Air Heating Systems

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

MODULE 8

AIR-HEATING SYSTEMS

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INTRODUCTION

Components of a solar heating system must be compatibly sized and carefully assembled in order to ensure that the system will function properly. Collectors, heat storage units, blowers, controls and the heat exchanger for domestic water heating must be compatible. Generally, the collector area is decided first, and from the collector area storage volume is then selected. The air flow rate through the collector is selected to be within a nominal range and blower size can then be decided. The air delivery rate to the rooms is based upon the size of the house, and the size of the auxiliary furnace is determined from the building heating load. Selection of the types and locations of dampers in the solar system is particularly important. If attention is not given to details in system layout and during assembly, the system may not perform as expected, even if the best available components in the market are selected.

OBJECTIVE

The objective of this module is to describe the relationships between the components of an air heating system. The participants of this workshop should be able to:

1. Develop schematic and working plans for air heating solar systems;
2. Select and specify the components of a solar air-heating system;
3. Describe the different modes of operation of a solar air-heating system;

4. Determine the size of the system components;
5. Estimate the fraction of annual load that the solar system is expected to supply.

SYSTEM ARRANGEMENTS

DOUBLE BLOWER DESIGN

A schematic design of a two-blower air-heating solar system for both space and domestic water heating is shown in Figure 8-1 and comprises six principal components; solar collector, heat storage unit, air handler, auxiliary heater, two water heating coils and a controller (not shown). One water heating coil is used for winter operation and the

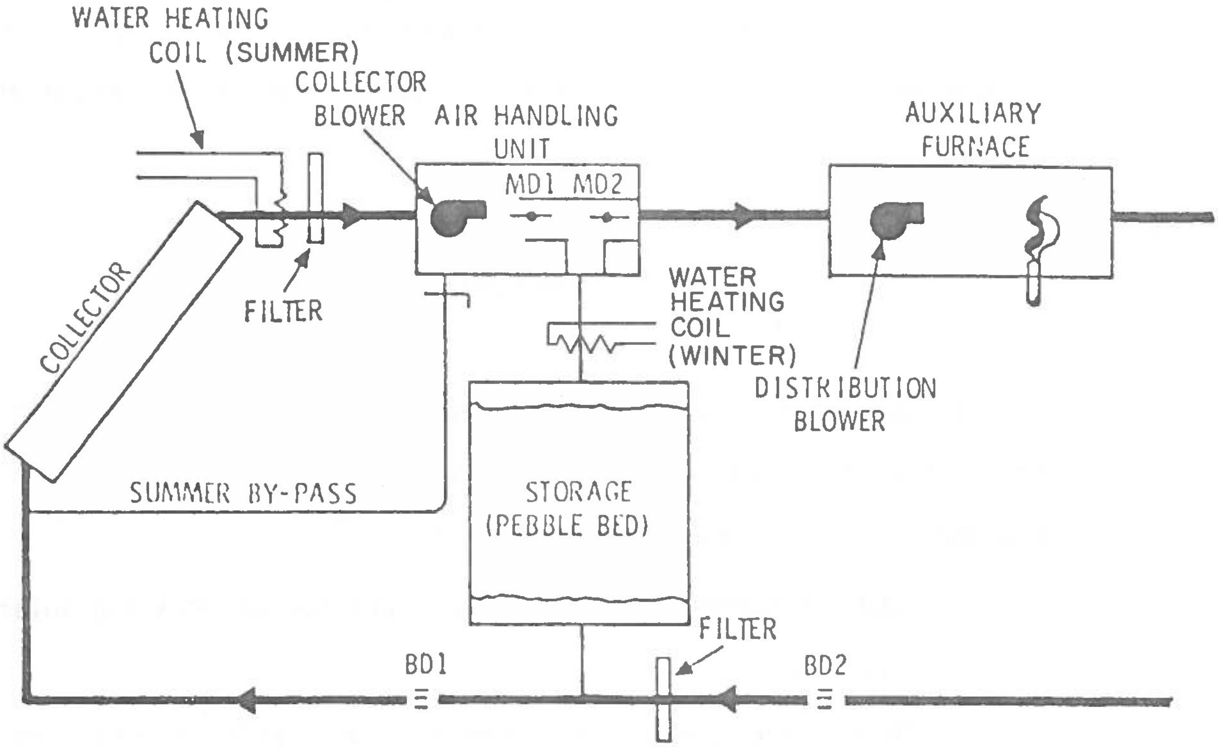

Figure 8-1. Heating Building Directly from Collectors

other for summer operation. By combining the blower and dampers in an "air handler", installation and operation of the system can be simplified. The control sequences to operate the system in all modes are detailed in a "truth table" (Table 8-1). The operating modes are shown in Figures 8-1 through 8-4. In the table and figures the abbreviations, MD, denotes a motorized damper and BD, a back draft damper.

Table 8-1

Control Truth Table for a Two-Blower, Air-Heating Solar System Operation

Mode	MD 1	MD 2	BD 1	BD 2	Collector Blower	Distribution Blower
Room Heating from Collector (Figure 8-1)	Open	Open	Open	Open	On	On
Heating Storage (Figure 8-2)	Open	Closed	Open	Closed	On	Off
Room Heating from Storage (Figure 8-3)	Closed	Open	Closed	Open	Off	On
Heating from Auxiliary (Figure 8-3)	Closed	Open	Closed (auxiliary on)	Open	Off	On
Preheating water from Coil No. 1 (Figure 8-2)	Open	Closed	Open	Closed	On	On or Off (water pump) on)
Preheating Water from Coil No. 2 (Figure 8-4)	Closed	Closed	Closed	Closed	On	Off

