorimeter include the following:

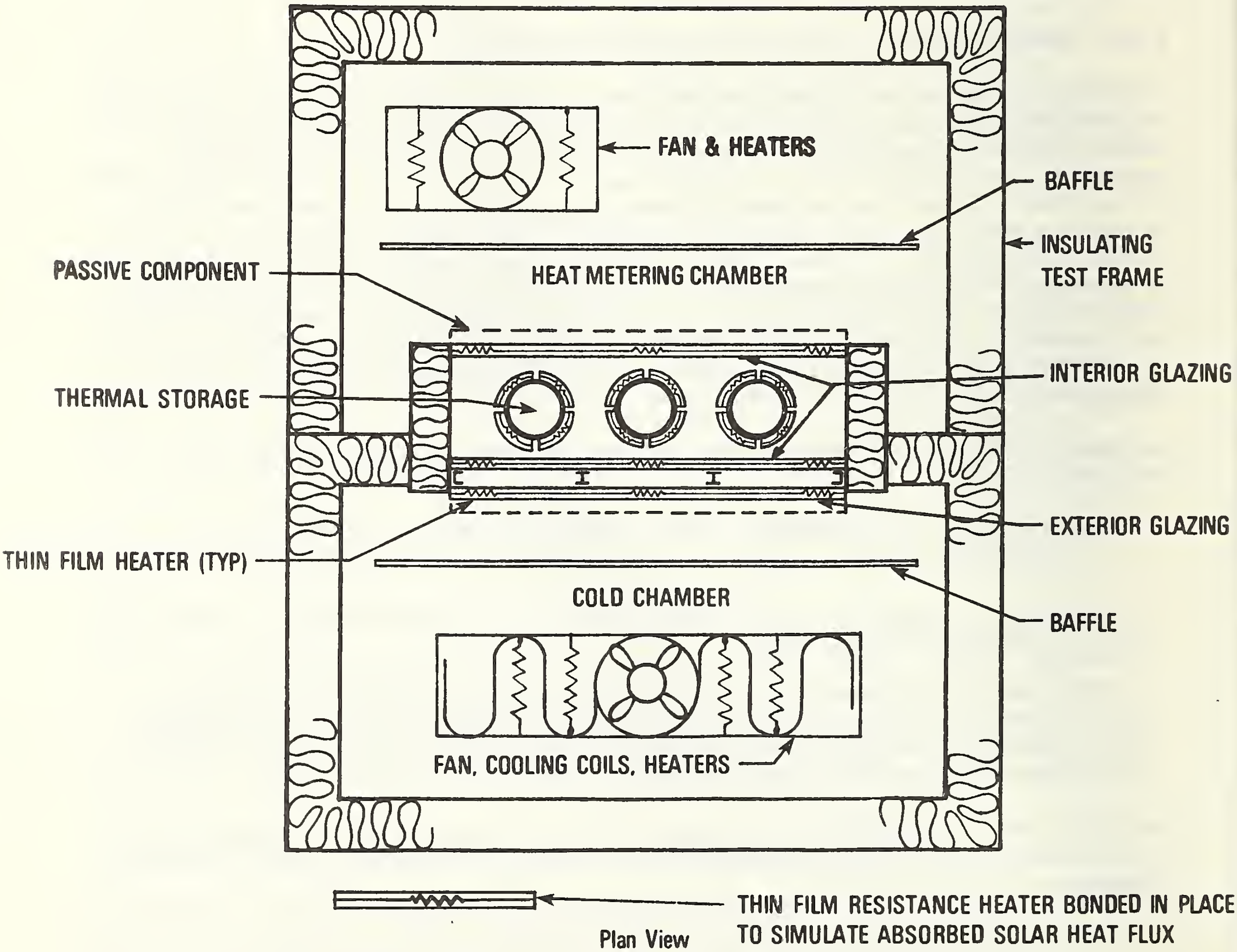
1. There are no independent test laboratories known to have such a facility,

2. Testing schedules and therefore costs can be significantly impacted by the weather conditions,

3. A method of correlating the measured thermal performance with the climatic variables and system operating modes needs to be developed in order to apply the test results from the particular microclimate where measured to other locations and time of year.

The third issue is addressed in a paper [36] which describes analytical studies of potential outdoor test procedures for a modular Trombe-wall type of passive component.

Figure 16. Conceptual general arrangement of an indoor test facility for thermal performance testing of a passive component having direct gain and integral thermal storage features



5. PROGRAM TO DEVELOP LABORATORY BASED THERMAL TEST PROCEDURES FOR PASSIVE SOLAR COMPONENTS

This section outlines the basic approach and suggested research and evaluation tasks to develop laboratory-based thermal test procedures for both Direct Gain Fenestration Systems (DGFS) and Collector Storage Wall Module (CSWM) types of passive solar components. When the suggested research and evaluation tasks for a passive solar component are completed, a draft test procedure will be submitted to a national voluntary standards committee for review and consideration as a national consensus standard. A preliminary proposed schedule for the development of draft test procedures for the ten passive component classifications described in section 2 is also outlined.

5.1 TEST PROCEDURE OBJECTIVES

The basic objective in developing standard test methods for passive solar components is to characterize each product in such a way that its thermal response for worst-case design conditions, as well as for normal or average conditions, can be readily evaluated. This implies that thermal characteristics that exhibit significant variation either with the climatic variables of ambient temperature, wind speed and direction, and solar irradiance, or with the product design parameters such as operating mode, product size, orientation and configuration, must be identified and considered in the test procedure.

The use of these performance data would assist purchasers of passive solar components to choose between alternative products, would assist designers in the sizing of the passive system and its backup auxiliary system, and would assist the evaluation of the thermal performance of the building in terms of estimated energy savings that accrue as a consequence of installation of the particular product.

It is recommended that laboratory-based standard testing procedures be developed that are both practical and economically feasible to perform, such that accurate and repeatable test results can be obtained by different testing laboratories utilizing the same procedures. The test procedures should neither impede the development of new technology and the marketing of innovative components nor discriminate against one product or technology in favor of another because of technical difficulties in applying the test method.

5.2 METHODOLOGY

The development of draft test methods that comply with the stated objectives will require a combination of the following activities:

- product selection
- determination of the thermal characteristics that best quantify performance of the component
- thermal model preparation and simulation
- field testing under controlled conditions
- laboratory testing
- draft test procedure development

The following section describes in general terms some of the requirements for each of the above activities.

5.2.1 Selection of Products

Representative products for each classification should be procured from manufacturers and prepared for testing in both laboratory and field facilities. A number of different products should be tested for each of the component classifications to ensure that a single test procedure is suitable for each generic grouping of components.

5.2.2 Thermal Model Preparation and Simulation

Detailed thermal models should be prepared for each of the passive solar components undergoing test. Sufficient detail should be provided in each thermal model to permit instantaneous thermal energy balances to be made at all surfaces for which temperatures are measured during test. Validation of each thermal network model should be accomplished by comparison of predicted surface temperatures and surface temperatures measured during testing. Validated thermal network models can be used to perform sensitivity analyses to assist in identifying ambient conditions and operating modes that result in significant variation in thermal performance.

