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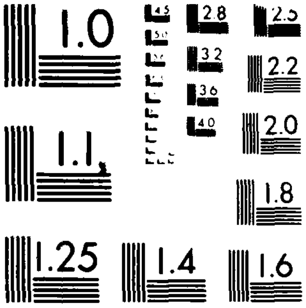

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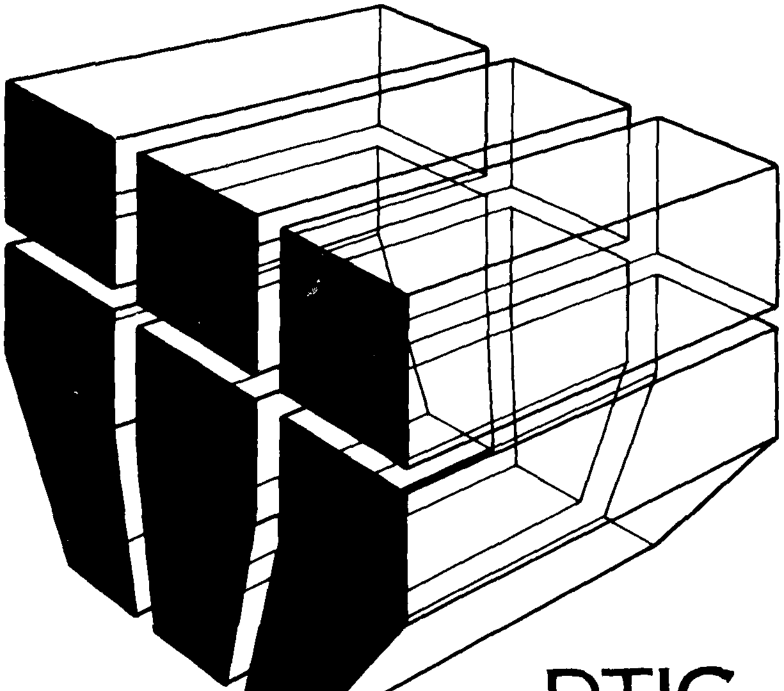
April 1984

PROCEDURES FOR ACCEPTANCE TESTING OF SOLAR ENERGY SYSTEMS

by
D. L. Johnson
D. M. Joncich



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This report describes research on the use of simple, low-cost meters for measuring the performance of solar energy systems in Army buildings and for comparing the measured performance with the design specification requirements.

The requirements of meters for measuring the performance of solar energy systems were defined. A BTU-Meter for measuring heat transfer was designed, and commercial meters for taking other measurements were obtained. The meters were

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installed in a solar system in the laboratory and a pilot test of the acceptance test was done. Suggested draft revisions to Corps of Engineers design documents were prepared; designers could use these revisions to include acceptance testing provisions in solar energy system design.

It was found that in a short-duration test, simple, low-cost meters can be used to determine whether a newly installed solar energy system is operating as specified. The simplicity of the metering approach allows designers to routinely include metering in the solar system design. The contractor can easily install the meters with the other solar components. Since the meters are so versatile, they can be used continuously for long-term performance monitoring. This gives the designer performance data and allows maintenance personnel to detect and diagnose solar equipment malfunctions. Thus, solar energy system metering can provide a unified, low-cost pproach for meeting the wide range of measurement needs of Army solar energy systems.

FOREWORD

This work was done for the Directorate of Engineering and Construction, Office, Chief of Engineers (OCE), under Project 4A762781AT45, "Energy and Energy Conservation"; Task C, "Installation Energy Systems Strategy"; Work Unit 001, "Solar Energy Implementation Techniques." Mr. Ed Zulkofske (DAEN-ECE-E) was the OCE Technical Monitor.

This study was performed by the Energy Systems Division (ES) of the U.S. Army Construction Engineering Research Laboratory (CERL). Mr. R. G. Donaghy is Chief of ES.

Appreciation is expressed to Tim Magrino (CERL) for his help with the construction and testing of the BTU-Meter and to Lee Edgar (CERL) for his help with data collection during the pilot test

COL Paul J. Theuer is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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PROCEDURES FOR ACCEPTANCE TESTING OF SOLAR ENERGY SYSTEMS

1 INTRODUCTION

Background

The goal of installing solar energy systems in Army buildings is to reduce consumption of energy from scarce conventional sources. However, the energy savings expected from these new systems may not be realized unless the building contractor correctly installs the proper solar equipment. An acceptance test can help insure that installation of the new solar system complies with the construction specifications.

In a previous study,[1] CERL developed and field-tested procedures for an acceptance test of solar energy systems. A sophisticated instrumentation package was used to measure system performance in that study. Although researchers widely use this equipment for such measurements, the equipment is expensive and requires highly trained personnel to operate it. The study showed potential for performing an acceptance test using low-cost metering installed during building construction. If the changes recommended by this report are adopted into the guide specifications on solar equipment (CEGS 13985), new solar energy systems will perform properly before final acceptance.

Objective

The objective of this study was to develop acceptance test procedures in which simple low-cost meters could be used to measure solar energy system performance.

Approach

Meter requirements for measuring solar energy systems were defined. A BTU-Meter for measuring heat transfer was designed and constructed, and meters for taking the other measurements were purchased "off the shelf."

The meters were installed in CERL's solar test facility and a pilot acceptance test was done.

Scope

The solar acceptance test described in this report focuses on the performance of the solar collector array, storage tank, and controls. The performance of auxiliary and distribution components (e.g., heat pumps, chillers, boilers) is not included, because these units are off-the-shelf items and are covered by conventional acceptance procedures. In addition, the test is limited to systems containing liquid, flat-plate collectors and using sensible heat storage.

The acceptance test described here is directed toward checking a contractor's work to determine compliance with construction specifications. Although the designer's work greatly affects a solar system's overall performance, the Military Construction-Army (MCA) process already includes design reviews which insure that design specifications meet a Corps District's performance requirements. Thus, the goal of these test procedures was to provide a clear-cut check of only the construction contractor's performance, and to avoid interfering with the designer's work (e.g., component sizing).

Mode of Technology Transfer

The information in this report will initially be disseminated through the Engineering Improvement Reporting System (EIRS). Later, the information will be incorporated as revisions to Corps of Engineers Guide Specification (CEGS) 13985 and Technical Manual 5-804-2.

2 METERS FOR TESTING AND MONITORING SOLAR ENERGY SYSTEMS

The Metering Approach

The need for an acceptance test for newly installed solar energy systems has been demonstrated.[2] Testing solar energy systems is more complex than testing conventional systems because solar system performance depends greatly on weather conditions and the system's history (e.g., the solar collector performance depends on tank temperature). In the previous study, a sophisticated data acquisition system was used to perform the acceptance test measurements; the study demonstrated that an acceptance test of solar energy systems was feasible.

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[1] D. M. Joncich and D. L. Johnson, *Development of an Acceptance Test for Solar Energy Systems*, Technical Report E-173/ADA101654 (U.S. Army Construction Engineering Research Laboratory [CERL], 1981).

[2] CERL Technical Report E-173.

The metering approach (Figure 1) presented here provides a straightforward method for meeting a solar energy system's testing and monitoring needs. Compared to the sophisticated instrumentation normally used for performance measurements,[3] the metering approach has a number of advantages (see Table 1). Besides the lower costs of the meters and removing the need for highly trained operators, the meters' simplicity allows this approach to fit smoothly into the MCA process; it also eliminates the need for special arrangements normally associated with instrumentation.

Although this report is concerned mostly with using meters for acceptance testing, the meters can continue to be used after the testing (see Table 1 and Figure 1). The monitoring meters provide performance data and detect system malfunctions. The designer is provided with performance data feedback, which is particularly important when a new solar system design is being tried or when a standard design is being tried in a new geographical area. Detecting solar system malfunctions is difficult for two reasons: (1) maintenance personnel are not familiar with solar systems, and (2) if a backup system is present, a complete failure of the solar system may go unnoticed, since the backup can provide all the heating or cooling needed. Thus, this aspect of the monitoring meters is important.

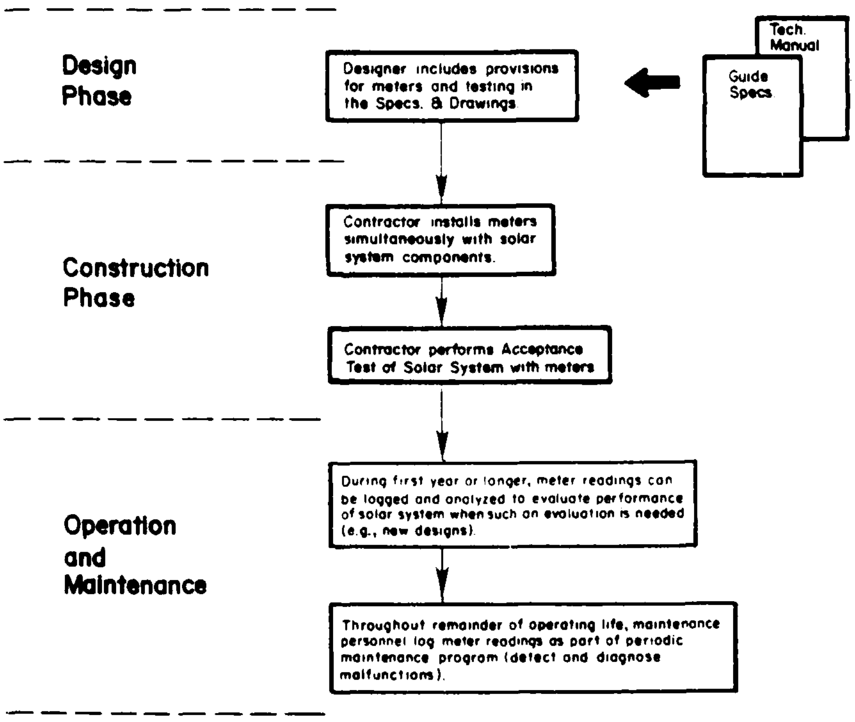

Figure 1. The metering approach to testing and monitoring of solar energy systems.

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[3] CERL Technical Report E-173, *Instrumentation Installation Guidelines for the National Solar Heating and Cooling Demonstration Program*, SHC-1006 (ERDA, 1976).

Table 1
Comparison of Metering Approach With Use of Sophisticated Instrumentation

Item	Metering Approach	Sophisticated Instrumentation
Equipment Costs	Meters are low in cost.	Instrumentation is expensive.
Operator Requirements	Meter readings can be taken by building contractor and maintenance technicians.	Requires highly trained operators for its use.
Compatibility with MCA Process	Fits smoothly into MCA process.	Requires special consultation with experts in el[illegible]tronics during design and installation; requires spe[illegible]rangements for trained operators during actual use.
Versatility	Meters are useful throughout life of solar system for both testing and monitoring; they can be used for detecting severe malfunction.	Normally dedicated to meeting specific nee[illegible]ly. Equipment maintenance and requirement[illegible]ghly trained operators are too costly for long-term use

Description of Meters

To meet the objectives of this study, meters must (1) provide the basic measurement functions (heat transfer, temperature, flow, etc.) and accuracy required for testing and monitoring, (2) be low in cost, (3) be easily incorporated by the designer into solar system design, (4) be easily installed by the building contractor simultaneously with the solar system, (5) be simple enough to use that the building contractor and maintenance technicians can take readings, and (6) be rugged enough to last throughout the useful life of the solar system. These characteristics were the basis of selecting the meters described below.

BTU-Meters

Since solar collectors produce heat, and heat is ultimately used for heating or cooling, measurement of heat transfer is very important to performance measurements. Therefore, the meter which measures heat transfer (the BTU-Meter) is the "heart" of the metering system. Since this meter is relatively new and many people are not familiar with it, its characteristics will be described in detail.

Figure 2 shows the similarities between the BTU-Meter and the Kilowatt-hour Meter, which is widely used by utility companies for electricity measurements. Both meters provide measurements on the supply and return lines to a particular device, and both sum the energy transfer to or from that device.

To understand how a BTU-Meter works, the equation for heat transfer must be examined. For a hydronic system, the heat transfer to or from a device is given by Eq 1:

$$Q = \int C p \dot{M} (T_o - T_i)\, dt \qquad \text{[Eq 1]}$$

where:

Q = heat output or input by the heat transfer fluid

C_p = specific heat capacity of the heat transfer fluid

$\dot{M}$ = mass flow rate of the fluid

T_o, T_i = the inlet and outlet temperatures of the fluid

t = time.

Figure 3 illustrates the basic elements of a BTU-Meter which can measure the heat transfer given by Eq 1. The elements include (1) sensors to detect flow and temperatures, (2) an electronic computer to calculate the rate of heat transfer, and (3) a component to display the results to the operator.

Table 2 lists desirable characteristics of a BTU-Meter appropriate for the wide range of potential Army applications. When this research began, no commercial unit was available with all these characteristics, so CERL designed one (see the appendix). The design uses platinum resistance thermometers and a venturi for the temperature and flow sensors, respectively. The venturi offers several special features: (1) it is low-cost, especially for large pipe sizes; (2) it is useful for a wide range of pipe sizes and different types of fluids; (3) it is simple to maintain since all electronics are mounted external to the piping and are easily accessible.