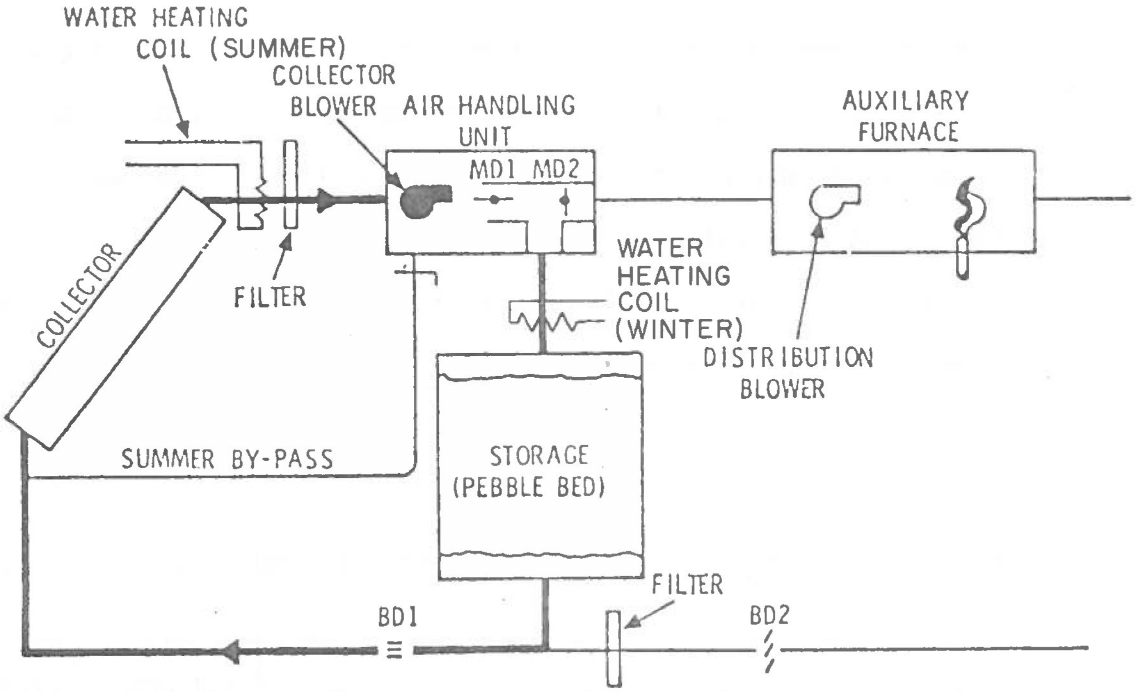

Figure 8-2. Storing Heat from Collectors

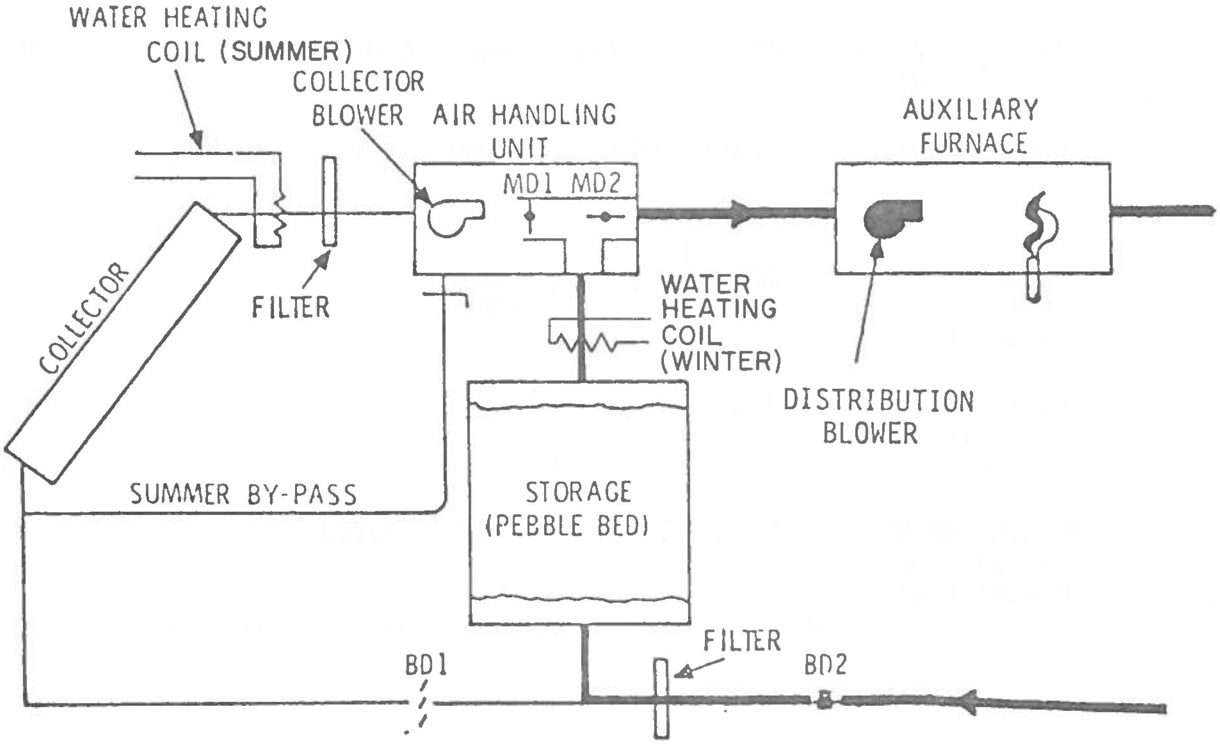

Figure 8-3. Heating Building from Storage Unit (Also Heating from Auxiliary)

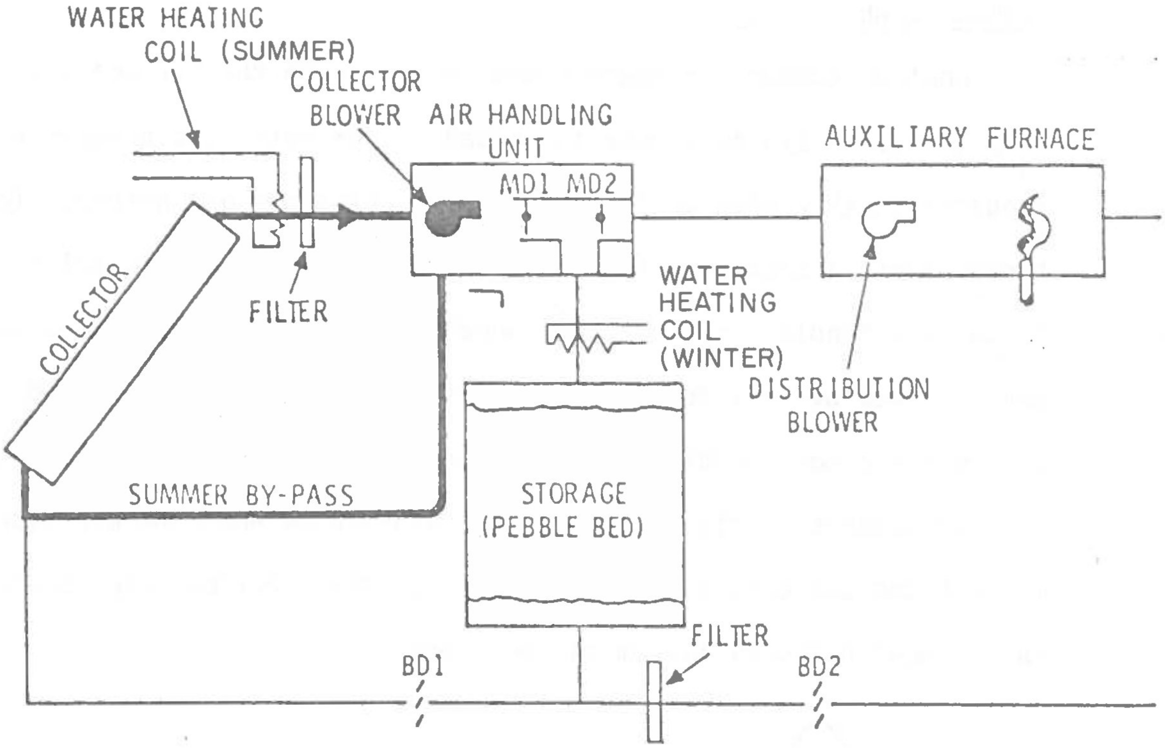

Figure 8-4. Service Hot Water Heating (Summer Operation)

So that the domestic hot water supply can be solar heated in the summer when no space heating is needed, the heat storage unit and heated space can be by-passed as shown in Figure 8-4. A manual damper is opened in the by-pass duct so that air is circulated in a closed loop between collector, water heating coil, and the collector blower. Dampers MD 1 and MD 2 in closed positions prevent flow of hot air to storage or the rooms.

Most commercially available warm-air furnaces for residential use contain a blower for circulation of warm air through the building via the distribution ducts. In a typical all-air solar installation, the furnace blower is used in the normal manner for distributing warm air, supplied either from the collectors or from storage. The solar system blower operates only when air is circulated through the collector.

SINGLE BLOWER DESIGN

Another damper arrangement does not require the furnace blower, so only the solar system blower is needed. Four motorized dampers are required (rather than two), but only two actuators are needed. This system type is shown in Figure 8-5, with the blower and motorized dampers in an "air handler" cabinet. Although the cost of a blower and motor can be saved by this design, two additional dampers are required, the controls are more complicated, and airflow rates in the several modes are less adjustable. This arrangement is applicable when the air flow rate through the collectors is nearly equal to the air flow rate required in the heat delivery system to the rooms.

