ANSI/ASHRAE Standard 95-1981(RA87) (W)

Intent to Withdraw

Methods of Testing to Determine the Thermal Performance of Solar Domestic Water Heating Systems

First Withdrawal Review (October 2024)

This standard will be submitted to the American National Standards Institute Board of Standards Review (BSR) with a notice of Intent-to-Withdraw.

This intent-to-withdraw draft has been recommended for public review by the cognizant technical committee and approved by a subcommittee of the Standards Committee. To submit a comment on this proposed withdrawal, go to the ASHRAE website at http://www.ashrae.org/technology/page/331 and access the online comment database. The draft is subject to modification until it is approved for publication by the ASHRAE Board of Directors and ANSI. Until this time, the current edition of the standard (as modified by any published addenda on the ASHRAE Web site) remains in effect. The current edition of any standard may be purchased from the ASHRAE Bookstore at www.ashrae.org or by calling 404-636-8400 or 1-800-527-4723 (for orders in the U.S. or Canada).

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CONTENTS

ASHRAE Standard 95-1987, Methods of Testing to Determine the Thermal Performance of Solar Domestic Water Heating Systems

NOTE

Approved addenda, errata, or interpretations for this standard can be downloaded free of charge from the ASHRAE Web site at www.ashrae.org/technology.

This Foreword is not part of this Standard but is included for information purposes only.

FOREWORD

This Standard falls under the Standards Committee classification of a standard method of measurement or test. It was prepared by Standards Project Committee 95P, formed in February 1977, and it was approved for publication by the Board of Directors on July 2, 1981. ANSI approved it as an American National Standard on December 17, 1981.

The 1981 Standard was recommended for reaffirmation with minor editorial changes by the Standards Committee on April 18, 1986. Since the ASHRAE Journal intent-to-reaffirm notice elicited no negative comments, the Board of Directors approved the reaffirmation with minor editorial changes on July 2, 1987.

Although the performance of some solar domestic water heating systems can be approximately predicted based on the thermal characteristics of their collector array and J storage tanks, it is also affected by the interconnecting piping, control equipment, and interactions between the components. Consequently, a standard test is outlined for the complete system.

It became apparent early in the deliberations of the Committee that testing a completely assembled system with the collector array irradiated was only feasible using a solar simulator. Since such simulators are not yet widely avail-able, an alternate method has been allowed. Under the alternate method, the collector is first tested separately in accordance with ASHRAE Standard 93-1986. Using these data, the thermal output of the collector array in the solar domestic hot water system is calculated for test conditions and input to the system by using a combination of the non-irradiated collector array and a conventional energy source in the test loop.

This Standard specifies the method of testing the solar domestic hot water system but does not specify the test conditions to be used for obtaining a standard rating. This is normally done in a rating standard which should be developed at a later time by a separate organization such as an industry association.

The Committee remained concerned throughout its deliberations about the potentially large costs for conducting the tests. It is hoped that research completed in the near future will indicate how the tests can be shortened and/or replaced by calculations.

NOMENCLATURE

A_a = collector module aperture area, m^2 (ft^2)

$\frac{A_a}{A_g} F_R(\tau\alpha)_{e,n}$ = intercept of the collector efficiency curve determined in accordance with ASHRAE Standard 93-1986, dimensionless

$\frac{A_a}{A_g} F_R U_L$ = slope of the collector efficiency curve determined in accordance with ASHRAE Standard 93-1986, $W/(m^2 \cdot °C)$ 1Btu/(hr·ft²·°F)]

A_g = gross collector area, m^2 (ft^2)

$c_{p,c}$ = specific heat of the transfer fluid used in the collector during the ASHRAE Standard 93-1986 tests, kJ/(kg·°C) [Btu/(lb·°F)]

$c_{p,s}$ = specific heat of the transfer fluid used in the collector during the solar hot water system test, kJ/(kg· °C) [Btu/(lb·°F)]

$c_{p,w}$ = specific heat of water, kJ/(kg·°C) [Btu/(lb·°F)]

D = nozzle throat diameter, m (ft)

e = fractional energy savings, dimensionless

F' = collector absorber plate efficiency factor, dimensionless

F_R = collector heat removal factor, dimensionless

I' = total (global) irradiance incident upon the aperture plane of the collector, W/m^2 [$Btu/(hr \cdot ft^2)$]

$K_{\alpha\tau}$ = incident angle modifier, dimensionless

M = number of rows of collector modules in parallel in the collector array, dimensionless

$\dot{m}_c$ = mass flow rate of the transfer fluid through the collector during the ASHRAE Standard 93-1986 tests, kg/s (lb/hr)

m_j = the mass of the j^{th} withdrawal of water, kg (lb)

$\dot{m}_s$ = mess flow rate of the transfer fluid through the collector array during the solar hot water system test, kg/s (lb/hr)

N = number of collector modules in series in each parallel row in the collector array, dimensionless

Q_{AUX} = daily energy consumed for auxiliary heating in the solar hot water system, kJ (Btu)

Q_{CON} = daily energy consumed for heating in the conventional domestic water heater chosen for comparison and used to calculate e, kJ (Btu)

Q_L = daily system hot water load defined as the product of the mass, specific heat, and temperature increase of the water as it passes through the solar hot water system, kJ (Btu)

$\dot{Q}_{\ell h}$ = rate of energy output from the collector loop heater in series with the non-irradiated solar collector array (if used), W(Btu/hr)

Q_{PAR} = daily energy consumed for parasitic power by pumps, controls, solenoid valves, etc. in thethe solar hot water system, kJ (Btu)

Q_{OUTPUT} = energy output from the collector loop heater (if used) during the test, Wh (Btu)

Q_s = daily net energy output from the solar collector and solar storage parts of the solar hot water system, kJ(Btu)

$\dot{Q}_u$ = rate of useful heat output from the collector, W (Btu/hr)

sf = fraction of hot water load supplied by solar energy, dimensionless

t_a = ambient air temperature, ºC (ºF)

$t_{a,\ell}$ = ambient air temperature in the laboratory during the system test, ºC (ºF)

$t_{a,t}$ = ambient air temperature specified for the test solar day, ºC (ºF)

$t_{f,i}$ = temperature of the transfer fluid entering the collector, ºC (ºF)

$t_{f,e}$ = temperature of the transfer fluid leaving the collector, ºC (ºF)

t_i = mixed temperature of the water withdrawn from the solar hot water system, ºC (ºF)

$t_{p,m}$ = mean plate temperature of the collector absorber, ºC (ºF)

$t_{p,m,non}$ = mean plate temperature of the collector absorber under non-irridated conditions, ºC (ºF)

t_{set} = ultimate desired hot water delivery temperature after the addition of supplemental energy, ºC (ºF)

$t_{w,j}$ = mixed temperature of the j^{th} withdrawal of water, ºC (ºF)

t_{main} = temperature of the incoming cold water supply to the solar hot water system, ºC (ºF)

U_L = collector heat transfer loss coefficient, W/(m^2·ºC) [Btu/(hr·ft^2·ºF)]

α_n = absorptance of the collector absorber coating to the solar spectrum at normal incidence, dimensionless

θ = angle of incidence between the direct solar beam and the normal to the collector aperture, deg

ς_d = specular reflectance of the cover plate assembly at an incident angle of 60º, dimensionless

τ_n = transmittance of the cover plate assembly to the solar spectrum at normal incidence, dimensionless

$(\tau\alpha)_{e,n}$ = effective transmittance-absorptance product for the collector at normal incidence, dimensionless

$\sum_{j=1}^{v}$ = represents a summation over all water withdrawal periods during a test day

1. PURPOSE

1.1 The purpose of this Standard is to establish a uniform method of testing solar domestic water heating systems for thermal performance.

1.2 This Standard is not intended to be used for testing the individual components of the system.

1.3 This Standard is not intended to abridge any safety or health requirements.

2. SCOPE

2.1 This Standard applies to solar domestic water heating systems designed to heat potable water to be supplied for domestic water usage.

2.1.1 This Standard is not intended for other than solar water heating systems designed solely for domestic water usage.

2.1.2 The test procedures in this Standard are generally applicable to systems of 0.45 m^3 (120 gal) storage capacity or less, and use demands on the order of 0.38 m^3 (100 gal) of hot water per day, or less.

2.1.3 The test procedures in this Standard employing a non-irradiated solar collector array do not apply to an integral collector storage system, a system in which thermosyphon flow occurs, or to any system employing a collector/heat transfer fluid combination which cannot be tested in accordance with ASHRAE Standard 93-1986.[1]

2.1.4 The test procedures in this Standard do not re-quire the solar water heating system to be subjected to freezing conditions. Consequently, the energy consumed or lost by a system while operating in the freeze protection mode will not be determined.

2.2 This Standard provides the method of testing such systems for thermal performance.

3. DEFINITIONS

accuracy: the ability of an instrument to indicate the true value of the measured physical quantity.

***ambient air*:** air in the space surrounding the thermal energy storage device or solar collectors, whichever is applicable.

***angle of incidence*:** the angle between the solar beam and the normal to the aperture plane of the solar collector.

***aperture plane*:** the projected plane at or above the solar collector through which the unconcentrated solar radiation is admitted.

***area, gross collector*:** the maximum projected area of the completed solar collected module exclusive of integral mounting means and liquid connectors. For an array of collectors, gross area includes the entire area of the array.

***auxiliary energy*:** see *auxiliary thermal source*.

***auxiliary fuel*:** that fuel used in an auxiliary thermal source.

***auxiliary thermal source*:** a source of thermal energy, other than solar, used to provide the service water heating; usually in the form of electrical resistance heat or thermal energy derived from combustion of fossil fuels.

***beam irradiance*:** irradiance received from the sun without significant change of direction from the sun's apparent position.

***collector, concentrating*:** a solar collector which uses reflectors, lenses, or other optical elements to redirect and possibly concentrate the solar radiation passing through the aperture onto an absorber of which the surface area may be smaller than the aperture area.

***collector, flat-plate*:** a non-concentrating solar collector in which the absorbing surface is essentially planar.

***collector loop heater*:** a heater installed within the collector loop when testing the solar domestic water heating system with a non-irradiated array.

***components*:** parts of the solar hot water system including but not limited to collectors, storage, pumps, etc.

***control*:** any device for regulation of the solar hot water system or component in normal operation, manual or automatic.

***domestic*:** refers to use in residential and small commercial buildings.

***drain back*:** refers to systems in which the fluid in the solar collectors is allowed to drain back to storage whenever solar energy is not being collected, i.e., the fluid circulating pump is not operating.

