Liquid Heating Systems

WORKSHOP IN
THE PRACTICAL ASPECTS OF
SOLAR SPACE AND DOMESTIC WATER HEATING SYSTEMS
FOR
RESIDENTIAL BUILDINGS

MODULE 9

LIQUID-HEATING SYSTEMS

SOLAR ENERGY APPLICATIONS LABORATORY
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO
NOVEMBER, 1978

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Component selection is important for liquid-heating systems as it is for air-heating systems. The best components when assembled poorly or provided with an ineffective controller will yield poor system performance.

In a liquid-heating system heat from the collectors is generally always delivered to storage, and the heating load is always supplied from storage. An auxiliary heater is needed to provide heat when there is insufficient delivery rate of solar heat to meet the heating load. Such occasions can occur on excessively cold nights (or days) and after one or two successive cloudy days. The solar system should function automatically, provide the desired comfort level in the building at all times, require little maintenance and operate reliably over a long period of time.

OBJECTIVE

The objective of this module is to describe the interdependence of components of a liquid-heating system. The participants of the workshop should be able to:

1. Develop schematic and working plans of liquid solar systems,
2. Specify compatible system components
3. Identify all the system operating modes
4. Determine the size of system components
5. Estimate the fraction of annual load that the solar system is expected to supply.

SYSTEM ARRANGEMENTS

DUAL-LIQUID SYSTEM

A recommended liquid-heating system in cold regions where freezing temperatures are dominant during the winter months is shown in Figure 9-1. The system is arranged to deliver solar heat first to storage and solar heat for space and domestic water are delivered from storage. When solar heat cannot provide the load requirements of either domestic water or space heating, auxiliary heating is then required. While the solar space heating system can be separated from the solar domestic hot water system, it is more convenient and economical to arrange an integrated system because during the warm months of the year the collectors can supply practically all of the domestic water heating that is needed.

SINGLE-LIQUID SYSTEM

An alternative system arrangement that is suitable for regions where the winter low temperatures are above the freezing point of water is shown in Figure 9-2. Water can then be circulated through the collector. While there are other liquids that could be used in the system, water is lowest in cost and has excellent thermo-physical properties.

COMPONENTS AND INTERACTIONS

COLLECTORS AND STORAGE

The efficiency of collectors in a solar system is influenced by all other components in the system. For maximum efficiency, the collector

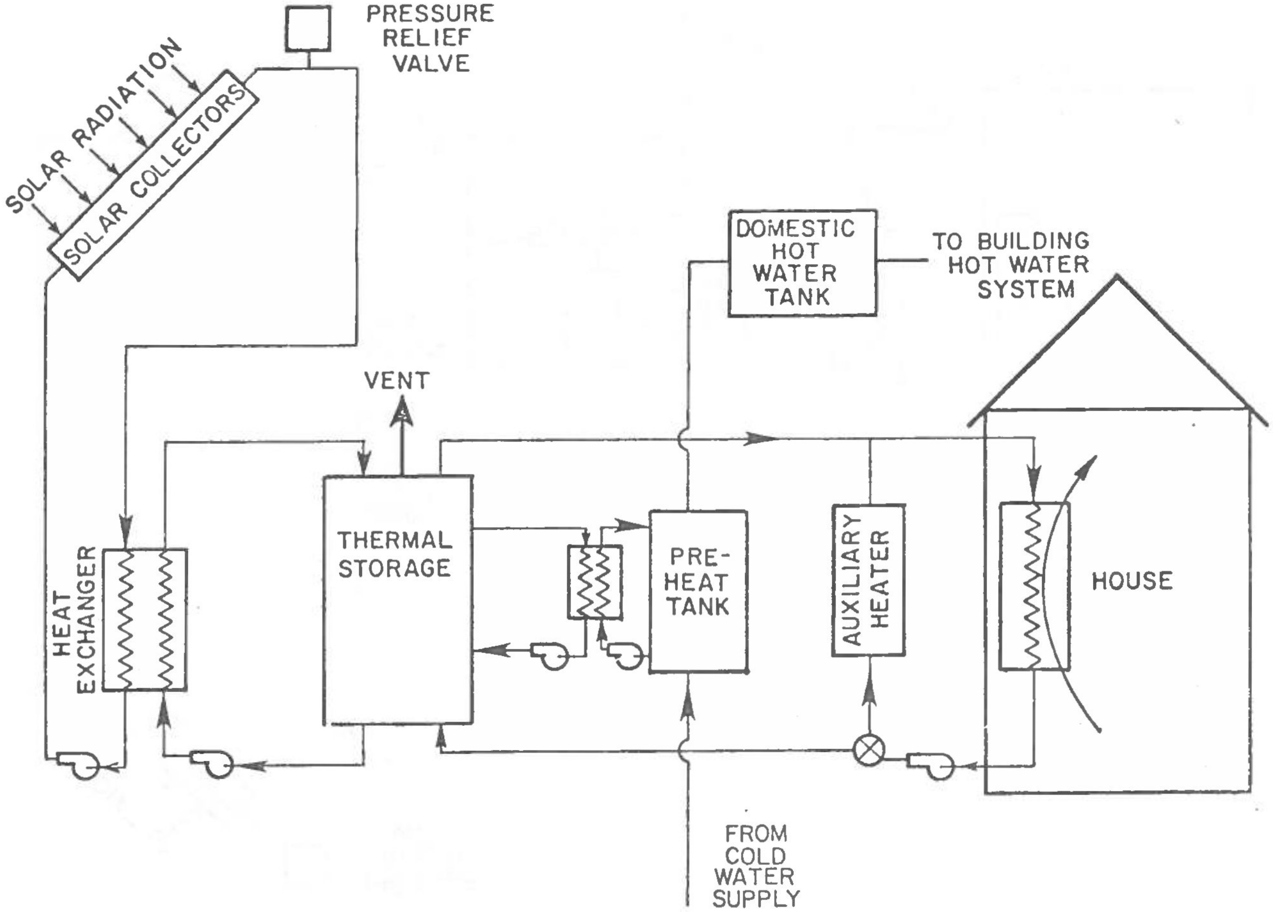

Figure 9-1. Schematic Diagram of Dual-Liquid Space and Water Heating System

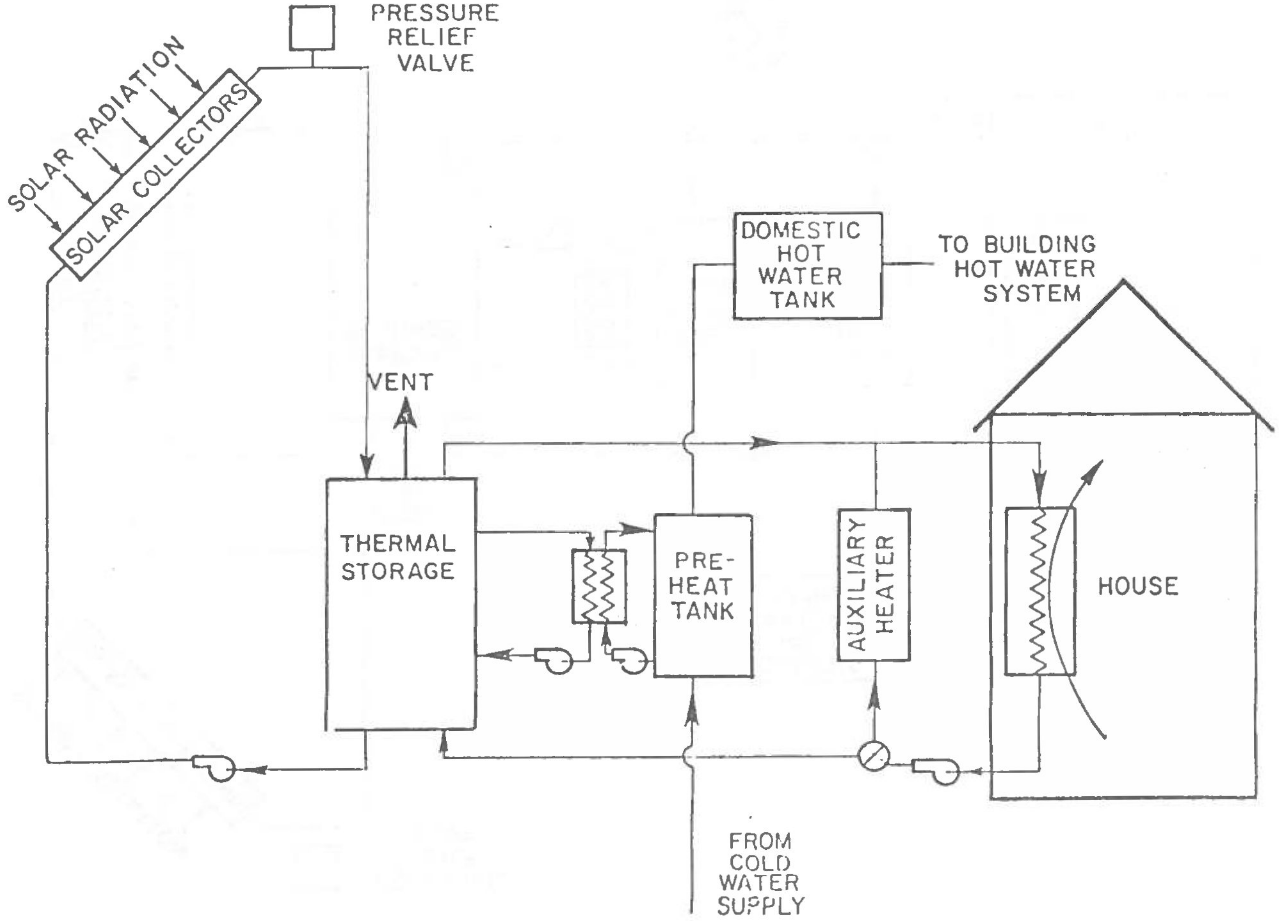

Figure 9-2. Schematic Diagram of a Single Liquid Space and Water Heating System

should be supplied with liquid at the lowest available temperature. It follows therefore that liquid from the bottom of the storage tank should be circulated to the collector loop. If there is a heat exchanger in the circulation loop, as in Figure 9-1, the liquid is circulated from the bottom of the storage tank, through the heat exchanger and returned to the top of the storage tank. In a direct circulation loop, as in Figure 9-2, the liquid is taken from the bottom of storage and circulated through the collector. The heated liquid is then returned to the top of storage.

Storage temperatures are strongly influenced by the type and size of heat exchanger that is used to deliver heat to the load, and the type and size of heat exchanger used in the collector loop can influence the temperature of the liquid recirculated to the collector. The sizing of heat exchangers is therefore an important part of the system design. While oversizing the heat exchangers will have little influence on system performance, undersizing can seriously penalize the quantity of solar heat collection.

LOAD HEAT EXCHANGER

The temperature of water in storage is influenced by the type of load heat exchanger, and the arrangement of the auxiliary heater. The auxiliary heater can be placed in parallel with the solar storage tank as is shown in Figures 9-1 and 9-2, or in series with the solar storage tank to boost the temperature of the solar heated water. The parallel arrangement limits useful heating of space with solar heat in storage to a water temperature of about 90°F because at low temperatures, heat cannot be exchanged to the room air at a rate large enough to meet load demands. In a series arrangement, auxiliary heat can be added to solar heat from storage, but the returning water temperature from the load heat exchanger can be higher than storage water temperature. When auxiliary heating is required frequently, as in the winter months, the series arrangement will result in auxiliary heating of the solar storage tank which in effect stores auxiliary energy. Use of auxiliary energy over the heating season is greater with the series arrangement than with the auxiliary heater in parallel.

AUXILIARY HEATER

The arrangement for auxiliary boosting shown in Figure 9-3 is preferable to either the parallel or series arrangement for minimizing auxiliary energy use. The capital and operating costs, however, are greater because an extra coil and circulation pump are required.