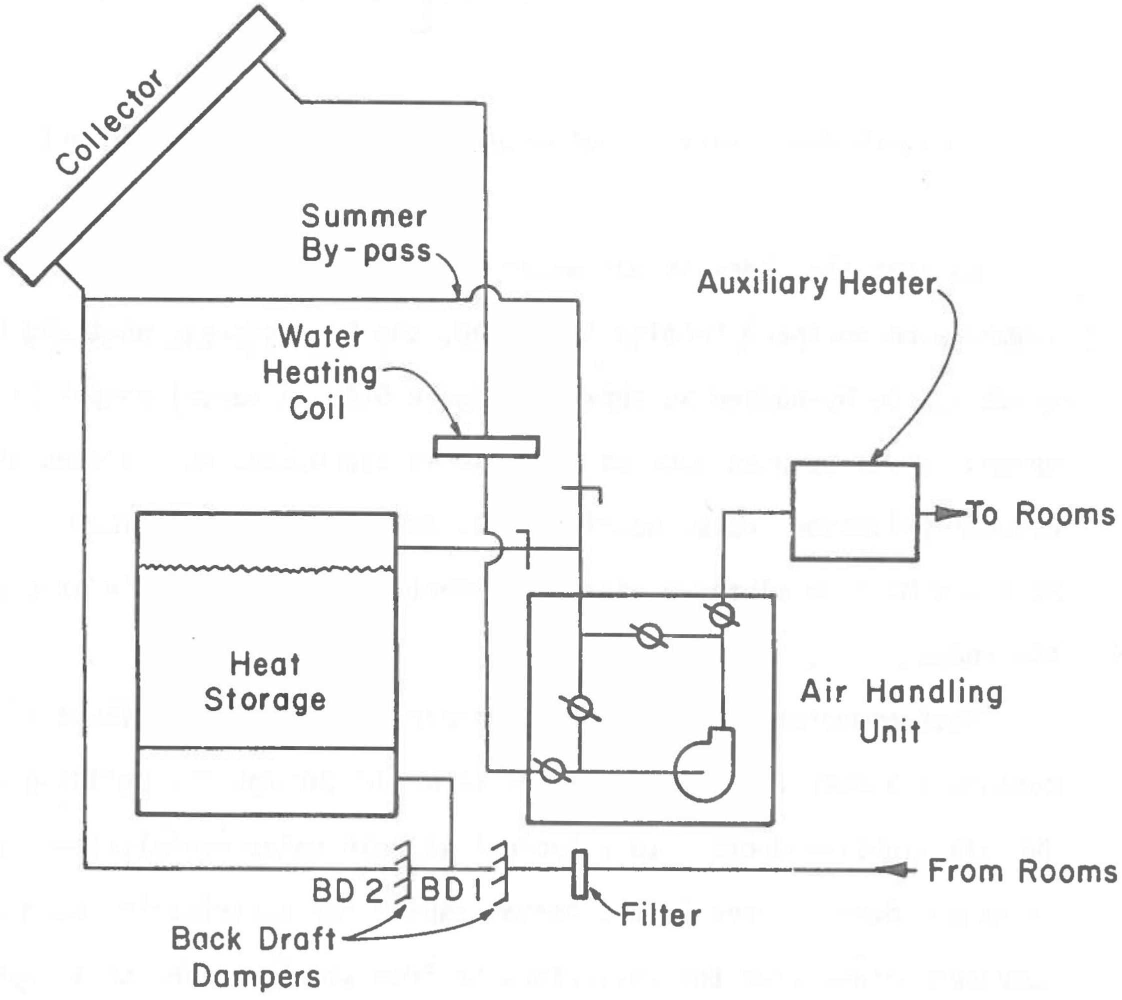

Figure 8-5. Single Blower System

COMPONENTS AND INSTALLATION

Important operating considerations in the air-type system are blower power requirements and air leakage. A well-designed air system has approximately equal pressure loss through the collectors and pebble-bed, typically about 0.3 inch water gauge in each unit. With ducting and filters, the total system pressure drop can approach one inch of water which is about twice that usually encountered in a conventional forced air distribution system, so additional blower power is required to operate the solar system. Typical requirement in a conventional system is one-half to three-fourths horsepower for a 1500 cfm system. In a double blower system the collector blower motor should be three-fourths or one horsepower depending on collector area, and the distribution blower motor is of conventional size. In a one blower system a one horsepower motor will generally be required. The blowers also operate for longer periods than in the conventional system because of their use both for solar heat collection and for heat distribution. A one-inch water gauge pressure loss is about the maximum acceptable from the standpoint of blower power cost.

Leakage of air in ducts, collectors, and storage is of greater concern in a solar heating system than in a conventional system because the pressure is higher, there is more ducting, the system operates for longer periods, and there may be more ducting through unheated space. Ducts should therefore be carefully inspected during installation and all joints should be sealed with a silicone sealing compound if sheet metal ducts are used. Ducts made of fiberglass board should be taped carefully at all corners and joints. Insulation is needed to reduce heat loss through the duct walls, particularly in unheated spaces such as attics. At least one inch of fiberglass with a rating of R-4 is recommended for duct insulation, with two inches for ducts in unheated spaces.

It is especially important with a solar air system that a well scheduled installation be made. More space and access must be provided in the building for ducting than for pipes in a liquid system. Ductwork and component assembly can be done at the same time that the distribution ducts and furnace are installed in a typical construction schedule. There must be provision for construction and installation space and for full access to the space for systems and components.

If fiberglass ductboard is used for the air duct, it should not be in locations where it can be damaged by moving objects or occupants. Joints should be well sealed with tapes or mastics recommended by the industry. Duct bends should be provided with turning vanes to reduce losses. Ducts should be sized for air velocities between 600 and 800 feet per minute.

Blowers, dampers, and auxiliary heaters may be provided by a single solar system supplier or they may be purchased separately. If separately purchased, blowers should be forward-curved squirrel cage type and preferably belt-driven to enable adjustments in air-flow rates. Direct coupled blowers with motors in the air stream may be used and have the advantage of quieter operation but a disadvantage is that no adjustment can be made so that initial sizing is important. Flexible connections between blowers and ducts are recommended.

Louver-type dampers with neoprene or live silicon rubber seals are recommended for positive shutoff and smooth stroking. Damper drive motors should be located on the outside of ducts and direct coupled to the damper shaft or through linkages. Special attention should be given to linkages during installation to assure tight damper closure. Damper pairs may be operated by the same drive motor such that one is closed when the other is open. Damper motors are available which operate on low voltage (24 volt) and have spring returns.

Back draft dampers, used in ducts to prevent reverse flow, may be of the flexible flat type or shutter type. They must be mounted to provide a positive seal against reverse airflow.

To prevent fouling and increased pressure loss in the pebble-bed, filters should be installed in the air streams entering both ends of the storage unit. The filters should be changed or cleaned every few weeks during the first several months of operation to remove the initial dust in the system and building.

Provision for supply of domestic hot water can be easily made in the air system by the use of an air-to-water heat exchanger in the hot air duct between the blower and storage unit. The particular location is chosen to prevent freezing during winter operation. The heat exchanger coil is a finned type, with one or two rows of tubes. A small pump circulates water from the bottom of an insulated tank (usually about 80-gallon capacity), through the coil, and back to the top of the tank. The cold water enters the solar-heated tank and warm water flows to a conventional automatic water heater whenever a hot water faucet is opened in the building. During the summer, an alternate heat exchanger coil located between the collector and blower is used. A duct by-pass, as shown in Figure 8-4 permits operation of the service hot water coil without heating the pebble-bed. The water line to the summer heating coil should be purged when winter operation begins. A thermostatic mixing value can be installed in the line connected to the service hot water tank from the cold water main to prevent delivery of scalding hot water.

The complete solar heating installation will require heating and sheet metal workers to install collectors, ducts, dampers, and the conventional system, electricians to wire blowers and dampers, plumbers to connect the domestic water heating system, and carpenters or masonry workers to construct the pebble-bed container. Consequently, the general contractor and the solar system contractor should coordinate their activities so that each task is accomplished at the most appropriate and convenient stage during construction. Quality installation is an important requirement to obtain a high performance air-heating solar system.

SYSTEM SIZING

Solar heating systems are sized to provide a desired fraction of the total annual heating load of the building. The desired fraction of heating load can be chosen arbitrarily, or determined from economic analysis, so that the annual heating cost of the solar-auxiliary system is minimized. The collector area is the main component to be determined and from the collector area the storage size is selected. The size of the auxiliary furnace is based upon the design heating load and desired heat delivery rate. The blowers and duct sizes depend primarily upon collector area and heat delivery rate.

There are various methods for determining the fraction of annual heating load supplied by solar systems, varying from detailed hour-by-hour computer simulations to rules of thumb. There are two methods described in this module, one is the "f-chart" method developed by Klein, Beckman and Duffie at the University of Wisconsin, and the other is the "relative-areas" method introduced by Barley and Winn at Colorado State University. The f-chart method is based on hour by hour simulations of performance for typical solar heating systems covering a wide range of system parameters at several geographic locations. Generalized correlation charts (f-charts) for predicting average solar fraction of the monthly heating load were developed. There is one chart which applies to a liquid-heating system and another for an air-heating system.

The relative areas method requires tabulated values of 4 constants and a simple equation to determine the annual solar fraction directly. The tabulated values are based on the results of computerized f-chart calculations.

RULES OF THUMB

Rules of thumb have been suggested for relative sizing of components for solar systems based upon computer designs, experiments and several years of practical experience. They are presented in Table 8-2 and are to be used only as general guides in selecting component sizes. Collector area is not listed in the table because there is considerable freedom to choose areas arbitrarily. For a selected collector area, other components of the system may be established and the total system can be tested by one of the performance prediction methods.

Table 8-2

Rules of Thumb for Air System Component Sizing

Collector slope	Latitude +15°
Collector airflow rate	1.5 to 2.5 cfm/ft^2 of collector
Pebble-bed storage size	1/2 to 1 ft^3 of rock/ft^2 of collector
Rock depth	4 to 8 feet in airflow direction
Pebble size	3/4" to 1-1/2" washed and screened concrete aggregate
Duct insulation	1"-2" fiberglass
Pressure drops:	
Pebble-bed	0.1 to 0.3" W.G.
Collector (12-14 ft lengths)	0.2 to 0.3" W.G.
Collector (18-20 ft lengths)	0.3 to 0.5" W.G.
Ductwork	~0.08" W.G./100 ft duct length

THE f-CHART METHOD

Basic Approach

The procedure for calculating the long-term performance of solar heating and/or domestic hot water systems is applicable for liquid- and air-based systems. Performance of the system is characterized by the fraction of the monthly space and water heating load, f, provided by the solar system.