***drain down*:** refers to systems in which the fluid in the solar collectors is drained from the system under prescribed circumstances.

draw rate: see *water draw rate*.

equivalent length: the length of a straight section of pipe or duct causing the same pressure drop as actually occurs within the system at the same flow rate.

fluid transport: the transfer of air, water, or other fluid between components.

fractional energy savings: that fraction of energy used by a conventional domestic water heating system that is saved by using the solar system.

heat exchanger: a device specifically designed to transfer heat between two physically separated fluids. Heat exchangers can have either single or double walls.

incident angle: the angle between the outward drawn nor-mal to the solar collector aperture plane and the solar beam.

insolation: solar radiation incident on the solar collector.

irradiance, instantaneous: the quantity of solar radiation incident on a unit surface area in unit time.

irradiance, integrated average: the solar radiation incident on a unit surface area during a specific time period divided by the duration of that time period.

outside air: external air; the atmosphere exterior to the building.

potable: suitable for human consumption.

precision: the measure of the closeness of agreement among repeated measurements of the same physical quantity.

preheating: to heat the water prior to heating by the auxiliary thermal source.

pressure-temperature relief device: an automatic pressure and temperature sensitive device actuated by a predetermined internal pressure, or temperature, or both, and in-tended to prevent or relieve excessive pressure or temperature within a tank.

pyranometer: a radiometer used to measure the total (global) irradiance incident upon a surface. This energy includes the beam irradiance, the diffuse sky irradiance, and irradiance reflected from the foreground.

pyrheliometer: a radiometer used to measure the beam irradiance on a surface normal to the sun's rays.

service water heating: the supply of hot water for domestic or commercial purposes other than space heating.

solar collector: a device designed to absorb incident solar radiation and to transfer the energy to a fluid passing through it.

solar energy: thermal energy derived directly from the sun's rays, both as diffuse and beam radiation (excludes indirect methods such as photosynthesis, wind, etc.).

solar fraction: the fraction of the hot water load supplied by solar energy.

solar radiation: the transmission of radiant energy from the sun.

solar simulator: a source of radiant energy simulating the solar radiation.

solar time: the time of the day as indicated by the apparent position of the sun. Solar noon is that instant at which the sun reaches the maximum altitude at any given location.

solar hot water system: a system bounded such that the sole inputs are solar radiation, cold water supply, and if applicable, auxiliary thermal energy and energy for pumps and blowers. Its sole outputs are heated water and system heat losses. The system includes, as a minimum, the collector and storage and when used the piping, control valves, expansion tank, heat exchangers, pumps, blowers, mixing valve, and auxiliary thermal source.

stagnation temperature: the maximum temperature attained in the solar collector under conditions of no flow and with conditions of maximum irradiance and ambient temperature.

standard air: air weighing 1.2 kg/m^3 (0.075 lb/ft^3) which approximates dry air at a temperature of 21.1°C (70°F) and a barometric pressure of 1.01 E + 05 Pa (29.92 in. of Hg).

standard barometric pressure: the barometric pressure of 1.01 E + 05 Pa [29.92 in. of Hg at 0°C (32°F)].

standby condition: the condition of operation in which no energy is deliberately being put in or withdrawn from the tank.

storage device: the container(s) plus all contents of the container(s) used for storing thermal energy. The transfer fluid and accessories such as heat exchangers, flow switching devices, valves, and baffles which are firmly fixed to the thermal storage container(s) are considered a part of the storage device. The container is usually a tank storing hot water.

system: a combination of equipment and/or controls, accessories, interconnecting means, and terminal elements by which energy is transformed so as to perform a specific function, such as water heating.

tank capacity: the measured volume of the fluid in the tank when full and at ambient temperature.

temperature, ambient air: the temperature of the air surrounding the thermal energy storage device or solar collectors being tested.

tilt angle: the angle between the aperture plane of the solar collector and the horizontal.

time constant: the time required for a first order system to have its output change by 63.2970 of its final change in output following a step change in its input.

transfer fluid: the fluid that carries energy in and out of the storage device.

thermopile: a number of thermocouples wired consistently in series or parallel to measure small or average temperature differences.

water draw rate: the rate at which the hot water is withdrawn from the system over a specified period at a specified time.

4. CLASSIFICATIONS

4.1 In this Standard, solar domestic hot water systems are classified:

4.1.1 According to their ability to be combined with non-solar sources of energy; and

4.1.2 According to the relationship of their various components.

4.2 There are three basic classifications according to their ability to be combined with non-solar sources of energy.

4.2.1 Solar-Only System. A solar-only system is a system designed to provide solar heated domestic water directly to the plumbing system without the use of non-solar energy sources other than that required for fluid transport and control functions.

4.2.2 Solar-Preheat System. A solar-preheat system is a system designed to supply preheated water to a conventional water heater which is separately furnished and not part of the system.

4.2.3 Solar-Plus-Supplemental System. Asolar-plus-supplemental system is a system designed to utilize both solar and non-solar energy sources. The non-solar energy source can be integral with the principal solar storage tank, or can be provided through a separate heat exchanger or separate water heater.

4.3 Solar hot water systems are also classified into three categories, according to the relationship between solar collector and storage. Some are further classified according to the method by which they provide protection against freezing.

4.3.1 Integral Collector-Storage System. An integral collector-storage system is a system which has the storage within the collector, directly exposed to solar radiation.

4.3.2 Thermosyphon System. A thermosyphon system is a system which utilizes only the change in density of the fluid at various temperatures to cause circulation of fluid between the collector and the storage.

4.3.3 Forced Circulation System. A forced circulation system is a system which utilizes mechanical means to circulate fluid through the collector.

4.3.3.1 Direct Forced Circulation System. A direct forced circulation system is a system which circulates the potable water through both the collector and storage tank.

4.3.3.2 Indirect Forced Circulation System. An indirect forced circulation system is a system which provides separation between the collector fluid and the potable water.

5. REQUIREMENTS

5.1 Solar domestic hot water systems shall be tested in accordance with the provisions set forth in this Section and in Section 8.

5.1.1 Installation Requirements. Tests shall be performed with the system components installed in accordance with manufacturer-published installation instructions. If the collectors are normally mounted remote from the storage, the tests shall be performed with the total connecting pipe length between the storage tank and the collectors equal to 15 m (50 ft), 7.5 m (25 ft) in both the supply and return lines. In the case of an air collector array, the total duct length shall be the maximum specified by the manufacturer and the total of the duct and pipe length shall be equal to 15 m (50 ft). The connection piping and ducting shall be insulated in accordance with the manufacturer's installation instructions. The collectors shall be mounted at the tilt angle specified in an associated rating standard. If the system is to be tested using a non-irradiated solar collector array, a black radiation shield shall be mounted approximately 0.6 m (2 ft) above the collector array and extend approximately 0.6 m (2 ft) beyond the perimeter on all sides. The shield shall consist of very low thermal capacity/insulative capacity material (i.e., poster board).

5.1.2 Solar Collector Performance. If the system is to be tested using a non-irradiated solar collector array, then the collector which is to be used with the solar water heater components to be tested shall have been tested in accordance with ASHRAE Standard 93-1986.[1]

5.1.3 Solar Conditions. The incident solar radiation conditions to be used in the test shall be as specified for the test solar day. (See Table Bl, Appendix B for an example of what may be specified in an associated rating standard.)

5.1.4 Ambient Air Temperatures

5.1.4.1 The average ambient air temperature surrounding the collector array to be used in the test shall be specified for the test solar day. (See Table Bl, Appendix B for an example of what may be specified in an associated rating standard.)

5.1.4.2 The average ambient air temperature at the storage tank and components during the test shall be controlled to a value specified in an associated rating standard +2°C (+3.6°F) on a continuous 24 hour basis. (See Table B2, Appendix B for an example.)

5.1.5 Input Water Temperature. The water supply temperature to the system shall be controlled to t_{main} (specified in an associated rating standard) within +1°C (+1.8°F).

5.1.6 Water Draw. Water shall be withdrawn at times and rates as specified in an associated rating standard. (See Table B2, Appendix B for an example.)

6. INSTRUMENTATION

6.1 Solar Radiation Measurement (required when using a solar simulator)

6.1.1 A pyranometer shall be used to measure the total (global) irradiance and a pyrheliometer shall be used to measure the beam irradiance. The instruments shall have the following minimum characteristics, which are consistent with current practice and/or the requirements of a first class pyranometer or pyrheliometer as classified by the World Meteorological Organization (WMO).[2, 3, 4]

6.1.1.1 Change of Response Due to Variation in Ambient Temperature. The instruments shall be equipped with a built-in temperature compensation circuit and have a temperature sensitivity of less than ±1% over the range –20 to +40°C (–40 to +104°F).

6.1.1.2 Variation in Spectral Response. Pyranometer and pyrheliometer errors caused by a departure from the required spectral response of the sensor shall not exceed ±2% over the range of interest. The WMO specification for a first class pyranometer is ±1%.

6.1.1.3 Nonlinearity of Response. Unless the pyranometer was supplied with a calibration curve relating the output to the irradiance, its response shall be within ±1%

of being linear over the range of irradiance existing during the tests.

6.1.1.4 Time Response of Pyranometer and Pyrheliometer. The time constant of the pyranometer shall be less than 5 s. The time constant for the pyrheliometer shall be less than 25 s.

6.1.1.5 Variation of Response with Angle of Incidence. Ideally the response of the pyranometer is proportional to the cosine of the incident angle and is constant at all azimuth angles. The pyranometer's deviation from a true cosine response shall be less than ±1% for the incident angles encountered during the test(s).

6.1.1.6 Precautions for Effects of Humidity and Moisture. The pyranometer shall be provided with a means of preventing accumulation of moisture that may condense on surfaces within the instrument and affect its reading. An instrument with a desiccator that can be inspected is required. The condition of the desiccator should be observed prior to and following any daily measurement sequence.

6.1.2 The pyranometer shall be calibrated for solar response within 12 months preceding the test(s) against another pyranometer whose calibration uncertainty relative to recognized measurement standards is known. The calibration should account for tilt angle effects. Any change of more than ±1% over a year period shall warrant the use of more frequent calibration or replacement of the instrument. If the instrument is damaged in any significant manner, it shall be recalibrated or replaced.

6.1.3 Mounting of Pyranometer. The pyranometer shall be mounted such that its sensor is coplanar with the plane of the collector aperture. It shall not cast a shadow onto the collector aperture at any time during the test period. The pyranometer shall not be mounted so as to receive a percentage of radiation that is disproportionate with that received by the collector. It is recommended that the pyranometer be mounted near the upper half periphery of the collector, and in the upper center for the collector array. The pyranometer should be oriented so that the emerging leads or the connector are shaded to minimize solar heating of the electrical connections. Care should be taken to minimize reflected and reradiated energy from the solar collector onto the pyranometer. Some pyranometers are supplied with shields. Pyranometers not supplied with a shield may be susceptible to error due to reflections of radiation that originate below the plane of the detector.

6.1.4 Determination of Direct and Diffuse Component of Radiation. If the solar collector used in the system is a concentrating type, a normal incidence pyrheliometer is required to be used to determine the beam irradiance. If a non-concentrating solar collector is used, two pyranometers may be used, one of which uses a shading bands to determine the diffuse irradiance and hence indirectly obtain the beam irradiance.

6.2 Temperature Measurement

6.2.1 Reference. Temperature measurements shall be made in accordance with ASHRAE Standard 41.1-1986.[5]

6.2.2 Accuracy and Precision. The accuracy and precision of the instruments including their associated readout devices shall be within the limits as follows:

	Instrument Accuracy	Instrument Precision
Temperature	±0.5°C (±0.9°F)	±0.2°C (±0.36°F)
Temperature Difference Across Collector (and Loop Heater if used)	±0.1°C (±0.18°F)	±0.1°C (±0.18°F)
Temperature Difference Across Hot Water System (Entering Cold Water to Leaving Hot Water)	± 0.5°C(± 0.9°F)	±0.2°C (±0.36°F)

6.2.3 Scale Division. In no case shall the smallest scale division of the instrument or instrument system exceed 2 times the specified precision. For example, if the specified precision is ±0.1°C (±0.18°F), the smallest scale division shall not exceed 0.2°C (0.36°F).

6.2.4 Ambient Temperature. The ambient air temperature shall be measured approximately 1.2 m (4 ft) from the floor and not closer than 1.5 m (5 ft) to the tank and system components.

6.2.5 Temperature Difference. Temperature difference between the entering and leaving fluids where required may be measured with any of the following:

a. A type-T thermopile.
b. Calibrated resistance thermometers.
c. Precision thermometers.
d. Calibrated thermistors.
e. Calibrated type-T thermocouples.
f. Quartz thermometers.

6.2.6 Thermopile Construction. If a thermopile is used, it shall be made from calibrated thermocouple wire taken from a single spool. Extension wires to the recording device shall also be made from that same spool. The wire diameter must be no larger than 0.51 mm (24 AWG).

6.3 Liquid Flow Measurements

6.3.1 The accuracy of the liquid flow rate measurement, using the calibration if furnished, shall be equal to or better than ±1.0% of the measured value in mass units per unit time.