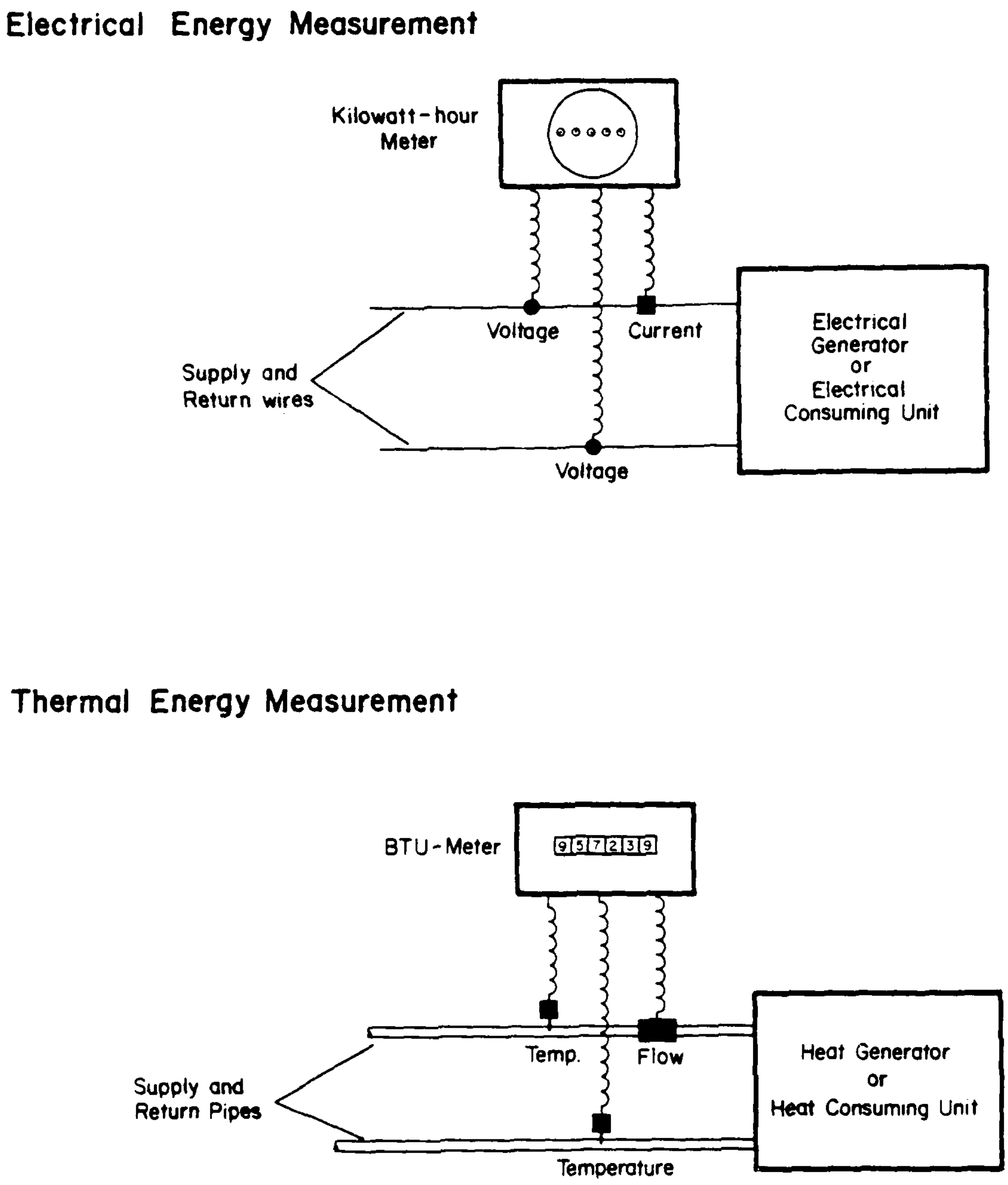


Figure 2. Similarities between BTU-Meter and Kilowatt-Hour Meter.

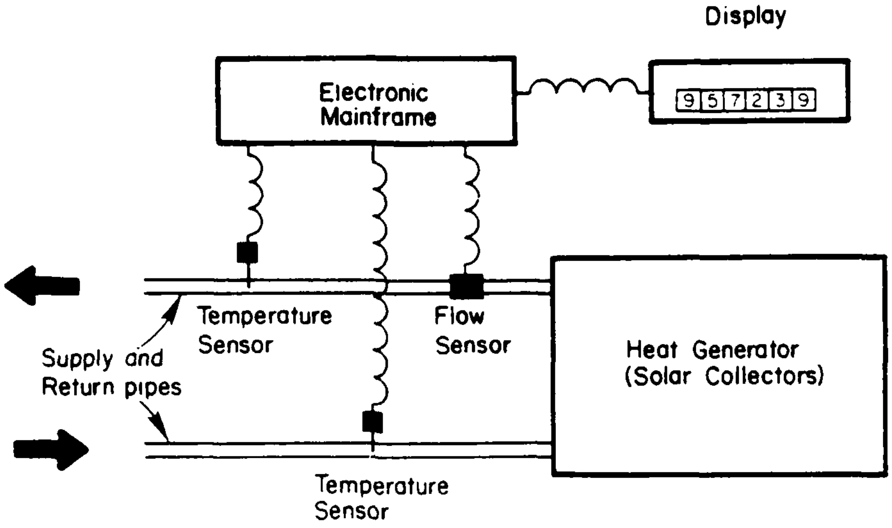


Figure 3. Basic elements of the BTU-Meter.

Table 2
Characteristics To Be Considered When Selecting BTU-Meter

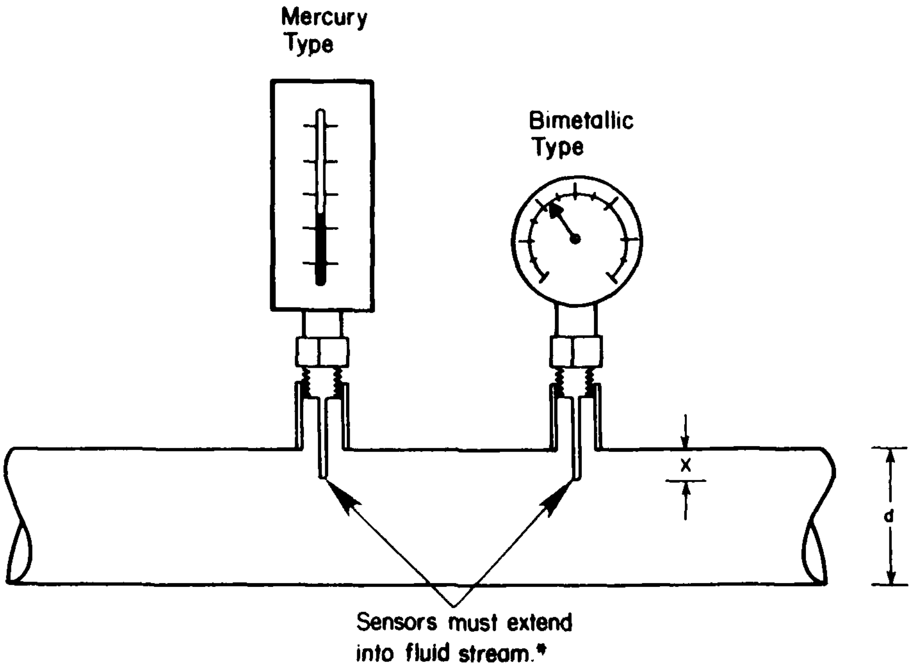
Characteristic	Characteristic Needed for Army Applications
Cost	Unit should be low-cost, particularly for measurements on small pipes.
Pipe Size	Unit must be able to take measurements for the pipe size of the intended application; potential Army applications range from 1 to 8 in. (25.4 to 203.2 mm).
Calibration	Unit should be factory-calibrated (no field calibration should be required).
Sensor Accessibility	Sensors which are susceptible to damage should be accessible for repair or replacement.
Accuracy	Flow Sensor 5 percent of nominal flow value. Temperature Sensor 0.1°C from 0 to 100°C. Electronic Computer 1 percent for calculation of rate of heat transfer for $\Delta T = 10°C$ or higher.
Temperature Range	32° to 212°F (0° to 100°C).
Fluid Compatibility	Must be compatible with fluid in pipe; for collector loop applications, compatibility with glycol solutions or silicone oil might be required.
Pressure Drop	Pressupe drop produced by sensors in pipes should be small (e.g., less than 0.1 psi [70.3 kg/m^2]).

Several commercial meters have recently become available and are being tested by various laboratories.[4] However, most of these units were designed for measuring hot water consumption and are restricted to use on small pipes (diameters of about 1 in. [25.4 mm]). At least one manufacturer has listed specifications for a BTU-Meter which meets most of the requirements listed in Table 2; however, the test results for this model are not yet available.

Thermometers

Thermometers must measure the following: (1) temperature of fluid in piping, (2) outside air temperature, and (3) average temperature of solar storage tar

For the pipe-mounted thermometers, simple indicating thermometers with an accuracy of 1°F (0.5°C) over a temperature range of roughly 30° to 240°F (− 1° to 115°C) should be used. For this application, direct-reading mercury thermometers, such as the U.S. Navy Type GG-T-321C, are adequate. Some bimetallic thermometers also have the required accuracy and are acceptable. To insure that the unit accurately measures temperature, it should be mounted as in Figure 4. The sensor should extend into the fluid stream at least 1 in. (25.4 mm) for pipe diameters of 2 in. (50.8 mm) or larger; for smaller pipes, the sensor should extend into the pipe a distance which is at least one-half the pipe diameter.



*FOR d = 2 in. or more, X = 1 in. minimum.
FOR d = less than 2 in., X = 1/2d minimum.

Figure 4. Mounting of mercury and bimetallic thermometers in piping.

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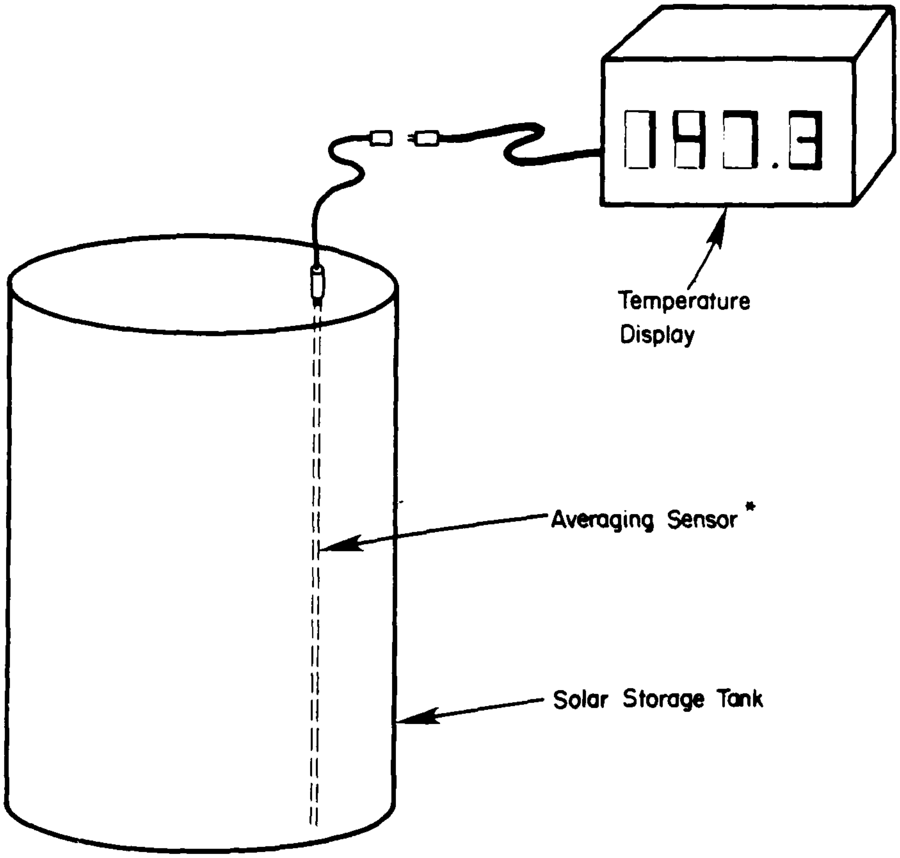
[4] NASA Report for DOE, *Federal Solar Flares No. 3* (NASA, 1981); Gerald R. Guinn and Leigh Hummer, *Testing and Evaluation of BTU (Heat) Meters for Measuring Solar System Performance*, Workshop on Performance Monitoring of Solar Domestic Hot Water Systems, Cape Canaveral, Florida (December 1980).

To measure outside air temperature, a thermometer similar to the pipe-mounted units can be used if it is mounted properly. The mounting should shade the thermometer from direct sunlight but should allow air to flow freely across the sensor. The thermometer should provide an accuracy of 1°F (0.5°C) over a temperature range of about 0° to 110°F (− 18° to 43°C).

The requirements for measuring average temperature in the solar storage tank are quite different. Although the accuracy requirement is also 1°F (0.5°C), the thermometer must provide a repeatability/resolution of 0.1°F (.05°C) and provide an average over the vertical dimension of the tank. The following combination (see Figure 5) met these requirements: (1) a platinum resistance thermometer with a long sensing element mounted vertically in the tank, and (2) a portable display unit for temperature readout accurate to within 0.1°F (.05°C).