5.2.3 Field Testing

Each representative passive solar component should be field tested under controlled interior conditions to establish thermal performance under actual environmental conditions for subsequent correlation with laboratory test results. The field test facility should be a calibrated, highly-insulated and leaktight, heat flow measuring calorimeter, in which interior air and surface temperatures are maintained constant by the addition or removal of thermal energy and in which infiltration air leakage can be excluded or included as desired. Separate measurements of solar irradiance transmitted directly through transparent areas, and thermal energy transferred indirectly by conduction, convection and long wave radiation through the test article are desired. Measurements should be performed on each test article for consecutive 30-day periods during both the winter and the summer/fall seasons. Identical test articles should be tested at field test stations in three to four different locations with diverse climatic conditions, to establish a broad data base for passive component thermal performance under different environmental conditions.

5.2.4 Laboratory Testing

Laboratory-based test procedures are currently available for thermal performance measurements on building envelope assemblies such as windows, doors and wall sections, although some controversy exists as to the suitability of thermal data derived from these measurement procedures for energy calculations. It is desired to determine whether current laboratory test methods to measure overall heat transfer coefficient, shading coefficient and infiltration rate are sufficient for the DGFS classification of passive solar component. In addition, since no current laboratory-based testing procedure is suitable for CSWM thermal performance measurements, it is necessary to develop such a procedure.

5.2.4.1 Direct Gain Fenestration System

A range of DGFS products should be tested which include fixed configurations, such as multiple-glazed windows with reflective films, and variable configurations, such as movable-insulations installed in tandem with a reference glazing. Preparation for testing would involve the installation of each test article in a suitable insulating test frame and the installation of sensors and automatic deployment devices for products having movable insulation.

The overall heat transfer coefficient is measured for each representative DGFS product using commercial testing laboratory "hot box" facilities. Each of the following test procedures should be used:

- ASTM C 236,
- Modified ASTM C 236 (with parallel wind),
- AAMA 1502.6 (with normal wind).

Measurements should be performed for each operating mode (position of movable insulation and summer/winter mode), for various combinations of simulated wind speed, wind direction, and outdoor temperature, with indoor temperature fixed. Moisture conditions in the test chambers should be controlled to prevent condensation on surfaces of the test article.

The solar transmittance and the Shading Coefficient for several of the DGFS components utilizing transparent insulation and/or heat-absorbing films should be measured using both ASTM E 424 (method B) and ASHRAE Standard 74-73.

For correlation of these results with analytical procedures, it is desirable to obtain samples of each of the solar films and to measure the solar-optical properties both spectrally and at various angles of incidence. These measurements are required to develop the thermal models described in 5.2.2.

Air leakage is measured in both infiltration mode and exfiltration modes using ASTM E 283.

5.2.4.2 Collector/Storage Wall Modules

The CSWM products tested should be commercially available rather than prototypical and should include different sensible energy storage media such as masonry and water and different latent energy storage media such as hydrated salts or paraffin waxes. The CSWM products tested should also include a range of other design features such as free-convection or forced-convection heat exchange between the thermal storage element and the building space, and movable insulation between thermal storage and ambient.

Since there are no standard methods currently available for thermal performance testing of a CSWM in a laboratory, this section outlines several tasks required to develop the two alternate testing procedures previously discussed.

(a) Facility Development for Dynamic Testing with Solar Simulation - Develop a test facility which has the capability to simultaneously impose time-variable solar flux, ambient dry-bulb temperature and wind environments, on the exterior surface of a vertically oriented CSWM. The solar simulator should have the capability to vary the solar radiant intensity and the angle of incidence between the beam component and the test article, in order to simulate both diurnal and seasonal irradiance levels and beam incident angles. The spectral intensity of the solar beam received at the test article should simulate an air-mass 1.5 spectrum at winter conditions and should not result in a difference in the total absorbed flux of $\pm$ 10 percent over the solar spectrum when compared with the spectral intensity of natural solar energy at the air-mass 1.5 condition in winter. Long-wave radiation exchange between the test article and the solar simulator optical surfaces should be limited either by cooling of these surfaces or by lamp placement geometry to reduce the view factor.

(b) Development for Dynamic Testing in an Environmental Chamber with Film Resistance Heaters - Develop techniques for fabrication and installation of thin film (i.e., nichrome foil) heaters on solar energy absorbing surfaces found in passive solar components such as masonry, metal, glass and plastic. Develop techniques for modifying the emittance of heaters installed on solar irradiated surfaces to approximate the actual emittance of the passive product surface.

Using the detailed thermal models described in 5.2.2, develop computer programs to calculate absorbed solar flux at each surface. Develop analog or microprocessor-based controls to automatically adjust the power dissipation of each individual heater circuit to simulate absorption of solar energy.

For both procedures discussed above, the test articles should be installed in a test frame that is designed to minimize heat transfer between the test frame and the CSWM test article and between the hot and cold chambers. The interior surface of the test article is exposed to a constant temperature volume of air in a heat flow metering box (calorimeter) and the exterior surface is exposed to the dynamically varying dry-bulb temperature and wind speed provided by the chamber. Depending on the facility, solar irradiation is provided either by the lamps or by film resistance heaters. Static pressure conditions within the metering box should be maintained in all tests involving simulated winds to assure that no air infiltration through the test article occurs due to static or dynamic pressure differentials.

Measurements of directly transmitted solar energy (if appropriate) and thermal energy transferred between the metering box and the outdoor chamber through the SWM test article are made on a continuous basis.

A significant portion of the development of a laboratory-based test procedure will be the identification of appropriate environmental sequences.

The following test conditions are suggested for study:

- a long sequence of test days using measured winter weather data conditions for a particular location,

- a short sequence of test days using synthetic winter weather data based on statistical analysis of measured weather conditions at a particular location,

- a sequence of identical 24-hour cycles of synthetic weather data,

- a step-function change in either or both ambient temperature and solar irradiance.

5.2.5 Draft Test Procedure Development

Reference [12] describes general guidelines in the development of a draft test procedures that appear to be appropriate for passive solar components. Additional activities include utilizing the detailed computer models described in 5.2.2, the results of field testing described in 5.2.3, and the results of the laboratory testing described in 5.2.4, to perform studies for each product to determine the laboratory test procedures and test conditions that provide the best correlation with the results of the field test measurements. Verify that each test procedure developed as the test procedure for a class of passive components is applicable to all the components in that class, and if not, develop the necessary modification to the corresponding draft test procedure.

The final development activity is to establish, for each test procedure, the number of tests to be performed on a component to provide useful data in support of building energy consumption calculations. Computer simulations of reference residential buildings located in different climatic regions, each containing various passive solar components, is suggested. In this study, seasonal building energy consumption would be evaluated as a function of the level of data provided by the laboratory test results, where results from selected combinations of test conditions are compared. The difference in calculated energy consumption should be used as a parameter to establish the level of testing required to produce energy calculations consistent with the reported accuracy of the calculation procedures selected by DoE for energy analysis of passive solar systems.