Summary of Performance Specifications for Solar Radiometers

	Sensitivity, mW/cm^2	Stability, %	Temperature Compensation, %	Spectral Selectivity, %	Linearity, %	Time Constant	Cosine Response, %
Pyrheliometer	± 0.4	±1.0	±1.0	±2.0	±1.0	<25 s	—
Pyranometer	±0.1	±1.0	±1.0	±2.0	±1.0	<5 s	±1.0

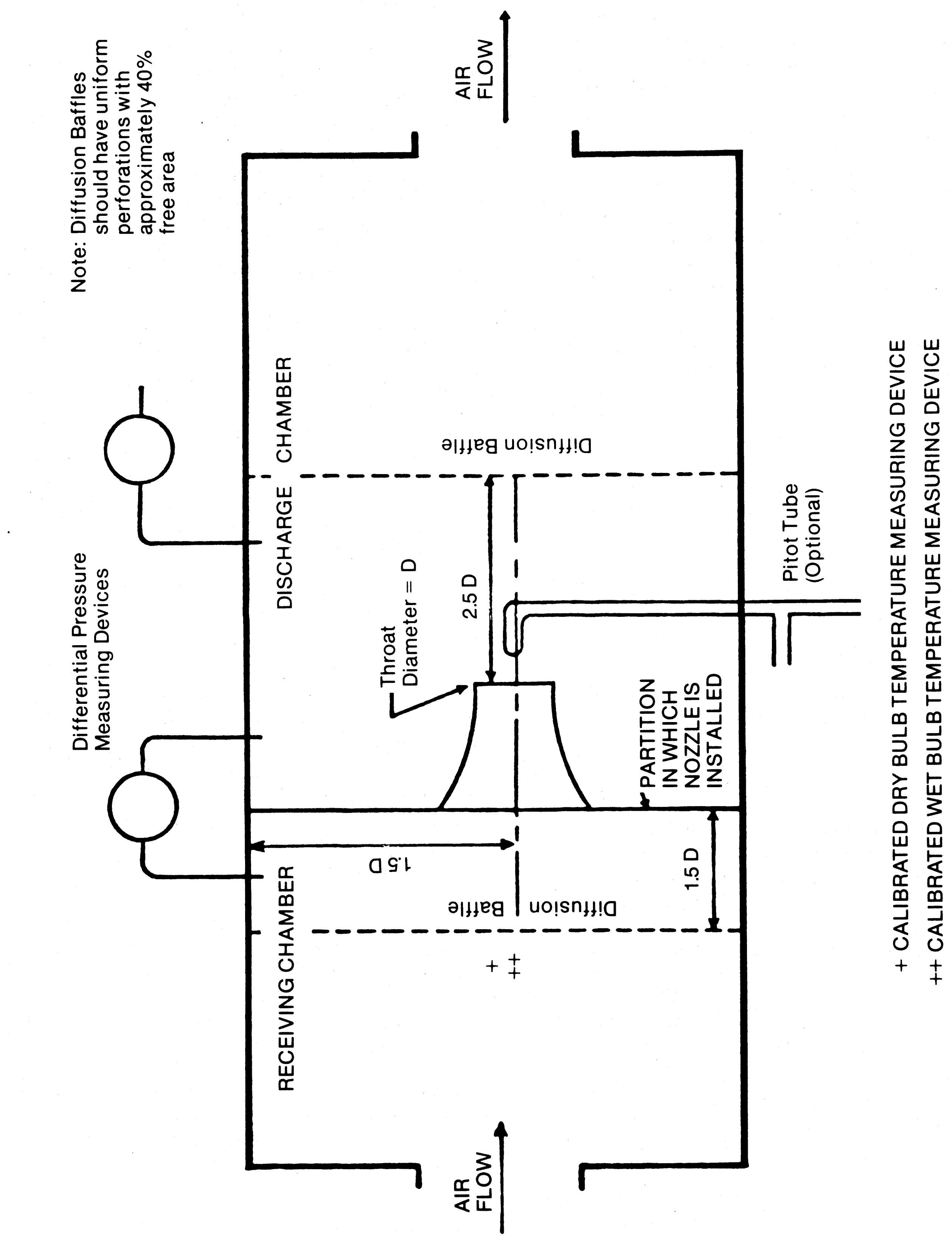

Figure 1 Nozzle Apparatus for Measuring Air Flow Rate

6.4 Air Flow Measurements. If the collector is an air heater and the test is being conducted with a non-irradiated array, the air flow in the collector loop shall be measured with the nozzle apparatus described in Section 5.1 of ASHRAE Standard 70-72[6] or in Section 7 of ASHRAE Standard 37-1978[7] or a device of equivalent accuracy. As shown in Figure 1, this apparatus consists basically of a receiving chamber, a discharge chamber, and an air flow measuring nozzle. The distance from the center of the nozzle to the side walls shall not be less than 1.5 times the nozzle throat diameter, and the diffusion baffles shall be installed in the receiving chamber at least 1.5 nozzle throat diameters upstream of the nozzle. The apparatus shall be designed so that the nozzle can be easily changed and the nozzle used on each test shall be selected so that the throat velocity is between 15 m/s (2960 ft/min) and 35 m/s (6900 ft/min). Details on nozzle construction and discharge coefficients are contained in Section 5.1.1 of ASHRAE Standard 70-72.[6]

The dry-bulb and the wet-bulb temperature of the air entering the nozzle shall be measured in accordance with ASHRAE Standard 41.1-1986.[5] The velocity of the air passing through the nozzle shall be determined by either measuring the velocity head with a commercially available Pitot tube or by measuring the static pressure drop across the nozzle with a differential pressure measuring device. If the latter method is used, one end of the device shall be connected to a static pressure tap located flush with the inner wall of the receiving chamber and the other end to a static pressure tap located flush with the inner wall of the discharge chamber or, preferably, several taps in each chamber shall be connected through a manifold to a single differential pressure measuring device. A means shall also be provided for measuring the absolute pressure of the air in the nozzle throat.

6.5 Pressure Measurement

6.5.1 Nozzle Throat Pressure. The pressure measurement at the nozzle throat shall be made with instruments accurate to within + 2.0% of the absolute pressure measured and whose smallest scale division shall not exceed 2 times the specified accuracy.

6.5.2 Air Flow Measurements. The static pressure across the nozzle and the velocity pressure at the nozzle throat shall be measured with instruments that have been calibrated and are accurate to within ±1.0% of the reading.

6.6 Electric Energy. The electrical energy used shall be measured with an instrument and associated readout devices that are accurate to within ±1.0% To of the reading or 15 Wh whichever is greater.

6.7 Fossil Fuels. The quantity of fuel used for auxiliary energy by the solar hot water system shall be measured with an instrument and associated readout device that is accurate within ±1.0% of the reading.

6.8 Mass Measurements. Mass measurement shall be made with an accuracy of ±1.0%.

7. APPARATUS

7.1 Test Configurations. The test configuration to be utilized is to be determined by the classification of the system as described in Section 4. Representative test configurations are shown in Figures 2 and 3 for the case where a non-irradiated collector array is used and the collector loop heater is downstream of the non-irradiated collector array. The purpose of the by-pass loop is to circulate the transfer fluid through the collector loop heater during those times when solar irradiation occurs but the solar domestic hot water system controller does not require the collector loop pump to be on. The by-pass loop pump should not operate when the collector loop is on. For the case where a solar simulator is used, the heater and by-pass loop shown in the solar collector loop of Figures 2 and 3 shall not be used.

7.2 Test Environment. All equipment shall be mounted indoors. Ambient conditions are specified in Section 5.

7.3 Storage Tank Mounting. When provided as a separate component, the storage tank(s) shall be placed upon a 3/4-in. thick plywood platform supported by 2 × 4 runners.

7.4 Water Supply. The water supply shall be capable of delivering water at conditions as specified in Section 5.

7.5 Water Inlet and Outlet Configuration. The cold water inlet and hot water outlet piping to and from the system being tested shall be turned to a horizontal position in the shortest possible vertical distance practical when the fittings are in a vertical plane. The hot water outlet shall be provided with a quick-acting valve located beyond the point of temperature measurement and as close to the tank as possible.

7.6 Insulation of Piping. Inlet and outlet connections and all piping to the point of temperature measurement in the system being tested shall be insulated with a material having a thermal resistance, R. not less than 0.70 $°C \cdot m^2/W$ [4.0 $(hr \cdot ft^2 \cdot °F/Btu)$] based on the area of pipe surface.

7.7 Flow Control. A flow control valve shall be installed to provide flow as specified in Section 8.

7.8 Installation of Fossil-Fuel-Fired Auxiliary Energy Sources. Natural draft gas auxiliary water heaters shall be equipped with a 1.5 m (5 ft) vertical extension of flue pipe connected to the draft hood outlet pipe. The pipe diameter shall be equivalent to the largest flue collar size of the draft hood. For other gas or oil-fired auxiliary heaters, the draft shall be adjusted as specified by the manufacturer.

7.9 Indoor Testing with a Solar Simulator. If a solar simulator is employed, it shall directly irradiate the collector array in the test of the complete system.

7.9.1 Solar Simulator Characteristics. The solar simulator employed in the testing procedure shall have the characteristics specified in ASHRAE Standard 93-1986.[1]

7.9.2 Tilting Device. A tilting device shall be provided to allow for attaining incident angles of ±80 ° normal to the solar simulator beam so that all realistic incident angles can be obtained. The motion can be over 5° step increments or on a continuous basis.