Flow Sensor

Several types of meters can measure the flow rate of fluid in a pipe. A venturi sensor accurately



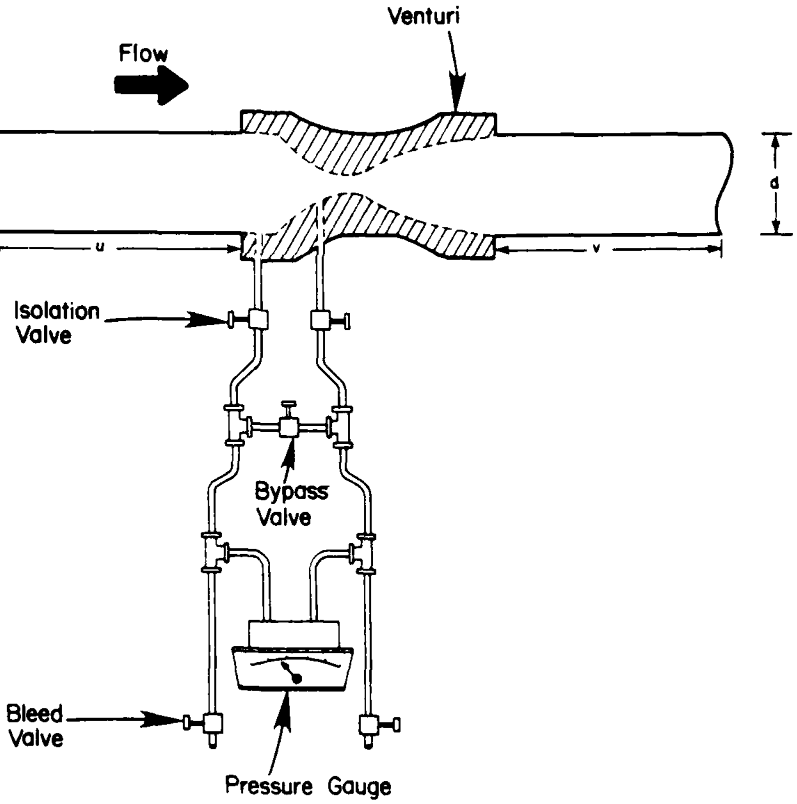
* The sensing length must be mounted along vertical dimension of the tank and the length must be at least 95% of the vertical dimension of the tank.

Figure 5. Averaging probe and temperature display unit used for measuring average tank temperature.

measures flow (about 5 percent) for a wide range of pipe fluids and is available for a wide range of pipe sizes. A differential pressure gauge must be used with this sensor (see Figure 6); this gauge can be a simple manometer or a direct-reading gauge with a movable piston or diaphragm which is magnetically coupled to a dial pointer.

When the piping fluid is water, direct-reading flowmeters with an accuracy of 5 percent are useful and easily read. Figure 7 shows an example of this type of meter. For this meter, a float in a transparent tube mounted vertically indicates the amount of fluid flow by rising to a higher level for a higher rate of flow. The flow rate is indicated by the position of the float on the graduated scale provided with the meter.

For small solar systems, a permanently installed flowmeter may not be needed, and the flow measurement station shown in Figure 7 can be constructed. Since the flowmeter is used as a portable unit and inserted just briefly for measuring flow, only one is needed for a large number of systems.



The minimum length of straight, uninterrupted piping upstream and downstream of the venturi must be u=5d v=2d

Figure 6. Combination of venturi flow sensor and differential pressure gauge (Schematic sketch; not to scale.) (useful for flow measurements on a wide range of liquids).

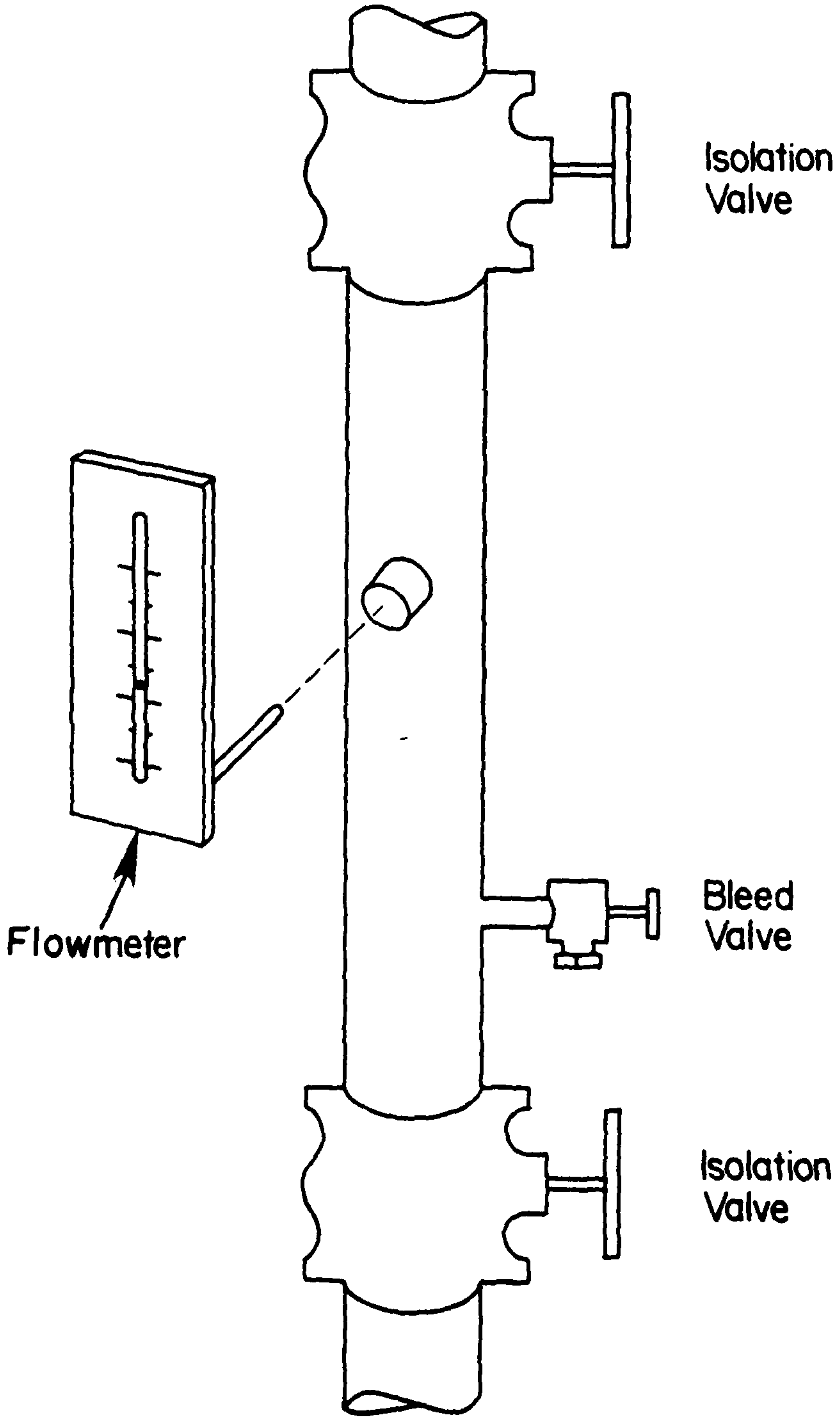


Figure 7. Flow measurement station which permits the Flowmeter to be employed as portable flowmeter. (This is a schematic sketch and is not to scale.)

Pyranometer and Integrator

A pyranometer and integrator are needed to measure incident solar energy. Although pyranometers for precise, scientific studies are available, the units have several disadvantages: (1) they are expensive, (2) they are fragile, and (3) they require frequent recalibration (about once every 6 months). The newer, solid-state sensors overcome these disadvantages and still provide the needed accuracy of 5 percent for measuring incident solar radiation.

An integrator with an accuracy of about 1 percent can be used to sum the pyranometer's output. For long-term measurements (e.g., monitoring), protection against power failures is essential; this can be provided by an electromechanical counter or by giving the integrator a battery backup.

Miscellaneous Gauges

When antifreeze solutions are used in the collector loop, the concentration of the fluid should be checked with a refractometer. Since the solutions can become acidic with age, the fluid's pH should be checked periodically with pH papers. A service kit which contains both these items is available commercially.

A measurement of the "on" time of the collector pump provides valuable information; the meter is very important for monitoring since it indicates common system malfunctions reliably. AC hour meters are available at very low cost and provide an accuracy of 0.1 hour.

Pressure gauges are also useful for checking pump performance. Isolation valves (see Figure 8), which are opened only briefly for the measurement, keep the gauge from deteriorating rapidly as a result of continuous pump vibration. When these valves are used, only a single gauge is needed for pressure difference measurement; this allows the pump's pressure head to be determined more accurately.

Selection and Placement of Meters

Many different configurations are included in current design practice; the meter requirements for each configuration must be considered individually. The designer will select the meters and indicate their placement for a particular solar design. The metering plans for two common solar designs are used in the following examples to demonstrate meter selection

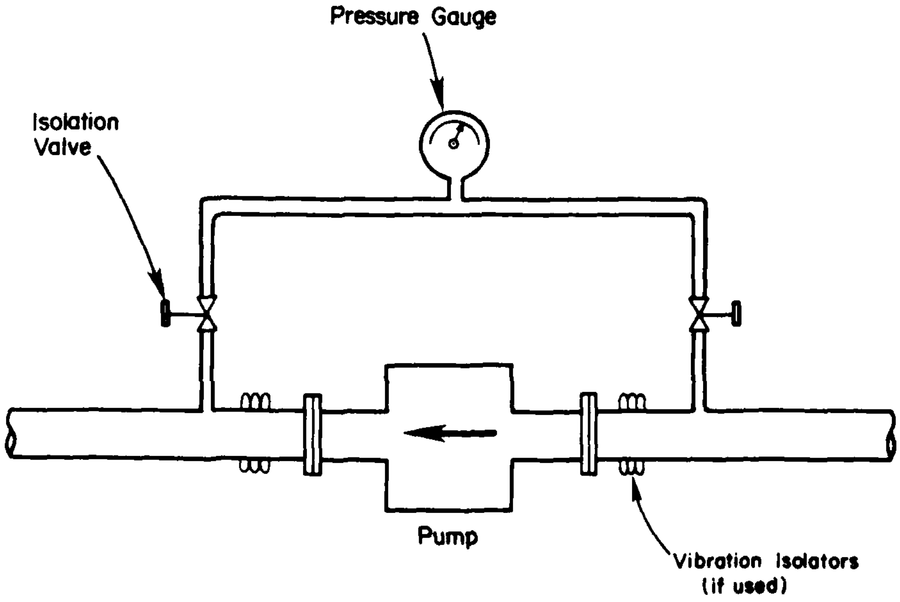


Figure 8. Mounting of pressure gauge for checking pump performance.

and placement. Table 3 lists mounting notes applicable to the meters discussed in these examples.

Figure 9 is a sketch of the metering layout for a solar system which uses an antifreeze solution in the collectors and whose heat exchanger is mounted in the storage tank. Some simple meters measure the temperatures and flow associated with the solar collectors; others check the pressure head and "on" time of the collector pump. A pyranometer, mounted in the plane of the solar collectors to measure incident solar energy, is connected to an integrator.

The BTU-Meter measures the heat output of the collectors. Since the sensors for this unit are placed in the antifreeze solution, the antifreeze's properties must be considered for this measurement. One approach is to have the BTU-Meter calibrated for the

Table 3
Mounting Notes for Meters and Sensors Illustrated in Figures 9, 10, and 11

Meter or Sensor	Note on Mounting
All Readouts or Indicators	All readouts and indicators should be readable from the floor. It is not practical to require that they all be mounted in a central location, since many simple meters (for example, mercury thermometers) mount directly on a pipe and do not provide remote readout.
Pyranometer	This unit must be mounted outside in the vicinity of the collectors. The location should have the same amount of solar radiation as a typical collector in the array. The unit must be mounted in the plane of the collectors.
Integrator	This device is the remote readout for the pyranometer and can be mounted in the mechanical room, preferably near the BTU-Meter to facilitate readings during acceptance testing.
Outside Air Sensor	This unit must be mounted outside. Housing must shield the sensor from direct sunlight but allow air to flow freely across the unit. Commercial housings are available for this purpose.
BTU-Meter	Sensors for the BTU-Meter should be mounted on piping in the mechanical room. The meter should be mounted nearby to minimize the length of wiring run between sensors and electronics. To further aid in minimizing the length of wiring, it is preferable to mount sensors where supply and return collector piping are close together
Venturi Flowmeter	The venturi sensor should be mounted on a horizontal section of pipe in the manner illustrated in Figure 6. The venturi must be mounted such that the arrow marked on the venturi by the manufacturer is aligned with the direction of flow in the pipe. The length of straight, uninterrupted piping upstream of the venturi must be at least five pipe diameters, and the length downstream must be at least two pipe diameters long. The pressure gauge should be mounted immediately below the venturi to minimize the piping run between the venturi and the gauge.
Direct-Reading Flowmeter	This meter should be mounted on piping in the mechanical room. It should be mounted in accordance with the manufacturer's instructions.
Mercury Thermometers	Thermometers should be mounted on piping in the mechanical room The unit should be mounted to permit easy access for taking readings. The scale should be vertical (use straight stem types on horizontal piping and 90-degree angle stem types on vertical piping).
Pressure Gauge	Mount on piping near pump as indicated in Figure 8. Since vibration isolators are used for large pumps, the gauge should be mounted on the isolated pipes for such applications.
Temperature Display (for tank)	The display for the tank temperature should be mounted in the mechanical room, preferably near the solar controls unit with built-in diagnostics.
Averaging Temperature Sensor for Tank	The sensor must be mounted so that the sensing element is along the vertical dimension of the tank, and the length of the sensing element must be at least 95 percent of the vertical dimension of the tank. Note that "flexible" averaging sensors are commercially available. With these units, a sensing element longer than the vertical tank dimension can be selected and the unit bent in a curved shape to accommodate the tank size.
AC Hour Meter	This should be mounted in the mechanical room near the controls unit. To keep installation costs low and permit easy removal, base mount meters should be selected and installed on the exterior of a control cabinet (for example, one that houses the manual override switch).
Manual Override Switch	For systems in which large pumps are involved, this switch should be provided in the customary manner as part of the control panel which houses the motor starters (e.g., a hand-off auto switch). For small systems, a simple electrical switch (SPDT with center-off) can be mounted on a standard control cabinet immediately below the controls with built-in diagnostics.