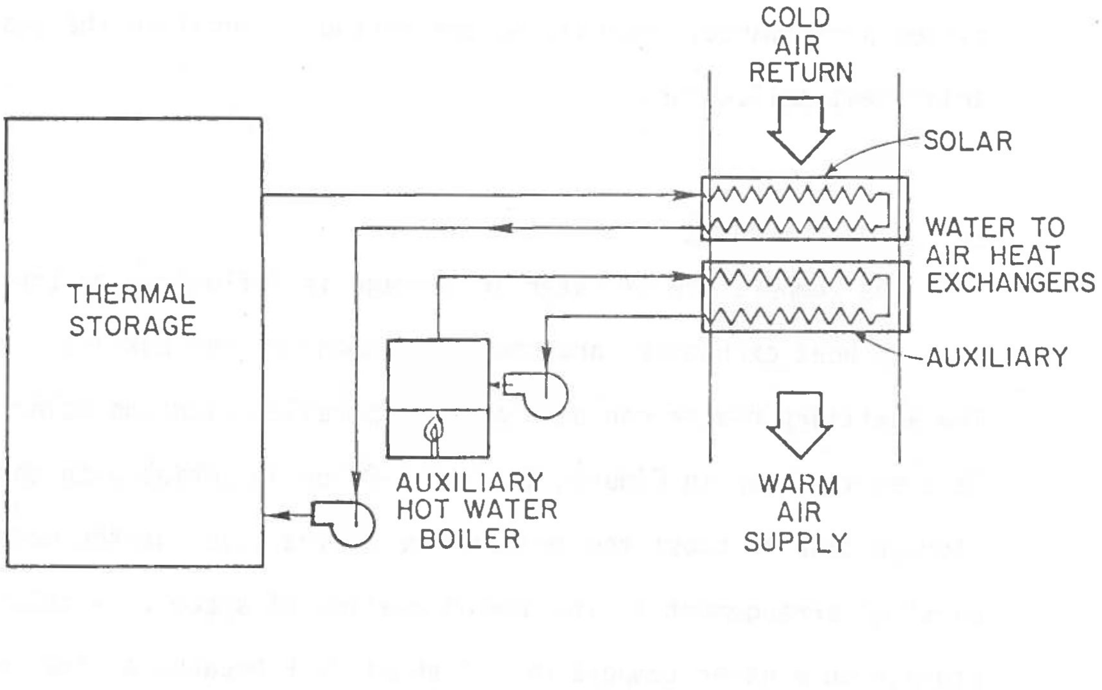

Figure 9-3. Solar Heating with Auxiliary Boosting

If a central air distribution system is provided in the building, the auxiliary warm air furnace in the arrangement shown in Figure 9-4 may be used effectively.

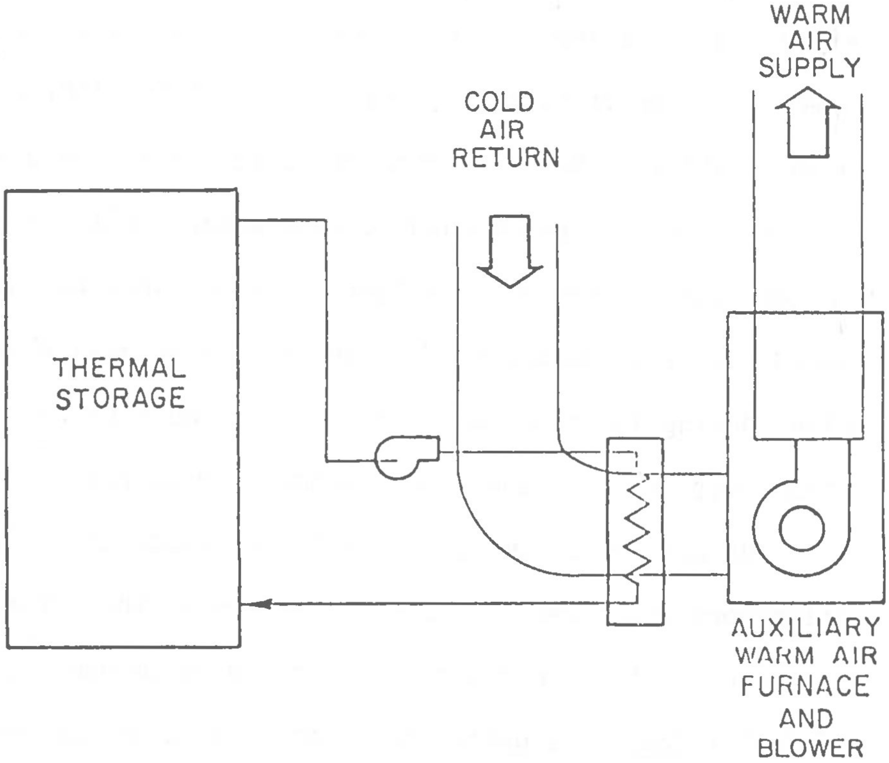

Figure 9-4. Solar Heating with Auxiliary Furnace

PUMPS AND OTHER EQUIPMENT

Centrifugal pumps should be used for circulating liquids in various loops of a solar system. With centrifugal pumps, pumping pressure is limited and if valves fail to open, or the pipeline becomes clogged, the danger of developing excessive pressures which could burst pipes is minimized. With known flow rate and system head losses, pumps may be selected from stock items in catalogs, or made to specifications by pump manufacturers. Impellers of stock item pumps may be trimmed to meet specifications. Centrifugal pumps should be located so that priming is not necessary, which could be a particular problem in a vented system or where a storage tank is located underground. Five feet of head on the suction side is sufficient to keep most pumps primed.

A check valve, micron filter, ion getter and an expansion tank should be installed in the collector loop as shown in Figure 9-5. The check valve prevents thermal cycling of the collector fluid when the pump is off and the collectors are colder than the building interior. A micron filter is recommended to remove particulate matter in the collector fluid. Particular attention is required at initial start-up because a large amount of foreign substances always seems to enter the pipes during installation. The filter should be changed immediately after initial operation, and changed as required thereafter.

The getter is simply a sacrificial anode to protect absorbers in collectors and pipes of disimilar metals in the system from galvanic corrosion. If the collector consists of aluminum absorbers, and the piping is copper, a getter may consist of aluminum window screen rolled up within a one-foot long neoprene hose and placed at the inlet to the collector manifold. The copper piping would terminate at one end of the neoprene hose and aluminum piping which joins the header would start at the other end.

An expansion tank is recommended to conserve the fluid in the collector when boiling occurs. The volume of the tank should be equal to the volume of fluid in the collectors and header, and should be positioned as close as possible to the top of the collector array. An open vent or pressure relief valve at the top of the tank will prevent pressure build up in the collector loop when boiling occurs.

Two connectors in the collector loop on the suction side of the pump are required to fill the collector loop with fluid, one is connected to the liquid source and the other to the same source to

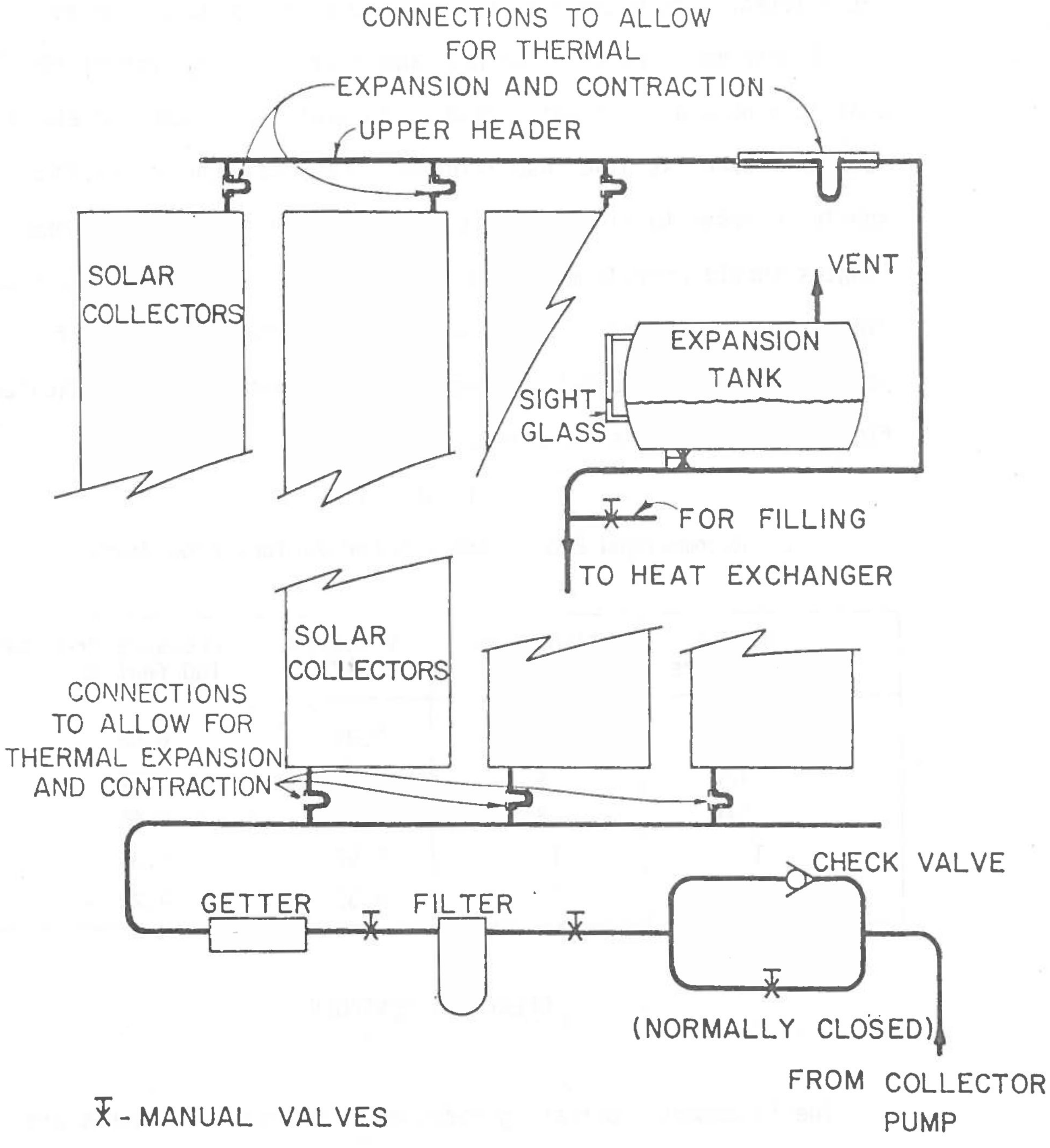

Figure 9-5. Ancillary Devices in Collector Loop

detect when filling is complete. If the filling connection is a few feet above the centrifugal pump, the filling operation will be facilitated. Drain and fill points should be suitably labeled.

Piping may consist of either copper or high temperature (CPVC) plastic pipe and all pipes should be insulated with appropriate material such as fiberglass pipe insulation at least one inch in thickness. Care should be taken to allow thermal expansion of the pipes and long pipe lengths should provide more freedom for expansion than short lengths. Pipes should be sized so that water velocity does not exceed five feet per second. In Table 9-1, recommended pipe diameters are indicated for flow rates in gallons per minute.

Table 9-1

Recommended Pipe Diameters for Various Flow Rates

Select Pipe Size	Gallons per Minute	Velocity FPS	Pressure Drop per 100 feet PSI
3/8	2	3.36	6.58
1/2	4	4.22	7.42
3/4	8	4.81	6.60
1	15	5.57	6.36
1-1/4	25	5.37	4.22

OPERATING CONTROLS

The fundamental operating modes of solar heating systems are collecting and storing solar heat and delivering heat from storage to load. The auxiliary unit must be controlled to provide heating when there is insufficient solar heat in storage to meet the demand.

A practical method for controlling the solar collection process involves use of temperature sensors which actuate the collector pump (and also the storage circulation pump if a heat exchanger is used), whenever the temperature of the liquid leaving the collector exceeds the lowest temperature in storage by a preset amount, say 15°F. A sensor placed in the flow passage as close as possible to the collector exit, and a sensor near the bottom of the storage tank where storage water is likely to be coldest are compared electronically to preset temperatures to start and stop the circulation pumps. The temperature difference which shuts off the pumps is less than the temperature difference which starts the pumps, say 3°F, and the hysteresis in the temperature difference between on and off set points prevents cycling of the pumps at the beginning of the collection day and also at the end of the day.

When the liquid first circulates through the collectors at the beginning of the collection day, the temperature rise from inlet to the exit is only a few degrees because of the low solar intensity. Typically the temperature rise is 4 or 5°F. As the solar intensity increases, the temperature rise in the circulating liquid increases until by mid-day 15 to 20°F temperature rise occurs. During the circulation period, the storage water temperature increases gradually and by midafternoon when the solar intensity decreases, the collectors can no longer provide useful heat to storage and circulation stops.

The best control strategy to deliver heat to the building space is to use a room thermostat with a dual set point. Whenever the rooms require heat, the stage contact of the thermostat is completed and water from the storage tank is circulated to the load heat exchanger, regardless of storage tank temperature. If the storage water is warm enough, the room temperature rises, and the circulation system stops. The contact in the thermostat regulates the circulation pump and air blower.

If the storage water is not warm enough to deliver heat at a rate that is greater than the heat loss rate, the room temperature continues to fall until the second contact is made in the thermostat. The auxiliary water boiler or the auxiliary furnace is then activated to restore the room to the comfort temperature set at the thermostat. If the auxiliary water boiler is in series, only the auxiliary energy source is activated, but in a parallel arrangement a valve is also activated to direct heat flow from the auxiliary unit to the load heat exchanger. In an auxiliary arrangement, solar heat from storage continues to be utilized while auxiliary heating takes place until storage water reaches about 90°F. A low temperature over-ride switch then shuts off circulation of solar-heated water.

Solar preheating of domestic water is best regulated by a temperature difference comparator similar to the control of the collection loop. The temperature sensor at the bottom of the solar storage tank may also be used for the DHW preheater loop control, and the difference in temperature between the bottom of the storage tank and top may be included in the temperature difference setting. Alternatively, a sensor may be installed at the top of the solar storage tank to control the preheater circulation pumps.