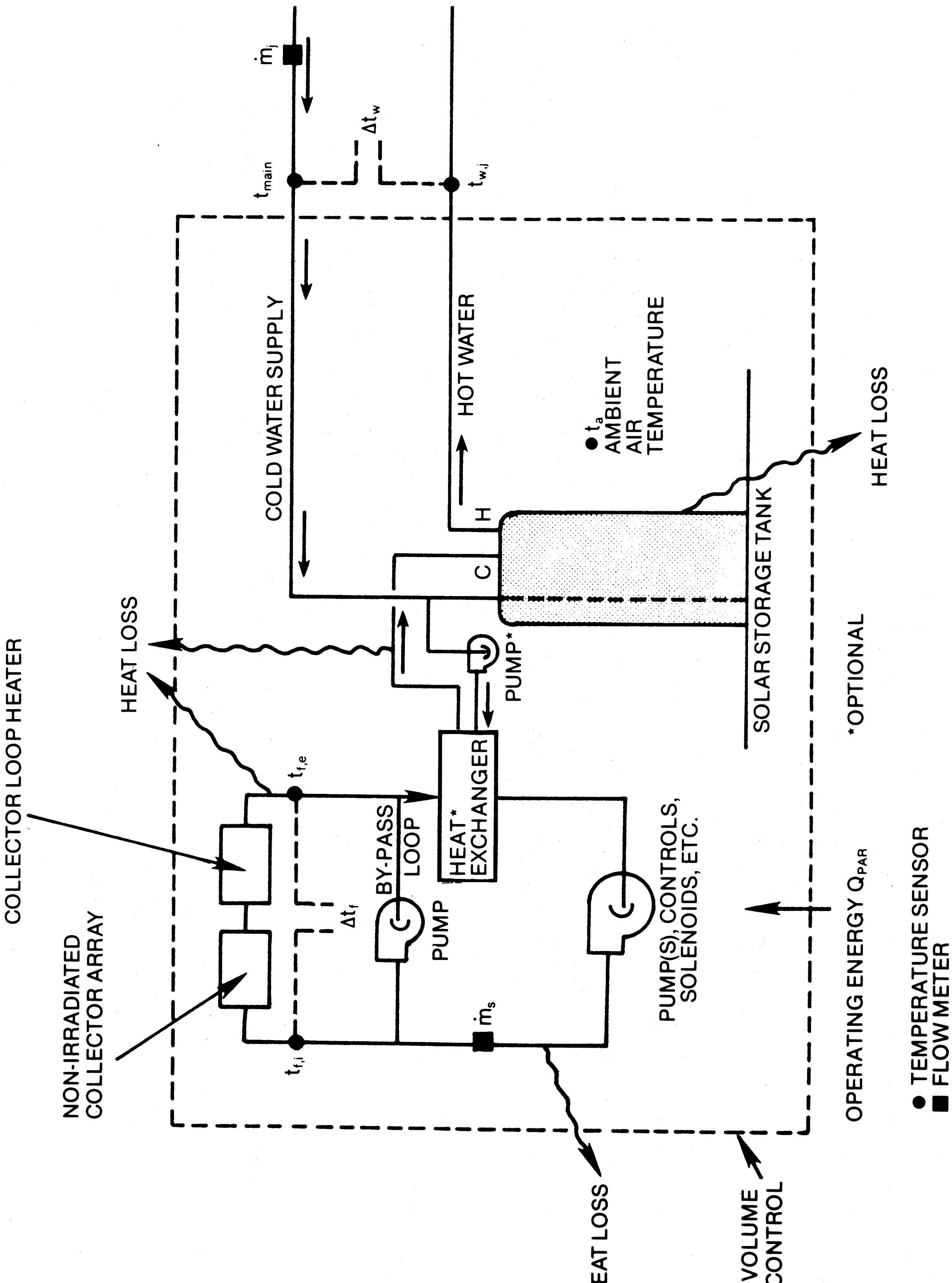

Figure 2 Solar Preheat or Solar Only System

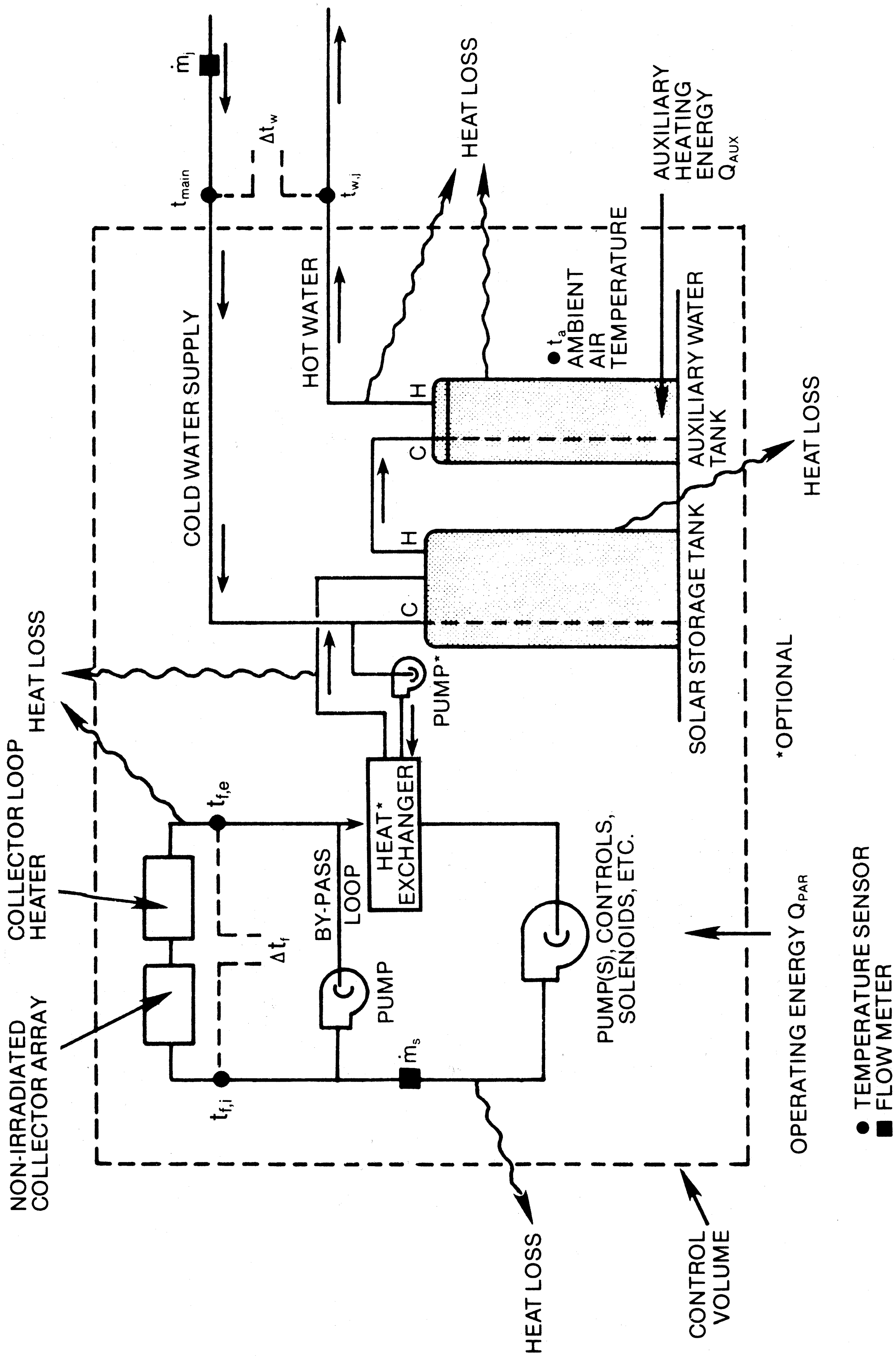

Figure 3 Solar Plus Supplemental

7.9.3 Thermal Simulation of Collector Output. In case the complete collector array of the hot water system cannot be irradiated and provided the array consists of modules connected in parallel, the test can be conducted with an integer number of collectors, but with a minimum of 30% of the gross collector area irradiated and an auxiliary heater providing the remaining heat output from the collector array to the rest of the system. The flow rate through the irradiated collector shall be in proportion to the gross collector area being irradiated. The auxiliary heater shall be controlled so that its energy output, weighted according to the collector area it represents, is equal to within 2% of that coming from the irradiated panels at all times.

7.10 Indoor Testing with a Non-irradiated Collector Array. An irradiated solar collector array may be simulated in the test of the system in lieu of using a solar simulator as described in Section 7.9. The collector is tested separately in accordance with ASHRAE Standard 93-1986[1] and the array's thermal output in the system test is obtained by using a combination of the non-irradiated collector array and a heater in series in the collector loop.

7.10.1 Collector Controller Temperature Sensor. The temperature sensor designed to be installed on or in the vicinity of the solar collector array and connected to the system controller for starting and stopping the collector loop pump or blower shall be installed on the surface or inside of the pipe or duct (under the insulation) downstream of the non-irradiated array and collector loop heater but as close to the exit of the second device as is practical.

7.10.2 Electric Heaters. If an electrical heating element is used in the collector loop heater, the heating element shall be immersed in the fluid stream of the transfer fluid and the thermal losses shall be less than 2% of the input. Under these conditions, the measured collector heater input can be taken as the heater output. If the losses are more than 2% of the input, a means of measuring the energy delivered to the fluid by the heater shall be provided.

7.10.3 Fossil-Fuel-Fired Heaters. If a fossil-fuel-fired source is used in the collector loop heater, a means of measuring the energy delivered to the fluid by the heater shall be provided.

7.10.4 Peak Thermal Output. The collector loop heater shall be sized to deliver the peak rate of solar collector absorbed energy.

7.10.5 Pressure Drop. The pressure drop across the collector loop heater shall be less than the pressure drop in an equivalent 6 m (20 ft) length of pipe or duct in the collector loop.

7.10.6 Time Constant. The time constant of the collector loop heater shall be less than 2 min.

8. TEST PROCEDURES

8.1 Introduction. Procedures are described in this Section for testing the performance of three categories of solar domestic hot water systems; solar-only systems, solar-preheater systems, and solar-plus-supplemental systems. The test can be done by assembling the complete system in the laboratory and irradiating the collector array by use of a solar simulator as described in Section 8.2. Alternately, the collector array may be non-irradiated if a controlled heating device (collector loop heater) is added in series with the collector array as described in Section 8.3. In either case, the system is tested until its performance is the same for two successive days and then data are taken for rating purposes. For all systems, either the solar fraction, sf, or the fractional energy savings, e, will be determined. In addition, Section 8.6 describes a test to determine the energy delivery capability of the system during a continuous draw-down.

8.2 Solar Simulator. If a solar simulator is used, it shall meet all the requirements of Section 7.9.

8.3 Non-irradiated Solar Collector Array. If the non-irradiated solar collector array is used, the complete system is assembled in the laboratory with the addition of the collector loop heater in series with collector array so that the combination of the two devices supplies the net thermal output of an irradiated array.

8.3.1 Separate Test for the Solar Collector. The solar collector shall have been previously tested according to ASHRAE Standard 93-1986[1] and the following determined:

1. a value of the collector time constant,
2. a curve of collector efficiency as a function of $(t_{f,i} - t_a)/I_t$ with the collector operating at near-normal incidence to the beam of the sun (see Figure C-l in Appendix C for the results on a typical water-heating flat-plate collector),
3. a curve of incident angle modifier as a function of incident angle θ (see Figure C-2 in Appendix C for a plot of incident angle modifier versus $(1/\cos\theta) - 1$ for a typical water-heating flat-plate collector), and
4. the mass flow rate and the specific heat of the fluid used during the ASHRAE Standard 93-1986[1] tests.

The fluid used in the solar water heating system shall be the same as that used in the ASHRAE Standard 93-1986[1] tests.

8.3.2 Control of the Collector Loop Heater. The thermal output of the collector loop heater is calculated and changed every 30 minutes throughout the test day using the equations governing its thermal output (Appendix C) and the values of $t_{f,i}$ and $\dot{m}_s$, and $c_{p,s}$ that are measured (or calculated) prior to every change in input energy.

8.3.3 Collector Loop Thermal Output. The collector loop thermal output, $t_{f,i}$, and $\dot{m}_s$ should all be monitored as a function of time during the test. After the test is completed, a calculation of total daily collector ar-ray thermal output is required using the known variation of I_t and t_a throughout the test solar day, the measured values of $t_{f,i}$ and $\dot{m}_s$, and the collector thermal performance characteristics determined from the ASHRAE Standard 93-1986[1] tests. The measured value of total daily collector loop thermal output from the system test must be within ±5% of this calculated value.

8.3.4 Calculation Procedure for the Collector Loop Heater Thermal Output. The calculation procedure to determine the desired thermal output of the collector loop heater is as follows:

1. The incident radiation on the collector surface, I_t, is specified on an hour-by-hour basis for the test solar day. (An example of such a specification is given in Table B1 in Appendix B.) Values at more frequent time intervals are determined by interpolation.
2. The incident angle is specified or calculated as a function of time throughout the test day.
3. Using the results of step 2 and the incident angle modifier data (from a figure similar to Figure C-2 for the col-lector under consideration), the incident angle modifier is calculated as a function of time throughout the day.
4. The value of F_R is calculated as a function of time throughout the test day using equation (C.24).
5. The quantity $\dot{Q}_{\ell h}$ is calculated as a function of time throughout the test day using equation (C.15).

8.4 Solar-Only and Solar-Preheat System Test

8.4.1 Purpose. The purpose of this test is to determine the performance of a solar-only hot water system or of a solar-preheat hot water system.