The f-chart for air-based systems is given in Figure 8-6. The coordinate axes X and Y characterize collector performance in relationship to the heating load for a specific month. In the tradition of labeling graphs, X is the abscissa (horizontal axis) and Y is the

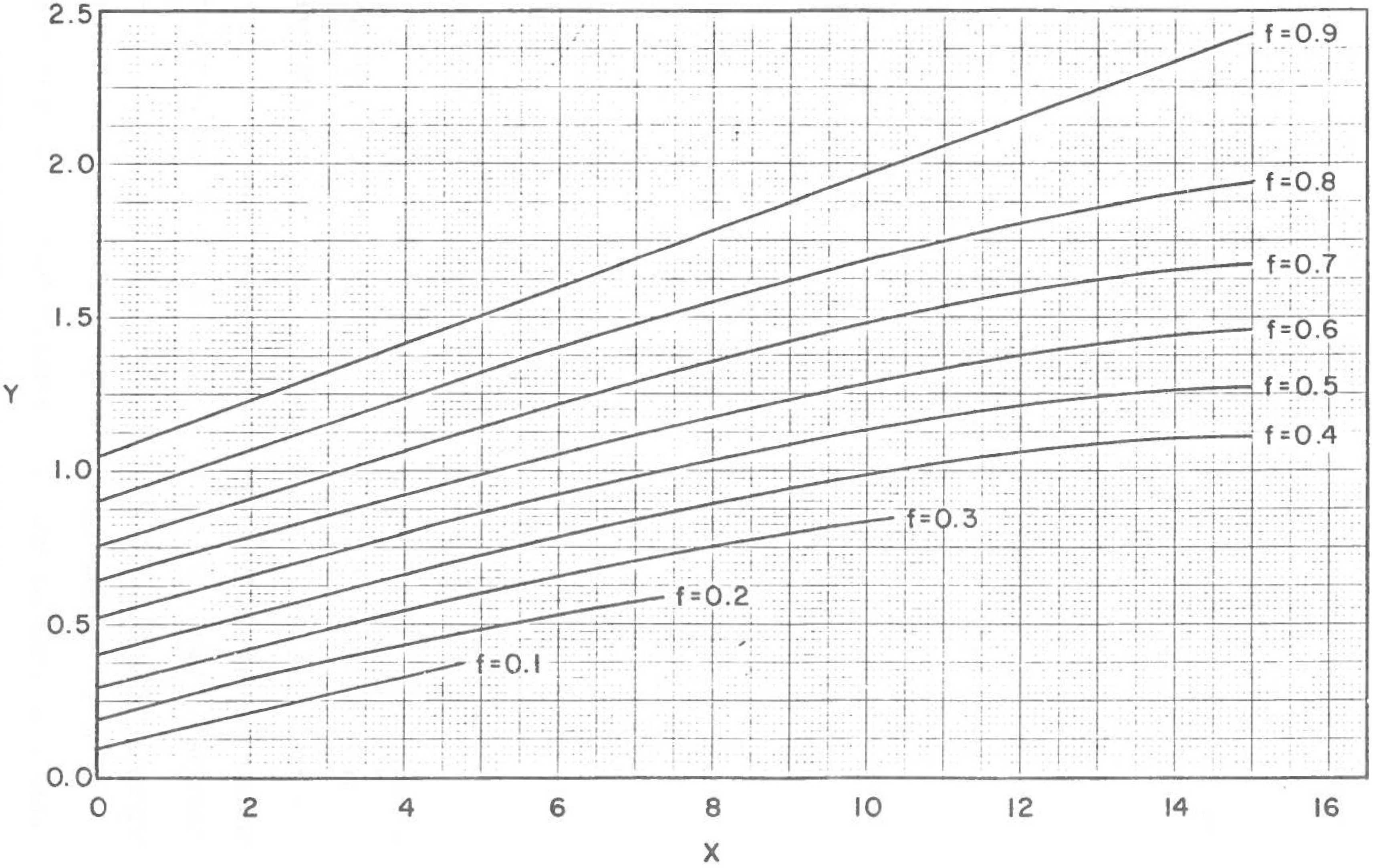

Figure 8-6. f-Chart for Solar Air Heating Systems

ordinate (vertical axis). In particular,

$$X = \frac{\text{collector losses}}{\text{monthly heating load}} = \frac{A_c\ F_R U_L\ (T_{ref} - T_a)\ \Delta t}{L} \tag{8-1}$$

and

$$Y = \frac{\text{collector heat gain}}{\text{monthly heating load}} = \frac{A_c\ F_R\ \overline{\tau\alpha}\ S}{L} \tag{8-2}$$

Both X and Y are dimensionless

In Equations (8-1) and (8-2)

A_c	is the total collector area, ft^2
$F_R U_L$	is the slope of the collector efficiency curve, $Btu/(hr \cdot ft^2 \cdot {}^\circ F)$
$F_R\ \overline{\tau\alpha}$	is the intercept on the collector efficiency curve, corrected for effective value throughout a day, dimensionless
T_{ref}	is 212°F
T_a	is the average ambient (air) temperature for a specific month, °F
Δt	is the number of hours for a specific month, hr/mo
L	is the monthly space and water heating load, Btu/mo
S	is the average monthly solar radiation on a tilted collector per unit area, $Btu/(ft^2 \cdot mo)$

The area is chosen arbitrarily, $F_R U_L$ and $F_R\ \overline{\tau\alpha}$ are determined for a specific collector from performance curves, and T_a for specific cities are given in Table 5-5 (for Colorado cities). The monthly heating load, L is the sum of the DHW and space heating load, and S is determined from the monthly average daily solar radiation on a tilted surface (as described in Module 5), multiplied by the number of days in the month.

Correction for Collector Air Flow Rate (K_1)

In an air system, collector efficiencies are sensitive to airflow rates through the collector and correction factors are appropriate if the air flow rate is different from the collector manufacturer's recommendation. The correction factor is applied to the X value as follows:

$$X\ (\text{new value}) = X\ (\text{from Eq. 8-1}) \cdot K_1 \qquad (8\text{-}3)$$

where K_1 is determined from Figure 8-7.

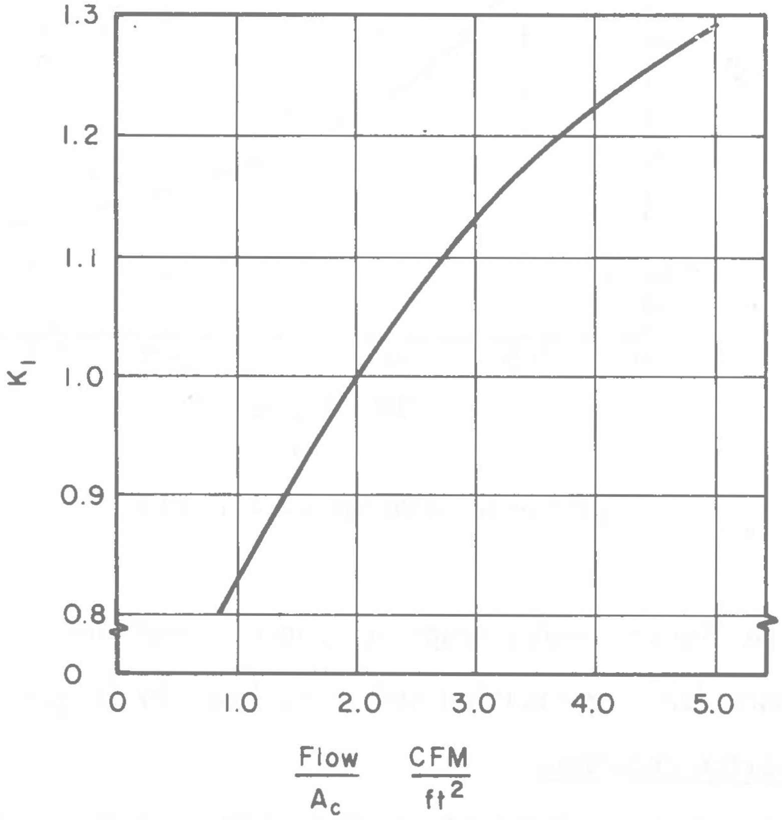

Figure 8-7. Collector Flow Factor (Air), K_1

<u>Correction for Storage Size (K_2)</u>

The nominal storage capacity is assumed to be 0.75 ft^3 of pebbles per square foot of collector for an air system. When storage size differs from this value, the system performance is affected. The correction is made to the X value in the following way:

$$X\ (\text{corrected value}) = X\ (\text{from Eq. 8-1 or 8-3}) \cdot K_2 \qquad (8\text{-}4)$$

where K_2 is determined from Figure 8-8.