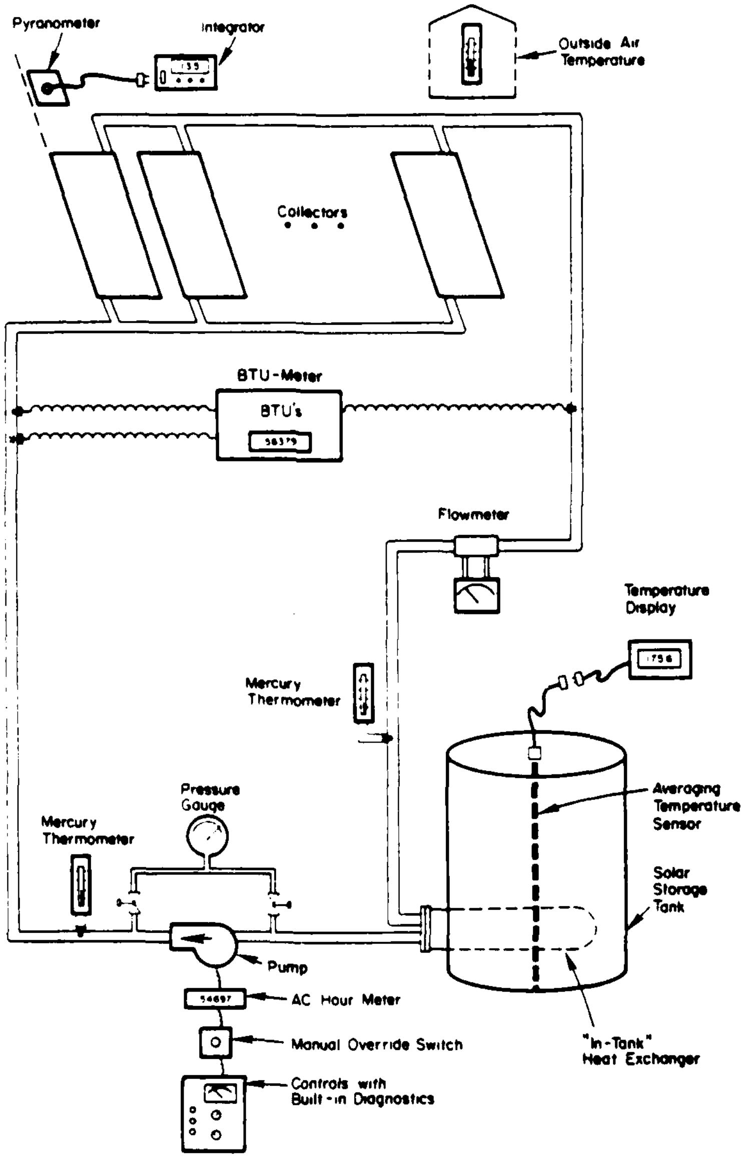


Figure 9. Metering layout for solar system with "in-tank" heat exchanger.

particular collector fluid expected for this application. However, when the collector fluid is a solution prepared at the site (e.g., ethylene or propylene glycol solutions), the preferred method is as follows: (1) calibrate the BTU-Meter for use in water; (2) check the concentration of the fluid using the refractometer; and (3) correct the BTU-Meter readings using correction factors from a table supplied by the meter manufacturer. This three-step method is preferred, because the measurements remain accurate, despite variations in the concentration of the antifreeze solution.

An example of a table supplied by a manufacturer is as follows:

Concentration of Solution	Multiply Readings by
20%	0.97
25%	0.95
30%	0.93
35%	0.92
40%	0.90

As an illustration of the procedure, suppose that a BTU-Meter reading advanced from 8700 to 9700 during a one-hour interval. If the collector fluid were water, this would correspond to 1000 Btus of heat. However, for a solution with a concentration of 30 percent, the user would look up the correction factor (.93 in this case) and multiply the reading by this value to obtain 0.93 × 1000 = 930 Btus.

Figure 10 shows a second example of the metering plan. This example design uses an antifreeze solution for the collectors, but the heat exchanger is mounted external to the tank. The metering plan is similar to the first example's; however, more thermometers and a flowmeter are used for the added loop. Also, the BTU-Meter's sensors are on the "water-side" of the heat exchanger. This location is preferred, since it provides nearly the same heat transfer value, but avoids the complications associated with taking measurements in the antifreeze solution.

Economic Considerations of Metering

When selecting meters, benefits should be weighed against costs. The benefits of metering are insurance that the investment in the solar energy system produces the expected dividends. Hence, a handy way of evaluating the cost-vs.-benefit ratio is to compare metering costs with the investment costs of the solar energy system.

Table 4 gives estimates of the list prices (in effect during 1981) of meters suitable for a solar system that would provide domestic hot water heating for a 250-man Army barracks building (i.e., a collector area of 3500 sq ft [315 m^2] with 3-in. [76.2-mm] piping). The installed cost of the meters for this example would be about $4000 and represents only a small fraction of the installed solar system's projected cost of $140,000. The small added cost of the metering is certainly worthwhile for protecting the investment in a solar system of this size.

The instrumentation commonly used in the past, which involved a data acquisition system, had an installed cost of $50,000 or more. The low cost of the metering approach is especially evident when compared to this approach. It provides a much more favorable cost-vs.-benefit ratio and economically justifies acceptance testing for a wide range of solar energy systems.

Even greater cost savings can be gained by using meters when several small solar systems are being built at one site (e.g., solar systems for heating

Table 4
Estimated Purchase Prices of Meters for Representative Solar System

Quantity	Meter Type	Purchase Price*
1	BTU-Meter	$ 800
1	Venturi flowmeter	$ 200
1	Pyranometer integrator	$ 800
1	Averaging tank probe and temperature display	$ 600
3	Mercury thermometers, @ $ 30 each	$ 90
1	AC Hour Meter	$ 25
1	Pressure Gauge	$ 8
1	Solar controls with built-in diagnostics	$ 300

*From 1981 price lists of manufacturers.

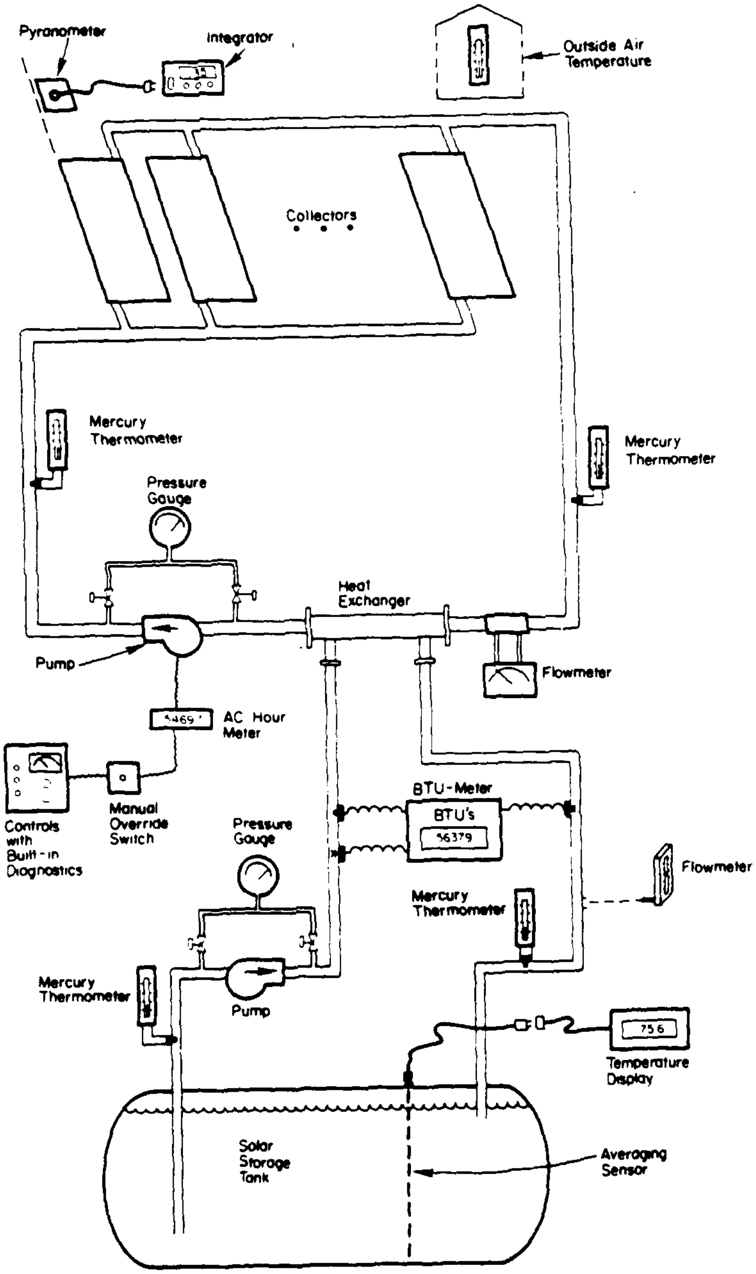


Figure 10. Metering plan for solar system with heat exchanger external to tank.

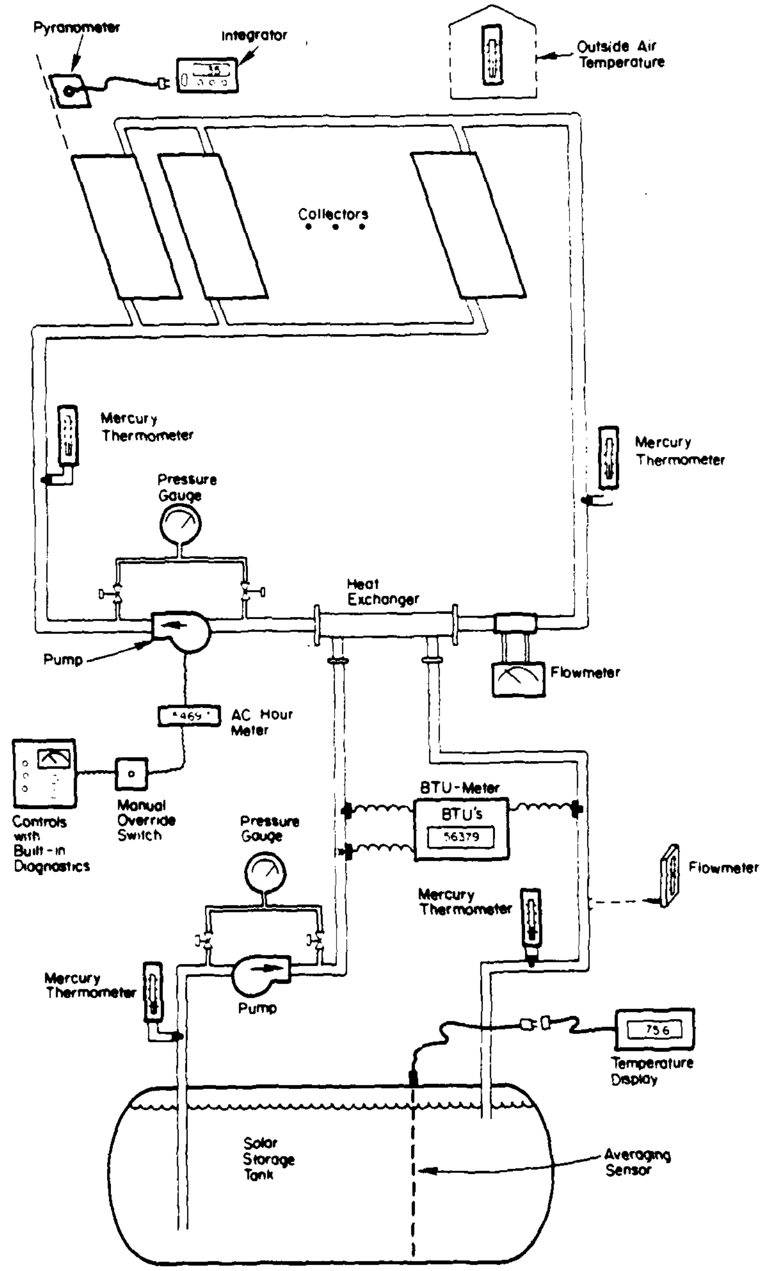


Figure 10. Metering plan for solar system with heat exchanger external to tank.

domestic hot water for family housing units). One obvious cost-saving technique is to stop using separate meters to measure the incident solar energy and the outside air temperature for each solar system. Also, the following approach can be used to test identical designs. First the contractor should build a small number of solar systems and submit these for testing. This small sample should then be given a complete set of meters, as shown in Figures 9 and 10. Finally, after testing has indicated that the basic design meets the requirements, the remaining solar systems can be built with the minimal metering layout shown in Figure 11. The remainder of the solar systems can then be checked for acceptability, using a combination of these meter readings and a thorough visual inspection.