8.4.2 Test Procedure. The storage device(s) shall be filled with water at a specified temperature, t_{main}, on the morning of the first day (See Table B2, Appendix B for an example.) The system shall be energized and shall be allowed to operate in its normal mode during the day and each successive day of the test. The time for the beginning of the first and subsequent 24-h test days shall be specified in an associated rating standard. Any device which is intended to limit or control the operation of the solar energy collection equipment shall be set as recommended by the manufacturer. On each test day, water shall be withdrawn from the system at times, rates, and duration as specified in an associated rating standard. (See Table B2, Appendix B as an example.) The energy content of the water withdrawn shall be determined. Although the use of an in-stalled flow meter and temperature sensors is allowed, a preferred method is to collect the water in an insulated container of known thermal capacity and tare weight. The water in the container is thoroughly mixed during the withdrawal period and its temperature, t_{wj}, measured within 30s after withdrawal is complete. The reported value should account for the thermal capacity of the weigh tank and/or the time constant of the temperature sensor. The weight of the collected water is measured. If an installed flow meter and temperature sensors are used, the delivery temperature shall be measured and recorded at no greater than 4.5 kg (l0 lb) intervals throughout the withdrawal period.

The test shall be performed until the daily system solar fraction (see equation 8.3) is within 3% of the value on the previous test day.

8.4.3 Measurements. During the test period, measurements of the daily energy consumed by the circulation system (pumps, controls, solenoid valves, etc.) shall be made, and daily thermal energy output from the collector loop heater (if used) shall be determined from measurements. These shall be recorded at the end of each test day. The energy consumed by the by-pass loop controls, pump, fan, and valves if measured shall be obtained separately from the energy consumed by the solar domestic hot water system components. During the withdrawal period, the mixed temperature of the incoming water and the mass and mixed temperature of each withdrawal shall be measured. If the collector loop heater is used, the thermal energy output from the heater, the mass flow rate through the collector array, and the entering fluid temperature to and temperature increase across the collector loop shall all be determined from measurements for each 30 min. time period when the collector loop is in operation.

8.4.4 Calculations. The daily system hot water load shall be calculated as:

$$Q_L = (t_{set} - t_{main}) c_{p,w} \sum_{j=1}^{n} m_j \tag{8.1}$$

The daily net energy supplied by solar energy shall be calculated as,

$$Q_s = \sum_{j=1}^{n} c_{p,w} (t_{w,j} - t_{main}) m_j \tag{8.2}$$

The fraction of the daily system hot water load supplied by solar energy shall be calculated by

$$sf = \frac{Q_s - Q_{PAR}}{Q_L} \tag{8.3}$$

All measurements used in this calculation shall be those tor the final test day.

8.5 Solar Hot Water System Test with Integral Supplemental Heaters

8.5.1 Purpose. The purpose of this test is to determine the performance of a solar hot water system with integral supplemental heaters.

8.5.2 Test Procedure. The storage device(s) shall be filled with water at a specified temperature, t_{main}, on the morning of the first day. The system shall be energized, including integral heaters and controls, and shall be allowed to operate in its normal mode during the day and each successive day of the test. The time for the beginning of the first and subsequent 24 hour test days shall be specified in an associated rating standard. Any device which is intended to limit or control the operation of the solar energy collection equipment shall be set as recommended by the manufacturer. If the system is designed so that the temperature of the delivered water is controlled by a thermostatic control on the auxiliary energy delivery system, this thermostat shall be set to deliver water at t_{set}. If the system is designed so that the temperature of the delivered water is controlled by a mixing valve, the mixing valve shall be set to deliver water at t_{set} and the control of the auxiliary heating system shall be set as recommended by the manufacturer. On each test day, water shall be withdrawn from the system at times, rates, duration, and temperature, t_{set}, as specified in an associated rating standard. If the outlet water temperature from the system is not maintained at t_{set}, an energy integrator may be used and the length of the time of the draw adjusted so that the same total amount of thermal energy output, measured above t_{main}, is delivered. The energy content of the water withdrawn shall be determined. Although the use of an installed flow meter and temperature sensors is allowed, a preferred method is to collect the water in an insulated container of known thermal capacity and tare weight. The water in the container is thoroughly mixed during the withdrawal period and its temperature, $t_{w,j}$, measured within 30 s after withdrawal is complete. The reported value should account for the thermal capacity of the weigh tank and/or the time constant of the temperature sensor. The weight of the collected water is measured. If an installed flow meter and temperature sensors are used, the delivery temperature shall be measured and recorded at no greater than 4.5 kg (10 lb) intervals throughout the withdrawal period.

The test shall be performed until the daily system supplemental energy required (Q_{AUX}) is within 3% of the value on the previous test day.

8.5.3 Measurements. During the test periods, measurements of the daily energy consumed by the circulation system (pumps, controls, solenoid valves, etc.) and the energy consumed every 30 min. for auxiliary heating shall be made. The energy consumed by the bypass loop controls, pump, fan, and valves if measured, shall be obtained separately from the energy consumed by the solar domestic hot water system components. The daily thermal energy output from the collector loop heater (if used) shall also be determined from measurements. All daily quantities shall be recorded at the end of each test day. During the withdrawal periods, the mixed temperature of the incoming water and the mass and mixed temperature of each withdrawal shall be measured. If the collector loop heater is used, the thermal energy output from the heater, the mass flow rate through the collector array, and the entering fluid temperature to and temperature increase across the collector loop shall all be recorded for each 30 min. time period when the collector loop is in operation.

8.5.4 Calculations. The daily system hot water load shall be calculated as

$$Q_L = \sum_{j=1}^{n} c_{p,w}(t_{w,j} - t_{main})m_j \tag{8.4}$$

The fractional energy savings shall be calculated by

$$e = 1 - \frac{Q_{AUX} + Q_{PAR}}{Q_{CON}} \tag{8.5}$$

All measurements used in this calculation shall be those for the final test day. Q_{CON} is specified in an associated rating standard. See Appendix D for an example.

8.6 Hot Water Supply Rating—Continuous Draw

8.6.1 Hot Water Supply—Solar Energy Only

8.6.1.1 Purpose. The purpose of this test is to determine the capability of the solar hot water system to deliver hot water with no auxiliary energy source operating and during a continuous draw-down.

8.6.1.2 Test Procedure. The solar hot water system shall be installed, adjusted, and operated as described in Section 8.4.2 or 8.5.2. Ten minutes after the last draw on the final test day, a special draw test shall be conducted. All auxiliary energy source thermostats (if any) shall be disabled. The cold water supply shall be adjusted to supply water at t_{main} ± 1.0°C (± 1.8°F). Water shall be withdrawn at a uniform flow rate as specified in an associated rating standard.

8.6.1.3 Measurements. The temperature of the water shall be measured at a point as close to the storage tank(s) as possible and recorded immediately at the start of the draw and at not less than 4.5 kg (10 lb) intervals thereafter. The draw shall continue until the discharge temperature equals the inlet temperature within 3.0°C (5.4°F).

8.6.1.4 Calculations. A curve with outlet water temperature as the ordinate and quantity of water withdrawn as the abscissa shall be drawn using the test results.

8.6.2 Hot Water Supply—Auxiliary Energy Only

8.6.2.1 Purpose. The purpose of this test is to determine the capability of a solar-plus-supplemental hot water system to deliver hot water with the auxiliary energy source operating and during a continuous draw-down.

8.6.2.2 Test Procedure. The solar hot water system shall be installed, adjusted, and operated in accordance with Section 8.5.2. Upon completion of the test described in Section 8.6.1, the unit shall be allowed to recover using the auxiliary energy source with the thermostat set to deliver water at t_{set}, until the temperature reaches t_{set} ± 3.0°C (± 5.4°F) and the thermostat shuts off the auxiliary energy source. The system shall be allowed to remain at rest for 10 minutes after which the draw described in Section 8.6.1.2 shall be performed.

8.6.2.3 Measurements. The temperature of the water shall be measured at a point as close to the storage tank(s) as possible and recorded immediately at the start of the draw and at not less than 4.5 kg (10 lb) intervals thereafter. The draw shall be discontinued when the mixed temperature of any 4.5 kg (10 lb) discharge quantity drops below 38°C (100°F).

8.6.2.4 Calculations. A curve shall be prepared for this test in the same manner as described in Section 8.6.1.4.

9. DATA TO BE RECORDED AND TEST REPORT

9.1 Test Data. Table 1 lists the measurements which are to be made throughout the tests to determine the fraction of the daily total hot water load supplied by solar energy.

9.2 Table 2 specifies the data and information that shall be reported in testing the solar domestic hot water system.

10. REFERENCES

1 "Methods of Testing to Determine the Thermal Performance of Solar Collectors," *ASHRAE Standard 93-1986*.

2 "Guide to Meteorological Instrumentation & Observing Practices," Secretariat of the World Meteorological Organization, Geneva, Switzerland, 4th Edition, 1971.

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4 Coulson, K.L., *Solar and Terrestrial Radiation, Methods and Measurements*, p. 129, Academic Press, New York, 1975.

5 "Standard Method for Temperature Measurements," *ASHRAE Standard 41.1-1986*.

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7 "Methods of Testing for Rating Unitary Air-Conditioning and Heat Pump Equipment," *ASHRAE Standard 37-1978.*

8 Morrison, C.A., and E.A. Farber, "Clear-day design values," Chapter IV, *Applications of Solar Energy for Heating and Cooling of Buildings*, ASHRAE GRP 170, 1977.

9 Oonk, R.L., Jones, D.E., and Cole-Appel, B.E., "Calculation of performance of n collectors in series from test data on a single collector," *Solar Energy*, Vol. 23, pp. 535-536, 1979.

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TABLE 1
Measurements to be Made and Test Data and Information to be Recorded

Item	Test Involving Solar-Only or Solar-Preheat Systems	Test Involving Solar–Plus-Supplemental Systems
Date	X	X
Observers	X	X
Equipment name plate data for system components	X	X
Number of collectors in system	X	X
Collector aperture area, m^2 (ft^2)	X	X
Collector gross area, m^2 (ft^2)	X	X
Storage tanks' outside dimensions, m (ft)	X	X
Storage tanks' volumetric capacity, m^3 (ft^3)	X	X
Number and location of integral heating elements		X
Rating of integral heating elements		X
*Mass flow rate through collector during the ASHRAE Standard 93-1986 tests, mc, kg/s (lb/hr)	X	X
*Specific heat of heat transfer fluid used during the ASHRAE Standard 93-1986 tests, cpc, kJ/(kg·°C) [Btu/(lb·°F)]	X	X
*Intercept of the collector efficiency curve determined in accordance with ASHRAE Standard 93-1986, $A_a/A_g\ F_R\ (\tau\alpha)_{e,n}$, dimensionless	X	X
*Slope of the collector efficiency curve determined in accordance with ASHRAE Standard 93-1986 determined at a value of $t_{set} - t_{a,t}$ at solar noon during the system test, $A_a/A_g\ F_R U_L$, W/(m^2·°C) [Btu/(hr·ft^2·°F)]	X	X
*The effective transmittance-absorptance product at normal incidence as determined in Section 8 (equations in Appendix C) of this Standard, $(\tau\alpha)_{e,n}$, dimensionless	X	X
*Collector heat removal factor as determined in Section 8 of this Standard, F_R, dimensionless	X	X
*Collector overall heat transfer coefficient as determined in Section 8 of this Standard, U_L, (W/m^2·°C) [Btu/(hr·ft^2·°F)]	X	X
*Collector efficiency factor as determined in Section 8 of this Standard, F', dimensionless	X	X
*Mass flow rate of the transfer fluid through the solar collector array during the system test (recorded every 30 min.), $\dot{m}_s$, kg/s (lb/hr)	X	X

TABLE 1
Measurements to be Made and Test Data and Information to be Recorded *(Continued)*

Item	Test Involving Solar-Only or Solar-Preheat Systems	Test Involving Solar–Plus-Supplemental Systems
*Specific heat of the transfer fluid through the solar collector array during the system test (determined every 30 min.), $c_{p,s}$, kJ/(kg·°C) [Btu/(lb·°F)]	X	X
*Temperature of the transfer fluid entering the solar collector array during the system test (recorded every 30 min.), $t_{f,i}$, °C (°F)	X	X
*Temperature difference across the solar collector loop during the system test (recorded every 30 min.) $t_{f,e} - t_{f,i}$, °C (°F)	X	X
Ambient air temperature surrounding the system during the test (recorded every 30 min.), $t_{a,\ell}$, °C (OF)	X	X
*Energy output from the collector loop heater (if used) during the test (recorded every 30 min.), QO_{UTPUT}, Wh (Btu)	X	X
Energy consumed for auxiliary heating (recorded every 30 min.), kWh(Btu)		X
Inlet water temperature to the system during the test (recorded during every draw), t_{main}, °C (°F)	X	X
Outlet water temperature from the system during the test (recorded during every draw), $t_{w,j}$, °C(°F)	X	X
Mass of water withdrawn from the system during the test (recorded during every draw), m_j, kg (lb)	X	X
*Daily energy output from the collector loop heater (if used), Q_{OUTPUT}, kWh (Btu)	X	X
Daily energy consumed by the system's circulation and control apparatus (pumps, controls, solenoid valves, etc.), Q_{PAR}, Wh (Btu)	X	
Daily energy consumed for auxiliary heating Q_{AUX}, kWh (Btu)		X

*Only to be recorded if the collector loop heater is used.