The proposed DGFS and CSWM research and evaluation tasks described in this section are believed to be necessary to develop draft standard test methods for submittal to a consensus-based standards-writing organization. By performing these tasks and following the consensus review path, it is believed that the resulting test procedures will have wide acceptance and promote the development of an industry to manufacture passive solar components.

Proposed research and evaluation tasks for the eight other passive component classifications listed in table 1 have not been discussed. However, it is appropriate that attention be directed as soon as possible toward development of standard test procedures for thermosyphon solar collectors and domestic hot water systems. For the remainder of the passive component classes in table 1, development of standard test procedures should proceed cautiously until it is established that these components will be further developed for commercialization. Based on the assumption that all the classes of passive components identified in table 1 will be commercialized, the outline in table 5 is an estimate for a schedule to develop draft test procedures for passive solar components. The schedule in table 5 represents a program that relies on the results from the technical organizations and laboratories that are or will be performing the necessary research and evaluation tasks that must precede development of draft standard test procedures.

TABLE 5

PROPOSED TEST PROCEDURE DEVELOPMENT PLAN FOR PASSIVE SOLAR COMPONENTS - PRELIMINARY

	FY 81	FY 82	FY 83	FY 84	FY 85
Direct Gain Fenestration Systems	———	———▽			
Collector/Storage Wall Modules	———	———	———▽		
Sunspace/Greenhouse Modules		———	—▽		
DHW Systems	———	———	—▽		
Thermosyphon Collector		———	———▽		
Thermal Storage Units		———	———▽		
Roof Pond Modules			———	——▽	
Radiative Cooling Modules		———	———▽		
Ground Coupling Modules			———	———▽	
Evaporative-Cooling/Natural Ventilation Modules				———	———▽

▽ Denotes completion of Draft Standard Thermal Test Method.

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APPENDIX A

SAMPLE LETTER SENT TO MANUFACTURERS AND DISTRIBUTORS OF PASSIVE SOLAR PRODUCTS

January 9, 1979

XYZ Solar Company
1 Main Street
Anytown, USA

Dear Sir:

The National Bureau of Standards is currently conducting a project to develop standard test procedures for thermal performance rating of modular elements used for passive solar heating and cooling. A part of this project is to identify commercially available passive solar components, to classify them according to their functional role, and to obtain information of their anticipated thermal performance.

Your firm was identified in the September, 1978 issue of Solar Age as being involved in the production or distribution of products used for passive solar heating and cooling. To assist us in our project, we request that you send us any available information on your passive solar products. We are particularly interested in technical descriptions of each product, recommended installation and operating procedures, thermal performance data, and any other information you believe to be pertinent to our project.

Thank you for your cooperation. If you have any questions about this request, please call me at (301) 921-3871.

Yours truly,

Michael E. McCabe, P.E.
Mechanical Engineer
Building 226, Room B-104
National Bureau of Standards
Washington, D.C. 20234

APPENDIX A

LIST OF MANUFACTURERS AND DISTRIBUTORS OF PASSIVE SOLAR PRODUCTS SENT SURVEY LETTER

<u>January 9, 1979 Mailing</u>

Advance Cooler Manufacturing Corp.
Rt. 146, Bradford Industrial Park
Clifton Park, N.Y. 12065

AETA Solar Incorporated
P.O. Box 452
Durham, N.C. 03824

American German Industries, Inc.
14611 North Scottsdale Rd.
Scottsdale, Ariz. 85260

Appropriate Technology Corp.
1798 Green St.
Brattleboro, Vt. 05301

Architectural Research Corporation
13030 Wayne Road
Livonia, MI 48105

ARC Systems
142 Cannon Street
Poughkeepsie, N.Y. 12601

Ark-tic-seal Systems Inc.
P.O. Box 428
Butler, Wis. 53007

Aztec Solar Company
P.O. Box 272
Maitland, FL 32751

Bio-Energy Systems Inc.
Box 87
Ellenville, N.Y. 12428

Brown Manufacturing Co.
P.O. Box 14546
Oklahoma City, Okla. 73114

Cementitious Products, Inc.
3136 North 28th Avenue
Phoenix, AZ 85017

Colorado Sunworks Corp.
P.O. Box 455
Boulder, Colo. 80306

Continental Solar Systems, Inc.
1901 Avenue of the Stars
Century City, CA 90067

Contemporary Systems, Inc.
CSI Solar Center
Route 12
Walpole, NH 03603

Creighton Solar Concepts
662 Whitehead Road
Lawrenceville, NJ 08648

Dalen Products, Inc.
201 Sherlake Drive
Knoxville, TN 37922

Day & Lachy, Inc.
P.O. Box 8327
Aspen, CO 81611

Egge Research
Box 394B R.F.D.
Kingston, NY 12401

Energy Factory
5622 E. Westover, Suite 105
Fresno, CA 93727

Entropy, Ltd.
5735 Arapahoe Avenue
Boulder, CO 80303

Federal Energy Corporation
5505 E. Evans
Denver, CO 80222

Fred Rice Productions
P.O. Box 634
48780 Eisenhower Dr.
La Quinta, CA 92253

Garden Way Laboratories
P.O. Box 66
Charlotte, Vt. 05445

Gila River Products
510 S. 52nd Street
Tempe, AZ 85281

Green Mountain Homes
Royalton, Vt. 05068

Habitat
123 Elm St.
Deerfield, Mass. 01373

Housewarming Development Corp.
Box 8
1928 6th Street
Boulder, CO 80306

Insulating Shade Co., Inc.
P.O. Box 282
Branford, Conn. 06405

Kalwall Corp.
Solar Components Div.
P.O. Box 237
Manchester, N.H. 03105

Koolshade Corp.
P.O. Box 210
Solana Beach, Calif. 92075

Kuss Corp.
1331 Broad Avenue
Findlay, OH 45840

Madico
64 Industrial Parkway
Woburn, MA 01801

Martin Processing Inc.
Film Division
P.O. Box 5068
Martinsville, VA 24112

Metallized Products
2544 Terminal Drive South
St. Petersburg, FL 33712

Multi-Research Corp.
Highway 35
Keyport, NJ 07735

North Wind Power Company
Box 315
Warren, VT 05674

One Design Inc.
Mountain Falls Route
Winchester, VA 22601

Ozark Solar Energy Systems
406 Summit
Carl Junction, MO 64834

Passive Solar Variant Homes by Savell
575 Birch Court
Suite A
Colton, Calif. 92324