SYSTEM SIZING

There are various methods for determining the fraction of annual heating load supplied by solar systems as explained in Module 8. "Rules of Thumb" for sizing components of combined space and DHW systems and stand-alone DHW systems using liquids as the heat transfer fluid are given in Table 9-2. The detailed sizing procedure will

Table 9-2

Rules of Thumb for System Component Sizing

SOLAR HYDRONIC HEATING/COOLING SYSTEMS	
Collector slope	Latitude + 15°
Collector flow rate	~0.02 gpm/ft^2 of collector
Water storage size	1.5 to 2.5 gallons/ft^2 of collector
Pressure drop across collector	0.5 to 10 psi/collector module
Collector heat exchanger	F_R'/F_R greater than 0.9
Load heat exchanger	$\frac{\varepsilon_L C_{min}}{UA}$, greater than 1, less than 5
SOLAR DOMESTIC HOT WATER HEATING SUBSYSTEMS	
Preheat tank size	1.5 to 2.0 times DHW auxiliary tank size
Water-water heat exchanger	ε_{Hx}, greater than 0.5, less than 0.8

follow the f-chart method for liquid systems and the relative areas method described in Module 8. Additional explanations for f-chart application to liquid systems is explained in this section.

THE f-CHART METHOD

The basic approach to the f-chart method is explained in Module 8 and the f-chart for liquid-based systems is given in Figure 9-6. The coordinate axes, X and Y are defined by Equations (8-1) and (8-2).

Corrections for Collector Heat Exchanger

When a heat exchanger is used between the collector and storage in a dual-liquid system, corrections to X and Y must be applied as follows:

$$X \text{ (new value)} = X \text{ (from Eq. 8-1)} \cdot \frac{F_R'}{F_R} \qquad (9\text{-}1)$$

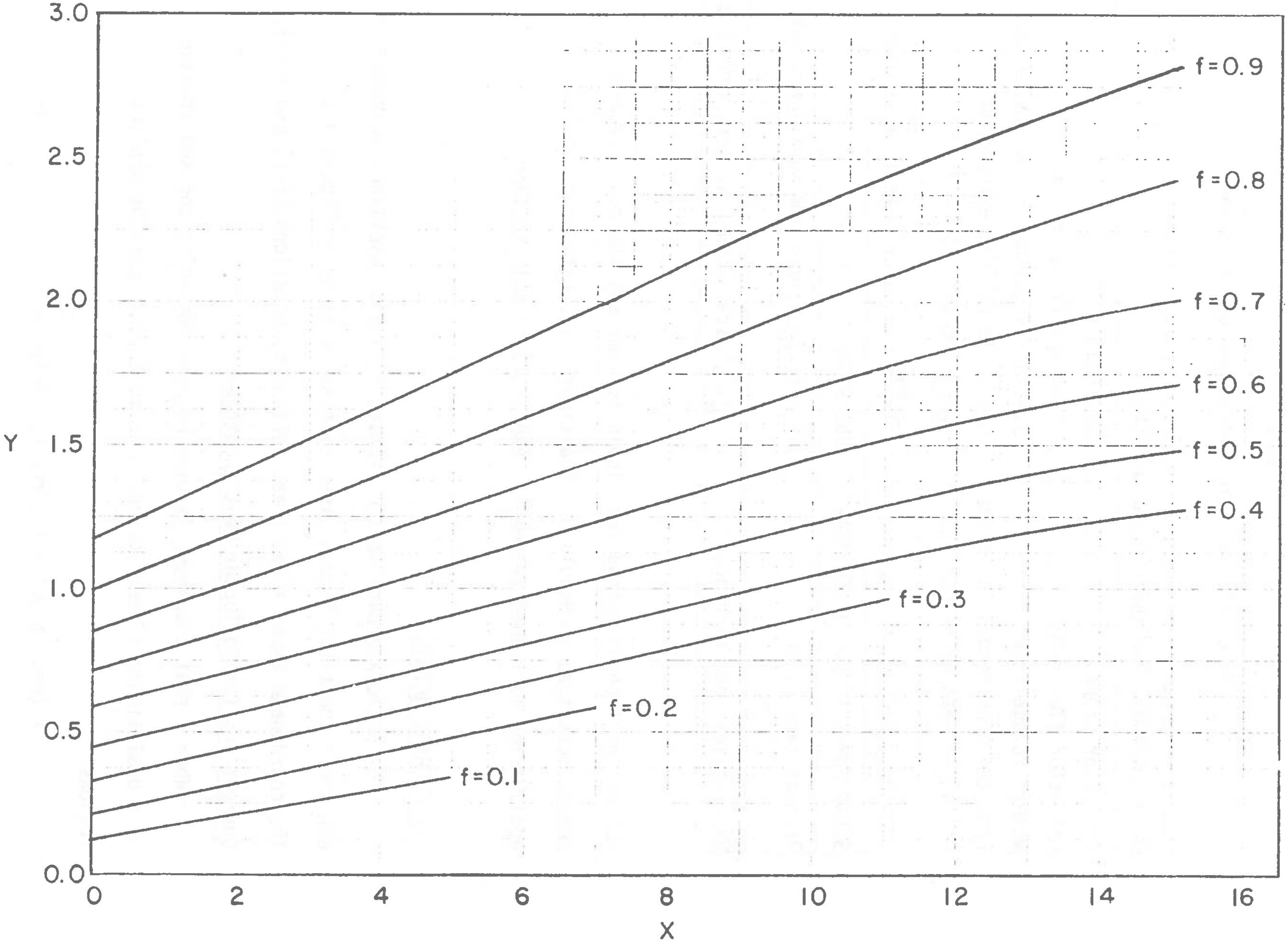

Figure 9-6. f-Chart for Solar Liquid Heating Systems

where F_R'/F_R is the heat exchanger correction factor and depends on the heat exchanger effectiveness (See Module 7).

$$Y \text{ (new value)} = Y \text{ (from Eq. 8-2)} \cdot \frac{F_R'}{F_R} \qquad (9\text{-}2)$$

The new values of X and Y are used to estimate monthly solar fractions, s, from the chart.

Once the heat exchanger is selected and effectiveness ε_{cs} is determined or calculated, the heat exchanger factor F_R'/F_R for collector performance estimates can be determined from Figure 9-7.

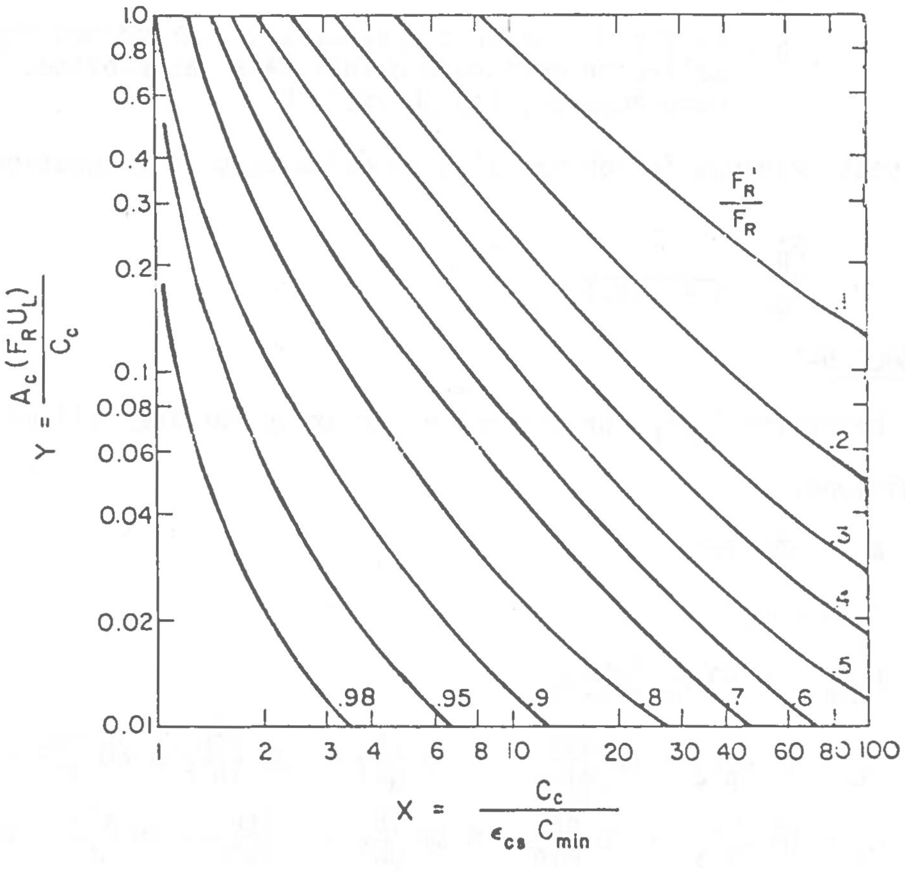

Figure 9-7. Heat Exchanger Factor F_R'/F_R

The coordinates for the chart are determined as follows:

$$x = \frac{C_c}{\varepsilon_{cs} C_{min}} \qquad (9\text{-}3)$$

in which

C_c is the collector fluid heat capacity rate Btu/(hr·°F)

ε_{cs} is the heat exchanger effectiveness, dimensionless

C_{min} is the minimum of the collector or storage fluid capacitance ratio, Btu/(hr·°F)

and

$$y = \frac{A_c(F_R U_L)}{C_c} \qquad (9\text{-}4)$$

where

A_c is the collector area, ft^2

$F_R U_L$ is the collector characteristic determined from the collector performance test data, as provided by the manufacturer, Btu/(hr·ft^2·°F)

The heat exchange factor may also be calculated from Equation (9-5)

$$\frac{F_R'}{F_R} = \frac{1}{1 + y(x-1)} \qquad (9\text{-}5)$$

<u>EXAMPLE 9-1</u>

Determine F_R'/F_R for the collector array for the following conditions:

$A_c = 500 \text{ ft}^2$

$F_R \tau\alpha = 0.7$

$F_R U_L = 0.93 \frac{\text{Btu}}{\text{hr·ft}^2\text{·°F}}$

$C_c = (\dot{m}\, c_p)_c = 10 \frac{\text{gal}}{\text{min}} \times 8.25 \frac{\text{lb}}{\text{gal}} \times .85 \frac{\text{Btu}}{16\text{°F}} \times 60 \frac{\text{min}}{\text{hr}} = 4207 \frac{\text{Btu}}{\text{hr°F}}$

$C_s = (\dot{m}\, c_p)_s = 20 \frac{\text{gal}}{\text{min}} \times 8.34 \frac{\text{lb}}{\text{gal}} \times 1 \frac{\text{Btu}}{\text{lb°F}} \times 60 \frac{\text{min}}{\text{hr}} = 10008 \frac{\text{Btu}}{\text{hr°F}}$

$\varepsilon_{cs} = 0.87$ (From Module 7)

The heat exchanger factor is determined as follows:

$$x = \frac{4207}{0.87(4207)} = 1.15$$

$$y = \frac{500(0.93)}{4207} = 0.111$$

From Figure 9-7, $F_R'/F_R \approx 0.98$ or from Equation (9-5),

$$F_R'/F_R = \frac{1}{1 + (0.111)(1.15-1)} = 0.98$$

It should be noted that unless a very small or ineffective heat exchanger is used, the heat exchanger factor will generally be greater than 0.95.

Corrections for Storage Size

The nominal storage capacity for a liquid system is two gallons of water per square foot of collector. When storage sizes differ from the nominal size, corrections to the value of X should be made as follows:

$$X \text{ (corrected value)} = X \text{ (from Eq. 8-1 or 9-1)} \cdot K_2 \qquad (9\text{-}6)$$

where K_2 is determined from Figure 9-8.

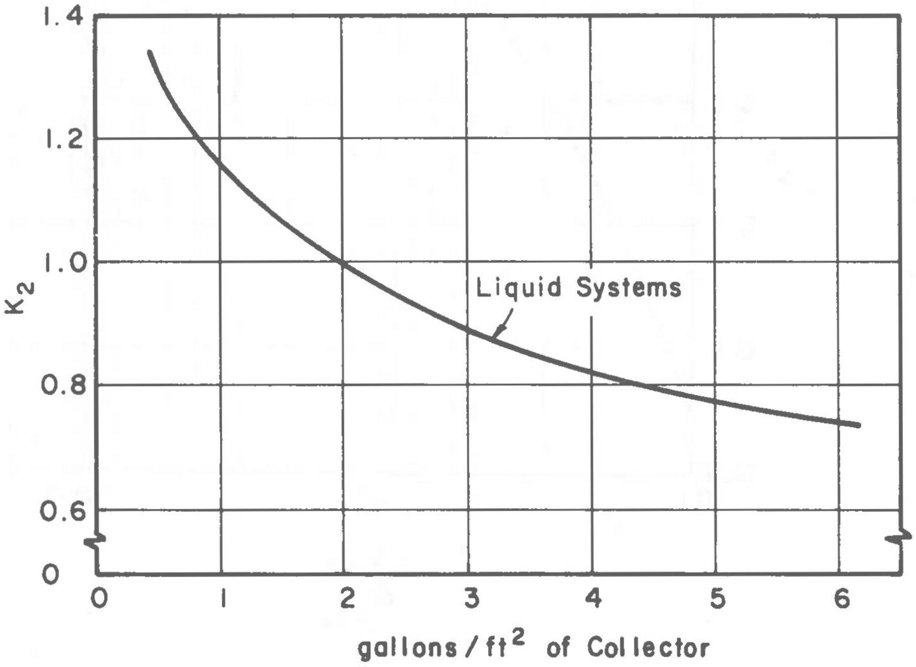

Figure 9-8. Storage Capacitance Factor, K_2

Corrections for Load Heat Exchanger

One additional correction factor should be considered for a liquid-based system, which is the size of the load heat exchanger. A load heat exchanger that is small, will affect the storage tank temperature and consequently the temperature of the fluid to the collector. Hence, the system performance is affected. The correction factor is expressed as a function of the load heat exchanger effectiveness in comparison to the UA of the building, and is applied to Y as follows:

$$Y \text{ (corrected value)} = Y \text{ (from Eq. 8-2 or 9-2)} \cdot K_4 \qquad (9\text{-}7)$$

where K_4 is determined from Figure 9-9.