3 PROCEDURES FOR ACCEPTANCE TESTING

The procedures for acceptance testing a solar system with a sophisticated instrumentation system were developed and field-tested in a previous study.[5] This chapter describes how those procedures can be adapted to the metering approach.

Testing the Solar Collector Array

The most important check of the solar collector performance is measuring the collector efficiency and comparing this value with the efficiency value given in the specifications. The meters described in Chapter 2 allow the testing to follow the standard of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE).[6] The meter readings allow collector efficiency, η, and fluid parameter, F, as defined in Eqs 2 and 3, to be computed.

$$\eta = \frac{Q_{out}}{IA_c} \qquad \text{[Eq 2]}$$

$$F = \frac{T_c - T_a}{I/t} \qquad \text{[Eq 3]}$$

where:

t = the duration of the time interval for the measurement

Q_{out} = energy output of the collector array during time t

I = incident solar energy per unit area during time t

A_c = gross collector area

T_c = temperature of the fluid in the collector supply pipe

T_a = outside air temperature.

The energy output of the collectors, Q_{out}, is obtained by computing the difference in the BTU-Meter readings taken at the beginning and end of each test interval and multiplying by the appropriate scale factor supplied with the BTU-Meter. The incident solar energy, I, is obtained by starting the integrator at the beginning of the test interval and recording the value of the integrator's output at the end of the test interval. The average temperature values of the outside air and collector supply fluid can be obtained by averaging the thermometer readings taken periodically during the test interval.

To permit a valid comparison of the measured efficiency with the specified value, the conditions during the test interval must meet the qualifications specified by the ASHRAE standard; Table 5 summarizes the most important of these test conditions.

Table 5
Summary of Important Test Conditions for Collector Efficiency Measurements

Quantity	Test Condition
Irradiation	Magnitude ≥ 200 Btu/hr-sq ft (0.63 kW/m²).
	Irradiation must be steady throughout each test interval.
	Incident angle < 30 degrees (prevents measurements in early morning or late afternoon).
Steady-State	Pumps must have been operating long enough for temperatures to reach a steady value; pumps must continue operating throughout test interval.

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[5] CERL Technical Report F-173

[6] *Methods of Testing to Determine the Thermal Performance of Solar Collectors*, ASHRAE Standard 93-77 (American Society of Heating, Refrigerating, and Air-Conditioning Engineers [ASHRAE], 1978).

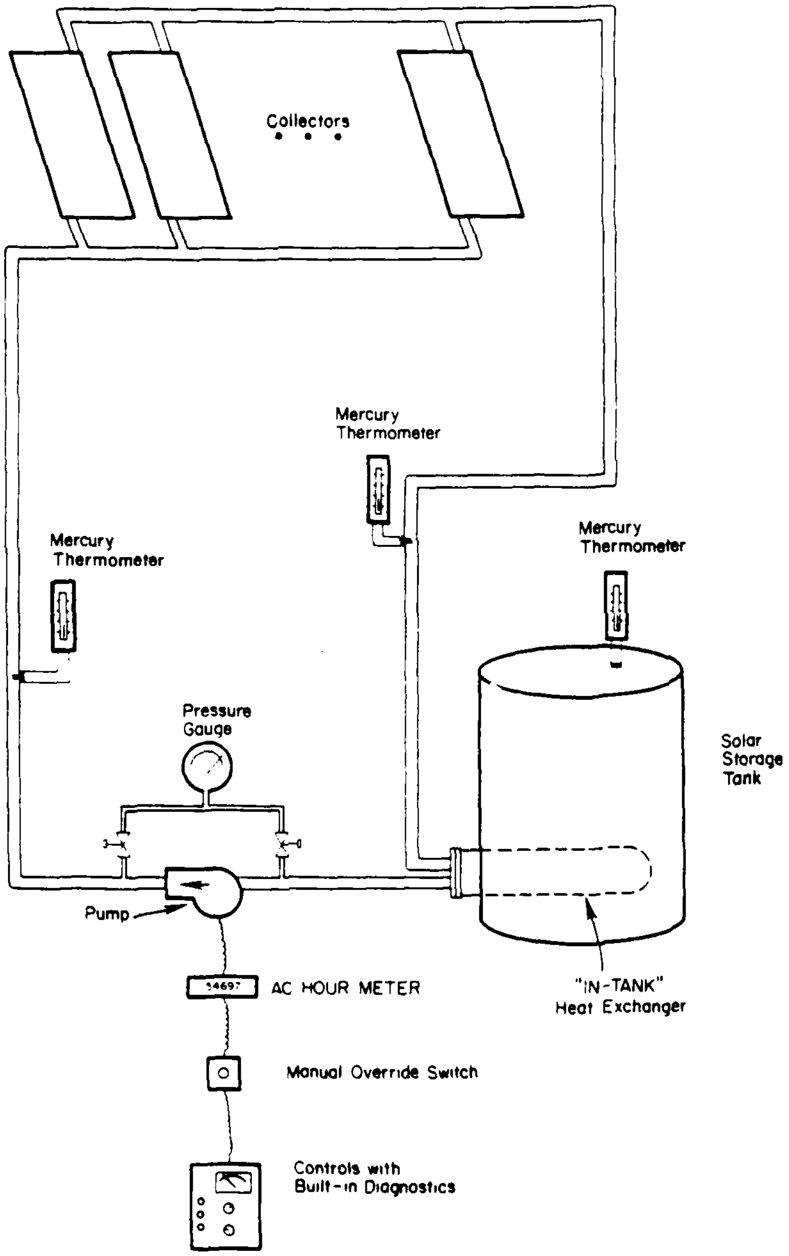

Figure 11. Minimum metering layout for small solar system.

If one of the test conditions is not met during a test interval (e.g., the sky becomes partly cloudy and the radiation suddenly drops to a low value), then the meter readings from this test interval must be discarded.

The meters are also helpful for checking test conditions. For example, taking readings on the AC hour meter on the collector pump is a convenient way of checking whether the pump was "on" throughout the test interval. Examining the instantaneous output of the pyranometer allows a check of whether the irradiation is above the minimum level and that it is reasonably steady. The unsteadiness of the radiation can also be checked by observing the amount of cloudiness in the sky.

Since the test conditions require relatively clear skies, efficiency can be measured only during sunny weather. For a thorough check of collector efficiency, values over a wide range of fluid parameter values should be measured and compared with specified values. This can be done by taking measurements over 5 or more sunny days with different tank temperatures.

Three other minor tests associated with the collectors should be done and the measured values compared to those in the specifications.

1. The flow rate through the solar collectors should be measured with the simple flowmeter installed on the collector loop.

2. The pressure head of the collection pump(s) should be measured.

3. If the collector fluid is mixed at the site (e.g., a solution of either ethylene or propylene glycol), the concentration should be tested with a refractometer.

Testing the Solar Storage Tank

Since the solar storage tank stores thermal energy from the collectors, the tank should be checked for large thermal losses. The Sheet Metal and Air Conditioning Contractor's National Association (SMACNA) has developed a stringent standard which defines the maximum tolerable loss from an insulated storage vessel;[7] any loss greater than 2 percent of the tank's thermal capacity over a 12-hour period is unacceptable.

Table 6 summarizes the steps for checking for large thermal losses from the tank. The first step is to insure that the tank is hot enough to allow a thorough check; since the tank temperature is increased to a high value during the collector efficiency measurements, the natural time to perform this test is right after these measurements are done. The tank is then isolated for the test interval by closing all valves and shutting off all pumps which could transfer energy to or from the tank. The values of the average tank temperature at the beginning and end of the test interval are then recorded. These values are inserted into Eq 4 to evaluate the thermal losses.

$$\text{Loss Rating} = f\,\frac{T_1 - T_2}{T_t - T_a} \qquad \text{[Eq 4]}$$

where:

T_1, T_2 = the tank temperatures at the beginning and end of the 12-hour test interval, respectively.
T_t = the average tank temperature during the interval, $(T_1 + T_2)/2$
T_a = the average temperature of the medium surrounding the tank
f = design factor which relates the temperature increment associated with the tank's storage capacity to the temperature difference between the tank and surroundings.

The percentage of loss found from Eq 4 can be compared directly with the maximum acceptable loss

Table 6
Procedure for Testing Thermal Losses From Solar Storage Tank

1. Insure that the tank temperature is 140°F (60°C) or higher
2. Select a time for a 12-hour test interval in which the pumps connected to the tank can be shut off (e.g., an overnight interval).
3. Isolate the tank for the entire test interval (close isolation valves and shut off pumps associated with the tank).
4. Take a reading of the average tank temperature at the beginning of the test interval. If the tank is located above ground, also measure and record the temperature of the air surrounding the tank.
5. Take another reading of the average tank temperature at the end of the test interval. If the tank is above ground, repeat temperature measurement of the air surrounding the tank
6. Return system pumps and valves to normal operating condition.

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[7] *Heating and Air Conditioning Systems Installation Standards for One and Two Family Dwellings and Multifamily Housing Including Solar* (Sheet Metal and Air Conditioning Contractor's National Association [SMACNA], 1977).

of 2 percent specified by the SMACNA standard to determine if the tank installation is acceptable.

The transfer of heat from the solar collectors to the tank can also be evaluated using measurements made with simple thermometers and flowmeters. These measurements should be taken after the pumps have been operating long enough for the temperatures to reach a steady-state value.

For a tank which does not have an internal heat exchanger, the tank outlet temperature should be compared to the average tank temperature; a tank outlet temperature greater than the average tank temperature indicates that there is at least a partial short-circuiting of flow in the tank and that there is an unacceptable solar storage unit. For solar systems which have a heat exchanger to isolate the collector fluid from the tank fluid, temperature and flow can be measured with simple meters; these values can then be compared to those listed for the heat exchanger in the design specifications. The methods for evaluating the heat transfer data obtained with meters are the same as those used to evaluate data obtained with the sophisticated instrumentation system.

Testing the Controls

The previous study[8] provided a simple procedure for checking solar system controls using simple thermometers and water baths. Although this method can only be used before the controls are installed, it is acceptable because this testing is done when the solar system is installed.

However, a preferred method of testing the controls is with a controls unit that has built-in diagnostics which checks the unit with the self-test features. This approach has the advantage that the controls unit can be conveniently checked any time during the solar system's operating life; thus, it takes care of the need for such checks during monitoring as well as during the acceptance test.

Table 7 lists desirable features for a controls unit. The specific steps to be followed in using the built-in diagnostics of a particular controls unit are mainly prescribed by the electronics design and hence should be supplied with the controls unit. Generally, the following can be examined and compared to the specifications requirements: (1) the values of all setpoints, and (2) all modes of operation (i.e., the status of outputs as a function of the temperatures indicated by control sensors). The accuracy of the temperatures displayed by the controls unit can also be checked by comparing them to values taken from the simple thermometers provided by the metering approach. (Note that a valid comparison of thermometers mounted in the piping can only be done after the pumps have been run long enough for temperatures to reach a steady-state value.)

A controls unit with the features listed in Table 6 is available commercially. Chapter 4 presents the results of CERL's pilot test on this unit.

4 A PILOT TEST OF THE ACCEPTANCE TEST

A pilot test was performed to check the viability of the metering approach for acceptance testing of solar energy systems. To perform the pilot test, a set

Table 7
Desirable Features for Solar Controls Unit

Hardware Feature	Function
Status Lights	Lights should indicate current status of all outputs of controls unit
Temperature Display	Allows operator to read temperature sensed by control sensor; the sensor on display is selected by front-panel switch. Also allows display of temperature differential which controls collector pump
Adjustable Setpoints	Setpoints can be adjusted to match values required by specifications, independent adjustments allowed for high and low setpoints for temperature differential control output
Sensor Simulation	Switch-selectable internal variable resistor allows sensor to be simulated throughout entire temperature range. In conjunction with status lights and temperature display, this permits setpoints to be measured and all modes of operation to be checked

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[8] CERL Technical Report E-173.

of meters was installed in the Solar Test Facility at CERL. This facility has a solar system with 240 sq ft (22.2 m^2) of collectors, a 500-gal (1.9 m^3) storage tank, and an external heat exchanger. The meters were installed as described in Chapter 2 (see Figure 10) and included the BTU-Meter described in Appendix A. The procedures presented in Chapter 3 were then used to test the solar system. To compare the metering approach with the more conventional approach, simultaneous measurements were made, where appropriate, with the meters and a data acquisition system (Hewlett-Packard Model 3052A).

Collector Test

Collector efficiency was measured on several sunny days. Table 8 gives an example of the meter readings that were logged for one day. The data were taken during 15-min test intervals; the meters were used to check whether the ASHRAE test conditions discussed in Chapter 3 were met. The most difficult test condition to meet was the requirement for steady irradiation; in particular, it was noted that one can simply look at the skies and avoid wasted effort by not taking data on days in which skies are not reasonably clear of clouds.

The meter readings were analyzed to determine collector efficiency and fluid parameter values. Table 9 gives the results of the analysis for the meter readings listed in Table 8. To assess the accuracy of the BTU-Meter for measuring the collector energy output, the BTU-Meter values were compared with those of the data system (see Table 9). The comparision shows that the BTU-Meter measures the energy output with an accuracy of about 5 percent.