Pawling Rubber Corp.
157 Maple Blvd.
Pawling, NY 12564

Payne, Inc.
1933 Lincoln Drive
Annapolis, MD 20854

Robert Mitchell Solar
Systems Design
Route 3
Box 239
Selkirk, NY 12158

Rainbow Energy Works
3765 17th St. No. B.
San Francisco, Calif. 94114

R. L. Kuss & Company
1331 Broad Avenue
Findlay, OH 45840

RM Products
5010 Cook St.
Denver, Colo. 80216

Rolscreen Co.
Pella, IA 50219

Sebra Solar Energy
500 N. Tucson Blvd.
Tucson, AZ 85716

Serrande Shutters
P.O. Box 1034
West Sacramento, CA 95691

Shutter Shield,
C.D. Davidson & Assoc.
1014 Baldwin Avenue
Pontiac, MI 48057

Skytherm Processes & Engineering
2424 Wilshire Blvd.
Los Angeles, CA 90057

SOLEX Solar Energy
Systems, Inc.
Concord House
Suite 2B
Scarsdale, NY 10583

Solar Central
7213 Ridge Rd.
Mechanicsburg, OH 43044

Solar Energy Construction Co (SECO)
Box 718
Valley Forge, PA 19481

Solar Energy Products, Inc.
1208 N.W. 8th Avenue
Gainesville, FL 32601

Solargencis, Inc.
9713 Lurline Avenue
Chatsworth, CA 91311

Solar Home Systems, Inc.
8732 Camelot
Chesterland, OH 44026

SolarKit of Florida, Inc.
1102 139th Avenue
Tampa, FL 33612

Solar Masters, Inc.
719 Haddon Avenue
Collingswood, NJ 08108

Solarnetics Corp.
1645 Pioneer Way
El Cajon, CA 92020

Raymond Auger
Solar Power West
709 Spruce Street
Aspen, CO 81611

Solar Sunstill, Inc.
15 Blueberry Ridge Road
Setauket, NY 11733

Solar Systems by Sun
Dance, Inc.
12929 N.W. 60th Avenue
Hialeah, FL 33014

Solartec Corp
8210 Engineer Road
San Diego, CA 92111

Solar Technology Corp.
2160 Clay St.
Denver, CO 80211

Solartherm, Inc.
110 Spring Street
Silver Spring, MD 20910

Solar West, Inc.
P.O. Box 892
Fresno, CA 93714

Solartran Corp.
P.O. Box 496
Escanaba, MI 49329

Solar Room Corp.
P.O. Box 1848
Taos, NM 87571

Southeastern Solar Systems, Inc.
2812 New Spring Rd.
Suite 150
Atlanta, GA 30339

Solar Access Inc.
320 Cedar Street
Santa Cruz, CA 95060

Solag
Rural Route 2
Roseville, IL 61473

Solar American, Inc.
2620 San Mateo, N.E.
Albuquerque, NM 87110

Solar American Company
106 Sherwood Drive
Williamsburg, VA 23185

Solar Energy Engineering
31 Maxwell Court
Santa Rosa, CA 95401

Solar Building Systems, Inc.
610 W. Broadway
Tempe, AZ 85282

Solar Dynamics of Arizona
1100 N. Lake Havasu Drive
Lake Havasu City, AZ 86403

Solardyne, Inc.
8736 Production Avenue
San Diego, CA 92126

Solar Energy Components, Inc.
212 Walsh Pool Road
Lionville, PA 19353

Solar Science Industries, Inc.
10762 Tucker Street
Beltsville, MD 20705

Suntek Research Associates
500 Tamal Vista Blvd.
Corte Madera, CA 94925

Sun Spot Research
1070 S. Leyden
Denver, CO 80224

Sunverter Company, Inc.
Route 1
Box 269
Murphyboro, IL 62966

S.W. Energy Options
Route 8, Box 30-H
Silver City, NM 88061

Telluride Solarwords
Box 700
Telluride, CO 81435

Thermal Technology Corp.
P.O. Box 130
Snowmass, Colo. 81654

Therma-Roll Corp.
512 Orchard Street
Golden, Colo. 80408

Transparent Glass-Coating Company
1959 S. La Cienage Blvd.
Los Angeles, CA 90034

Transparent Shade Company
501 N. Figueroa Street
Los Angeles, CA 90012

Trol-A-Temp
740 Federal Avenue
Kenilworth, NJ 07013

U.S. Solar Pillow Corp.
2458 Highway 6 & 50
Grand Junction, CO 81501

U.S. Solar Pillow
P.O. Box 987
Tucumcari, NM 88401

Vita Green Farms
P.O. Box 878
Vista, CA 92083

Zomeworks Corp.
P.O. Box 712
Albuquerque, NM 87103

March 25, 1980 Mailing

AAI Corporation
P.O. Box 6767
Baltimore, MD 21204

AFG Industries
P.O. Box 929
Kingsport, TN 37662

American Klegecell Corporation
204 North Dooley Street
Grapevine, TX 76051

Approtech
770 Chestnut Street
San Jose, CA 95110

Century Fiberglass
P.O. Box 6069
Anaheim, CA 92806

CY-RO Industries
697 Route 46
Clifton, NJ 07015

The Dampney Company
85 Paris Street
Everett, MA 02149

Dyrelite Corporation
63 David Street
New Bedford, MA 02747

E.I. Dupont Company
Flouropolymer Division
Plastics, Products and Resins
Department
Wilmington, DE 19898

Energy Distributions, Inc.
P.O. Box 353 Snug Harbor
Duxbury, MA 02332

ERGENIES
681 Lawlins Road
Wyckoff, NJ 07481

EXSUN
P.O. Box 3745
Washington, DC 20007

FANJET Division of
Mueller Mist Irrigation Co.
Representative at:
6153 Crabtree Road
Columbia, SC 29206

Fiber-Rite Products, Inc.
P.O. Box 38095
Cleveland, OH 44138

Ford Motor Company
Glass Division
1 Parklane Blvd.
Suite 1000E
Dearborn, MI 48126

Four Seasons Solar Products
Corporation
672 Sunrise Highway
West Babylon, NY 11704

General Solar Corporation
51 Monroe Street
Rockville, MD 20850

The Graetz Group
922 24th Street, North West
Suite 520
Washington, DC 20037

Heldor Associates
300 Kuller Avenue
Clifton, NJ 07015

Helix Solar Systems
P.O. Box 2038
City of Industry, CA 91746

Holland Plastics
P.O. Box 248
Gilman, IA 50105

Isophenol Division
Robert Mitchell Solar
Systems Design
Route 3, Box 239
Selkirk, NY 12158