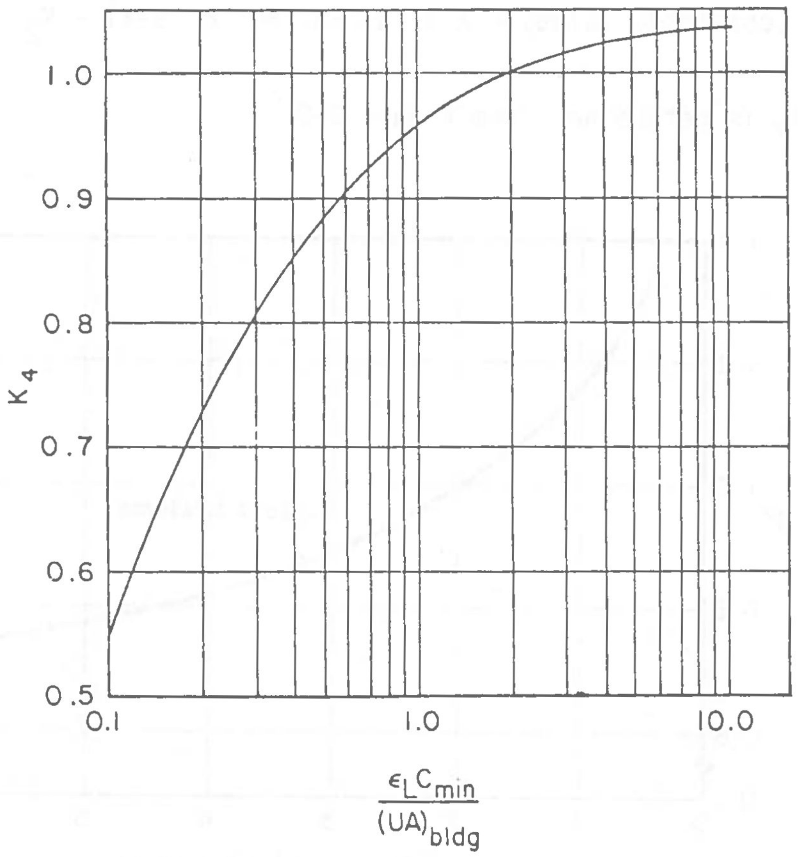

Figure 9-9. Load Heat Exchanger Factor, K_4

Calculation Procedure

The procedure to be followed in the f-chart calculations are listed below:

Step 1. List the data for the solar system by completing Worksheet A. Use available data from blueprints, specifications, inspections and handbooks. A heat load analysis for the building is required.

Step 2. Determine the monthly and annual heating/DHW loads, L. Use Worksheet B. If the design heating load for the building is not available, an analysis is required.

Step 3. Calculate the total monthly solar radiation, S. Use Worksheet C.

Step 4. Determine the collector performance parameters, $F_R'(\overline{\tau\alpha})$, $F_R'U_L$. Use Worksheet D. Lines 1, 2, 3 and 4 are transferred from Worksheet A.

Corrections to $F_R(\tau\alpha)_n$, F_RU_L are necessary when the horizontal axis on the collector efficiency chart is based on fluid temperature other than the inlet temperature to the collector, T_i. Although collector test standards are suggested, efficiency curves are not presented in a uniform manner by the manufacturers. The corrections to $F_R(\tau\alpha)_n$, and F_RU_L for different cases are explained below.

Case 1. In $\frac{T^* - T_a}{I_T}$, T^* is T_{in}. (fluid inlet temperature)

No correction is needed

Case 2. If T^* is $\frac{T_i + T_{out}}{2}$, which is the average of the inlet and outlet temperatures,

$$F_R(\tau\alpha)_n \text{ (new value)} = F_R(\tau\alpha)_n \text{ (from efficiency curve)} \cdot \left[\frac{1}{1 + \frac{F_R U_L\ A_c}{2C_c}}\right]$$

where C_c is heat capacitance rate of the collector fluid
$(\dot{m}\ c_p)_c$ Btu/(hr·°F)

$$F_R U_L \text{ (new value)} = F_R U_L \text{ (from efficiency curve)} \cdot \left[\frac{1}{1 + \frac{F_R U_L\ A_c}{2\ C_c}}\right]$$

$$C_c = \dot{m}\ c_p = \left(\begin{matrix}\text{volumetric}\\ \text{flow rate}\end{matrix}\right)\left(\begin{matrix}\text{fluid specific}\\ \text{weight}\end{matrix}\right)\left(\begin{matrix}\text{heat}\\ \text{capacitance}\end{matrix}\right)\left(\begin{matrix}\text{time}\\ \text{conversion}\end{matrix}\right)$$

$$\frac{\text{Btu}}{\text{hr°F}}$$

Case 3. If T* is T_{out}(fluid outlet temperature)

$$F_R(\tau\alpha)_n = F_R(\tau\alpha)_n \text{ (from efficiency curve)} \cdot \left[\frac{1}{1 + \frac{F_R U_L\ A_c}{C_c}}\right]$$

$$F_R U_L = F_R U_L \text{ (from efficiency curve)} \cdot \left[\frac{1}{1 + \frac{F_R U_L\ A_c}{C_c}}\right]$$

Corrections to transmittance, τ, through the cover plates and absorptance, α, for the absorber plate are necessary because of sun angle variations on the collector during the day. The $F_R(\tau\alpha)_n$ determined for normal incidence during collector testing, must be corrected for an effective $F_R(\overline{\tau\alpha})$ for a day on a fixed-position collector.

$$\frac{F_R\overline{\tau\alpha}}{F_R(\tau\alpha)_n} = \begin{cases} 0.91 \text{ for two cover plates} \\ 0.93 \text{ for one cover plate} \end{cases}$$

Step 5. Determine correction factors K_2 and K_4. Use Worksheet E.

Step 6. Calculate system performance parameters. Use Worksheet F.

Step 7. Determine system performance factors f (monthly) and F (annual). Use Worksheet G.

EXAMPLE 9-2

Design a solar heating and hot water system for a three bedroom house located in Fort Collins, Colorado. The house is wood framed with R-13 wall insulation and R-19 ceiling insulation. The overall dimensions of the house are 27 feet wide and 55 feet long, with a usable roof area of 954 ft^2, measuring 18 by 53 feet.

The heat loss calculations for the building have been made, and the overall UA (heat conductance) is 714 Btu/(hr·°F). Using the time conversion from hour to day, the heating load for the building is 17,136 Btu/DD. Complete Worksheets A through G.

Answer. For collector area of 500 ft^2, the liquid-heating system will provide 68 percent of the total annual space and DHW heating load.

(Text continues on page 9-31)

SOLAR SYSTEM DATA

Building Owner Mr + Mrs John Sunbody

Address 136 Sunshine Ave Fort Collins Co Ph. 482-0000

Contractor Solar Construction Co Ph. 482-0001

Type of System (liquid or air, H/DHW Liquid , H/DHW

Site and Building Data

1. Location: Nearest City Fort Collins Latitude 40.6°N
2. Building UA 714 Btu/(hr·°F)
3. DHW volume per day 80 gallons/day
4. Collector manufacturer Honeywell - Lennox
5. Collector area 500 ft^2
6. Collector tilt 50 degrees
7. Tilt = latitude + 10 degrees
8. Collector orientation 0 degrees ____ from south
9. Collector shading 0 % in December
10. Collector efficiency data
    - (a) $F_R(\tau\alpha)_n$ .73
    - (b) F_RU_L .54 Btu/(hr·ft^2·°F)
    - (c) Fluid temperature basis (circle one)
        - Case 1 [✓ T_i]
        - Case 2 $\frac{T_i + T_{out}}{2}$
        - Case 3 T_{out}
11. Collector Fluid:
    - (a) Composition: water-ethylene glycol, 30%
    - (b) Specific heat, c_p 0.90 Btu/(lb·°F)
    - (c) Specific weight γ 8.92 lb/gal or lb/ft^3
    - (d) Flow rate G 10 gal/min or ft^3/min

Storage Data

12. Storage medium water
13. Unit volume 1.5 gal/ft^2 or ft^3/ft^2
14. Total volume (item 5 x 13) 750 gal or ft^3

Worksheet A
Sheet 2 of 2
LIQUID SYSTEMS

15. Specific heat of storage material c_p 1 Btu/(lb·°F)

16. Specific weight 8.34 lb/gal or lb/ft^3

17. Total mass (14 x 16) M 6255 lb.

18. Total heat capacity (17 x 15) $C_s = Mc_p$ 6255 Btu/°F

19. Total heat capacity per unit collector area (18 ÷ 5) 12.5 Btu/(ft^2·°F)

Heat Exchangers

20. Collector/storage type Counter flow and manufacturer Young Radiator

21. Storage loop flow rate 15 gal/min, ft^3/min

22. Heat exchange effectiveness ε_{cs} 0.75

23. Load heat exchanger type Cross-flow, water-air and manufacturer Young Radiator

24. Load loop flow rate 12 gal/min

25. Building air supply flow rate 1200 ft^3/min

26. Heat exchange effectiveness ε_L 0.75

DHW Preheater

27. Collector/storage heat exchanger type Counterflow and manufacturer Young Radiator

28. Collector loop flow rate — gal/min, ft^3/min

29. Heat exchanger effectiveness ε_{HW} 0.7

30. Storage volume 80 gal

31. Storage mass, $M_{St.}$ (line 30 x 8.34) 667 lb

Auxiliary Furnace/Boiler

32. Type Cold Boiler

33. Manufacturer Lennox

34. Rated capacity 100,000 Btu/hr

35. Auxiliary energy source electricity

Auxiliary DHW Unit

36. Size 40 gal

37. Auxiliary energy source electric

38. Hot water set temperature 140 °F

HEATING AND/OR DOMESTIC HOT WATER LOAD, L

	1	2		3	4	5	6	7
Month	Monthly Degree Days DD °F·days	Monthly Space Htg Load Q_s Btu/Mo.	No. of Days/ Mo. N	Vol. of DHW Used/Mo. Gal./Mo.	Temp. Water Main Sup. T_m °F	DHW Temp. Rise $T_{HW}-T_m$ °F	Monthly DHW Load Q_w Btu/Mo.	Total Heating Load L Btu/Mo.
Jan.	1138	x 10⁶ 19.4	31	2480	39	101	x 10⁶ 2.1	21.5
Feb.	938	16.1	28	2240	40	100	1.9	18.0
March	887	15.2	31	2480	43	97	2.0	17.2
April	558	9.6	30	2400	49	91	1.8	11.4
May	288	5.0	31	2480	55	85	1.8	6.8
June	66	1.1	30	2400	60	80	1.6	2.7
July	6	.1	31	2480	63	77	1.6	1.7
Aug.	9	.2	31	2480	64	76	1.6	1.8
Sept.	117	2.0	30	2400	63	77	1.5	3.5
Oct.	428	7.3	31	2480	56	84	1.7	9.0
Nov.	819	14.0	30	2400	45	95	1.9	15.9
Dec.	1035	17.7	31	2480	37	103	2.1	19.8
						Total	21.0	129.3

1. From Table 3-2 or Figures 3-2 through 3-13
2. Q_s = (24)(UA)(Degree Day)
3. (Vol/day)x(no. days/mo.) = 80 (gal./day)x(no. days/mo.)
4. From Table 8-3 for selected cities.
6. Q_w = (vol. of water) x 8.34 x 1 x ($T_{HW}-T_m$).
7. L = Q_s + Q_w

Project Sunbody

Residence

Q_d = 51,410 Btu/h

(Given data or calculate as in Module 3)

DTD = 70 - T_o

= 70 - (-2) = 72

Where: T_o = 99% winter design temperature.