Incident solar energy was measured with a rugged, low-cost pyranometer (LI-COR Model LI-200SB) and an integrator (LI-COR Model LI-1776 Solar Monitor). A standard pyranometer (WeatherMeasure Model R413) and the data system measured data simultaneously to check the accuracy of the metering approach. A comparison of the results (See Table 10) shows that the two measurement techniques differ only by about 1 percent; thus, the accuracy is about the same for both techniques.

The integrator used with the pyranometer was very convenient since it contained the following features: (1) storage of more than 100 values of integrated irradiation, (2) user-selectable integration periods ranging from 7.5 min to 24 hr, and (3) an internal clock for synchronizing the integration periods according to the time of day. These features allowed the radiation measurement apparatus to be set up at the beginning of the day; it then acquired

Table 8
Example of Meter Readings for One Day During Collector Efficiency Measurements

Meter Reading No.	Time	Outside Air Temp.	Collector Inlet Temp. (°F)	BTU-Meter Reading (100 Btu)	Pyranometer-Integrator Reading (Btu/sq ft)
1	10:30	79	109	18449	start
2	10:45	80	111	18520	68
3	11:00	81	113	18592	71
4	11:15	82	115	18666	73
5	11:30	82	117	18743	75
6	11:45	83	119	18824	77
7	12:00	84	121	18909	78
8	12:15	84	123	18994	79
9	12:30	85	125	19076	79
10	12:45	85	127	19159	79
11	13:00	86	129	19240	79
12	13:15	86	130	19327	79
13	13:30	86	133	19413	78
14	13:45	86	134	19497	76

Table 9
Example of Analysis of Meter Readings Obtained During One Day of Collector Testing

Time	BTU-Meter (Btus)	Data System (Btus)	Difference (%)	Calculated Fluid Parameter ($\frac{F\text{-sq ft-hr}}{Btu}$)	Calculated Efficiency (%)
10:45	7100	7238	-2	0.113	47
11:00	7200	7599	5	0.115	45
11:15	7400	7897	-6	0.114	45
11:30	7700	8246	-7	0.116	46
12:00	8500	8443	1	0.120	49
12:15	8500	8569	1	0.123	48
12:30	8200	8584	-4	0.126	47
12:45	8300	8593	-3	0.132	47
13:00	8100	8443	-4	0.138	46
13:15	8700	8438	3	0.142	49
13:30	8600	8032	7	0.148	49
13:45	8400	7867	7	0.158	50

Table 10
Comparison of Measurement Results of Incident Solar Energy

Time	Low-Cost Pyranometer and Integrator (Btu/sq ft)	Data System (Btu/sq ft)
10:45	64	64.9
11:00	69	67.8
11:15	63	61.7
11:30	79	75.5
11:45	68	65.5
12:00	71	68.1
12:15	73	69.3
12:30	69	66.2
12:45	52	50.7
13:00	36	36.5
13:15	48	47.9
13:30	18	18.9
13:45	58	55.2
14:00	33	33.9
14:15	26	27.0
14:30	31	31.5
14:45	24	24.6
15:00	24	24.8
15:15	24	25.1
15:30	20	21.7
15:45	24	23.3
16:00	19	20.4

data automatically throughout the day. At the end of the day, the data was read from the unit's display and recorded.

The metering approach for acquiring and analyzing collector efficiency data was found to be straightforward; however, the procedure involves manipulation of data by hand and is time-consuming for large quantities of data. To reduce the labor, test intervals longer than the standard 15-min interval can be used. The measured values of the efficiency from these longer test intervals can then be considered "average" efficiency values.

The measured efficiency must be compared to specification values; therefore, it is essential to determine whether a valid comparison can be made of average efficiency values and specified values based on ASHRAE 93-77 test data. The validity of the comparison can be examined theoretically by noting that the efficiency of flat-plate collectors varies linearly with the fluid parameter (particularly for small ranges of the fluid parameter). Hence, average efficiency measurements will permit a valid comparison if the following conditions are met: (1) the ASHRAE test conditions are met during the entire measurement interval, and (2) the average fluid parameter is calculated by dividing the average temperature difference between the outside air and collector supply by the average irradiation during the interval.

To experimentally check the validity of comparing average efficiency data with specifications based on ASHRAE test data, data collected with a data acquisition system at a well instrumented solar site was studied. Table 11 compares the data measured for 1-hr intervals for several typical days with the ASHRAE test data (i.e., measured for 15-min intervals on a single collector). Data agreement was found to be excellent and indicates the use of 1-hr test intervals is acceptable.

The same data was then studied to see if using an even longer test interval of several hours would be feasible. Table 12 lists the values obtained from this study; it also shows that relatively long test intervals provide data which can be validly compared with specifications based on ASHRAE 93-77 test data.

The following method with longer test intervals will reduce the amount of labor needed for the collector efficiency test:

1. Measurements should be conducted on 5 or more sunny days with different tank temperatures; the average tank temperatures on each day should differ by 10°F (5°C) or more.

2. On each day, the average collector efficiency and fluid parameter should be measured for several hours or until ASHRAE test conditions are fulfilled.

3. Each average value of collector efficiency should be compared to the efficiency values required by the specifications.

Besides the collector efficiency measurement, several other minor checks of the collectors were performed during the pilot test:

Table 11
Comparison Between Collector Efficiency Values Determined From ASHRAE Standard Test Data and Average *Efficiency* Values *Measured Over 1-Hour Intervals*

Date	Hour	Average Fluid Parameter $\left(\frac{^\circ\text{F-sq ft-hr}}{\text{Btu}}\right)$	Average Collector Efficiency (1 hr interval)	Efficiency From ASHRAE Test Data
12/09/80	10:00	.346	36%	42%
	11:00	.333	40%	44%
	12:00	.353	40%	42%
	13:00	.406	36%	36%
	14:00	.509	29%	25%
12/20/80	10:00	.349	37%	42%
	11:00	.339	41%	43%
	12:00	.338	41%	43%
	13:00	.382	39%	39%
01/27/81	10:00	.418	31%	35%
	11:00	.384	37%	38%
	12:00	.387	38%	39%
	13:00	.412	36%	36%
	14:00	.512	28%	25%
02/22/81	10:00	.383	36%	39%
	11:00	.360	40%	41%
	12:00	.358	41%	41%
	13:00	.383	39%	39%
	14:00	.440	34%	33%
03/13/81	10:00	.437	33%	33%
	11:00	.359	42%	41%
	12:00	.358	44%	41%
	13:00	.398	42%	37%

Table 12
Comparison Between Collector Efficiency Values Determined From ASHRAE Standard Test Data and Average Efficiency Values Measured Over Time Intervals of Several Hours

Date	Measurement Interval (Hrs)	Average Fluid Parameter $\left(\frac{°F\text{-sq ft-hr}}{\text{Btu}}\right)$	Average Collector Efficiency	Efficiency From ASHRAE Test Data
12/09/80	5	0.41	36%	36%
12/20/80	4	0.35	40%	41%
01/27/81	5	0.42	34%	35%
02/05/81	5	0.34	41%	43%
02/22/81	6	0.40	37%	36%
03/13/81	6	0.42	36%	35%
04/10/81	7	0.39	40%	38%
04/28/81	6	0.35	43%	42%

1. The collector flow rate was measured with a simple, direct-reading flowmeter; the rate was 6 gpm (0.38 L/sec), which is within the range specified by the manufacturer for these collectors.

2. The pressure head of the collector pump was measured to be 8 psi (5624 kg/m^2); this value agrees with the value listed on the pump curve from the manufacturer for that flow rate.

3. The concentration of the ethylene glycol solution was verified with a refractometer to be 50 percent.

Tank Test

Just before the meters for the pilot test were installed, a new "above-ground" tank was installed to provide thermal storage. The storage vessel selected was a 500-gal, epoxy-lined, steel tank which was to be factory-insulated with 4 in. (101.6 mm) of polurethane foam. Specifications for the tank were prepared from DOE guide specifications[9] and from the conventional bidding process used to select the manufacturer with the winning bid. Hence, this part of the pilot test provided very realistic conditions for testing a newly installed solar storage tank.

An averaging resistance probe (Hy-Cal Eng. Model RTS-4205-B) was installed in the tank to measure the average tank temperature. Simple meter readings of the average tank temperature and the temperature of the surrounding air were done in overnight test intervals. For comparison, these measurements were performed simultaneously by the data system.

Figure 12 is a plot of tank temperature versus time which was produced by the data system during the first overnight test interval. The system also automatically produced a least-squares fit of the data to a straight line and yielded a decay rate of 0.337°F/hr (0.187°C/hr). Measurements with the simple metering approach gave a tank temperature of 175.3°F at 1800 hrs and 170.2°F at 0900 hrs the following morning. This corresponds to a decay rate of 5.1°F/15 hr or 0.34°F/hr, which is within 1 percent of the value provided by the data system.

The calculations used to compare the heat loss rate with the SMACNA standard are as prescribed in the DOE manual[10] which provided the guide specifications for the tank. The calculated value of the loss rate for a 12-hr interval was 3.63 percent, which exceeds the maximum allowable loss rate of 2 percent given in the standard. Also, the average R-value of the tank's insulation was automatically computed by the data system and listed on the printout. The average R-value was listed as 7, far below the value of 25 which is normally stated for this tank's insulation.

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[9] *Design and Installation Manual for Thermal Energy Storage*, Report Prepared for Department of Energy, ANL-79-15 (Argonne National Lab, 1979).

[10] *Design and Installation Manual for Thermal Energy Storage.*

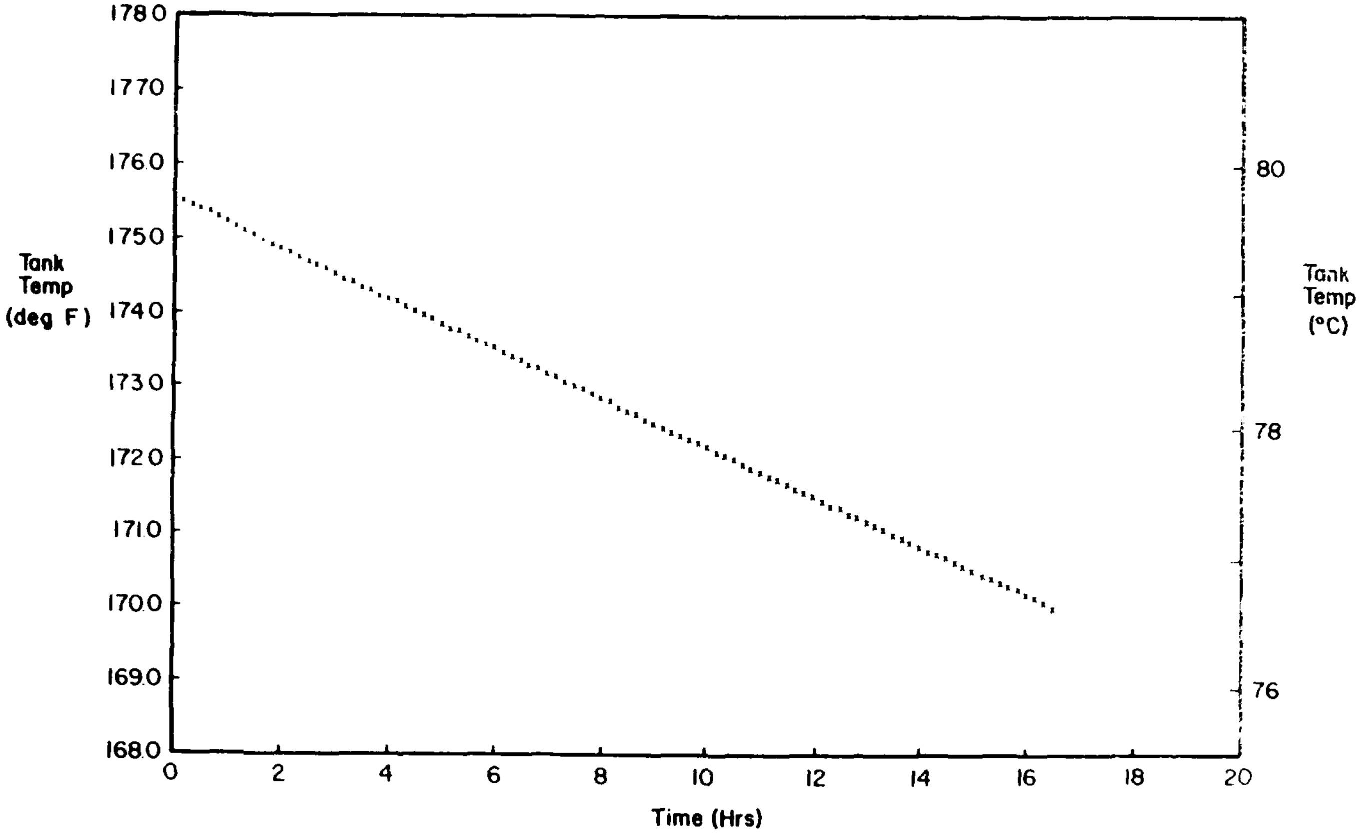


Figure 12. Plot of tank temperature versus time as measured during first overnight test interval.

The first overnight test indicated an excessively high rate of thermal loss; therefore, the test was repeated at a lower tank temperature of 133°F (58°C), but almost the same results were obtained. As a result, the tank was inspected, and the manhole on its top was found to be uninsulated. The manhole area is only about 5 percent of the total outside tank area; however, the very low R-value of 0.5 expected for an uninsulated horizontal metal plate was calculated to produce a thermal loss of the magnitude found during the measurements. The manhole was then covered with 4 in. (101.6 mm) of urethane foam insulation and the measurements repeated.