Lasco Industries
3256 East Miraloma
Anaheim, CA 92806

Lof Brothers
Solar Applicance, Inc.
1615 17th Street
Denver, CO 80202

MacBall Industries, Inc.
1820 Embarcardero
Oakland, CA 95606

National Metallizing
A Saxon Company
P.O. Box 5202
Princeton, NJ 08540

OEM Products, Inc.
2701 Adamo Drive
Tampa, FL 33605

Park Energy Company
Star Route 9
Jackson, WY 83001

Perkasie Industries Corp.
50 East Spruce Street
Perkasie, PA 18944

PolyCell Industries, Inc.
P.O. Box 99
Marion, IA 52302

Practical Solar Systems
7221 South 180th Street
Kent, WA 98031

Sealed Air Corp.
14428 Best Avenue
Santa Fe Springs, CA 90670

SMC Energy Company
P.O. Box 246
Omaha, NE 68102

Solar Aquasystems, Inc.
P.O. Box 88
Encinitas, CA 92024

J. Catalano & Sons, Inc.
301 Stagg Street
Brooklyn, NY 11206

Solar-En Corp.
3118 Route 10
Denbrooke Village
Denbrooke, NJ 07834

Solarflame Systems, Inc.
P.O. Box 99
Leroy, IL 61752

Solaron Corp.
720 South Colorado Blvd.
Denver, CO 80222

Solar-X Corp.
25 Needham Street
Newton, MA 02161

Solpub
Box 9209
College Station, TX 77840

Space Structures International
Corp.
155 Dupont Street
Plainview, NY 11803

Sun Craft
5001 East 59th Street
Kansas City, MO 64130

Sun-Wind- Home-Concepts
Division of TWR Enterprises
72 West Meadow Lane
Sandy, UT 84070

Texas Urethanes, Inc.
P.O. Box 9563
Austin, TX 78766

Thermics
8360A Industrial Avenue
Cotati, CA 94928

3-E Corp.
401 Kennedy Blvd.
Somerdale, NJ 08083

Vegetable Factory, Inc.
100 Court Street
Copaigue, NY 11726

Weather Energy Systems, Inc.
39 Barlows Landing Road
Pocasset, MA 02559

<u>April 24, 1980 Mailing</u>

Sunflake
P.O. Box 676
Ignacio, CO 81137

Victor Syzmanski, Inc.
105 Maple Avenue
Shrewsbury, MA 01545

Alpha Associates, Inc.
Two Amboy Avenue
Woodbridge, NJ 07095

One Design
Mountain Falls Rt.
Winchester, VA 22601

Heliothermics, Inc.
1070 Orion Street
Greenville, SC 20905

Texas Greenhouse
2717 St. Louis Avenue
Forth Worth, TX 76110

Pearl Mist
980 17th Avenue
Santa Cruz, CA 95062
Attn: Peter Reimuller

Bramen Company, Inc.
P.O. Box 70
Salem, MA 01970

Roll-A-Way
10597 Oak Street, NE
St. Petersburg, FL 33702

C. D. Davidson & Associates, Inc.
1014 Baldwin Avenue
Pontiac, MI 48055

Turner Greenhouses
Highway 117 South
Goldsboro, NC 27530

Solar Energy Components, Inc.
212 Welsh Pool road
Lionville, PA 19353

American Thermal Technology, Inc.
P.O. Box 6392
Providence, RI 02940

Dayton Corporation
11 Beacon Street
Boston, MA 02108

Sunglo Greenhouses
4441 26th Avenue West
Seattle, WA 98199

Sturdi-Built Manufacturing Co.
11304 S.W. Boones Ferry Road
Portland, OR 97219

Edward Owen Engineering
Snow Show, PA 16874

Santa Barbara Greenhouses
390 Dawson Drive
Camarillo, CA 93010

Greenhouse Specialties Co.
9849 Kimber Lane
St. Louis, MO 63127

Everlite Aluminum Greenhouses, Inc.
14605 Lorain Avenue
Cleveland, OH 44111

Plastic View Transparent Shades, Inc.
P.O. Box 25
15468 Cabrito Road
Van Nuys, CA 91408

Insul Shutter, Inc.
Box 338
Silt, CO 81652

Pease Company of Indiana
Ever-Strait Division-Rolling Shutters
2001 Troy Avenue
New Castle, IN 47362

Insulating Shade Company, Inc.
P.O. Box 406
Guilford, CT 06437

Shutters, Inc.
110 East 5th Street
Hastings, MN 55033

Sun Quilt Corporation
Box 374
Newport, NH 03773

Homesworth Corporation
34 Cumberland Street
Brunswick, ME 04011

Rohm and Haas Co.
Plastics Division
Independence Mall West
Philadelphia, PA 19105

APPENDIX B

Summary of Passive Solar Products Identified from the Letter Surveys[1]

Classification[2]	Component	Description	Trade Name	Manufacturer	Thermal Characteristics from Manufacturer's Information[3,4]
DGFS-MGW	Retrofit window	Acrylic or polycarbonate glazing in either a magnetic or adhesive system frame, for converting existing single-pane glass to a double glazing	Energlaze	Dayton Corp. 11 Beacon Street Boston, MA 02108	U_o = .53 for Energlaze and an existing single glazing.
DGFS-MGW	Double plastic glazing	Double skinned acrylic or polycarbonate sheets for greenhouses, clerestories, curtain walls, etc.	Exolite	CY/RO Industries 697 Route 46 Clifton, NJ 07015	U_o = .55 summer U_o = .58 winter $.31 < SC < .97$ acrylic; white (low value), clear (high value) $.25 < SC < .88$ polycarbonate; white (low value), clear (high value)
DGFS-MGW	Translucent multiple glazing	Panels are a heat and pressure bonded sandwich of two or more flat Sunlite fiberglass reinforced polymer faces on extruded aluminum grid cores.	Sunwall	Kalwall Corporation 1111 Candia Rd. Manchester, NH 03103	U_o = .41 two glazings, one airspace, calculated for 2 mph wind U_o = .35 three glazings, two airspaces, calculated for 2 mph wind U_o = .28 four glazings, three airspaces, calculated for 2 mph wind
DGFS-MGW	Double plastic glazing	A clear, double-walled, hollow-channeled polycarbonate sheet.	Tuffak-Twinwall	Rohm and Haas Co. Plastics Division Independence Mall West Philadelphia, PA 19105	U_o = .62
DGFS-MGW	Double plastic glazing	Rigid double fiberglass glazing with aluminum I-beam spacer.	Vegetable Factory Greenhouses	Vegetable Factory, Inc. 100 Court Street Copiague, LI, NY 11726	U_o = .46

See page B-9 for footnotes

LEGEND:

DGFS: Direct gain fenestration system
DGFS-MGW: Multiple glazed window
DGFS-MI: Movable insulation
DGFS-MSD: Movable shading device
DGFS-AFW: Air flow window

TSC: Thermosyphon solar collector

EC/NVM: Evaporative cooling/natural ventilation module

RCM: Radiative cooling module

CSWM: Collector/Storage wall module
CSWM-SES: Sensible energy storage
CSWM-LES: Latent energy storage

S/GM: Sunspace/greenhouse module

PSWH: Passive hot water system
PSWH-DCT: Discrete component thermosyphon
PSWH-IS: Integrated (batch) system

GCM: Ground coupling module

RPM: Roof Pond Module

TSU: Thermal storage unit

APPENDIX B[1] (Continued)