Table 2
Data and Information to be Reported

General Information

Name of Manufacturer ____________________

Solar Domestic Hot Water System No: ____________________

Construction details of the system:

collector aperture dimensions and area, m and m^2 (ft and ft^2) ____________________

collector gross dimensions and area, m and m^2 (ft and ft^2) ____________________

number of collectors in system ____________________

$A_a/A_g\ F_R\ (\tau\alpha)_{e,n}$ (From ASHRAE Standard 93-1986) ____________________

$A_a/A_g\ F_RU_L$ determined at a value of $t_{set} - t_{a,t},/I_t$ at solar noon during the system test (from ASHRAE Standard 93-1986) ____________________

storage tank dimensions including insulation thickness, m (ft) ____________________

____

description of the solar domestic hot water system including insulation, valves, circulation, piping, controls, and control set points ______________________________

____

____

Transfer fluid used and its thermal-physical properties (specific heat, density, viscosity)______________________________

____

Description of test apparatus, including configuration and instrumentation used in testing (include photographs). For a thermosyphon system, include the piping size and elevation of the storage tank above the solar collector array______________________________

____

Tests

The solar fraction or fractional energy savings shall be determined and reported for the system under test.

At the beginning of the tests to determine solar fraction or fractional energy savings and thereafter in 30 min. increments, the following shall be reported if the collector loop heater is used:

Q_{OUTPUT} ______________________________ kJ (Btu)

$t_{f,i}$ ______________________________ °C (°F)

$\dot{m}_s$ ______________________________ kg/s (lb/hr)

For each withdrawal of water from the system during the tests to determine solar fraction or fractional energy savings, the following shall be reported:

m_j ______________________________ kg (lb)

t_j ______________________________ °C (°F)

t_i ______________________________ °C (°F)

On a daily basis during the test to determine solar fraction or fractional energy savings, the following shall be reported:

Q_{PAR} ______________________________ J (Btu)

Q_{AUX} ______________________________ kJ (Btu)

For the hot water supply rating tests, a curve of outlet water temperature as the ordinate and quantity of water withdrawn as the abscissa shall be reported both with (if appropriate) and without the use of the auxiliary energy source.

This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX A—BIBLIOGRAPHY

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This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX B

TABLE B1 Example of Text Solar Day Conditions

Solar Time	Ambient Temperature, °C (°F)	Total, w/m^2	Irradiance, $Btu/(ft^2 \cdot hr)$	Incident Angle Degrees
	20.00 (68.0)	233	74	62.0
8:00	20.00 (68.0)	539	171	48.4
9:00	20.00 (68.0)	747	237	35.5
10:00	20.00 (68.0)	873	277	24.8
11:00	20.00 (68.0)	917	291	20.0
12:00	20.00 (68.0)	873	277	24.8
13:00	20.00 (68.0)	747	237	35.5
14:00	20.00 (68.0)	539	171	48.4
15:00	20.00 (68.0)	233	74	62.0

The values above were taken from Reference 8, page IV-12. The quoted values are for January 21, a 40 degree north latitude location, tilt angle 40 degrees with respect to the horizontal, and a surface facing due south.

TABLE B2 Example of Test Conditions for the Solar Hot Water Systems

t_{main}: 20°C (68°F)

t_{set}: 55°C (131°F)

volume flow rate during hot water draw: 0.2 l/s
(3.17 gal/min)

duration of hot water draw: 7 minutes

times of hot water draw: 0800 hours
1200 hours
1600 hours

ambient air temperature around solar hot water system components during the test: 20°C (68°F)

tilt angle of collectors: 45°

time at the beginning of the first and subsequent test days: 1600 hours

This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX C— USE OF A NON-IRADIATED SOLAR COLLECTOR ARRAY IN THE SOLAR DOMESTIC HOT WATER SYSTEM TEST

As outlined in Sections 7.0 and 8.0 in the body of the Standard, the solar hot water system may be tested in the laboratory using a non-irradiated solar collector array with a collector loop heater installed downstream of the array and controlled to supply the col-lector absorbed energy to the flow loop. The purpose of this Appendix is to derive the governing equations to be used in control-ling the thermal output of the heater. The derivations are taken substantially from References 9 and 10.

The thermal performance of an irradiated solar collector operating under quasi-steady-state conditions can be described by either of the following equations:

$$\frac{\dot{Q}_u}{A_a} = K_{\alpha\tau}F_R(\tau\alpha)_{e,n}I_t - F_RU_L(t_{f,i} - t_a) \quad (C.1)$$

or

$$\frac{\dot{Q}_u}{A_a} = K_{\alpha\tau}(\tau\alpha)_{e,n}I_t - U_L(t_{p,m} - t_a) \quad (C.2)$$

Equating the two equations and solving for $t_{p,m}$,

$$t_{p,m} = F_R(t_{f,i} - t_a) + \frac{K_{\alpha\tau}I_t(\tau\alpha)_{e,n}}{U_L}(1 - F_R) + t_a \quad (C.3)$$

If the collector were in the laboratory and not irradiated, equation (C.3) would reduce to:

$$t_{p,m,non} = F_R(t_{f,i} - t_{a,\ell}) + t_{a,\ell} \quad (C.4)$$

The above equations can be used to derive the equation for the required net energy output of a collector loop heater that will result in the same performance as with the irradiated collector.

Collector Loop Heater Downstream of the Non-irradiated Collector Array

In order for the net energy output for the collector loop to be the same when using a collector loop heater and non-irradiated col-lector compared to the use of an irradiated collector

$$\frac{\dot{Q}_{\ell h}}{A_a} - U_L(t_{p,m,non} - t_{a\ell}) = K_{\alpha\tau}F_R(\tau\alpha)_{e,n}I_t - F_RU_L(t_{f,i} - t_{a,t}) \quad (C.5)$$

The left side of the equation (C.5) represents the net energy out-put from the collector loop in the laboratory when the collector loop heater supplies energy to the loop and heat loss occurs from the non-irradiated collector. The right side of the equation represents the net output that would occur from an irradiated col-lector. Note that the loss coefficient for the collector, UL, IS assumed to be the same for both configurations. Since the collector loop heater is downstream of the non-irradiated collector, the inlet fluid temperature to the non-irradiated collector is identical to the inlet fluid temperature that would occur with the irradiated collector. Consequently, equation (C.4) can be introduced into the left side of equation (C.5) and the resulting equation solved for $\dot{Q}_{\ell h}$:

$$\dot{Q}_{\ell h} = K_{\alpha\tau}\frac{A_a}{A_g}F_R(\tau\alpha)_{e,n}I_tA_g - \frac{A_a}{A_g}F_RU_LA_g(t_{a,\ell} - t_{a,t}) \quad (C.6)$$

Equation (C.6) is for a one collector module array. The analysis is readily extended to combination of M parallel rows of N collectors connected in series. Consider the situation where there are M collectors connected in parallel and no collectors connected in series (N = 1). Equation (C.6) becomes:

$$\dot{Q}_{\ell h} = K_{\alpha\tau}\frac{A_a}{A_g}F_R(\tau\alpha)_{e,n}I_tMA_g - \frac{A_a}{A_g}F_RU_LMA_g(t_{a,\ell} - t_{a,t}) \quad (C.7)$$

Collector modules connected in series requires that the heat removal factor, F_R. in equation (C.7) be modified. For one solar collector module:

$$F_R = \frac{\dot{m}c_p}{U_LA_a}\left[1 - \exp - \left(\frac{A_aF'U_L}{\dot{m}c_p}\right)\right] \quad (C.8)$$

Where two collector modules are connected in series, each module has the same mass flow rate; however, the aperture area is doubled. With the assumption that UL and F' are equal for the two collectors, equation (C.8) becomes:

$$F_{R2} = \frac{\dot{m}c_p}{U_L2A_a}\left[1 - \exp - \left(\frac{2A_aF'U_L}{\dot{m}c_p}\right)\right] \quad (C.9)$$

Algebraic manipulation of equation (C.8) and equation (C.9) yields:

$$F_{R2} = F_R\left[1 - \frac{A_a/A_gF_RU_LA_g}{2\dot{m}c_p}\right] \quad (C.10)$$

Thus for two collectors in series:

$$(F_RU_L)_2 = (F_RU_L)\left[1 - \frac{(F_RU_L)A_a}{2\dot{m}c_p}\right] \quad (C.11)$$

and

$$(F_R(\tau\alpha)_{e,n})_2 = (F_R(\tau\alpha)_{e,n})\left[1 - \frac{(F_RU_L)A_a}{2\dot{m}c_p}\right] \quad (C.12)$$

Generalizing to any number, N, of identical collectors in series

$$(F_RU_L)_N = \frac{\dot{m}c_p}{NA_a}\left[1 - \left(1 - \frac{(F_RU_L)\ A_a}{\dot{m}c_p}\right)^N\right] \quad (C.13)$$

and

$$(F_R(\tau\alpha)_{e,n})_N = \frac{(F_R(\tau\alpha)_{e,n})\dot{m}c_p}{(F_RU_L)NA_a}\left[1 - \left(1 - \frac{(F_RU_L)NA_a}{\dot{m}c_p}\right)^N\right] \quad (C.14)$$

Therefore, in the most general case where the heat source is located downstream of M rows of N collectors connected in series:

$$\dot{Q}_{\ell h} = K_{\alpha\tau}\frac{A_a}{A_g}(F_R(\tau\alpha)_{e,n})_N I_t MNA_a - \frac{A_a}{A_g}(F_RU_L)_N MNA_g(t_{a,\ell} - t_{a,t}) \quad (C.15)$$

Collector Loop Heater Upstream of the Non-irradiated Collector Array

Equating the net energy output from the collector loop for the two alternate test configurations (collector loop heater plus non-irradiated collector and irradiated collector) as was done above,

$$\frac{\dot{Q}^*_{\ell h}}{A_a} - U_L(t^*_{p,m,non} - t_{a,\ell}) = K_{\alpha\tau}F_R(\tau\alpha)_{e,n}I_t - F_RU_L(t_{f,i} - t_{a,t}) \quad (C.16)$$

The * indicates that $t_{p,m,non}$ is different from the previous case because the collector loop heater is now upstream of the irradiated collector. Equation (C.4) is still valid except the inlet fluid temperature to non-irradiated collector is also different from the previous case due to the location of the collector loop heater:

$$t^*_{p,m,non} = F_R(t^*_{f,i} - t_{a,\ell}) + t_{a,\ell} \quad (C.17)$$

An energy balance on the collector loop heater results in the following expression for the exit fluid temperature from the heater (inlet fluid temperature to the non-irradiated collector, $t^*_{f,j}$) in terms of the inlet fluid temperature to the heater (identical to the inlet fluid to the non-irradiated collector in the previous case, $t_{f,j}$):

$$t^*_{f,i} = t_{f,i} + \frac{\dot{Q}^*_{\ell h}}{\dot{m}_s c_{p,s}} \quad (C.18)$$