Figure 13 compares the thermal losses before and after insulating the manhole as measured by the data system. The effect of adding just a small amount of insulation cuts the thermal losses in half. With the manhole insulation, the thermal loss was only 1.58 percent of the tank's capacity; this is below the maximum value of 2 percent specified by the SMACNA standard. A repeated measurement produced almost the same value.

Table 13 summarizes the results of the measurements. The data indicate that this measurement technique gives highly reproducible results; it also has the sensitivity to detect thermal losses which exceed the maximum prescribed by the SMACNA standard.

The most stringent condition of the tank test measurements is the need to measure relatively small (about 1°F [0.5°C]) temperature decreases in the average tank temperature during an overnight test interval. Hence, the viability of the metering approach for taking these measurements can be assessed by comparing its results for tank temperature

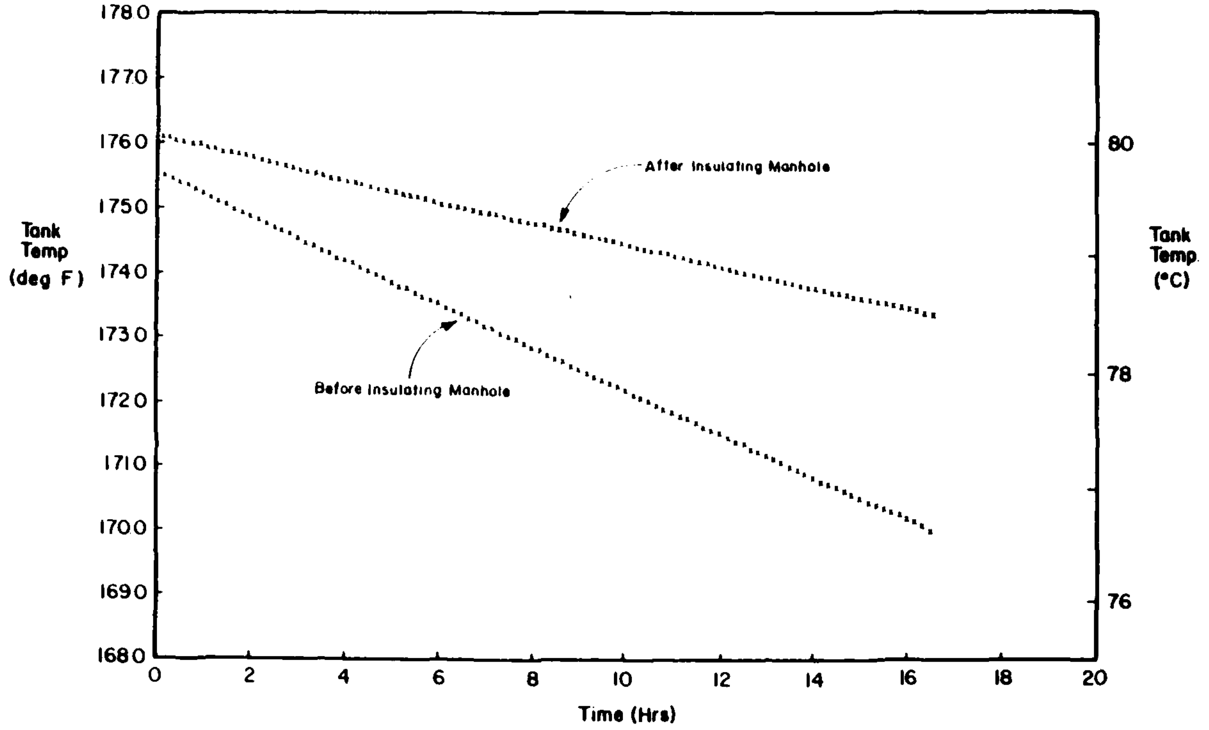


Figure 13. Comparison of tank temperature decay before and after insulating tank manhole.

Table 13
Summary of Results from Tank Test Measurements

Test No.	Average Tank Temperature (°C)	Air Temperature (°C)	SMACNA Loss Rating* (%/12 hrs)
Before Insulating Tank Manhole			
#1	78.2	26.7	3.6
#2	57.9	26.1	3.2
After Insulating Tank Manhole			
#3	54.2	26.1	1.6
#4	53.1	26.7	1.6
#5	79.2	28.9	1.8
#6	71.6	25.0	1.7

*Percentage loss of tank thermal capacity in 12-hour interval; upper limit in SMACNA standard is 2 percent per 12-hour interval.

decay with those measured by the data system. This comparison (Table 14) indicates that the two techniques agreed within an accuracy of 2 percent for all four test intervals. This excellent agreement is a result of the high degree of linearity in the temperature decay, as shown by Figures 12 and 13. Hence, the combination of an averaging temperature probe and a temperature resolution of 0.1°F (0.05°C) gives the precision needed to detect excessive thermal losses from a storage tank during an acceptance test.

Review of the pilot test results showed that one area of tank test data evaluation could be improved. Two shortcomings for comparing metering values with the SMACNA standard were noted: (1) design parameters must be used to calculate the percentage of thermal loss, and (2) compliance with the SMACNA standard depends on the amount and type of insulation selected for the tank, which is normally a design function. Thus, even though a contractor installed a tank with insulation of the specified type and amount, the tank could fail to meet the SMACNA requirements because the designer did not specify enough insulation.

Table 14
Comparison of Tank Test Data From Metering Approach and Data System

Date	Metering Approach $\frac{\delta T}{\delta T}$ tank (°F/12 hrs)	Data System $\frac{\delta T}{\delta T}$ tank (°F/12 hrs)
08/21/81	4.1	4.05
08/26/81	2.2	2.18
08/28/81	0.98	0.96
08/29/81	0.90	0.89

The following procedure was devised to remedy these shortcomings:

1. Designers should be directed (by instructions in Technical Manual 5-804-2) to select the R-value of the tank insulation that will comply with the SMACNA standard.

2. Using the sample provided in Guide Specifications 13985, designers should provide specifications which state simple requirements which the building contractor can easily compare to the tank test measurements. This can be done during the design by calculating the maximum percentage drop in the tank temperature in a 12-hour interval, using Eq 5.

$$\text{Maximum Decay Rate} = 24 \frac{1}{\rho C_p V} \frac{A}{R} (100\%) \qquad \text{[Eq 5]}$$

where:

ρC_p = the density and specific heat capacity of the liquid in the tank
V = the volume of the tank
A = the outside area of the tank
R = the R-value of the insulation of the tank

This value would then be inserted in the blank spaces in the guide specifications.

Solar Controls Test

A commercial controls unit with built-in diagnostics (Natural Power Model S26-725) was purchased for the pilot test. Table 15 lists the specified setpoints and control modes for this controller. The manufacturer listed an accuracy of 5 percent of full scale

Table 15
Specified Setpoints and Control Modes for Solar Controls Unit
(Metric Converstion Factor: [°F-32] [5/9])

Specified Setpoint	Controls Output	Specified Function
$(T_1 - T_2)_{Hi} = 15°F$	Relay K1 activated.	Power is supplied through relay K2 to collector pump.
$(T_1 - T_2)_{Lo} = 5°F$	Relay K1 deactivated.	Collector pump off.
$T_{2\,Hi} = 187°F$	Relay K2 activated.	Electrical path to collector pump interrupted, prohibiting operation of collector pump.
$T_{2\,Lo} = 180°F$	Relay K2 deactivated.	Continuity of electrical path restored, allowing operation of collector pump to be controlled by status of K1.
$T_{3\,Hi} = 97°F$	Relay K3 activated.	Output of K3 directs heating controls to use solar tank as source for space heating.
$T_{3\,Lo} = 90°F$	Relay K3 deactivated.	Output of K3 directs heating controls to use backup for space heating.

and a temperature resolution of 2.5° F for the absolute temperature and 1° F for the differential temperature measurements.

Before installing the unit, the controls unit was tested, using mercury thermometers and a pair of water baths. This check verified that the unit ran all control modes properly and that all setpoints were adjusted to the specified values. The accuracy of the temperature display was checked by comparison with the temperatures indicated by simple mercury thermometers; it was found to be within the range specified by the manufacturer.

The other method of checking the controls with the built-in diagnostics was also tested. The manufacturer's instructions supplied with the unit were followed. Each temperature input was simulated by switching the input to a variable resistor and observing the display temperature and status lights for the control outputs. This procedure, which can be performed quickly before or after the unit is installed, indicated that all setpoints were adjusted to the correct values and that all control functions were performed as specified.

Example of a Field Application

During this study, CERL was asked to help prepare a testing and monitoring program for solar systems to be installed at Fort Ord, CA. These systems were being designed to heat domestic hot water for a dining facility and eight enlisted men's barracks. Table 16 briefly describes the nine solar systems included in the program.

CERL prepared the following packages:

1. Suggested Revisions to the Drawings. These described the placement and connection of meters.

2. Suggested Revisions to the Specifications. These provided guidance on specifying the meters to be purchased by the contractor and guidance on how to include requirements for acceptance testing in the specifications.

3. List of Meters. This list summarized commercially available meters and included the names/addresses of manufacturers, model numbers, and estimated costs.

4. Package of Manufacturer's Data Sheets and Catalog Cuts. This package of manufacturer's literature was assembled to help Fort Ord's personnel purchase suitable meters.

CERL's participation in this program provided valuable experience in incorporating the metering approach during the design phase. When this report was being written, the solar projects were being sent out for bids; thus, no field measurement results could be included here.

5 DISCUSSION

The acceptance testing procedures for solar energy systems developed in this study are based on performance measurements. Although these measurements commonly use sophisticated instrumentation systems, this study showed that the use of simple meters offers a number of advantages. Not only do they cost less, but they can be used to monitor the system after the acceptance test is finished. This offers several potential benefits: (1) it provides performance data for feedback to the Corps District design process; and (2) it helps DEH personnel detect and diagnose malfunctions throughout the solar system's life.

Table 16
Brief Description of Solar Energy Systems Included in Field Application of Solar Metering

Function:	The solar system is designed to provide 50 percent of domestic hot water heating; backup is a steam-fired generator.
Solar Collectors:	Flat-plate, liquid, singly-glazed. Gross area = 1800 sq ft (167 sq m) for dining facility 990 sq ft (92 sq m) for each barracks
Freeze Protection:	Collector fluid is 30/70 solution of propylene gylcol and water; in-tank heat exchanger.
Thermal Storage:	Water storage tank, 2560 gal (9690 L)—Dining Facility. Water storage tank, 1250 gal (4730 L)—Each Barracks

The measurement capability that the meters must provide was determined by examining the performance measurements used in acceptance testing. The study showed that a BTU-Meter is needed to measure the heat input or output from a solar component. The desirable characteristics of the BTU-Meter were found to be low cost, ability to measure for the pipe size of the intended application, factory-calibrated sensor accessibility, accuracy, temperature measurement range from 0°C to 100°C, fluid compatibility, and production of only a small pressure drop by the sensors. A prototype was then designed and constructed by CERL. All other meters required for the test were available as "off-the-shelf" components from commercial suppliers. Due to the variety of solar system designs, it was not possible to prescribe specific numbers and placement of meters which would be appropriate for all possible solar systems.

An investigation of the economics of the metering approach showed that the installed cost for a medium-sized solar system (with 3-in [76.2mm] pipes) was an estimated $4000. This represents considerable savings over the instrumentation approach. Further cost savings can be gained if a large number of small solar systems is used. In this method, a few systems are selected as a representative sample and provided with a complete set of meters. The other solar systems are provided with only a minimum metering set; their performance is then evaluated by comparison with the sample measurements.

The acceptance test procedures were pilot tested at CERL's solar test facility. Performance measurements were taken, using both the meters and an automatic data acquisition system simultaneously. Since the data acquisition system had been used successfully in a previous field test of the procedures, the simultaneous measurements allowed a thorough check of the metering approach. All the comparisons of the pilot test results showed that the metering approach can be used with confidence in the field.

The pilot test results for the collector efficiency established that the metering approach, which is based on the CERL BTU-Meter, provides a level of accuracy comparable to that of the data system. The pilot test showed that manipulating data by hand can be very time-consuming if short test intervals are used. Thus, it was proposed that the measurements be conducted over long test intervals to provide an average collector efficiency; this would reduce the amount of data to be manipulated and thus decrease costs for labor. When the use of average efficiency values was studied, it was found that these values provide a valid comparison with specifications that are based on standard test data. As a result, the option of measuring average efficiency was incorporated into the acceptance test procedure.

The metering approach to testing a newly installed solar storage tank was investigated during the pilot test. The absence of just a small amount of insulation (less than 5 percent of the total tank area) was detected by the results from simple meter readings. The results showed that the metering approach provides reproducible results and provides enough sensitivity to detect insulation that does not meet the SMACNA standard.

A solar controls unit with built-in diagnostics was purchased and tested. Several self-test features desirable for a controls unit were identified, including status lights, temperature display, adjustable set-points, and sensor simulation. A commercial unit was tested, using the manufacturer's instructions; the results were verified by an independent test using simple thermometers and water baths. The unit was found to operate properly.

During this study, a Corps District asked CERL to help test and monitor a group of solar energy systems under design. A testing and monitoring program which used the metering approach was devised. For this application, it was found that appropriate metering and testing requirements could be incorporated into the construction specifications.