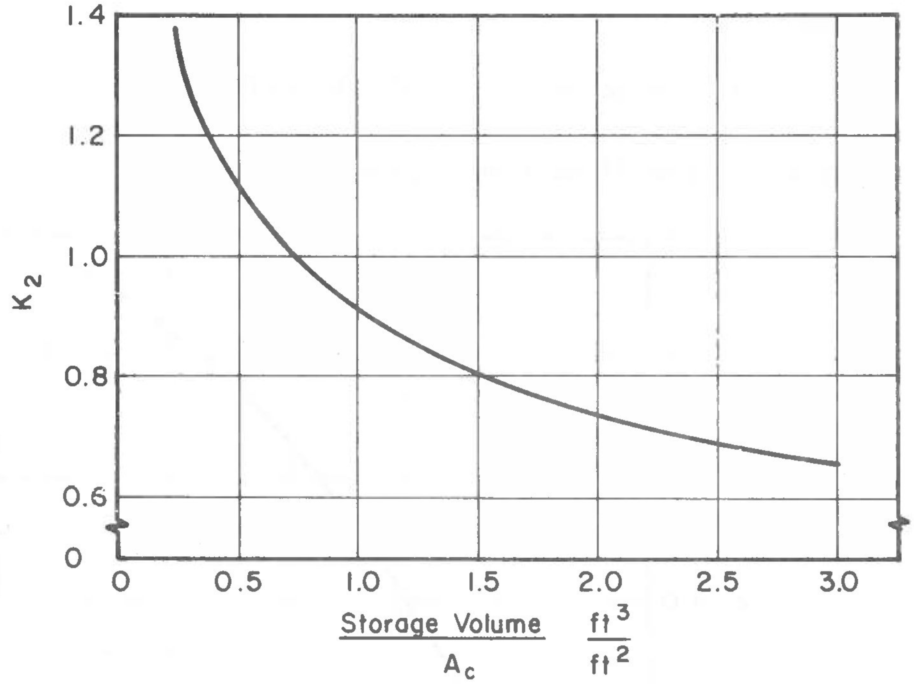

Figure 8-8. Storage Capacitance Factor, K_2

The f-chart method described above is outlined in a step-by-step procedure for clarification and is followed by an example calculation.

Calculation Procedure

The space and DHW heating loads must be known or determined before beginning an f-chart performance analysis of a solar system. It is helpful to use the worksheets included in this module to organize the computations necessary in the f-chart procedure.

Step 1. List the data for the solar system by completing Work-Sheet A. Use available data from blueprints, specifications, inspections and handbooks. A heat load analysis for the building (using techniques of Module 3) is required. A summary table useful for calculating monthly heating loads is given in worksheet B.

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 temepratures,

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

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

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

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

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.

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

EXAMPLE 8-1

Design a solar heating and hot water system for the sample home of Module 3 located in Denver, Colorado. We will assume the house has been weatherized to Level 3 (defined in Module 3).

The heat loss calculations for the building have been made, and the overall UA (heat conductance) is 276 Btu/(hr·°F). Using the time conversion from hour to day, the heating and domestic hot water load for the building is 9,415 Btu/DD. Complete Worksheets A through G.

Answer. For collector area of 200 ft², the air-heating system will provide 74 percent of the total annual space and DHW heating load.

(Text continues on page 8-27)

Worksheet A
Sheet 1 of 2
AIR SYSTEMS

SOLAR SYSTEM DATA

Building Owner Mr + Mrs John Sunbody

Address Denver, Colorado Ph. 482-0000

Contractor Solar Construction Co. Ph. 482-0001

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

Site and Building Data

1. Location: Nearest City Denver Latitude 39.5° N
2. Building UA 276 Btu/(hr•°F)
3. DHW volume per day 80 gallons/day
4. Collector manufacturer Solaron
5. Collector area 200 ft^2
6. Collector tilt 55 degrees
7. Tilt = latitude + 15 degrees
8. Collector orientation 0 degrees ____ from south
9. Collector shading 0 % in December
10. Collector efficiency data

    (a) $F_R(\tau\alpha)_n$ 0.69

    (b) $F_R U_L$ 0.80 Btu/(hr•ft²•°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: Air

(b) Flow rate G 600 ft³/min

Storage Data

12. Storage medium Pebble bed

13. Unit volume 1.0 ft³/ft²

14. Total volume (item 5 x 13) 200 ft³

Auxiliary Furnace/Boiler

Type Hot Air

Manufacturer Lennox

Rated Capacity 40,000 Btu/hr

Auxiliary energy source gas

Auxiliary DHW Unit

Size 40 gal

Auxiliary energy source gas

Hot water set temperature 140 °F

HEATING AND/OR DOMESTIC HOT WATER LOAD, L

Project Sunbody Residence

Denver

	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.	1132	X 10⁶ 7.5	31	2480	39	101	X 10⁶ 2.1	X10⁶ 9.6
Feb.	938	6.2	28	2240	40	100	1.9	8.1
March	887	5.9	31	2480	43	97	2.0	7.9
April	558	3.7	30	2400	49	91	1.8	5.5
May	288	1.9	31	2480	55	85	1.8	3.7
June	66	0.4	30	2400	60	80	1.6	2.0
July	6	0.04	31	2480	63	77	1.6	1.64
Aug.	9	0.06	31	2480	64	76	1.6	1.66
Sept.	117	0.8	30	2400	63	77	1.5	2.3
Oct.	428	2.8	31	2480	56	84	1.7	4.5
Nov.	819	5.4	30	2400	45	95	1.9	7.3
Dec.	1035	6.9	31	2480	37	103	2.1	9.0
	6283					Total	21	63.2

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

Q_d = 19,872 Btu/h

(Given data or calculate as in Module 3)

DTD = 70 - T_o
= 70 - (-2) = 72° F

Where: T_o = 99% winter design temperature.

(From ASHRAE Fundamentals, or Table 3-2)

70°F = indoor design temeperature

$UA = \frac{Q_d}{DTD} = 276 \frac{BTU}{Hr \cdot °F}$

T_{HW} = 140°

TOTAL MONTHLY SOLAR RADIATION AVAILABLE, S

Project Sunbody Residence

Location Denver

Collector Tilt Lat. + 15°

Nearest Data Site Denver

	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.	1975	31	61,225
Feb.	2057	28	57,596
March	2008	31	62,248
April	1816	30	54,480
May	1673	31	51,863
June	1710	30	51,300
July	1679	31	52,049
Aug.	1876	31	58,156
Sept.	2046	30	61,380
Oct.	2064	31	63,984
Nov.	1864	30	55,920
Dec.	1768	31	54,808

[1] From Table 5-5 for Colorado cities

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

Worksheet D
AIR SYSTEMS

COLLECTOR COMBINED PERFORMANCE CHARACTERISTICS, $F_R(\overline{\tau\alpha})$, F_RU_L

PROJECT Sunbody Residence

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

1. Intercept, $F_R(\tau\alpha)_n$ = 0.69

2. Slope, F_RU_L = 0,80

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

3. Collector area, A_c = 200 ft²

4. Collector volumetric flow rate (Worksheet A, 11(d))

600 ft³/min

Correction to t_{in} basis

5. Case 1: (no correction) $F_R(\tau\alpha)_n$ = 0.69

$F_R\,U_L$ = 0.80

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

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

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

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

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

Incident Angle Modifier, $\dfrac{F_R(\overline{\tau\alpha})}{F_R(\tau\alpha)_n} = \begin{cases} .91, & \text{for two cover plates} \\ .90, & \text{for one cover plate}\end{cases}$

8. $F_R(\overline{\tau\alpha})$ = 0.69 x 0.91 = 0.63

CORRECTION FACTORS, K_1, K_2

PROJECT Sun body Residence

Collector Flow Factor, K_1

1. Air Flow Rate (Worksheet A, line 11(b)) = 600 cfm
2. A_c (from Worksheet A, line 5) = 200 ft^2
3. $\frac{\text{Air Flow Rate}}{A_c}$ = 3 cfm/ft^2
4. K_1 = (from Figure 8-7) = 1.1

Storage Mass Capacitance Factor K_2

5. Unit Volume (Worksheet A, line 13) = 1.0 ft^3/ft^2
6. K_2 = (from Figure 8-8) = 0.92

SYSTEM PERFORMANCE PARAMETERS X, Y

PROJECT Sunbody House
LOCATION Denver Lat = 39.4°

	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.	61,225	x 10⁶ 9.6	.00638	0.81	182	182	744	2.29
Feb.	51,596	8.1	.00711	0.89	180	180	672	2.42
March	62,248	7.9	.00788	0.99	175	175	744	2.67
April	54,480	5.5	.00991	1.25	164	164	720	3.48
May	51,863	3.7	.01402	1.77	155	155	744	5.05
June	51,300	2.0	.02565	3.23	146	146	720	8.51
July	52,049	1.64	.03174	4.00	139	139	744	10.21
Aug.	58,156	1.66	.03503	4.41	140	140	744	10.17
Sept.	61,380	2.3	.02669	3.36	149	149	720	7.55
Oct.	63,984	4.5	.01422	1.79	160	160	744	4.29
Nov.	55,920	7.3	.00766	0.97	173	173	720	2.77
Dec.	54,808	9.0	.00609	0.77	180	180	744	2.41