Solving equations (C.16), (C.17), and (C.18) simultaneously:

$$\dot{Q}^*_{\ell h} = \frac{K\alpha\tau(A_a/A_g)F_R(\tau\alpha)_{e,n}I_tA_g - (A_a/A_g)F_RU_LA_g(t_{a,\ell} - t_{a,t})}{1 - [(A_a/A_g)F_RU_LA_g]/(\dot{m}_s c_{p,s})} \quad (C.19)$$

Equation (C.l9) is for a one collector module array. For the case where there are M collectors connected in parallel and no collec-tors connected in series (N = 1), equation (C.l9) becomes:

$$\dot{Q}^*_{\ell h} \quad \frac{K_{\alpha\tau}(A_a/A_g)F_R(\tau\alpha)_{e,n}I_tMA_g - (A_a/A_g)F_RU_LMA_g(t_{a,\ell} - t_{a,t})}{1 - [(A_a/A_g)F_RU_LMA_g]/(\dot{m}_s c_{p,s})} \quad (C.20)$$

In the most general case of M rows of N collectors connected in series:

$$\dot{Q}^*_{\ell h} \quad \frac{K_{\alpha\tau}(A_a/A_g)F_R(\tau\alpha)_{e,n}I_tMNA_g - (A_a/A_g)F_RU_LMNA_g(t_{a,\ell} - t_{a,t})}{1 - [(A_a/A_g)F_RU_LMNA_g]/(\dot{m}_s c_{p,s})} \quad (C.21)$$

Within the limits of the assumptions made in the above analysis, either configuration using the non-irradiated solar collector ar-ray could be used provided the appropriate equation were used to control the collector loop heater [equation (C.15) or (C.21)]. However, locating the collector loop heater downstream of the col-lector array was chosen due to the simpler expression for Q_{fh} equation (C.15).

It should be noted with reference to equation (C.l) and (C.15) that the value of FR is dependent upon mass flow rate and the specific heat of the transfer fluid. Therefore, if the flow rate of the transfer fluid through the collector in the operation of the solar hot water system is different from the value used during the ASHRAE 93-1986 tests on the collector, then the value of FR used in equation (C.15) must be modified from that value obtained from the ASHRAE 93-1986 tests. This can be done utilizing the followingprocedure:

1. Calculate $(\tau\alpha)_{e,n}$ for the solar collector. For an ordinary flat-plate collector

$$(\tau\alpha)_{e,n} = \frac{\tau_n\alpha_p}{1 - (1 - \tau_n)\varsigma} \quad (C.22)$$

where

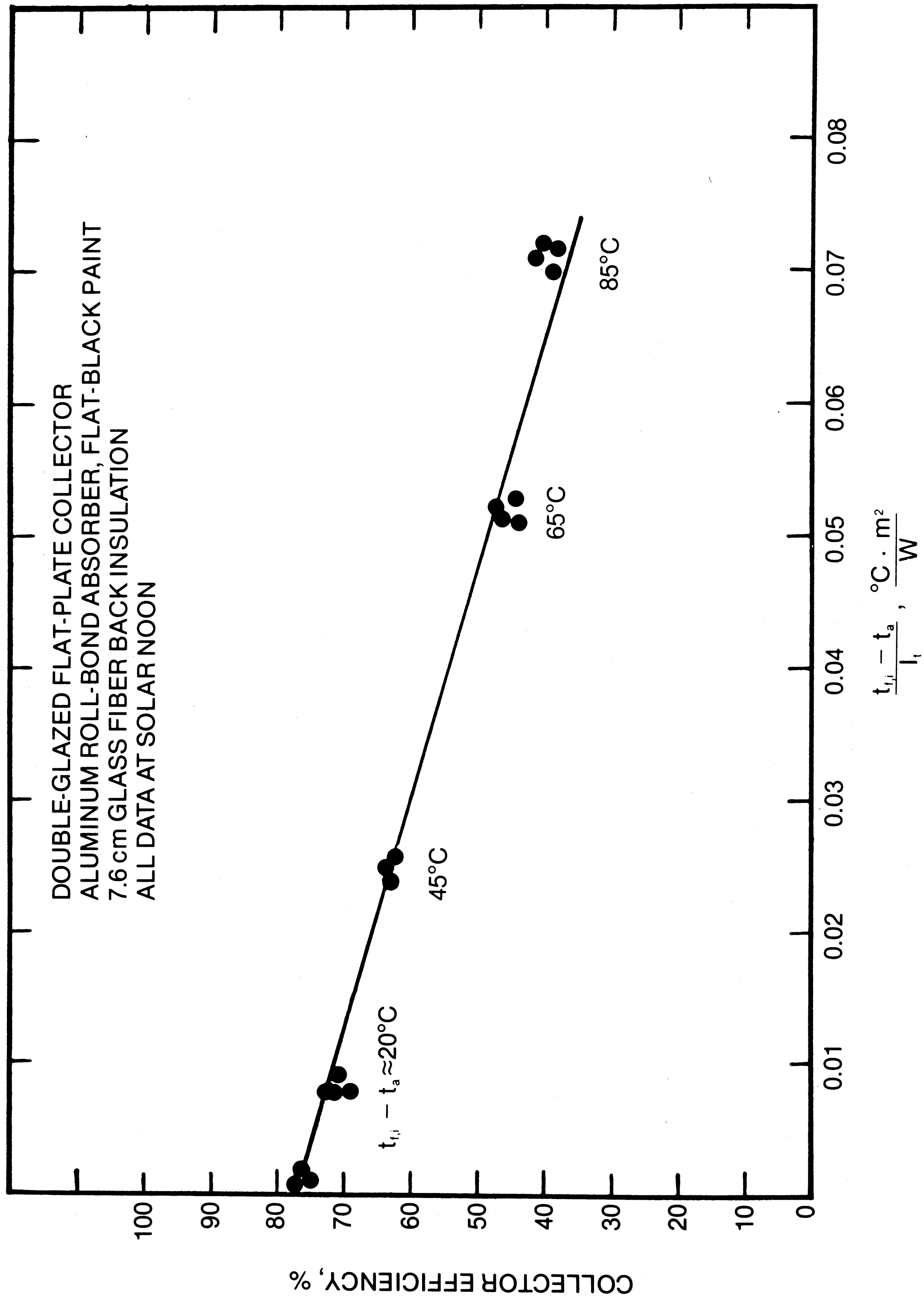
DOUBLE-GLAZED FLAT-PLATE COLLECTOR
ALUMINUM ROLL-BOND ABSORBER, FLAT-BLACK PAINT
7.6 cm GLASS FIBER BACK INSULATION
ALL DATA AT SOLAR NOON
$t_{f,i} - t_a \approx 20°C$
45°C
65°C
85°C
COLLECTOR EFFICIENCY, %
0
10
20
30
40
50
60
70
80
90
100
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
$\frac{t_{f,i} - t_a}{I_t}$, $\frac{°C \cdot m^2}{W}$

Figure C1

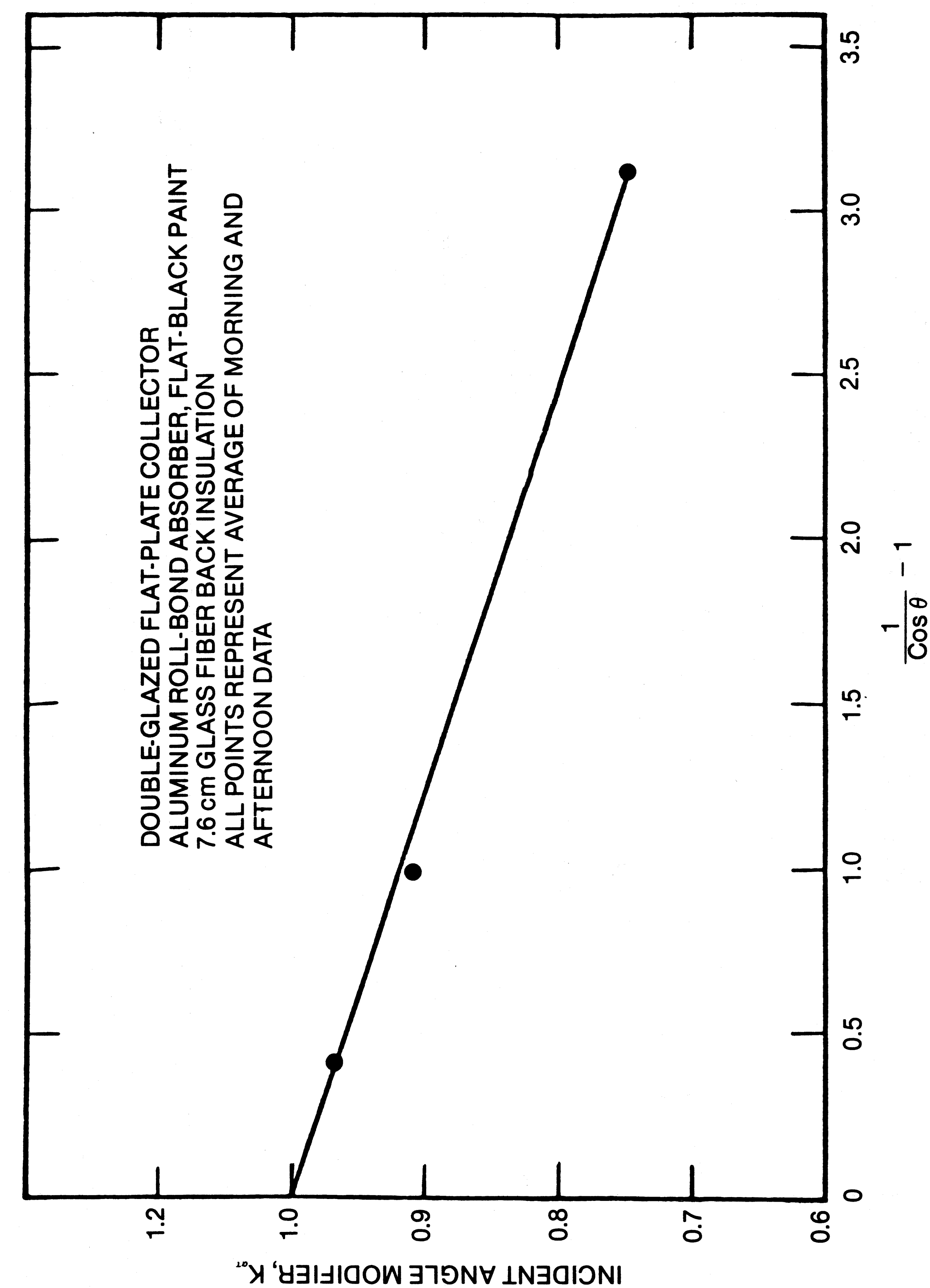
DOUBLE-GLAZED FLAT-PLATE COLLECTOR
ALUMINUM ROLL-BOND ABSORBER, FLAT-BLACK PAINT
7.6 cm GLASS FIBER BACK INSULATION
ALL POINTS REPRESENT AVERAGE OF MORNING AND
AFTERNOON DATA
INCIDENT ANGLE MODIFIER, $K_{\alpha\tau}$
1.2
1.0
0.9
0.8
0.7
0.6
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
$\frac{1}{\cos\theta} - 1$

Figure C2

ς_d = 0.16 for a one cover glass system
= 0.24 for a two cover glass system
= 0.29 for a three cover glass system

For concentrating or other types of collectors, the value of $(\tau\alpha)_{e,n}$ must be determined based on the geometrical and optical proper-ties of the collector.