(From ASHRAE Fundamentals, or Table 3-2)

70°F = indoor design

UA = $\frac{Q_d}{DTD}$ = 714 Btu/(hr · °F)

T_{HW} = 140° F

TOTAL MONTHLY SOLAR RADIATION AVAILABLE, S

Project Sunbody Residence
Location Fort Collins
Collector Tilt Lat + 15°
Nearest Data Site Boulder

	1	2	3
Month	Monthly Avg. Daily Rad. on Tilt Surf. $\overline{I}_T$ Btu/(Day·ft^2)	No. of Days in month N	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo·ft^2)
Jan.	1439	31	44,609
Feb.	1533	28	42,924
March	1409	31	59,179
April	1663	30	49,890
May	1425	31	44,175
June	1491	30	44,730
July	1535	31	47,585
Aug.	1458	31	45,198
Sept.	1702	30	51,060
Oct.	1659	31	51,429
Nov.	1507	30	45,210
Dec.	1418	31	43,958

[1] From Table 5-5 for Colorado cities

[3] Column [1] x Column [2]

Worksheet D
Sheet 1 of 2
LIQUID SYSTEMS

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

PROJECT Sunbody Residence

Collector Efficiency Data from Worksheet A (lines 10(a), (b))

1. Intercept, $F_R(\tau\alpha)_n$ = 0.73
2. Slope, $F_R U_L$ = 0.54

Reference Temperature Basis: 1. [✓ t_{in},] 2. $\frac{t_{in} + t_{out}}{2}$, 3. t_{out}

3. Collector area, A_c = 500 ft²
4. Collector volumetric flow rate (Worksheet A, 11(d))

   10 gal/min or ft³/min

Correction to t_{in} basis

5. Case 1: (no correction) $F_R(\tau\alpha)_n$ = 0.73

   $F_R U_L$ = 0.54

6. Case 2: $F_R(\tau\alpha)_n = F_R\ \tau\alpha \times \left[\dfrac{1}{1 + \dfrac{F_R U_L A_c}{2\,C_c}}\right]$ = ______

   $F_R U_L = F_R U_L \times \left[\dfrac{1}{1 + \dfrac{F_R U_L A_c}{2\,C_c}}\right]$ = ______

   $C_c = \dot{m}c_p = \left(\begin{matrix}\text{volumetric}\\\text{flow rate}\end{matrix}\right)(\text{density})\left(\begin{matrix}\text{time}\\\text{conversion}\end{matrix}\right)\left(\begin{matrix}\text{specific}\\\text{heat}\end{matrix}\right)$

   $= 10 \times 8.92 \times 60 \times 0.90 = 4817$ Btu/(hr · °F)

   where: for liquids, density - (8.34 lb/gal) x (specific gravity) for air, density = 0.075 lb/ft³ at 70° and 1 atm. specific heat = 0.24 Btu/lb·°F

7. Case 3: $F_R(\tau\alpha)_n = F_R(\tau\alpha)_n \times \left[\dfrac{1}{1 + \dfrac{F_R U_L A_c}{C_c}}\right]$ = ______

   $F_R U_L = F_R U_L \times \left[\dfrac{1}{1 + \dfrac{F_R U_L A_c}{C_c}}\right]$ = ______

8. Incident Angle Modifier, $\dfrac{F_R(\overline{\tau\alpha})}{F_R(\tau\alpha)_n}$ = { .91, for two cover plates
   [✓ .93,] for one cover plate

Worksheet D
Sheet 2 of 2
LIQUID SYSTEMS

Collector Loop Heat Exchanger Modifier, $\frac{F_R'}{F_R}$

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

Capacitance Rate:

10. C_c = (from line 6) = 4817 Btu/(hr•°F)

11. C_s = (calc. as for C_c above) = 7506 Btu/(hr•°F)

12. C_{min} = (lesser of C_c of C_s) = 4817 Btu/(hr•°F)

13. Collector Storage Heat Exchanger Effectiveness, ε_{cs} = 0.75

14. $x = \frac{C_c}{\varepsilon_{cs} C_{min}}$ = 4817 / 0.75 (4817) (from Worksheet A, line 22) = 1.33

15. $y = \frac{A_c(F_R U_L)}{C_c}$ = 500 (.54) / 4817 = .056

16. $\frac{F_R'}{F_R}$ = from Figure 9-7 or = $\frac{1}{1 + y(x-1)}$ = .98

17. $F_R'(\overline{\tau\alpha}) = F_R(\tau\alpha)_n \times \frac{(\overline{\tau\alpha})}{(\tau\alpha)_n} \times \frac{F_R'}{F_R}$ = (0.73)(.93)(.98) = .67

18. $F_R'U_L = F_R U_L \times \frac{F_R'}{F_R}$ = (.54)(.98) = .53

CORRECTION FACTORS, K_2, K_4

PROJECT Sunbody Residence

Storage Mass Capacitance Factor K_2

Note: M includes hot water sotrage volume where it is solar heated

1. gals/ft² of collector 1.5
2. K_2 = (from Figure 9-8) = 1.07

Load Heat Exchange Factor, K_4

3. ε_L (from Worksheet A, line 26) = 0.75
4. $C_{\text{hot water supply loop}} = \dot{m}c_p = C_H$ (from Worksheet A, lines 24 x 8.25 x 60) = 6005 Btu/(hr•ft²)
5. $C_{\text{air loop}} = \dot{m}c_p = C_A$ (from Worksheet A, line 25 x 0.075 x .24 x 60) = 1246 Btu/(hr•ft²)
6. $C_{\min}$ = smaller of C_H or C_A = 1246 Btu/(hr•ft²)
7. (UA) bldg = (from Worksheet A, or B) = 714 Btu/(hr•°F)
8. $\frac{\varepsilon_L C_{\min}}{UA}$ = 1.36
9. K_4 = (from Figure 9-9) = 0.97

SYSTEM PERFORMANCE PARAMETERS X, Y

PROJECT Sunbody Residence

	1	2	3	4	5	6	7	8
Month	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo·ft²)	Total Heating Load L Btu/Mo.	S/L	Y $F_1 \cdot [3]$	Mo. Av. Temp. $\overline{T}_a$ °F	$212-\overline{T}_a$ °F	Tot. Hrs in Mo. Δ time hr.	X
Jan.	44,609	x 10^6 21.5	.00207	.673	28	184	744	1.81
Feb.	42,924	18.0	.00238	.774	32	180	672	1.91
March	59,179	17.2	.00344	1.118	36	176	744	2.16
April	49,890	11.4	.00438	1.424	46	166	720	2.97
May	44,175	6.8	.00650	2.111	56	156	744	4.84
June	44,730	2.7	.0166	5.385	63	149	720	11.27
July	47,585	1.7	.0280	9.097	65	147	744	18.25
Aug.	45,198	1.8	.0251	8.161	65	147	744	17.23
Sept.	51,060	3.5	.0146	4.742	61	151	720	8.81
Oct.	51,429	9.0	.00571	1.856	51	161	744	3.77
Nov.	45,210	15.9	.00284	.923	38	174	720	2.23
Dec.	43,958	19.8	.00222	.722	32	180	744	1.92

1. From Worksheet C, Col. 3
2. From Worksheet B, Col. 7
4. $Y = \frac{A_c F_R' (\overline{\tau\alpha}) S}{L} \times K_4 = F_1 \cdot \frac{S}{L}$
5. From Table 5-5
8. $X = \frac{A_c F_R' U_L (T_{ref} - T_a) \Delta time}{L} \times K_2$

$$= F_2 \cdot \underbrace{\{[6] \cdot [7]\} \div [2]}_{\text{columns}}$$

A_c = 500 ft²

$F_R' \overline{\tau\alpha}$ = .67 (Wksht D)

$F_R' U_L$ = .53 (Wksht D)

K_1 = 1.0 (Wksht E)

K_2 = 1.07 (Wksht E)

K_4 = .97 (Wksht E)

$F_1 = A_c F_R' \overline{\tau\alpha} K_4$ = 325

$F_2 = A_c F_R' U_L K_2$ = 283.6

SOLAR FRACTION FOR DIFFERENT COLLECTOR SIZES

In Example 9-2, the detailed calculations yielded the result that solar energy, with 500 ft^2 of Honeywell-Lennox collectors and compatible system components, provide 68 percent of the total annual space and domestic hot water heating load for the building. To determine the annual solar fraction provided by a system with different collector areas, the f-chart used for the computations with 500 ft^2 of collectors, and only worksheet G are needed. It is not necessary to rework the entire calculation procedure from worksheet A through worksheet G.

As an example, the monthly and annual solar fractions for 300 ft^2 of collectors can be determined by following the procedure below:

Step 1. - Calculate the area ratio (new area/old area)
In this example 300/500 = 0.6

Step 2. - For each month multiply the f-chart parameters X and Y (Columns 2 and 3, Worksheet G) by the area ratio.

Step 3. - Use the f-chart (Figure 9-6) and determine the new solar fractions for each month.

Step 4. - Complete a new worksheet G and determine the annual fraction, F.

The procedure described above is followed and results are shown on the new worksheet G.. With 300 ft^2 of liquid-heating collectors, the system will provide 49 percent of the annual space and DHW heating load.

Worksheet G
LIQUID SYSTEMS

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

PROJECT Sunbody Residence

COLLECTOR AREA 300 ft^2

	1	2	3	4	5
Month	Tot. Mo. Htg. Load L Btu/mo.	System Parameters X	System Parameters Y	Solar Fraction/ mo. f	Actual Solar en/mo E Btu/mo.
Jan.	21.5	1.09	.40	0.31	6.7
Feb.	18.0	1.15	.46	0.36	6.5
March	17.2	1.30	.67	0.50	8.6
April	11.4	1.78	.85	0.60	6.8
May	6.8	2.90	1.27	0.79	5.4
June	2.7	6.76	3.23	1.0	2.7
July	1.7	10.95	5.46	1.0	1.7
Aug.	1.8	10.34	4.90	1.0	1.8
Sept.	3.5	5.29	2.84	1.0	3.5
Oct.	9.0	2.26	1.12	0.74	6.7
Nov.	15.9	1.34	.55	0.42	6.7
Dec.	19.8	1.15	.43	0.33	6.5

L_{tot} =

E_{tot} =

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

1. From Worksheet B
2. From Worksheet F, Column 9
3. From Worksheet F, Column 4
4. From "f chart", Figure 9-6
5. E = f x L

THE RELATIVE AREAS METHOD

The annual solar fraction for the solar system of Example 9-2 is calculated using the relative areas method described in Module 8.

EXAMPLE 9-3

Determine the annual solar fraction for the solar system of Example 11-2, using the relative areas method, first for 500 ft^2, then for 300 ft^2, using the values in Table 11-6 for Denver, Colorado.

For convenience, use the worksheet for the relative areas method:

Answer.

$F = \underline{0.73}$ for $A_c = 500$ ft^2

$F = \underline{0.58}$ for $A_c = 300$ ft^2

From the f-chart method the results were

$F = 0.68$ for $A_c = 500$ ft^2

$F = 0.49$ for $A_c = 300$ ft^2

SOLAR SYSTEM DATA

Building Owner Mr + Mrs John Sunbody

Address 736 Sunshine Ave Fort Collins Colo Ph. 482-0000

Contractor Solar Construction Ph. 482-0001

Type of System (liquid, air, H/DHW, DWH) Liquid, H/DHW

Site and Building Data

1. Location: Nearest City Fort Collins Latitude 40.6°N
2. Building UA 714 Btu/(hr·°F)
3. DHW volume per day 80 gallons/day

Collector Data

4. Collector manufacturer Lennox
5. Collector Area, A_c = 500 ft^2
6. Collector efficiency data from manufacturer's information:
   (a) $F_R(\tau\alpha)$ 0.73
   (b) F_RU_L 0.54 $\text{Btu/(hr}\cdot\text{ft}^2\cdot{}^\circ\text{F)}$
7. Correction for fluid temperature basis
   (a) Case 1: (no correction)
      (i) $F_R(\tau\alpha)_n = F_R\tau\alpha$ (from line 6) 0.73
      (ii) $F_RU_L = F_RU_L$ (from line 6) 0.54 $\text{Btu/(hr}\cdot\text{ft}^2\cdot{}^\circ\text{F)}$
   (b) Case 2: $\dfrac{T_{in} + T_{out}}{2}$ (correction needed)

$$C_c = (\dot{m}c_p)_c = \left(\begin{matrix}\text{Vol flow}\\ \text{rate}\end{matrix}\right)(\text{density})\left(\begin{matrix}\text{time}\\ \text{conversion}\end{matrix}\right)\left(\begin{matrix}\text{specific}\\ \text{heat}\end{matrix}\right)$$

$$= 10\ \frac{\text{gal}}{\text{min}} \times 8.92\ \frac{\text{lb}}{\text{gal}} \times 60\ \frac{\text{min}}{\text{hr}} \times 0.9\ \frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}$$

4817 Btu/(hr·°F)

$$\text{Correction Factor} = \left[\frac{1}{1 + \frac{F_R U_L A_c}{2C_c}}\right] = \underline{\qquad\qquad\qquad}$$

(i) $F_R(\tau\alpha)_n = F_R\tau\alpha$(from line 6a) x (correction factor)

$= \underline{\qquad\qquad} \times \underline{\qquad} = \underline{\qquad}$

(ii) $F_R U_L = F_R U_L$(from line 6b) x (correction factor)

$= \underline{\qquad\qquad} \times \underline{\qquad} = \underline{\qquad}$ Btu/(hr•ft^2•°F)