1. From Worksheet C, Col. 3
2. From Worksheet B, Col. 7
4. $Y = \frac{A_c F_R \overline{(\tau\alpha)} S}{L} = F_1 \cdot \frac{S}{L}$
5. From Table 5-5
8. $X = \frac{A_c F_R U_L (T_{ref} - T_a) \Delta time}{L} \times K_1 \times K_2$

$= F_2 \cdot [(6) \cdot (7)] : (2)$

A_c = 200 ft²
$F_R \overline{\tau\alpha}$ = 0.63 (Wksht D)
$F_R U_L$ = 0.80 (Wksht D)
K_1 = 1.1 (Wksht E)
K_2 = 0.92 (Wksht E)
$F_1 = A_c F_R \overline{\tau\alpha}$ = 126
$F_2 = A_c F_R U_L K_1 K_2$ = 162

Worksheet G
AIR SYSTEMS

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

PROJECT Sunbody Residence

COLLECTOR AREA 200ft²
LOCATION Denver

	1	2	3	4	5
Month	Tot. Mo. Htg. Load $L \times 10^6$ Btu/mo.	System Parameters X	System Parameters Y	Solar Fraction/ mo. f	Actual Solar en/mo $E \times 10^6$ Btu/mo.
Jan.	4.6	2.29	0.81	0.60	5.76
Feb.	8.1	2.42	0.89	0.64	5.18
March	7.9	2.67	0.99	0.69	5.45
April	6.5	3.48	1.25	0.83	4.57
May	3.7	5.05	1.77	1.00	3.70
June	2.0	8.51	3.23	1.00	2.00
July	1.64	10.21	4.00	1.00	1.64
Aug.	1.66	10.17	4.41	1.00	1.66
Sept.	2.3	7.55	3.36	1.00	2.30
Oct.	4.5	4.29	1.79	1.00	4.50
Nov.	7.3	2.77	0.97	0.66	4.82
Dec.	9.0	2.41	0.77	0.55	4.95

$L_{tot} = 63.2 \times 10^6$ Btu

$E_{tot} = 46.5 \times 10^6$ Btu

$F_{Annual} = \frac{E_{tot}}{L_{tot}} = \frac{46.5}{63.2} = 0.74$

1. From Worksheet B
2. From Worksheet F, Column 8
3. From Worksheet F, Column 4
4. From "f chart", Figure 8-6
5. E = f x L

SOLAR FRACTION FOR DIFFERENT COLLECTOR SIZES

In Example 8-1, the detailed calculations yielded the result that solar energy, with 200 ft^2 of Solaron collectors and compatible system components, provide 74 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 200 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 150 ft^2 of collectors can be determined by following the procedure below:

Step 1. - Calculate the area ratio $(\frac{\text{New Area}}{\text{Old Area}})$

(In this example $\frac{150\ ft^2}{200\ ft^2} = 0.75$

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

Step 3. - Use the f-chart (Figure 8-6) 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 a new worksheet G. With 150 ft^2 of collectors, the system will provide 63 percent of the annual space and DHW heating load.

Worksheet G
AIR SYSTEMS

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

PROJECT Sunbody Residence

COLLECTOR AREA 150 ft^2
LOCATION Denver

	1	2	3	4	5
Month	Tot. Mo. Htg. Load $L \times 10^6$ Btu/mo.	System Parameters X	System Parameters Y	Solar Fraction/ mo. f	Actual Solar en/mo $E \times 10^6$ Btu/mo.
Jan.	9.6	1.72	0.61	0.48	4.61
Feb.	8.1	1.82	0.67	0.51	4.13
March	7.9	2.00	0.74	0.56	4.42
April	5.5	2.61	0.94	0.69	3.80
May	3.7	3.79	1.33	0.86	3.18
June	2.0	6.38	2.42	1.00	2.00
July	1.64	7.66	3.00	1.00	1.64
Aug.	1.66	7.63	3.31	1.00	1.66
Sept.	2.3	5.66	2.52	1.00	2.30
Oct.	4.5	3.22	1.34	0.90	4.05
Nov.	7.3	2.08	0.73	0.56	4.09
Dec.	9.0	1.81	0.58	0.45	4.05

$L_{tot} = 6.32 \times 10^6$ Btu

$E_{tot} = 39.9 \times 10^6$ Btu

$F_{Annual} = \frac{E_{tot}}{L_{tot}} = \frac{39.9}{63.2} = 0.63$

1. From Worksheet B
2. From Worksheet F, Column 8
3. From Worksheet F, Column 4
4. From "f chart", Figure 8-6
5. E = f x L

THE RELATIVE AREAS METHOD

The solar fraction of the annual heating load is determined from the quantity of solar heat expected from the solar system and the total annual heat requirements calculated for the building. The solar fraction therefore describes the performance of a solar system either for space heating or space and domestic water heating combined. As is evident from Example 8-1, the f-chart calculations when undertaken by "hand", requires considerable time. To facilitate calculations computer programs have been written and are available for sale through the University of Wisconsin, for both large computers and small programmable hand held calculators. However, because not everyone has ready access to either large or small computers, a hand calculation method which saves computational time has considerable utility. The relative areas method, developed by Barley and Winn at Colorado State University is one such method.

The performance calculations for a solar system with two different collector areas were made in Example 8-1. If the f-chart calculations are continued for different collector areas, there would result a set of F values (annual solar fraction) corresponding to the set of collector areas, A_C. This has been done for a different building and the F values corresponding to six different collector areas, are listed in Table 8-3 along with two other values, A/A_{50} and $\log_e A/A_{50}$.

The collector areas A_{50} is identified as the area which provides 50 percent of the annual heating needs. That is, if the building of Table 8-4 is provided with 310 ft^2 of air-heating collectors, with the characteristics specified in the problem the system will provide 50 percent of the average annual heating needs. The last column in the table is the natural logarithm of the ratio A/A_{50}.

Table 8-3

Monthly Temperature (T_m) in °F at Source for City Water in 14 Selected Cities

City	Source[1]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1. Phoenix	Ri, Re, W	48	48	50	52	57	59	63	75	79	69	59	54
2. Miami	W	70	70	70	70	70	70	70	70	70	70	70	70
3. Los Angeles	Ri, W	50	50	54	63	68	73	74	76	75	69	61	55
4. Albuquerque	W	72	72	72	72	72	72	72	72	72	72	72	72
5. Las Vegas	W	73	73	73	73	73	73	73	73	73	73	73	73
6. Denver	Ri	39	40	43	49	55	60	63	64	63	56	45	37
7. Ft. Worth	L	56	49	57	70	75	81	79	83	81	72	56	46
8. Nashville	Ri	46	46	53	66	63	69	71	75	75	71	58	53
9. Washington D.C.	Ri	42	42	52	56	63	67	67	78	79	68	55	46
10. Salt Lake City	W, C	35	37	38	41	43	47	53	52	48	43	38	37
11. Seattle	Ri	39	37	43	45	48	57	60	68	66	57	48	43
12. Boston	Re	32	36	39	52	58	71	74	67	60	56	48	45
13. Chicago	L	32	32	34	42	51	57	65	67	62	57	45	35
14. New York City	Re	36	35	36	39	47	54	58	60	61	57	48	45

[1] Data from Handbook of Air Conditioning System Design, p. 5-41, McGraw Hill Book Company, New York (1965). Abbreviations: C-creek, L-lake, Re-reservoir, Ri-river, W-well.

Table 8-4

F Values for Different Collector Areas
(for a given building and location)

$A(ft^2)$	F	A/A_{50}	$Log_e(A/A_{50})$
500	0.68	1.61	0.48
400	0.59	1.29	0.25
310*	0.50	1.00	0.00
300	0.49	0.97	-0.03
200	0.33	0.65	-0.44
150	0.22	0.48	-0.78

*A_{50} = 310 ft^2

When the annual solar fraction F is plotted against $\log_e(A/A_{50})$, a straight line can be fitted along the points on a graph as shown by the solid line in Figure 8-9. Using the solid line, a collector area for any specified solar fraction F can be determined, or conversely the solar fraction F can be easily calculated for any collector area between 150 and 500 ft^2. If the solid line is extended, F can be determined for larger collector areas directly from the graph.

The solid curve applies to a specific building with a UA of 714 Btu/(hr•°F) and for a specified collector. If a different collector is chosen for the solar system or the design is made for a different building with a different heating load, a different line would apply as shown by the dashed lines in the figure.