Classification[2]	Component	Description	Trade Name	Manufacturer	Thermal Characteristics from Manufacturer's Information[3,4]
DGFS-MI	Insulating window	Manufacturer supplies polystyrene foam beads, bead transport and storage assemblies, aluminum frame and wood spacers for glazings. Glazings are not supplied. When foam beads are sprayed between a double glazing, window becomes an opaque insulated wall. When foam beads are drained from between glazings, the double glazings, the double glazing is a window.	Beadwall	Zomeworks Corporation P.O. Box 712 Albuquerque, NM 87103	R=8 when beads are sprayed between 2 1/2" core double glazing
DGFS-MI	Interior insulating shutters	Rigid insulation core with reflective metal foil layer on both sides and an air space sealed between wood panels.	Insul Shutter	Insul Shutter, Inc. by Eriksen 110 North Seventh St. Silt, CO 81652	U_o=.11 includes component with a single glazing, manufacturer reports reciprocal of U_o which=9.1
DGFS-MI	Roll-down interior insulation shutter	One inch thick solid rectangular sections for rolling up (or to the sides of) a window.	Sol-R-Fold	Raymond N. Auger 707 Spruce St. Aspen, CO 81611	manufacturer reports insulation value is ten times that of a single pane of glass
DGFS-MI	Interior sliding insulation & window	Integral assembly of two sections; one is a visible single glazing and the other is a concealed pocket to house the sliding urethane insulating panel.	Sunflake Window	Sunflake 625 Goddard Ave. P.O. Box 676 Ingnacia, CO 81137	R=16.33 for empty concealed pocket. R=16.25 for insulated panel and single glazing.
DGFS-MI	Roll-down exterior shutter	Roll-down exterior mounted wood or treated PVC adjustable slat shutter. Shutter is controlled indoors either manually or electrically.	Serrande Shutter	Serrande Shutter P.O. Box 1034 West Sacremento, CA 95691	
DGFS-MI	Interior insulating quilt shade	Three layer accordian fold quilt; window facing layer is a polyester, middle layer is Fiberfill insulation, and interior facing layer is nylon tricot with aluminum face protected by a plastic film. Automatically operated by electric motor controlled by photoelectric cell.	Sun Quilt	Sun Quilt Box 374 Newport, NH 03773	

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APPENDIX B[1] (Continued)

Classification[2]	Component	Description	Trade Name	Manufacturer	Thermal Characteristics from Manufacturer's Information[3,4]
DGFS-MI	Exterior insulated bi-fold shutters	Shutter panels are 1" urethane core, tempered hardboard front and back; anodized aluminum track weather-stripped, nylon slides; closing mechanism nylon housing and gears.	Thermafold Shutters	Shutters, Inc. 110 East 5th St. Hastings, MN 55033	R = 7.1 for shutters
DGFS-MSD	Interior quilt window shade	Roller operated multilayer quilt; from window facing to indoor facing layers are: fabric, Fiberfill, reflective vapor barrier, Fiberfill and fabric; shade slides in side track when rolled up or down.	Window Quilt	Appropriate Technology Corporation P.O. Box 975 Brattleboro, VT 05301	U_o = .22 overall value for shade and single glazing. U_o = .18 overall value for shade and double glazing. manufacturer reports reciprocal of U_o which = 4.5 and 5.5 for shade with single and double glazing respectively.
DGFS-MSD	Exterior rolling shutter	Horizontal PVC plastic hollow slats linked together that slide up and down in aluminum side channels. Operation may be manual by crank or strap or automatic by electric motor.	Ever-Strait Rolling Shutter	Pease Company 2001 Troy Avenue New Castle, IN 47362	U_o = .405 overall winter value for shutter (slat V type) and single glazing. U_o = .301 overall winter value for shutter (slat V type) and double glazing. manufacturer's data contains numerious U_o and R values for different configurations for summer and winter conditions.
DGFS-MSD	Insulating adjustable louvers	Reflective aluminum faced honeycomb core louvers which pivot in wood frames beneath skylights; automatic gravity control via a driver louver blade which has refrigerant canisters at opposite ends.	Skylid	Zomeworks Corporation P.O. Box 712 Albuquerque, NM 06405	U_o = .25 overall value for louver and single glazed skylight. U_o = .20 overall value for louver and double glazed skylight. manufacturer reports reciprocal of U_o which = 4 and 5 for applications with single and double glazed skylights respectively.

See page B-9 for footnotes

Classification[2]	Component	Description	Trade Name	Manufacturer	Thermal Characteristics from Manufacturer's Information[3,4]
DGFS-MSD	Interior roller shades	Shade has five layers of plastic film, separated from one another by polyester laminated spacers; room side layer is a vinyl laminate, other layers are aluminized plastic film; head and jamb seals are provided; roller actuated by pull chain.	Heatstopper shade	Insulating Shade Co., Inc. P.O. Box 282 Brandford, CT 06405	U_o = .071 for shade with a single glazing U_o = .067 for shade with a double glazing manufacturer reports reciprocal of U_o which = 14 and 15 for applications with single and double glazing respectively.
DGFS-MSD	Interior roller insulating curtain	Several layers of metalized reflective fabric; when in place layers entrap air spaces; curtain seals on all sides; intended for large vertical windows; automatic operation by electric drive motor actuated from outdoor temperature and solar radiation sensor signals.	Insulating Curtain Wall	Thermal Technology Corp. P.O. Box 130 Snowmass, CO 81654	$9 < R < 12$ for insulating curtain wall alone
DGFS-MSD	Interior roller shade	Shade material is a transparent polyester film, vacuum deposited with aluminum and laminated with another polyester film to provide a barrier against moisture and contaminants.	Nunsun Shade	National Metallizing P.O. Box 5202 Princeton, NJ 08540	$.1 < U_o < .2$ depends on number of plys and color; values for shade with a double strength single glazing $.12 < SC < .28$ same note as above
DGFS-MSD	Exterior louvers	Exterior horizontal or vertical adjustable aluminum blade louver assembly, controlled manually or automatically from the interior. Horizontal blades interlock in closed position to minimize convective heat transfer to or from the exterior window surface.	Sun Controls	Brown Manufacturing Co. Street 13431 Broadway Extension Oklahoma City, OK 73114	

See page B-9 for footnotes

Classification[2]	Component	Description	Trade Name	Manufacturer	Thermal Characteristics from Manufacturer's Information[3,4]
DGFS-MSD	Interior roller shade	A system of three roller polyester film shades; window facing film is aluminized, middle film is clear and room facing film is gray blue. The aluminum frame has automatically actuated air vents in the top and bottom for thermosyphon heating when the clear and blue gray films are in place. The reflective film is used to reject solar gain; the clear is used to absorb ultra-violet radiation and create a dead air space between it and the window; the blue gray film is used to absorb infra-red and ultra-violet radiation.	Insealshaid	Ark-Tic-Seal System, Inc. Box 428 Butler, WI 53007	U_o = .36 winter daytime with single glazing U_o = .185 winter nighttime with single glazing U_o = .19 summer daytime, all shades drawn, with a single glazing
DGFS/MSD	Exterior rolling shutter	Interlocking PVC hollow slats and steel or aluminum track, housing reel, etc. Interior roller control by manual strap or crank or by push button electric operator.	Roll-A-Way	Roll-A-Way 10597 Oak St., N.E. St. Petersburg, FL 33702	U_o = .405 winter value with single glazing U_o = .395 summer value with single glazing U_o = .301 winter value with double glazing U_o = .297 summer value with double glazing
EC/NVM	Roof evaporative cooling system	System of copper piping with spray holes (typically on 9 ft centers) to deliver 15 psi water spray onto roof; control by low voltage solenoid value actuated by master time control and thermostat.	Fanjet roof cooling system	Muellermist Irrigation Company P.O. Box 478 Maywood, IL 60153	