(c) Case 2: T_{out}(correction needed)

$$\text{Correction Factor} = \frac{1}{1 + \frac{F_R U_L A_c}{C_c}} = \underline{\qquad\qquad}$$

(i) $F_R(\tau\alpha)_n = F_R(\tau\alpha)$(from line 6a) x (correction factor)

$= \underline{\qquad\quad} \times \underline{\qquad\quad} = \underline{\qquad\quad}$

(ii) $F_R U_L$(from line 6b) x (correction factor)

$= \underline{\qquad\quad} \times \underline{\qquad\quad} = \underline{\qquad\quad}$ Btu/(hr•ft^2•°F)

Heat Exchanger Factor (F_R'/F_R)

8. For air collectors $F_R'/F_R = 1$

9. For liquid collectors

(a) C_c(from line 7b) = $\underline{4817}$ Btu/(hr•°F)

(b) $C_s = \underline{15} \times 8.34 \times 60 \times 1 = \underline{7506}$ Btu/(hr•°F)

(c) Heat exchanger effectiveness = $\underline{0.75}$

(d) $x = \frac{C_c}{\varepsilon_{cs} C_{min}} = \frac{4817}{(0.75)(4817)} = \underline{1.33}$

(e) $y = \frac{A_c F_R U_L}{C_c} = \frac{(500)(.54)}{4817} = \underline{0.06}$

(f) $F_R'/F_R = \frac{1}{1 + y(x-1)} = \underline{0.98}$

Corrections to Collector Parameters

10. Incident angle modifier

(a) $F_R(\overline{\tau\alpha}) = F_R(\tau\alpha)_n \times 0.91$ (for two cover plates)

$= \_\_\_\_\_\_ \times 0.91 = \_\_\_\_\_\_$

(b) $F_R(\overline{\tau\alpha}) = F_R(\tau\alpha)_n \times 0.93$ (for one cover plate)

$= \underline{0.73} \times 0.93 = \underline{0.68}$

11. (a) $F_R'\overline{\tau\alpha} = \dfrac{0.68}{\text{line 10a or 10b}} \times \dfrac{.98}{\text{line 8 or 9f}} = \underline{0.67}$

(b) $F_R'U_L = \dfrac{0.54}{\text{line 7a(ii) or 7b(ii) or 7c(ii)}} \times \dfrac{.98}{\text{line 8 or 9f}} = \underline{0.53}$ Btu/(hr•°F)

List c_1, c_2, A_S, A_D, Z from Table 11-5

12. A_S or A_D = $\underline{.197}$ $Z = \underline{.241}$ $c_1 = \underline{.531}$ $c_2 = \underline{.301}$

For Solar Heating and DHW Systems:

13. $$A_{50} = \frac{A_S(UA)_L}{F_R'\overline{\tau\alpha} - F_R'U_L(Z)}$$

$$A_{50} = \frac{(.197)\quad(714)}{(0.67) - (.53)(.241)} = \underline{259}\ \text{ft}^2$$

14. $A_c/A_{50} = \underline{500/254} = \underline{1.93}$

15. $\log_e(A_c/A_{50}) = \underline{0.66}$

16. $F = c_1 + c_2 \log_e(A/A_{50})$

$= \underline{.531} + \underline{(.301)(0.66)} = \underline{0.73}$

17. $A_c/A_{50} = 300/259 = 1.16$

18. $\text{Log}_e(A_c/A_{50}) = 0.15$

19. $F = \underline{.531} + (.301)(.15) = \underline{0.58}$

REFERENCES

1. Klein, S. A., Beckman, W. A., and Duffie, J. A., "Design Procedure for Solar Heating Systems," Solar Energy, Vol. 18, pp. 113-127.
2. ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc., 345 East 47th Street, New York, N.Y. 10017, 1972.
3. ASHRAE Systems Handbook, Chapter 43, American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc., 345 East 47th Street, New York, N.Y. 10017, 1976.
4. Climate Atlas of the United States, U.S. Department of Commerce NOAA, National Climatic Center, Federal Building, Asheville, N.C. 28801.
5. Load Calculation for Residential Winter and Summer Air Conditioning, Manual J, National Environmental Systems Contractors Association, 1501 Wilson Blvd., Arlington, Va. 22209.
6. Heat Loss Calculation Guide, No. H-21, The Hydronics Institute, 35 Russo Place, Berkeley Heights, N.J. 07922.
7. ASHRAE Applications of Solar Energy for Heating and Cooling of Buildings, American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc., 345 East 47th Street, New York, N.Y. 10017, 1977.
8. Klein, S. A., Beckman, W. A., and Duffie, J. A., "A Design Procedure for Solar Air Heating Systems," Proceedings of American Section ISES Meeting, Winnipeg, Canada, Vol. 4, August, 1976.
9. "f-chart Computer Program," Solar Engineering Laboratory, University of Wisconsin, Madison, Wisconsin.
10. Solar Heating and Cooling of Residential Buildings, Training Manuals, Sizing Installation and Operation of System, Design of Systems, Solar Energy Applications Laboratory, Colorado State University, Fort Collins, 1977.
11. Barley, C. D. and Winn, C. B., "The Relative Areas Method for Optimal Collector Sizing of Solar Systems," Solar Energy Applications Laboratory, Colorado State University, Fort Collins, Colorado, 1978.

Worksheet A
Sheet 1 of 2
LIQUID SYSTEMS

SOLAR SYSTEM DATA

Building Owner ______________________________

Address ______________________ Ph. __________

Contractor ______________________ Ph. __________

Type of System (liquid or air, H/DHW ______________________

Site and Building Data

1. Location: Nearest City __________ Latitude __________
2. Building UA ______________ Btu/(hr·°F)
3. DHW volume per day ______________ gallons/day
4. Collector manufacturer ______________________
5. Collector area ______________ ft^2
6. Collector tilt ______________ degrees
7. Tilt = latitude + ______________ degrees
8. Collector orientation ______ degrees ______ from south
9. Collector shading ______________ % in December
10. Collector efficiency data
    - (a) $F_R(\tau\alpha)_n$ __________
    - (b) F_RU_L __________ Btu/(hr·ft^2·°F)
    - (c) Fluid temperature basis (circle one)
      - Case 1 T_i
      - Case 2 $\frac{T_i + T_{out}}{2}$
      - Case 3 T_{out}
11. Collector Fluid:
    - (a) Composition: ______________________
    - (b) Specific heat, c_p __________ Btu/(lb·°F)
    - (c) Specific weight γ __________ lb/gal or lb/ft^3
    - (d) Flow rate G __________ gal/min or ft^3/min

Storage Data

12. Storage medium ______________________
13. Unit volume __________ gal/ft^2 or ft^3/ft^2
14. Total volume (item 5 x 13) __________ gal or ft^3

Worksheet A
Sheet 2 of 2
LIQUID SYSTEMS

15. Specific heat of storage material c_p ________ Btu/(lb·°F)
16. Specific weight ________ lb/gal or lb/ft^3
17. Total mass (14 x 16) M ________ lb.
18. Total heat capacity (17 x 15) $C_s = Mc_p$ ________ Btu/°F
19. Total heat capacity per unit collector area (18 ÷ 5) ________ Btu/(ft^2·°F)

Heat Exchangers

20. Collector/storage type ________________________ and manufacturer ____
21. Storage loop flow rate ________ gal/min, ft^3/min
22. Heat exchange effectiveness ε_{cs} ________
23. Load heat exchanger type ________________________ and manufacturer ____
24. Load loop flow rate ________ gal/min
25. Building air supply flow rate ________ ft^3/min
26. Heat exchange effectiveness ε_L ________

DHW Preheater

27. Collector/storage heat exchanger type ____________ and manufacturer ____
28. Collector loop flow rate ________ gal/min, ft^3/min
29. Heat exchanger effectiveness ε_{Hw} ________
30. Storage volume ________ gal
31. Storage mass, $M_{St.}$ (line 30 x 8.34) ________ lb

Auxiliary Furnace/Boiler

32. Type ____
33. Manufacturer ____
34. Rated capacity ________ Btu/hr
35. Auxiliary energy source ________

Auxiliary DHW Unit

36. Size ________ gal
37. Auxiliary energy source ________
38. Hot water set temperature ________ °F

HEATING AND/OR DOMESTIC HOT WATER LOAD, L

	1	2		3	4	5	6	7
Month	Monthly Degree Days DD °F·days	Monthly Space Htg Load Q_s Btu/Mo.	No. of Days/ Mo. N	Vol. of DHW Used/Mo. Gal./Mo.	Temp. Water Main Sup T_m °F	DHW Temp. Rise $T_{HW}-T_m$ °F	Monthly DHW Load Q_w Btu/Mo.	Total Heating Load L Btu/Mo.
Jan.			31					
Feb.			28					
March			31					
April			30					
May			31					
June			30					
July			31					
Aug.			31					
Sept.			30					
Oct.			31					
Nov.			30					
Dec.			31					
						Total		

1. From Table 3-2 or Figures 3-2 through 3-13
2. Q_s = (24)(UA)(Degree Day)
3. (Vol/day)x(no. days/mo.) = _______________(gal./day)x(no. days/mo.)
4. From Table 8-3 for selected cities
6. Q_w = (vol. of water) x 8.34 x 1 x ($T_{HW}-T_m$).
7. L = Q_s + Q_w

Project _______________

____

Q_d = _______________ Btu/h

(Given data or calculate as in Module 3)

DTD = 70 - T_o

= 70 - ____ =

Where: T_o = 99% winter design temperature.

(From ASHRAE Fundamentals, or Table 3-2)

70°F = indoor design

$$UA = \frac{Q_d}{DTD} =$$

T_{HW} = _______________

TOTAL MONTHLY SOLAR RADIATION AVAILABLE, S

Project____

Location____

Collector Tilt____________________________________

Nearest Data Site__________________________________

	1	2	3
Month	Monthly Avg. Daily Rad. on Tilt Surf. $\bar{I}_T$ Btu/(Day·ft^2)	No. of Days in month N	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo·ft^2)
Jan.		31	
Feb.		28	
March		31	
April		30	
May		31	
June		30	
July		31	
Aug.		31	
Sept.		30	
Oct.		31	
Nov.		30	
Dec.		31	

[1] From Table 5-5 for Colorado cities

[3] Column [1] x Column [2]

Worksheet D
Sheet 1 of 2
LIQUID SYSTEMS

COLLECTOR COMBINED PERFORMANCE CHARACTERISTICS, $F'_R(\overline{\tau\alpha}) \cdot F'_R U_L$

PROJECT ____________________

Collector Efficiency Data from Worksheet A (lines 10(a), (b))

1. Intercept, $F_R(\tau\alpha)_n$ = ____________
2. Slope, $F_R U_L$ = ____________

Reference Temperature Basis: 1. t_{in}, 2. $\frac{t_{in} + t_{out}}{2}$, 3. t_{out}

3. Collector area, A_c = ____________ ft^2
4. Collector volumetric flow rate (Worksheet A, 11(d))

____________ gal/min or ft^3/min

Correction to t_{in} basis

5. Case 1: (no correction) $F_R(\tau\alpha)_n$ = ____________

$F_R\ U_L$ = ____________

6. Case 2: $F_R(\tau\alpha)_n = F_R\ \tau\alpha \times \left[\frac{1}{1 + \frac{F_R U_L\ A_c}{2\ C_c}}\right]$ = ____________

$F_R U_L = F_R U_L \times \left[\frac{1}{1 + \frac{F_R U_L\ A_c}{2\ C_c}}\right]$ = ____________

$C_c = \dot{m}c_p = \binom{\text{volumetric}}{\text{flow rate}}(\text{density})\binom{\text{time}}{\text{conversion}}\binom{\text{specific}}{\text{heat}}$

= ____________ = ____________

where: for liquids, density - (8.34 lb/gal) x
(specific gravity) for air, density = 0.075 lb/ft^3
at 70° and 1 atm. specific heat = 0.24 Btu/lb·°F

7. Case 3: $F_R(\tau\alpha)_n = F_R(\tau\alpha)_n \times \left[\frac{1}{1 + \frac{F_R U_L\ A_c}{C_c}}\right]$ = ____________

$F_R U_L = F_R U_L \times \left[\frac{1}{1 + \frac{F_R U_L\ A_c}{C_c}}\right]$ = ____________

8. Incident Angle Modifier, $\frac{F_R(\overline{\tau\alpha})}{F_R(\tau\alpha)_n} = \{$ .91, for two cover plates
.93, for one cover plate

Collector Loop Heat Exchanger Modifier, $\frac{F'_R}{F_R}$

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

Capacitance Rate:

10. C_c = (from line 6) = ______________ Btu/(hr·°F)

11. C_s = (calc. as for C_c above) = ______________ Btu/(hr·°F)

12. C_{min} = (lesser of C_c of C_s) = ______________ Btu/(hr·°F)

13. Collector Storage Heat Exchanger Effectiveness, ε_{cs} = _______

14. $x = \frac{C_c}{\varepsilon_{cs} C_{min}}$ = ______________________________ (from Worksheet A, line 22) = _______