To make this simple procedure applicable for any air heating collector and any building load (i.e. different buildings) we need to know the

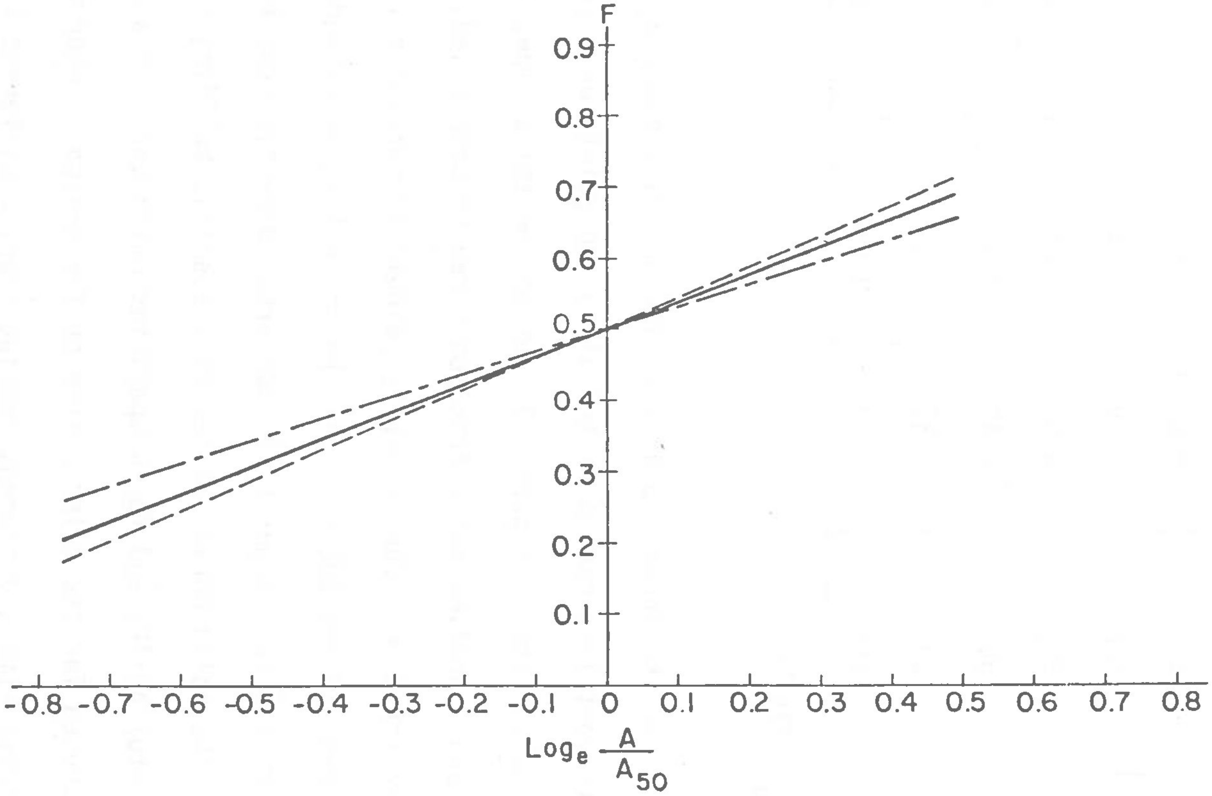

Figure 8-9. Annual Solar Fraction as a Function of $\log_e(A/A_{50})$

slope of the line, and the value of A_{50}. The collector area required to supply 50 percent of the building heating load obviously depends upon the building load as well as the quality of collectors used. With these factors known, A_{50} can be calculated from Equation (8-5).

$$A_{50} = \frac{A_S(UA)_L}{F_R' \overline{\tau\alpha} - F_R' U_L (Z)} \tag{8-5}$$

where

A_S	is a location dependent constant
$(UA)_L$	is the thermal conductance for the building but it also may include the water heating load,
$F_R' \overline{\tau\alpha}$	is the $F_R(\tau\alpha)_n$ (intercept) of the collector efficiency curve corrected for effective $\tau\alpha$ and heat exchanger in the collector loop
$F_R' U_L$	is the $F_R U_L$ (slope) of the collector efficiency curve corrected for the effect of a heat exchanger in the collector loop,
Z	is another location dependent constant

In Equation (8-5) once A_S and Z are known for a specific location, and with knowledge of $(UA)_L$ and the characteristics of the collector, the annual fraction can be determined from

$$F = 0.5 + c_2 \log_e(A/A_{50}).$$

The lines in Figure 8-9 are drawn so that the point $F = 0.5$, $\log_e(A/A_{50}) = 0$ is on the line. If however, a "best fit" curve is drawn through the calculated points of F and $\log_e(A/A_{50})$, the intersept is not always at 0.5. The general equation for the best fit line is

$$F = c_1 + c_2 \log_e(A/A_{50}) \tag{8-6}$$

where

F is the annual fraction,

c_1 is the intercept on the $\log_e(A/A_{50}) = 0$ axis, and may be different from 0.5

c_2 is the slope of the line.

Values of c_1, c_2, A_S and Z for liquid and air-heating systems are listed on Table 8-5 for 170 cities in the United States and Canada. Included in the tables also are the latitudes and heating "degree-days" expressed in (°F•hr)/year.

An additional set of columns are given in Table 8-5 for stand-alone domestic hot water systems. The form of the F-equation for systems that heat only domestic water is the same as Equation (8-6), however, A_{50} is determined by

$$A_{50} = \frac{A_D\, D\, \Delta T \times 10^{-3}}{F_R'\overline{\tau\alpha} - F_R'U_L(Z)} \tag{8-7}$$

where

A_D and Z are location dependent constants that are listed in the table

D is the daily hot water demand, gal/day

ΔT is the difference between the temperature of water in the mains and set temperature of water in the conventional hot water tank; °F

EXAMPLE 8-2

Determine the annual solar fraction for the solar system of Example 8-1, using the relative areas method, first for 200 ft², then for 150 ft², using the values in Table 8-5 for Denver, Colorado.

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

Answer.

F = 0.68 for A_c = 200 ft^2

F = 0.58 for A_c = 150 ft^2

From the f-chart method the results were

F = 0.74 for A_c = 200 ft^2

F = 0.63 for A_c = 150 ft^2

Worksheet

SOLAR SYSTEM DATA
RELATIVE AREAS METHOD

Building Owner Mr + Mrs John Sanbody

Address 736 Sunshine Ave Denver Ph. 482-0000

Contractor Solar Construction Co Ph. 482-0001

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

Site and Building Data

1. Location: Nearest City Denver Latitude 39.5 °N
2. Building UA 276 Btu/(hr•°F)
3. DHW volume per day 80 gallons/day

Collector Data

4. Collector manufacturer Solaron
5. Collector Area, A_c = 200 ft^2
6. Collector efficiency data from manufacturer's information:
   (a) $F_R(\tau\alpha)$ 0.69
   (b) F_RU_L 0.80 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) 0.69
      (ii) $F_RU_L = F_RU_L$ (from line 6) 0.80 Btu/(hr•ft^2•°F)

   (b) Case 2: $\frac{T_{in} + T_{out}}{2}$ (correction needed)

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

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

$$= \_\_\_\_ \text{ Btu/(hr} \cdot \text{°F)}$$

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

(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) $x = \frac{C_c}{\varepsilon_{cs} C_{min}}$ = $\frac{}{(\quad\quad)(\quad\quad)}$ = _______

(e) $y = \frac{A_c F_R U_L}{C_c}$ = $\frac{(\quad\quad)(\quad\quad)}{}$ = ________

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

Corrections to Collector Parameters

10. Incident angle modifier

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

$$= \underline{\;0.69\;} \times 0.91 = \underline{\;0.63\;}$$

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

$$= \underline{\hspace{2cm}} \times 0.93 = \underline{\hspace{2cm}}$$

11. (a) $$F_R'\overline{\tau\alpha} = \frac{\hspace{3cm}}{\text{line 10a or 10b}} \times \frac{\hspace{3cm}}{\text{line 8 or 9f}} = \underline{\hspace{2cm}}$$

(b) $$F_R'U_L = \frac{0.80}{\begin{array}{l}\text{line 7a(ii)}\\ \text{or 7b(ii)}\\ \text{or 7c(ii)}\end{array}} \times \frac{1}{\text{line 8 or 9f}} = \underline{\;0.80\;} \text{ Btu/(hr·°F)}$$

List c_1, c_2, A_S, A_D, Z from Table 8-5

12. A_S or A_D = $\underline{0.1638}$ $Z = \underline{0.15696}$ $c_1 = \underline{0.549}$ $c_2 = \underline{0.347}$

For Solar Heating and DHW Systems:

13. $$A_{50} = \frac{A_S(UA)_L}{F_R\overline{\tau\alpha} - F_RU_L(Z)} \qquad \text{where } (UA)_L = \frac{\text{Design Heating Load}}{\text{Design Temp. Diff.}}$$

$$A_{50} = \frac{(0.1658)\qquad(419)}{(0.63) - (0.8)(0.15696)} = \underline{\;138\;} \text{ ft}^2$$