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APPENDIX B[1] (Continued)

Classification[2]	Component	Description	Trade Name	Manufacturer	Thermal Characteristics from Manufacturer's Information[3,4]
CSWM/SES	Stackable water container	A sculptured rectangular stackable black water container made of fiberglass and reinforced polyester; each 95" long x 16 1/2" wide x 24 1/2" high.	IBB One Design Waterwall	One Design, Inc. Mountain Falls Road Winchester, VA 22601	Heat storage capacity: 793 Btu/°F temperature rise (for 94 gallons of water)
CSWM/SES	Collector/storage wall assembly	Consists of four primary components: (i) a fiberglass glazing (single or multiple) (ii) solar absorber fiberglass storage tubes (usually to be filled with water, 22-128 gal each) (iii) an enclosure (surrounds the tubes on three sides, top and bottom) (iv) blower and controls (to circulate air to and from the collector/storage assembly.	Kalwall Solar Furnace	Solar Components Kalwall Corporation P.O. Box 237 Manchester, NH 03105	U_o = .4 for Sun-Lite/aluminum grid core panels and Clamp-Tite system $.08 < U_o < .12$ for reflective curtain in combination with Sunwall window.
CSWM/LES	Translucent latent heat storage module	Each Pod contains a phase change material factory sealed in a translucent, fiberglass reinforced polymer container. Each Pod 48" wide x 16" high x 2" thick or 24" x 16" x 2", and weighs 29 lbs. or 14.5 lbs. respectively.	Kalwall Thermal Storage Pod	Solar Component Div. Kalwall Corporation P.O. Box 237 Manchester, NH 03105	Melting temp: 81°F Latent heat: 82 Btu/lb. Specific heat: .53 Btu/lb.·°F liquid .34 Btu/lb.·°F solid

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APPENDIX B[1] (Continued)

Classification[2]	Component	Description	Trade Name	Manufacturer	Thermal Characteristics from Manufacturer's Information[3,4]
S/GM	Sunspace	Double glazed plastic panels in a baked enamel finish aluminum frame; assembly includes roof and side vents. Optional equipment includes: triple glazed panels, exhaust fan, louvers, interior and exterior shades, tinted glass, insulated sliding patio door.	Four Seasons Solar Greenhouse	Four Seasons Solar Products Corp. 672 Sunrise Highway West Babylon, NY 11704	U_o = .62 for double glazed plastic panels U_o = .53 for double glazed glass with 1 1/2" airspace U_o = .36 for triple glazing consisting of a single glass sheet and a double glazed plastic panel.
S/GM	Sunspace	Double-strength single glazed panels & aluminum glazing strips in a film dried redwood frame. Assembly also includes roof vents and glazed aluminum storm door.	Ezyrected Winter Gardner Lean-T_o	Texas Greenhouse, Co. 2717 St. Louis Ave. Fort Worth, TX 76110	
S/GM	Sunspace	Twin-Skin translucent plastic sheets supported by galvanized steel frames and held in place by a two part aluminum extrusion. A small fan is used to inflate and separate the plastic sheets.	Solar Room	Solar Room Co. Box 1377 Taos, NM 87571	U_o = .65 for double glazing
S/GM	Sunspace	Pre-fabricated modular panel structure, with south facing vertical or tilted glazing, insulated side walls and vents, & corrugated fiberglass roof with insulation and vents.	The Solera	Solar Technology Corp. 2160 Clay Street Denver, CO 80211	

See page B-9 for footnotes

APPENDIX B[1] (Continued)

Classification[2]	Component	Description	Trade Name	Manufacturer	Thermal Characteristics from Manufacturer's Information[3,4]
S/GM	Sunspace	Pre-cut redwood frame, hardware, glass base, roof vent included	Sturdi-Built Lean-T_o models	Sturdi-Built Manufacturing Co. 11304 S.W. Boones Ferry Rd. Portland, OR 97219	
S/GM	Sunspace	Glazing is two layers of high impact acrylic with a dead air space between them. All units include automatic power ventilation and aluminum bench framework.	Sunglo Lean-T_o models	Sunglo Solar Greenhouses 4441 26th Ave. W Seattle, WA 98199	
S/GM	Sunspace	Includes double glazing, insulated walls and ceiling, quarry-tile floor, automatic ventilation system, insulated casement windows. Options include rock or eutectic salt thermal mass for heat storage.	Sun Haus Solarium	Weather Energy Systems Inc. 39 Barlows Landing Rd. Pocasset, NA 02559	R = 11 fiberglass insulation in walls R = 19 fiberglass insulation in ceiling
S/GM	Sunspace	Includes covering material, either polyethylene or flat Lascolite fiberglass, supported by Galvalume steel framework, with aluminum fastners, manual vent and door. Automatic vent systems may be ordered.	Turner Leanto	Turner Greehnouses P.O. Box 1260 Highway 117 South Goldsboro, NC 27530	
S/GM	Sunspace	Includes ice-clear acrylic/fiberglass reinforced rigid panels permanantly bonded to a supporting aluminum grid core, aluminum extrusions for arches, purlins, base channels; stainless steel hardware and PVC gaskets. GE-Lexan window clear panels and vent system may be ordered.	Vegetable Factory Lean-T_o models	Vegetable Factory, Inc. 100 Court St. Copiague, NY 11726	

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APPENDIX B[1] (Continued)

Classification[2]	Component	Description	Trade Name	Manufacturer	Thermal Characteristics from Manufacturer's Information[3,4]
PSWH-DCT	Thermosyphon solar water heating system	Includes a 66 gallon glass lined tank with integral heat exchanger, two 17 square foot glazed solar collectors, expansion tank and pressure valve.	The Domestic Solar Water Heater	Zomeworks Corporation P.O. Box 712 Albuquerque, NM 87103	
PSWH-IS	Batch integrated collector/ storage water heater	A 30 gallon water tank coated with high absorptance paint in an insulated enclosure with plastic glazing and reflective sides. A temperature-pressure relief valve is provided.	Summersun	Solar American Co. 106 Sherwood Dr. Williamsburg, VA 23185	
TSU	Ceiling tile with phase change material	Suspended 2 square foot reinforced lightweight polymer concrete ceiling tile with a core of anhydrous sodium sulfate (glauber salts)	Sol-ar-tile	Architectural Research Corporation Solar Group 13030 Wayne Road Livonia, MI 48150	Heat storage capacity = 220 Btu/ft^2 (each tile 2' x 2')

Notes: 1 Additional passive solar products are identified in references 15-17.