15. $y = \frac{A_c(F_R U_L)}{C_c}$ = ______________________________ = _______

16. $\frac{F'_R}{F_R}$ = from Figure 9-7 or = $\frac{1}{1 + y(x-1)}$ = ____________________

17. $F'_R(\overline{\tau\alpha}) = F_R(\tau\alpha)_n \times \frac{(\overline{\tau\alpha})}{(\tau\alpha)_n} \times \frac{F'_R}{F_R}$ = ____________________

18. $F'_R U_L = F_R U_L \times \frac{F'_R}{F_R}$ = ____________________

CORRECTION FACTORS, K_2, K_4

PROJECT ______________________

Storage Mass Capacitance Factor K_2

Note: M includes hot water sotrage volume where it is solar heated

1. gals/ft^2 of collector ______________________

2. K_2 = (from Figure 9-8) = ______________________

Load Heat Exchange Factor, K_4

3. ε_L (from Worksheet A, line 26) = ______________________

4. $C_{\text{hot water supply loop}} = \dot{m}c_p = C_H$
(from Worksheet A, lines 24 x 8.25 x 60) =
____________ Btu/(hr·ft^2)

5. $C_{\text{air loop}} = \dot{m}c_p = C_A$
(from Worksheet A, line 25 x 0.075 x .24 x 60) =
____________ Btu/(hr·ft^2)

6. C_{min} = smaller of C_H or C_A = ____________ Btu/(hr·ft^2)

7. (UA) bldg = (from Worksheet A, or B) =
____________ Btu/(hr·°F)

8. $\dfrac{\varepsilon_L \, C_{min}}{UA}$ = ______________________

9. K_4 = (from Figure 9-9) = ______________________

Worksheet F
LIQUID SYSTEMS

SYSTEM PERFORMANCE PARAMETERS X, Y

PROJECT________________

	1	2	3	4	5	6	7	8
Month	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo·ft^2)	Total Heating Load L Btu/Mo.	S/L	Y $F_1\cdot[3]$	Mo. Av. Temp. $\overline{T}_a$ °F	$212-\overline{T}_a$ °F	Tot. Hrs in Mo. Δ time hr.	X
Jan.							744	
Feb.							672	
March							744	
April							720	
May							744	
June							720	
July							744	
Aug.							744	
Sept.							720	
Oct.							744	
Nov.							720	
Dec.							744	

1. From Worksheet C, Col. 3
2. From Worksheet B, Col. 7
4. $Y = \frac{A_c F_R'(\overline{\tau\alpha})S}{L} \times K_4 = F_1 \cdot \frac{S}{L}$
5. From Table 5-5
8. $X = \frac{A_c F_R' U_L (T_{ref}-T_a)\Delta time}{L} \times K_2$

$$= F_2 \cdot \underbrace{\{[6]\cdot[7]\}\div[2]}_{\text{columns}}$$

A_c = ____________ ft^2

$F_R'\,\overline{\tau\alpha}$ = ____________ (Wksht D)

$F_R'U_L$ = ____________ (Wksht D)

K_1 = ____________ (Wksht E)

K_2 = ____________ (Wksht E)

K_4 = ____________ (Wksht E)

$F_1 = A_c F_R'\,\overline{\tau\alpha}\,K_4$ = ____________

$F_2 = A_c F_R' U_L K_2$ = ____________

Worksheet G
LIQUID SYSTEMS

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

PROJECT______________________

COLLECTOR AREA ____ft^2

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

L_{tot} =

E_{tot} =

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

1. From Worksheet B
2. From Worksheet F, Column 9
3. From Worksheet F, Column 4
4. From "f chart", Figure 9-6
5. E = f x L

SOLAR SYSTEM DATA

Building Owner______________________________

Address______________________________ Ph.______________

Contractor______________________________ Ph.______________

Type of System (liquid, air, H/DHW, DWH) ______________________

Site and Building Data

1. Location: Nearest City__________________ Latitude_______
2. Building UA__________________ Btu/(hr·°F)
3. DHW volume per day__________________ gallons/day

Collector Data

4. Collector manufacturer__________________
5. Collector Area, A_c = __________________ ft^2
6. Collector efficiency data from manufacturer's information:
   (a) $F_R(\tau\alpha)$ __________________
   (b) F_RU_L __________________ Btu/(hr·ft^2·°F)
7. Correction for fluid temperature basis
   (a) Case 1: (no correction)
      (i) $F_R(\tau\alpha)_n = F_R\tau\alpha$ (from line 6) _______
      (ii) $F_RU_L = F_RU_L$ (from line 6) _______ Btu/(hr·ft^2·°F)
   (b) Case 2: $\frac{T_{in} + T_{out}}{2}$ (correction needed)

$$C_c = (\dot{m}c_p)_c = \left(\begin{matrix}\text{Vol flow}\\\text{rate}\end{matrix}\right)(\text{density})\left(\begin{matrix}\text{time}\\\text{conversion}\end{matrix}\right)\left(\begin{matrix}\text{specific}\\\text{heat}\end{matrix}\right)$$

$$= \_\_\_\_ \frac{\text{gal}}{\text{min}} \times \_\_\_\_ \frac{\text{lb}}{\text{gal}} \times 60\ \frac{\text{min}}{\text{hr}} \times \_\_\_\_ \frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}$$

_______ Btu/(hr·°F)

Correction Factor = $\left[\dfrac{1}{1 + \dfrac{F_R U_L A_c}{2C_c}}\right]$ = ______________

(i) $F_R(\tau\alpha)_n$ = $F_R\tau\alpha$(from line 6a) x (correction factor)

= ______________ x ________ = ________

(ii) F_RU_L = F_RU_L(from line 6b) x (correction factor)

= ______________ x ________ = ________ Btu/(hr·ft^2·°F)

(c) Case 2: T_{out}(correction needed)

Correction Factor = $\dfrac{1}{1 + \dfrac{F_R U_L A_c}{C_c}}$ = __________

(i) $F_R(\tau\alpha)_n$ = $F_R(\tau\alpha)$(from line 6a) x (correction factor)

= __________ x __________ = __________

(ii) F_RU_L(from line 6b) x (correction factor)

= __________ x __________ = __________Btu/(hr·ft^2·°F)

Heat Exchanger Factor (F_R'/F_R)

8. For air collectors $F_R'/F_R = 1$

9. For liquid collectors

(a) C_c(from line 7b) = ________ Btu/(hr·°F)

(b) C_s = ____ x 8.34 x 60 x 1 = ________ Btu/(hr·°F)

(c) Heat exchanger effectiveness = ________

(d) $x = \dfrac{C_c}{\varepsilon_{cs}C_{min}} = \dfrac{\qquad}{(\qquad)(\qquad)}$ = _______

(e) $y = \dfrac{A_cF_RU_L}{C_c} = \dfrac{(\qquad)(\qquad)}{}$ = ________

(f) $F_R'/F_R = \dfrac{1}{1 + y(x-1)}$ = ________

Corrections to Collector Parameters

10. Incident angle modifier

(a) $F_R(\overline{\tau\alpha}) = F_R(\tau\alpha)_n \times 0.91$ (for two cover plates)

$= \_\_\_\_\_\_ \times 0.91 = \_\_\_\_\_\_$

(b) $F_R(\overline{\tau\alpha}) = F_R(\tau\alpha)_n \times 0.93$ (for one cover plate)

$= \_\_\_\_\_\_ \times 0.93 = \_\_\_\_\_\_$

11. (a) $F_R'\overline{\tau\alpha} = \dfrac{\_\_\_\_\_\_}{\text{line 10a or 10b}} \times \dfrac{\_\_\_\_\_\_}{\text{line 8 or 9f}} = \_\_\_\_\_\_$

(b) $F_R'U_L = \dfrac{\_\_\_\_\_\_}{\begin{array}{l}\text{line 7a(ii)}\\ \text{or 7b(ii)}\\ \text{or 7c(ii)}\end{array}} \times \dfrac{\_\_\_\_\_\_}{\text{line 8 or 9f}} = \_\_\_\_\_\_$ Btu/(hr•°F)

List c_1, c_2, A_S, A_D, Z from Table 11-5

12. A_S or A_D = ______ Z = ______ c_1 = ______ c_2 = ______

For Solar Heating and DHW Systems:

13. $$A_{50} = \frac{A_S(UA)_L}{F_R'\overline{\tau\alpha} - F_R'U_L(Z)}$$

$$A_{50} = \frac{(\quad)(\quad)}{(\quad) - (\quad)(\quad)} = \_\_\_\_\_\_ \text{ ft}^2$$

14. A_c/A_{50} = ______ = ______

15. $\log_e(A_c/A_{50})$ = ______

16. $F = c_1 + c_2 \log_e(A/A_{50})$

$= \_\_\_\_ + (\_\_\_\_)(\_\_\_\_) = \_\_\_\_$

17. $A_c/A_{50} = 300/259 = 1.16$

18. $\text{Log}_e(A_c/A_{50}) = 0.15$

19. $F = \_\_\_\_ + (\quad)(\quad) = \_\_\_\_$

Worksheet A
Sheet 1 of 2
LIQUID SYSTEMS

SOLAR SYSTEM DATA

Building Owner ______________________________

Address ______________________________ Ph. ______________

Contractor ______________________________ Ph. ______________

Type of System (liquid or air, H/DHW ______________________________

Site and Building Data

1. Location: Nearest City ______________ Latitude ____________
2. Building UA ______________________________ Btu/(hr·°F)
3. DHW volume per day ______________________________ gallons/day
4. Collector manufacturer ______________________________
5. Collector area ______________________________ ft^2
6. Collector tilt ______________________________ degrees
7. Tilt = latitude + ______________________________ degrees
8. Collector orientation ________ degrees ________ from south
9. Collector shading ______________________________ % in December
10. Collector efficiency data
    - (a) $F_R(\tau\alpha)_n$ ____________
    - (b) $F_R U_L$ ____________ Btu/(hr·ft^2·°F)
    - (c) Fluid temperature basis (circle one)
        - Case 1 T_i
        - Case 2 $\frac{T_i + T_{out}}{2}$
        - Case 3 T_{out}
11. Collector Fluid:
    - (a) Composition: ______________________________
    - (b) Specific heat, c_p ____________ Btu/(lb·°F)
    - (c) Specific weight γ ____________ lb/gal or lb/ft^3
    - (d) Flow rate G ____________ gal/min or ft^3/min

Storage Data

12. Storage medium ______________________________
13. Unit volume ____________ gal/ft^2 or ft^3/ft^2
14. Total volume (item 5 x 13) ____________ gal or ft^3

15. Specific heat of storage material c_p ________ Btu/(lb·°F)
16. Specific weight ________ lb/gal or lb/ft^3
17. Total mass (14 x 16) M ________ lb.
18. Total heat capacity (17 x 15) $C_s = Mc_p$ ________ Btu/°F
19. Total heat capacity per unit collector area (18 ÷ 5) ________ Btu/(ft^2·°F)

Heat Exchangers

20. Collector/storage type ______________________________ and manufacturer ____
21. Storage loop flow rate ________ gal/min, ft^3/min
22. Heat exchange effectiveness ε_{cs} ________
23. Load heat exchanger type ____________________________ and manufacturer ____
24. Load loop flow rate ________ gal/min
25. Building air supply flow rate ________ ft^3/min
26. Heat exchange effectiveness ε_L ________

DHW Preheater

27. Collector/storage heat exchanger type ______________ and manufacturer ____
28. Collector loop flow rate ________ gal/min, ft^3/min
29. Heat exchanger effectiveness ε_{Hw} ________
30. Storage volume ________ gal
31. Storage mass, $M_{St.}$ (line 30 x 8.34) ________ lb

Auxiliary Furnace/Boiler

32. Type ____
33. Manufacturer ____
34. Rated capacity ________ Btu/hr
35. Auxiliary energy source ________

Auxiliary DHW Unit

36. Size ________ gal
37. Auxiliary energy source ________
38. Hot water set temperature ________ °F

Worksheet B
LIQUID SYSTEMS

HEATING AND/OR DOMESTIC HOT WATER LOAD, L

Project ____________________

____

	1	2		3	4	5	6	7
Month	Monthly Degree Days DD °F·days	Monthly Space Htg Load Q_s Btu/Mo.	No. of Days/ Mo. N	Vol. of DHW Used/Mo. Gal./Mo.	Temp. Water Main Sup T_m °F	DHW Temp. Rise $T_{HW}-T_m$ °F	Monthly DHW Load Q_w Btu/Mo.	Total Heating Load L Btu/Mo.
Jan.			31					
Feb.			28					
March			31					
April			30					
May			31					
June			30					
July			31					
Aug.			31					
Sept.			30					
Oct.			31					
Nov.			30					
Dec.			31					
						Total		

1. From Table 3-2 or Figures 3-2 through 3-13
2. Q_s = (24)(UA)(Degree Day)
3. (Vol/day)x(no. days/mo.) = ________________(gal./day)x(no. days/mo.)
4. From Table 8-3 for selected cities
6. Q_w = (vol. of water) x 8.34 x 1 x $(T_{HW}-T_m)$.
7. $L = Q_s + Q_w$

Q_d = ____________________Btu/h

(Given data or calculate as in Module 3)

DTD = 70 - T_o

= 70 - ____ =

Where: T_o = 99% winter design temperature.