6 CONCLUSIONS AND RECOMMENDATIONS

The metering approach developed during this research can be a useful, economic means of measuring the performance of solar energy systems. The simple meters used in this approach cost less than the more sophisticated instrumentation systems generally used to obtain performance measurements. Metering will help detect system malfunctions, both early in system operations, and later throughout the system's life. In addition, the meters will provide performance data that will be useful to designers seeking to improve the solar systems.

It is recommended that the acceptance test procedures developed in this study be used to test newly installed solar energy systems. Construction specifications for solar energy systems should include provisions for installing meters and the requirement for acceptance testing.

APPENDIX:
DESCRIPTION OF CERL BTU-METER

A meter for measuring the heat output of a solar component is vital to the success of the metering approach. When this study began, no commercial meter met all the requirements for this measurement for the wide range of solar systems at Army installations (see Table 2 in Chapter 2). To meet this need, CERL designed a simple, low-cost BTU-Meter which meets all the testing and monitoring requirements. This appendix describes the design of the CERL BTU-Meter.

Sensors

To determine the heat output or input to a solar component from a heat transfer liquid, sensors are needed to detect the inlet and outlet temperatures of the heat transfer fluid and the flow rate of the heat transfer fluid through the component. The sensors for the CERL BTU-Meter were selected for their accuracy and on the basis of ruggedness and stability as demonstrated through years of field use.

Since the temperature difference between the inlet and outlet of a typical solar component is about 10°C, temperature sensors which are matched to 0.1°C are needed to determine heat output or input accurately. The temperature sensors selected were platinum resistance thermometers (Hy Cal Eng. Model RTS-36) with an ice-point resistance of 100 ohms; they conform to the international standard, DIN 43760. This type of temperature sensor is widely used for precision thermometry. The sensors maintain their stability well beyond the temperature range of typical solar components (0° to 100°C).

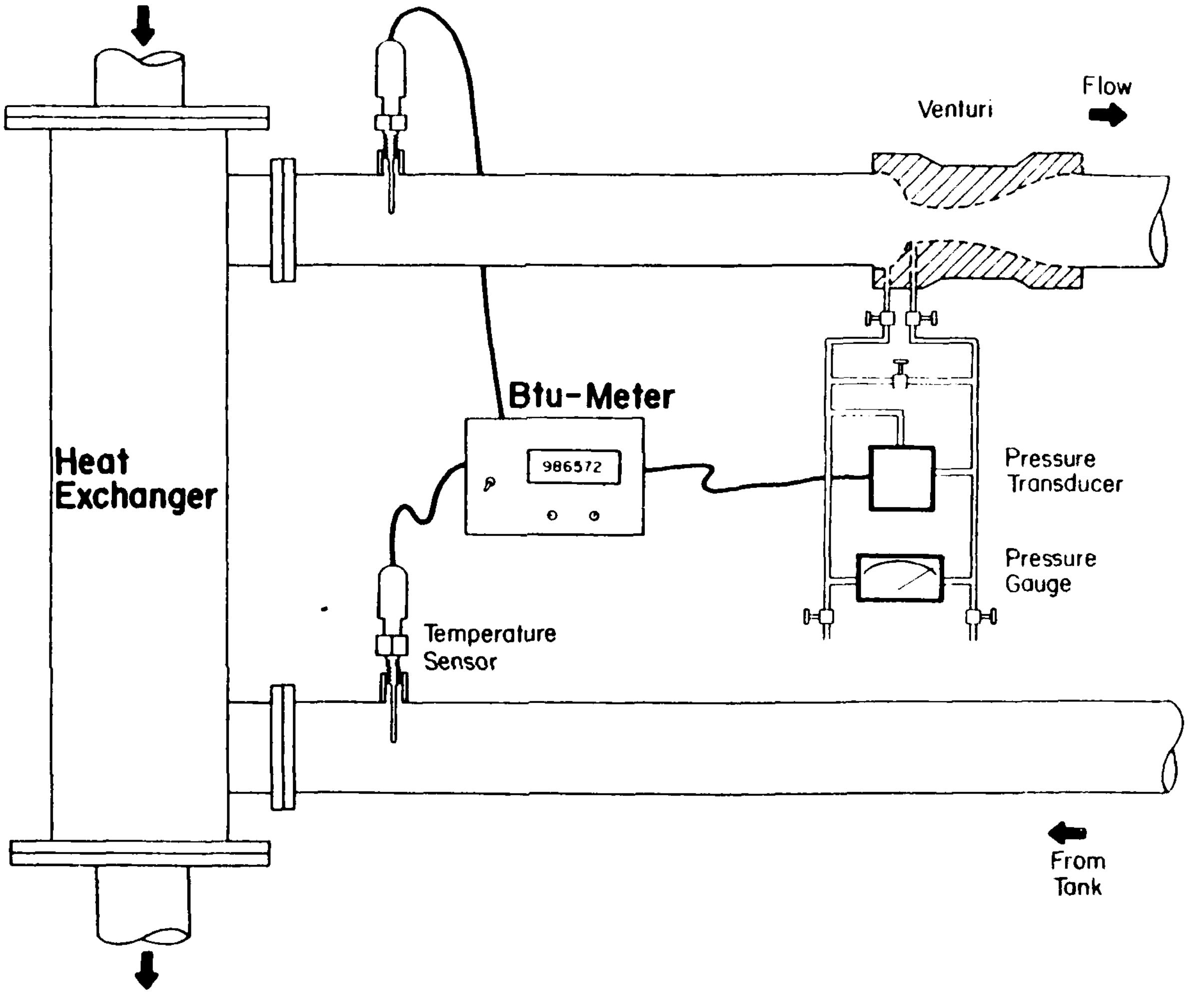
Proper selection of the flow sensor is critical to the overall success of the BTU-Meter design due to the variable characteristics of the sensors. For example, some types are only available for small pipe sizes and would not be suitable for many Army applications; others are more costly for the larger pipe sizes, which would undermine the effort to design a low-cost BTU-Meter. Some types lack the ruggedness needed for field use and are not readily accessible for repair after they are installed; others are not suitable for use in the collector fluids of some solar designs.

The combination of a venturi and a differential pressure transducer was selected because of its many advantages. For example, it is applicable to a wide range of pipe sizes and to almost any fluid used for heat transfer, and is relatively low in cost, especially for large pipe sizes. The inherent ruggedness of the venturi and the ability to match the ruggedness of the transducer to the application are other advantages.

Another advantage of this flow sensor combination is its ability to obtain a simple flow reading which is independent of the BTU-Meter. This can be done by attaching a manometer or a mechanical differential pressure gauge in parallel with the transducer. Besides checking for a proper amount of flow through the solar component, the flow reading can be used to check the flow calibration of the BTU-Meter.

One minor disadvantage of the venturi sensor is that the accuracy of measurements taken at low flow rates is relatively poor. This is not considered to be serious, since most applications of the BTU-Meter involve a solar component in which the fluid flow is produced by the simple on/off operation of a pump. Since a pump produces steady-state flow conditions a few seconds after being energized, the dominant amount of heat transfer occurs when the flow rate is near the nominal value; in this type of application, the poor performance of the venturi at low flow rates contributes very little to the overall error.

Figure A1 illustrates how the sensors are mounted in a typical application. Here, the sensors are on the "water side" of a heat exchanger which provides heat transfer from the solar collectors to the storage tank; hence, the BTU-Meter measures the heat output of the collectors. To measure heat output accurately, the sensing elements of the thermometers must be immersed in the fluid stream and the venturi must be aligned correctly with the direction of flow in the pipe.



MOUNTING DETAILS

Temperature Sensors

Sensor must extent into fluid stream of pipe at least a distance X as given below.

For pipe diameter of D,
X = 1" or more if D = 2" or more
X = ½D or more if D is less than 2"

Venturi

Install per manufacturer's instructions: example:

a) Arrow on venturi must be aligned with direction of flow
b) Venturi must be located at least 5 pipe diameters downstream and 2 pipe diameters upstream of any obstructions or elbows or other piping changes.

Figure A1. Mounting of BTU-Meter designed by CERL.

Btu Computer and Display

An electromechanical counter was chosen to display the amount of thermal energy transfer that the BTU-Meter detects. This device automatically prevents a power interruption from erasing the accumulated total. This method of providing immunity to power interruption was selected instead of a battery backup because it is straightforward and low in cost.

Figure A2 illustrates the circuit design for the Btu computer. As shown in the figure, analog voltages corresponding to the temperature and flow values are generated and routed to a Multifunction Converter Integrated Circuit (IC) (Burr-Brown Model 4301). The IC is configured to produce an output as given by:

$$E_o = V_y \cdot \sqrt{V_z} \qquad \text{[Eq A1]}$$

$$\alpha \, (T_o - T_i) \, M$$

where:

E_o = the output voltage of the Multifunction Converter IC

V_y = the voltage input representing the temperature difference, $(T_o - T_i)$

V_z = the voltage input from the flow sensor

T_i, T_o = the inlet and outlet temperatures

M = the mass flow rate.

As shown by Eq A1, the output voltage of the Multifunction Converter IC is proportional to the rate of heat transfer. This voltage is routed to a V-to-f converter, which produces output pulses at a frequency proportional to the input voltage. Each pulse corresponds to a certain amount of heat transfer detected by the BTU-Meter. For example, for

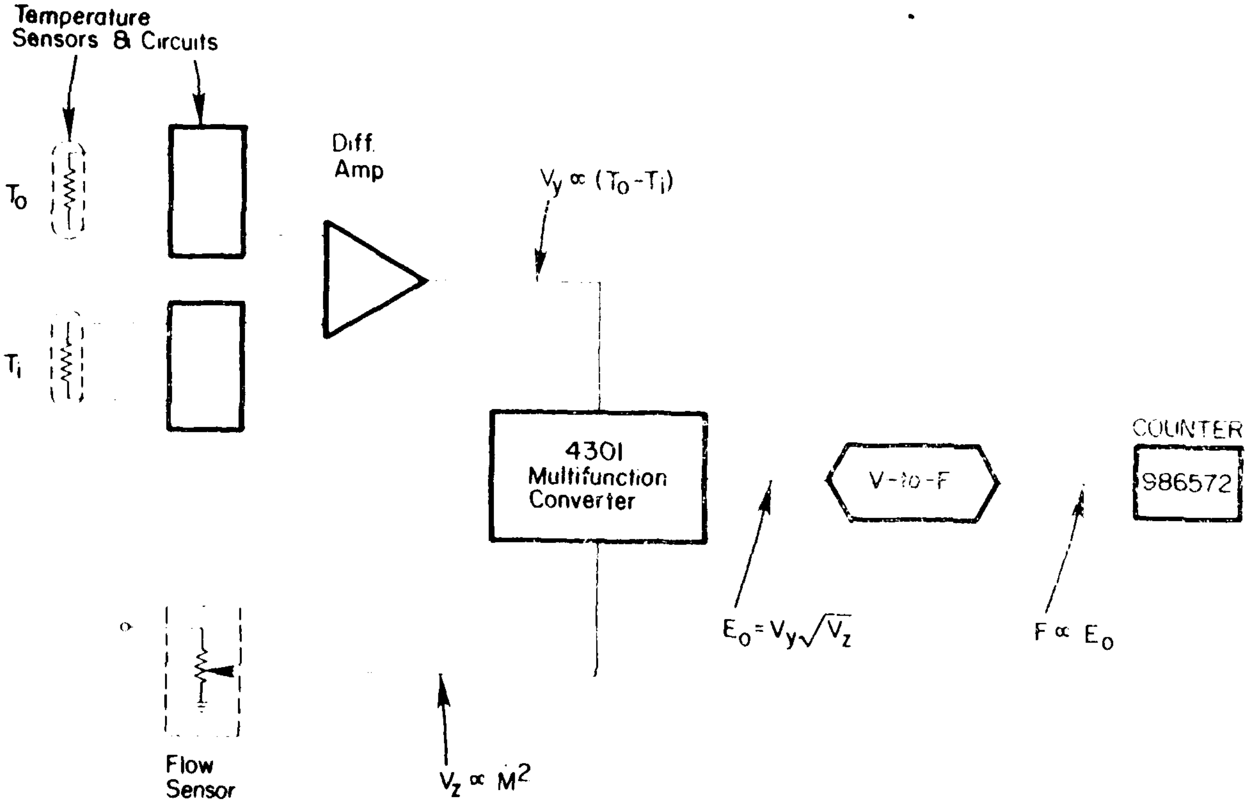


Figure A2. Functional diagram of circuits in CERL BTU-Meter.

the prototype used by CERL in the pilot test, each pulse corresponds to 100 Btus

The output pulses from the V-to-f circuit are then routed to an electromechanical counter which increments the register for each received pulse. Hence, the counter accumulates and displays the total number of pulses received from the circuitry and thereby shows how much heat was transferred (in units of 100 Btus for the prototype).

Since it is desirable to get separate readings of the temperatures and flows detected by the sensors, the analog voltages corresponding to these values are routed to connectors on the front panel. To help check the unit calibration, the voltages corresponding to the heat transfer rate are also routed to the front panel. A calibration check revealed that the overall accuracy of the Btu computer and display modules was better than 1 percent of full scale.

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Procedures for acceptance testing of solar energy systems / by D. L. Johnson, D. M. Joncich. – Champaign, Ill : Construction Engineering Research Laboratory ; available from NTIS, 1984.
57 p. (Technical report / Construction Engineering Research Laboratory ; E-192)

1. Solar buildings – quality control. I. Joncich, David M. II. Title. III. Series : Technical report (Construction Engineering Research Laboratory [U.S.]) ; E-192.

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