2 No passive solar components are listed for DGFS-AFW, TSC, RCM, GCM or RPM.

3 Manufacturer's data has not been verified in this study. Data as reported is not necessarily for comparible conditions.

4 Thermal characteristics are:

U_o = overall heat transmission coefficient based on indoor-outdoor air temperature difference (Btu/hr·ft^2·°F)

R = thermal resistance of the component based on surface-to-surface temperature difference (hr·ft^2·°F/Btu)

SC = shading coefficient, the ratio of the sum of solar transmission and fraction of absorbed solar convected and radiated indoors to the sum for a double strength 1/8" thick single glazing (dimensionless).

APPENDIX C

COMMERCIAL FACILITIES FOR THERMAL PERFORMANCE TESTING

Table C.1 summarizes the referenced test methods listed in table 2 of section 3. The published sources of information which can be used to locate testing laboratories qualified to perform some of the tests are listed in the footnotes to table C.1. The reader should be familiar with the related discussions in the text to understand the limitations of the test method as applied to passive solar products. These listings are for those laboratories that meet the qualification criteria for accreditation and demonstrate the capability to perform the tests by virtue of their trained personnel, equipment and required docmentation. These are not certification programs.

One of the National Voluntary Laboratory Accreditation Programs (NVLAP) is for thermal insulation; the list of test methods for which a laboratory may be accredited includes some of the test methods discussed in this report as applicable to passive products. A cross-index for locating accredited laboratories is given in the October 17, 1979 FEDERAL REGISTER. The NVLAP Thermal Insulation Program Plan also specifies that the listing of accredited laboratories (and the test methods they are accredited for) will be updated annually each October. The current requirements for laboratory qualifications criteria for accreditation in the program can be found in the January 23, 1980 FEDERAL REGISTER, which also discusses the development and philosophy of the program.

The listing in reference [B] is the result of a survey to locate laboratories qualified to perform the ASHRAE 93-77 test on solar collectors, including laboratories having the capability for performing the tests with a solar simulator.

The ASTM Directory of Standards Laboratories is more general than the published lists just cited and does not itemize the individual test methods. Rather the approach is to give a general category of tests which the laboratory is qualified to perform. It does not mention every applicable test article, nor every test possible; only direct query of each laboratory can supply such information. Using the directory as a screening tool, the user should be able to select one or more laboratories that provide the desired testing services.

For completeness, all the test methods reviewed in this paper, including those for which there is no published list of laboratories capable of performing the tests, are listed in table C.1.

TABLE C.1 PUBLISHED SOURCES OF LABORATORIES QUALIFIED TO TEST IN ACCORDANCE WITH REFERENCED PROCEDURES

TEST METHOD IDENTIFICATION METHOD	APPARATUS	SAMPLE	PUBLISHED SOURCE (see footnotes)	
			a/	c/
THERMAL TRANSMISSION				
ASTM C 177	Guarded Hot Plate	Homogeneous Dielectrics	A,	C
ASTM C 182	Guarded Calorimeter	Insulation Firebrick		C
ASTM C 201	Guarded Calorimeter	Refactories		C
ASTM C 202	Guarded Calorimeter	Refactory Brick		C
ASTM C 335	Hot Pipe with Guarded Ends	Pipe Insulation	A,	C
ASTM C 408	Cylindrical Heated Bar	Ceramics, Metals		C
ASTM C 518	Heat Flow Meter	Insulation and Dielectrics	A,	C
ASTM C 653	Guarded Hot Plate or Heat Flow Meter	Insulation Batts and Blankets	A,	C
ASTM C 687	Heat Flow Meter	Loose Fill Insulation	A,	C
ASTM C 691	Hot Pipe with Guarded Ends	Non-Homogeneous Pipe Insulation		C
ASTM C 745	Guarded Flat Plate, Boil off Calorimeter	Evacuated Multi-Layer Insulations		C
ASTM C 855	Guarded Hot Plate	Roof Insulation		C
ASTM D1518	Guarded Hot Plate	Fabrics, Layered Assemblies, Batting		C
ASTM D2717	Thermal Conductivity Cell with Platinum in-line Heater	Liquids		C
ASTM C 236	Guarded Hot Box	Non-Homogeneous Building Envelope Sections	A,	C
AAMA 1502.6	Calibrated Thermal Chamber	Windows and Sliding Glass Doors		
ASTM E 283	Sealed Air Chamber	Windows		C
SOLAR OPTICAL AND THERMAL RADIATION				
ASHRAE 74-73	Solar Sensor in Black Enclosure	Solid Disc		
ASTM E 424	Spectrophotometer and Integrating Sphere or Pyranometer in Black Enclosure Behind Sample	Solid Sheet or Disc		C
ASTM E 434	Solar Simulator and Vacuum Chamber with Cold Shroud	Solid Sheet		C
ASTM C 408	Portable Emissometer	Coatings, Finishings		C
ASTM C 445	Heated Cavity Reflectometer	Coatings, Finishings		
THERMAL STORAGE				
ASTM C 351	Drop Method of Mixtures Calorimeter	Insulation		C
ASTM D2766	Slug Calorimeter and Constant Heat Source	Liquids and Solids		C
ASTM E 457	Slug Calorimeter and Constant Heat Source	Solids, Large Samples		C
SOLAR COLLECTORS, WATER HEATING SYSTEMS, AND THERMAL STORAGE ASSEMBLIES				
			b/	
ASHRAE 93-77		Solar Collector	B	
BSE (German)		Solar Collector		
ASHRAE 95-P		DHW Package System		
ASHRAE 94-77		Thermal Storage Assembly		

a/ [A] FEDERAL REGISTER, October 14, 1979, Vol. 44, No. 202, "National Voluntary Laboratory Accreditation Program: Report of Accreditation Procedures"

b/ [B] NBSIR 78-1535, "Laboratories Technically Qualified to Test Solar Collectors in Accordance with ASHRAE Standard 93-77: A Summary Report", (Nov. 78).

c/ [C] ASTM Directory of Testing Laboratories, STP 333D, 04-333040-32, ASTM, 1916 Race St., Philadelphia, PA 19103.

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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*)

As part of a continuing program to develop standard test procedures to measure thermal performance of solar heating and cooling equipment, NBS has developed a plan and methodology that will be utilized for passive/hybrid solar components. A survey of passive solar products currently available or under development enabled the development of an interim classification system consisting of ten component classifications for purposes of thermal testing. A survey of currently available thermal test procedures was performed to assess the applicability of these test methods for passive/hybrid solar components. Existing test procedures that are useful for the Direct Gain Fenestration System classification are identified, and recommendations are made for evaluation of these laboratory-based procedures by comparison with field-based testing of components under controlled interior conditions. Recommendations are also made for the development of new test procedures for passive/hybrid components classifications for which existing test methods are not applicable. A proposed program to develop testing procedures for the Storage Wall Module classification is provided.

12. KEY WORDS (*Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons*)

passive/hybrid components; solar energy; steady-state tests; thermal test procedures; transient thermal tests.

13. AVAILABILITY

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