2. Calculate the value of F_R from the ASHRAE 93-1986 tests by

$$F_R = \frac{\text{y intercept of the efficiency curve}}{(A_a/A_g)(\tau\alpha)_{e,n}\ \text{from step 1. above}}$$

3. Calculate the value of the UL from the ASHRAE 93-1986 tests by:

$$U_L = \frac{\frac{A_a}{A_g}F_R U_L}{\frac{A_a}{A_g}F_R}$$

where $(A_a/A_g)\ F_R U_L$ is the absolute value of the slope of the efficiency curve at a value of $t_{set} - t_{a,t}/I_t$ at solar noon during the system test.

4. Calculate the collector efficiency factor, F' by

$$F' = \frac{\dot{m}_c c_{p,c}}{A_a U_L} \ln\left[1 - \frac{F_R A_a U_L}{\dot{m}_c c_{p,c}}\right] \qquad \text{(C.23)}$$

5. Once F' is determined, F_R can be calculated for any system's transfer fluid flow rate and specific heat by using

$$F_R = \frac{\dot{m}_s c_{p,s}}{M A_a U_L}\left[1 - e - \frac{M A_a U_L F'}{\dot{m}_s c_{p,s}}\right] \qquad \text{(C.24)}$$

It should be noted that the above correction technique is based on the assumption that the collector absorber plate efficiency factor, F' is not a function of flow rate. However, when using air as the transfer fluid the assump-tion is not valid. The correction technique should not be used under those conditions unless the flow rate per unit collector area of air through the array during the system test differs from that used in the ASHRAE Standard 93-1986 tests by less than 25%. Otherwise, the 93-1986 collector tests should be repeated with the collector flow rates per unit area existing in the system test used.

This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX D— EXAMPLE OF CONVENTIONAL WATER HEATER THERMAL PERFORMANCE TO BE USED IN THE CALCULATION OF FRACTIONAL ENERGY SAVINGS

In order to calculate the fractional energy savings of the solar hot water system in accordance with equation (8.5) in the body of the Standard, the daily energy consumed by a conven-tional water heater meeting the same load, Q_{CON}, must be known. The pur-pose of this Appendix is to show examples of what might be required to be used in an associated rating stan-dard.

In May 1977, the Arthur D. Little Co. published the results of a detailed study done for the Federal Energy Admin-istration to document the effect of design changes on water heater energy consumption and cost to the consumer.* The study included a detailed survey of the water heater market, computer simulation and laboratory validation experiments for typical gas-fired and electric water heaters, and an analysis of potential improvements that could be made in the energy efficiency of the devices. The in-formation below is taken from the report of that study.

Gas-fired and electrical water heaters accounted for 55% and 45%, respectively of the units sold in 1974. However, gas-fired water heaters are used in about 72% of U.S. homes based on the 1970 Census. Oil-fired water heaters are not often used due to the need for electric pilot and the difficulty of designing oil burners at low firing rates. The capacity of the tank is normally from 0.076 m^3 (20 gal) to 0.26 m^3 (70 gal). Based on these surveys and detail-ed discussions with the industry, it was decided the most "typical" units to be used for detailed analysis were a 0.15 m3 (40 gal) gas-fired unit and a 0.20 m^3 (52 gal) electric unit.

Based on detailed computer and experimental analysis of the performance of each unit heating 0.27 m^3 (71.4 gal) per day a total of 48°C (85°F), standby and combustion losses were deter-mined. For the electric unit, it was found that a total of 3.1 kWh [11,160 kJ (10,578 Btu)] per day of stand-by loss occurs. If this unit were chosen to be used as the conventional water heater for comparison purposes, then the following expression would be used for $Q_{CON'}$

$$Q_{CON} = Q_L + 11{,}160\ \text{kJ} \qquad \text{(D.1)}$$

This equation was used to compute fractional energy savings for six solar water heaters whose performance was recently reported on at an ASHRAE Semi-annual meeting.**

For the gas-fired unit, it was found that the total standby and combustion losses amounted to 53,910 kJ (51,000 Btu) per day. If this unit were chosen to be used as the conventional water heater for comparison purposes, then the following expression would be used for Q_{CON}:

$$Q_{CON} = Q_L + 53{,}910\ \text{kJ} \qquad \text{(D.2)}$$

* "Study of Energy-Savings Options for Refrigerators and Water Heaters, Volume 2: Water Heaters" a report to the Office of Trans-portation and Appliance Programs, Federal Energy Administra-tion, Contract No. C0-04-50228-00, Arthur D. Little, Inc., Cambridge Massachusetts 02140, May 1977.

** Fanney, A.H., and Liu, S.T., "Comparison of experimental and computer-predicted performance for six solar domestic hot water systems" *ASHRAE Transactions,* Vol. 86, Part 1, 1980.

This Appendix is not part of this Standard but is included for in-formation purposes only.

APPENDIX E

Figure El is a schematic representation of the energy flow in a solar hot water system. The nomenclature is consistent with that used in the body of the Standard. The diagram is valid for solar-only, solar-preheat, and solar-plus-supplemental systems. The purpose of this Appendix is to use the diagram to explain the relationship between solar fraction, sf, and fractional energy savings, e. When testing solar-only or solar-preheat systems in accordance with Section 8.4, the solar fraction, sf, is determined. When testing solar-plus-supplemental systems in accordance with Section 8.5, the fractional energy savings, e, is determined. They are not equivalent as will be explained below.

Consider the most general type of solar hot water system in which the auxiliary energy source is a gas or oil-fired water heater. An energy balance can be written for the system as follows:

$$Q_{AUX} = Q_L + HL_{AE} + CL_{AE} - Q_S \qquad (E.1)$$

where

HL_{AE} = daily heat loss from the auxiliary heating equipment, kJ (Btu)

CL_{AE} = daily combustion loss from the auxiliary heating equipment, kJ (Btu)

In a similar manner, an energy balance can be written for the conventional system that is being used for comparison in the calculation of fractional energy savings:

$$Q_{CON} = Q_L + HL_{CON} + CL_{CON} \qquad (E.2)$$

where

HL_{CON} = daily heat loss from the conventional water heater, kJ (Btu)

CL_{CON} = daily combustion loss from the conventional water heater, kJ (Btu)

Using the definition of fractional energy savings,

$$e = \frac{Q_{CON} - (Q_{AUX} + Q_{PAR})}{Q_{CON}} \qquad (E.3)$$

and the expressions for Q_{AUX} and Q_{CON} in equations (E.l) and (E.2), respectively,

$$e = \frac{Q_L + HL_{CON} + CL_{CON} - Q_L - HL_{AE} - CL_{AE} - Q_S - Q_{PAR}}{Q_L + HL_{CON} + CL_{CON}} \qquad (E.4)$$

Consider either of two cases: (1) where the auxiliary heating equipment and the conventional water heater are electric water heaters, and (2) where the auxiliary heating equipment and the conventional water heater are gas or oil-fired water heaters.

1. *Electric Auxiliary and Conventional Water Heaters*

$$CL_{AE} = CL_{CON} = 0$$

Equation (E.4) reduces to:

$$e = \frac{Q_s + HL_{CON} - HL_{AE} - Q_{PAR}}{Q_L + HL_{CON}} \qquad (E.5)$$

Comparing equations (8.3) and (E.5)

$$e = \frac{sfQ_L + HL_{CON} - HL_{AE}}{Q_L + HL_{CON}} \qquad (E.6)$$

As can be seen, the solar fraction as determined in Section 8.4 for solar-only and solar-preheat systems is identical to the fractional energy savings if the system is used with a perfectly-insulated electric water heater ($HL_{AE} = 0$) and the conventional water heater used for comparison is also perfectly insulated ($HL_{CON} = 0$). In order to estimate fractional energy savings for the conditions of the test, equation (E.6) can be used in conjunction with the value of sf and Q_L determined from the rest and an estimation of $HL_{AE}$for the auxiliary water heater to be used and HL_{C0N} for the conventional water heater. These latter quantities can be obtained from the results of the Standby Loss Test con-ducted on the auxiliary and conventional water heaters.*

As a simple numerical example, consider the case where the standby loss of both the auxiliary heating equipment and the conventional water heater are equal to the value given in Appendix D for heating 0.27 m^3 (71.4 gal) per day a total of 43 °C (85 °F).

$$HL_{AE} = HL_{CON} = 11,160 \text{ kJ}$$

$$Q_L = 53,500 \text{ kJ}$$

Therefore, per equation (E.6):

$$e = \frac{sf}{1 + (HL_{CON}/Q_L)} = \frac{sf}{1.208}$$

2. *Gas or Oil-Fired Auxiliary and Conventional Water Heaters*

Comparing equations (8.3) and (E.4)

$$e = \frac{sfQ_L + HL_{CON} + CL_{CON} - HL_{AE} - CL_{AE}}{Q_L + HL_{CON} + CL_{CON}} \qquad (E.7)$$

In order to estimate fractional energy savings for the conditions of the test for solar-preheat systems, equation (E.7) can be used in conjunction with the value of sf and Q_L. determined from the test and an estimation of the other terms in the equation for the auxiliary and conventional water heaters to be used. The other quantities can be obtained from the results of the Recovery Efficiency and Standby Loss Tests conducted on the auxiliary and conventional water heaters.*

* Federal Energy Administration, Energy Conservation Program of Appliances, Test Procedures for Water Heaters, Federal Register, Vol. 42, No. 192, Tuesday, October 4, 1977.

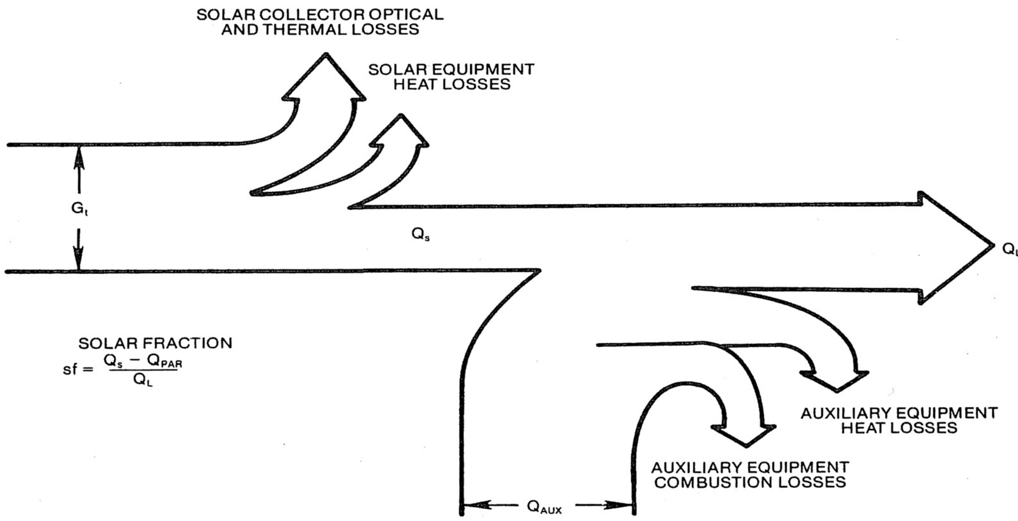

Figure E1 Energy Flow in Solar Domestic Hot Water Systems

POLICY STATEMENT DEFINING ASHRAE'S CONCERN FOR THE ENVIRONMENTAL IMPACT OF ITS ACTIVITIES

ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effect on the indoor and outdoor environment of the systems and components in their responsibility while maximizing the beneficial effects these systems provide, consistent with accepted standards and the practical state of the art.

ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor and outdoor environment to a greater extent than specified by the standards and guidelines as established by itself and other responsible bodies.

As an ongoing goal, ASHRAE will, through its Standards Committee and extensive technical committee structure, continue to generate up-to-date standards and guidelines where appropriate and adopt, recommend, and promote those new and revised standards developed by other responsible organizations.

Through its *Handbook*, appropriate chapters will contain up-to-date standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating standards and guidelines.

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