(From ASHRAE Fundamentals, or Table 3-2)

70°F = indoor design

$UA = \frac{Q_d}{DTD} =$

T_{HW} = ____________________

TOTAL MONTHLY SOLAR RADIATION AVAILABLE, S

Project____

Location____

Collector Tilt____

Nearest Data Site______________________________________

	1	2	3
Month	Monthly Avg. Daily Rad. on Tilt Surf. $\bar{I}_T$ Btu/(Day·ft^2)	No. of Days in month N	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo·ft^2)
Jan.		31	
Feb.		28	
March		31	
April		30	
May		31	
June		30	
July		31	
Aug.		31	
Sept.		30	
Oct.		31	
Nov.		30	
Dec.		31	

[1] From Table 5-5 for Colorado cities

[3] Column [1] x Column [2]

Worksheet D
Sheet 1 of 2
LIQUID SYSTEMS

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

PROJECT ____________________________

Collector Efficiency Data from Worksheet A (lines 10(a), (b))

1. Intercept, $F_R(\tau\alpha)_n$ = ______________
2. Slope, F_RU_L = ______________

Reference Temperature Basis: 1. t_{in}, 2. $\frac{t_{in} + t_{out}}{2}$, 3. t_{out}

3. Collector area, A_c = ______________ ft²
4. Collector volumetric flow rate (Worksheet A, 11(d))

______________ gal/min or ft³/min

Correction to t_{in} basis

5. Case 1: (no correction) $F_R(\tau\alpha)_n$ = __________

$F_R\ U_L$ = __________

6. Case 2: $$F_R(\tau\alpha)_n = F_R\ \tau\alpha \times \left[\frac{1}{1 + \frac{F_RU_L\ A_c}{2\ C_c}}\right] =$$ ______________

$$F_RU_L = F_RU_L \times \left[\frac{1}{1 + \frac{F_RU_L\ A_c}{2\ C_c}}\right] =$$ ______________

$$C_c = \dot{m}c_p = \left(\substack{\text{volumetric}\\ \text{flow rate}}\right)(\text{density})\left(\substack{\text{time}\\ \text{conversion}}\right)\left(\substack{\text{specific}\\ \text{heat}}\right)$$

= __________________ = __________________

where: for liquids, density - (8.34 lb/gal) x
(specific gravity) for air, density = 0.075 lb/ft³
at 70° and 1 atm. specific heat = 0.24 Btu/lb·°F

7. Case 3: $$F_R(\tau\alpha)_n = F_R(\tau\alpha)_n \times \left[\frac{1}{1 + \frac{F_RU_L\ A_c}{C_c}}\right] =$$ ______________

$$F_RU_L = F_RU_L \times \left[\frac{1}{1 + \frac{F_RU_L\ A_c}{C_c}}\right] =$$ ______________

8. Incident Angle Modifier, $\frac{F_R(\overline{\tau\alpha})}{F_R(\tau\alpha)_n} = \begin{cases} .91, \text{ for two cover plates} \\ .93, \text{ for one cover plate} \end{cases}$

Worksheet D
Sheet 2 of 2
LIQUID SYSTEMS

Collector Loop Heat Exchanger Modifier, $\frac{F_R'}{F_R}$

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

Capacitance Rate:

10. C_c = (from line 6) = ______________ Btu/(hr·°F)

11. C_s = (calc. as for C_c above) = ______________ Btu/(hr·°F)

12. C_{min} = (lesser of C_c of C_s) = ______________ Btu/(hr·°F)

13. Collector Storage Heat Exchanger Effectiveness, ε_{cs} = _______

14. $x = \frac{C_c}{\varepsilon_{cs}\,C_{min}}$ = ______________________________ = _______
(from Worksheet A, line 22)

15. $y = \frac{A_c(F_R U_L)}{C_c}$ = ______________________________ = _______

16. $\frac{F_R'}{F_R}$ = from Figure 9-7 or = $\frac{1}{1 + y(x-1)}$ = ____________________

17. $F_R'(\overline{\tau\alpha}) = F_R(\tau\alpha)_n \times \frac{(\overline{\tau\alpha})}{(\tau\alpha)_n} \times \frac{F_R'}{F_R}$ = ____________________

18. $F_R'U_L = F_R U_L \times \frac{F_R'}{F_R}$ = ____________________

CORRECTION FACTORS, K_2, K_4

PROJECT ____________________

Storage Mass Capacitance Factor K_2

Note: M includes hot water sotrage volume where it is solar heated

1. gals/ft^2 of collector ____________________

2. K_2 = (from Figure 9-8) = ____________________

Load Heat Exchange Factor, K_4

3. ε_L (from Worksheet A, line 26) = ____________________

4. $C_{\text{hot water supply loop}} = \dot{m}c_p = C_H$
(from Worksheet A, lines 24 x 8.25 x 60) =
____________ Btu/(hr·ft^2)

5. $C_{\text{air loop}} = \dot{m}c_p = C_A$
(from Worksheet A, line 25 x 0.075 x .24 x 60) =
____________ Btu/(hr·ft^2)

6. C_{min} = smaller of C_H or C_A = ____________ Btu/(hr·ft^2)

7. (UA) bldg = (from Worksheet A, or B) =
____________ Btu/(hr·°F)

8. $\dfrac{\varepsilon_L \; C_{min}}{UA} =$ ____________________

9. K_4 = (from Figure 9-9) = ____________________

Worksheet F
LIQUID SYSTEMS

SYSTEM PERFORMANCE PARAMETERS X, Y

PROJECT_______________

	1	2	3	4	5	6	7	8
Month	Tot. Monthly Radiation on Tilt Surf. S Btu/(Mo·ft^2)	Total Heating Load L Btu/Mo.	S/L	Y $F_1\cdot[3]$	Mo. Av. Temp. $\overline{T}_a$ °F	$212-\overline{T}_a$ °F	Tot. Hrs in Mo. Δ time hr.	X
Jan.							744	
Feb.							672	
March							744	
April							720	
May							744	
June							720	
July							744	
Aug.							744	
Sept.							720	
Oct.							744	
Nov.							720	
Dec.							744	

1. From Worksheet C, Col. 3
2. From Worksheet B, Col. 7
4. $Y = \frac{A_c F_R'(\overline{\tau\alpha})S}{L} \times K_4 = F_1 \cdot \frac{S}{L}$
5. From Table 5-5
8. $X = \frac{A_c F_R' U_L (T_{ref} - T_a)\Delta time}{L} \times K_2$

$= F_2 \cdot \underbrace{\{[6]\cdot[7]\} \div [2]}_{\text{columns}}$

A_c = __________ ft^2
$F_R' \overline{\tau\alpha}$ = __________ (Wksht D)
$F_R' U_L$ = __________ (Wksht D)
K_1 = __________ (Wksht E)
K_2 = __________ (Wksht E)
K_4 = __________ (Wksht E)
$F_1 = A_c F_R' \overline{\tau\alpha} K_4$ = __________
$F_2 = A_c F_R' U_L K_2$ = __________

Worksheet G
LIQUID SYSTEMS

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

PROJECT ____________________

COLLECTOR AREA ____ ft^2

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

$L_{tot} =$

$E_{tot} =$

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

1. From Worksheet B
2. From Worksheet F, Column 9
3. From Worksheet F, Column 4
4. From "f chart", Figure 9-6
5. E = f x L

SOLAR SYSTEM DATA

Building Owner____

Address_________________________________Ph.__________

Contractor_______________________________Ph.__________

Type of System (liquid, air, H/DHW, DWH) ______________________

Site and Building Data

1. Location: Nearest City________________ Latitude______
2. Building UA________________________Btu/(hr•°F)
3. DHW volume per day____________________gallons/day

Collector Data

4. Collector manufacturer_________________
5. Collector Area, A_c = __________________ft^2
6. Collector efficiency data from manufacturer's information:
   (a) $F_R(\tau\alpha)$ ______________
   (b) $F_R U_L$ ______________Btu/(hr•ft^2•°F)
7. Correction for fluid temperature basis
   (a) Case 1: (no correction)
      (i) $F_R(\tau\alpha)_n = F_R\tau\alpha$ (from line 6) ______
      (ii) $F_R U_L = F_R U_L$ (from line 6) ______ Btu/(hr•ft^2•°F)
   (b) Case 2: $\frac{T_{in} + T_{out}}{2}$ (correction needed)

$$C_c = (\dot{m}c_p)_c = \left(\begin{matrix}\text{Vol flow}\\ \text{rate}\end{matrix}\right)(\text{density})\left(\begin{matrix}\text{time}\\ \text{conversion}\end{matrix}\right)\left(\begin{matrix}\text{specific}\\ \text{heat}\end{matrix}\right)$$

$$= \_\_\_\_ \frac{\text{gal}}{\text{min}} \times \_\_\_\_ \frac{\text{lb}}{\text{gal}} \times 60\ \frac{\text{min}}{\text{hr}} \times \_\_\_\_ \frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}$$

_______Btu/(hr•°F)

Correction Factor = $\left[\frac{1}{1 + \frac{F_R U_L A_c}{2C_c}}\right]$ = ____________________

(i) $F_R(\tau\alpha)_n = F_R\tau\alpha$(from line 6a) x (correction factor)

= __________________ x ________ = ________

(ii) $F_R U_L$ = $F_R U_L$(from line 6b) x (correction factor)

= __________________ x ________ = ________ Btu/(hr·ft^2·°F)

(c) Case 2: T_{out}(correction needed)

Correction Factor = $\frac{1}{1 + \frac{F_R U_L A_c}{C_c}}$ = __________

(i) $F_R(\tau\alpha)_n = F_R(\tau\alpha)$(from line 6a) x (correction factor)

= __________ x __________ = __________

(ii) $F_R U_L$(from line 6b) x (correction factor)

= __________ x __________ = __________Btu/(hr·ft^2·°F)

Heat Exchanger Factor (F_R'/F_R)

8. For air collectors $F_R'/F_R = 1$

9. For liquid collectors

(a) C_c(from line 7b) = ________ Btu/(hr·°F)

(b) C_s = ____ x 8.34 x 60 x 1 = ________ Btu/(hr·°F)

(c) Heat exchanger effectiveness = ________

(d) $x = \frac{C_c}{\varepsilon_{cs} C_{min}}$ = $\frac{\rule{6em}{0.4pt}}{(\quad\quad)(\quad\quad)}$ = _______

(e) $y = \frac{A_c F_R U_L}{C_c}$ = $\frac{(\quad\quad)(\quad\quad)}{\rule{6em}{0.4pt}}$ = ________

(f) $F_R'/F_R = \frac{1}{1 + y(x-1)}$ = ________

Corrections to Collector Parameters

10. Incident angle modifier

(a) $F_R(\overline{\tau\alpha}) = F_R(\tau\alpha)_n$ x 0.91 (for two cover plates)

$= \underline{\qquad\quad} \times 0.91 = \underline{\qquad\quad}$

(b) $F_R(\overline{\tau\alpha}) = F_R(\tau\alpha)_n$ x 0.93 (for one cover plate)

$= \underline{\qquad\quad} \times 0.93 = \underline{\qquad\quad}$

11. (a) $$F_R'\overline{\tau\alpha} = \frac{\qquad\qquad}{\text{line 10a or 10b}} \times \frac{\qquad\qquad}{\text{line 8 or 9f}} = \underline{\qquad\quad}$$

(b) $$F_R'U_L = \frac{\qquad\qquad}{\begin{array}{l}\text{line 7a(ii)}\\ \text{or}\quad \text{7b(ii)}\\ \text{or}\quad \text{7c(ii)}\end{array}} \times \frac{\qquad\qquad}{\text{line 8 or 9f}} = \underline{\qquad\quad}\ \text{Btu/(hr}\cdot{}^\circ\text{F)}$$

List c_1, c_2, A_S, A_D, Z from Table 11-5

12. A_S or $A_D = \underline{\qquad}$ $\quad Z = \underline{\qquad}$ $\quad c_1 = \underline{\qquad}$ $\quad c_2 = \underline{\qquad}$

For Solar Heating and DHW Systems:

13. $$A_{50} = \frac{A_S(UA)_L}{F_R'\overline{\tau\alpha} - F_R'U_L(Z)}$$

$$A_{50} = \frac{(\qquad)\quad(\qquad)}{(\qquad) - (\qquad)(\qquad)} = \underline{\qquad}\ \text{ft}^2$$

14. $A_c/A_{50} = \underline{\qquad\qquad} = \underline{\qquad\qquad\qquad}$

15. $\log_e(A_c/A_{50}) = \underline{\qquad\qquad\qquad}$

16. $F = c_1 + c_2 \log_e(A/A_{50})$

$= \underline{\qquad} + \underline{(\qquad)(\qquad)} = \underline{\qquad}$

17. $A_c/A_{50} = 300/259 = 1.16$

18. $\text{Log}_e(A_c/A_{50}) = 0.15$

19. $F = \underline{\qquad} + (\qquad)(\qquad) = \underline{\qquad}$