14. A_c/A_{50} = $\underline{200/138}$ = $\underline{\;1.45\;}$

15. $\log_e(A_c/A_{50})$ = $\underline{\;0.37\;}$

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

$$= \underline{0.549} + \underline{(0.347)(0.37\;)} = \underline{\;0.68\;}$$

17. A_c/A_{50} = 150/138 = 1.09

18. $\text{Log}_e(A_c/A_{50})$ = 0.0834

19. $F = \underline{0.549} + (0.347)(0.0834) = \underline{\;0.58\;}$

Table 8-5

Constants for Relative Areas Method

				LIQUIO SYSTEM				AIR SYSTEM				OOMESTIC HOT WATER ONLY			
CITY	ST	LAT. (DEG.)	D-H (FHR/YR)	A_s $(\frac{^\circ F \cdot ft^2 \cdot Hr}{Btu})$	Z	C_1	C_2	A_s $(\frac{^\circ F \cdot ft^2 \cdot Hr}{8tu})$	Z	C_1	C_2	A_D $\frac{ft^2 \cdot D}{^\circ F\ kgal}$	Z $(\frac{^\circ F \cdot ft^2 \cdot Hr}{Btu})$	C_1	C_2
Annette	AK	55.0	172607	.309	.390	.510	.257	.289	.316	.514	.284	5.007	.392	.530	.309
Bethel	AK	60.5	316702	.485	.365	.508	.255	.453	.289	.511	.284	4.409	.417	.535	.314
Fairbanks	AK	64.5	342696	.638	.412	.506	.226	.595	.331	.505	.249	4.288	.407	.538	.322
Matanuska	AK	61.3	260371	.483	.413	.503	.231	.450	.330	.502	.253	4.818	.418	.539	.322
8irmingham	AL	33.3	68248	.161	.256	.529	.283	.152	.211	.548	.319	3.370	.211	.545	.341
Fort Smith	AR	35.2	80060	.195	.263	.528	.284	.184	.217	.547	.322	3.412	.217	.543	.338
Little Rock	AR	34.4	77255	.192	.268	.528	.282	.181	.221	.547	.320	3.421	.219	.543	.337
Page	AZ	36.4	129119	.149	.172	.535	.312	.140	.141	.545	.335	2.423	.177	.552	.356
Phoenix	AZ	33.3	37249	.063	.163	.536	.309	.059	.133	.543	.328	2.398	.134	.558	.367
Tucson	AZ	32.1	43199	.070	.159	.540	.314	.066	.130	.551	.338	2.396	.141	.557	.365
Yuma	AZ	32.4	24141	.046	.176	.530	.303	.043	.141	.533	.322	2.499	.132	.559	.369
Oavis	CA	38.3	60047	.137	.269	.516	.257	.129	.220	.529	.286	3.066	.204	.540	.331
Fresno	CA	36.5	62665	.130	.243	.519	.262	.123	.199	.531	.288	2.957	.188	.545	.340
Inyokern	CA	35.4	56878	.077	.140	.534	.307	.072	.115	.541	.325	2.052	.121	.559	.369
Los Angeles	CA	33.6	43657	.054	.197	.535	.305	.051	.154	.544	.330	2.834	.182	.551	.354
Pasadena	CA	34.1	40647	.060	.201	.535	.308	.057	.159	.546	.334	2.916	.183	.550	.353
Riverside	CA	33.6	46056	.065	.173	.538	.312	.061	.142	.551	.336	2.614	.165	.554	.359
Sacramento	CA	38.3	68225	.133	.255	.518	.259	.125	.206	.526	.286	3.028	.197	.543	.336
San Oiego	CA	32.4	36161	.053	.211	.536	.309	.050	.168	.547	.336	3.139	.200	.548	.347
San Francisco	CA	37.5	73911	.082	.227	.530	.310	.077	.180	.542	.340	3.232	.221	.543	.338
San Jose	CA	37.2	55967	.101	.254	.520	.270	.095	.206	.531	.294	3.336	.226	.541	.334
Santa Maria	CA	34.5	71207	.066	.183	.529	.310	.062	.146	.536	.334	2.600	.180	.551	.354
8oulder	CO	40.0	132960	.196	.241	.531	.301	.184	.196	.544	.334	3.295	.242	.540	.333
Denver	CO	39.5	144377	.175	.197	.538	.316	.165	.156	.549	.347	2.639	.197	.548	.348
Grand Junction	CO	39.1	135334	.196	.201	.531	.303	.185	.165	.544	.331	2.661	.193	.549	.349
Grand Lake	CO	40.2	259248	.262	.230	.526	.302	.246	.185	.537	.332	2.876	.256	.537	.327
Pueblo	CO	38.2	129448	.164	.184	.537	.316	.154	.147	.548	.345	2.547	.184	.551	.353
Hartford	CT	41.6	152395	.286	.286	.526	.287	.269	.232	.543	.328	3.653	.273	.536	.323
Washington	OC	38.5	101375	.237	.307	.520	.271	.224	.248	.533	.307	3.829	.260	.537	.325
Apalachicola	FL	29.5	31391	.066	.195	.538	.311	.062	.159	.550	.339	2.921	.168	.553	.358
Gainesville	FL	29.4	25941	.058	.202	.535	.306	.054	.164	.544	.334	3.057	.171	.553	.358
Jacksonville	FL	30.3	31843	.076	.217	.537	.309	.072	.177	.551	.341	3.292	.189	.550	.352
Key West	FL	24.3	1533	.004	.172	.544	.326	.004	.143	.562	.359	2.993	.145	.557	.365
Miami	FL	25.5	5137	.014	.160	.542	.333	.013	.132	.562	.368	2.919	.149	.556	.364
Pensacola	FL	30.3	37866	.093	.230	.534	.299	.087	.188	.548	.331	3.215	.187	.550	.351
Tallahassee	FL	30.3	37510	.076	.192	.535	.305	.072	.156	.545	.331	3.045	.178	.550	.352
Tampa	FL	27.6	17233	.036	.179	.536	.318	.033	.146	.544	.346	2.873	.156	.555	.363
Atlanta	GA	33.4	74262	.162	.240	.529	.289	.153	.198	.547	.324	3.338	.214	.545	.343
Griffin	GA	33.2	67201	.141	.228	.533	.291	.133	.187	.550	.323	3.142	.201	.548	.347
Macon	GA	32.4	53756	.122	.226	.536	.300	.115	.186	.553	.334	3.189	.192	.549	.350
Savannah	GA	32.1	46844	.108	.228	.534	.298	.102	.186	.550	.331	3.265	.193	.549	.351
Hilo	HI	19.4	0	.000	.000	.000	.000	.000	.000	.000	.000	3.470	.185	.550	.352
Honolulu	HI	21.2	0	.000	.000	.000	.000	.000	.000	.000	.000	2.617	.132	.558	.367
Ames	IA	42.0	163776	.312	.284	.525	.281	.295	.231	.542	.320	3.567	.271	.537	.325
Des Moines	IA	41.3	161033	.327	.295	.522	.269	.308	.243	.538	.308	3.495	.262	.537	.324
Boise	IO	43.3	139417	.238	.277	.515	.259	.223	.225	.524	.290	3.183	.237	.536	.323
Pocatello	IO	42.6	169513	.242	.24B	.522	.278	.228	.197	.531	.308	2.960	.229	.540	.331
Twin Falls	IO	40.4	151774	.263	.288	.518	.264	.247	.233	.529	.296	3.458	.260	.534	.319
Chicago	IL	41.6	147047	.314	.303	.522	.276	.296	.247	.540	.315	3.716	.270	.535	.321
Lemont	IL	41.4	147047	.316	.305	.522	.275	.298	.250	.540	.315	3.730	.271	.535	.321
Peoria	IL	40.4	146345	.315	.308	.519	.265	.296	.253	.535	.304	3.591	.263	.536	.322
Fort Wayne	IN	41.0	149012	.319	.315	.518	.262	.301	.261	.536	.302	3.651	.270	.534	.318
Indianapolis	IN	39.4	133847	.325	.340	.518	.257	.306	.279	.532	.295	3.857	.276	.532	.314
Dodge City	KS	37.5	121103	.176	.196	.534	.307	.166	.162	.549	.337	2.699	.191	.549	.350
Manhattan	KS	39.1	124369	.242	.269	.524	.282	.227	.218	.538	.316	3.411	.238	.541	.333
Wichita	KS	37.4	112481	.206	.237	.530	.293	.195	.189	.545	.327	3.103	.212	.546	.343
Lexington	KY	38.0	113495	.227	.268	.523	.271	.215	.216	.537	.303	3.162	.221	.540	.331
Louisville	KY	38.1	111353	.266	.311	.521	.267	.252	.253	.539	.307	3.690	.257	.536	.323
Lake Charles	LA	30.1	35015	.087	.231	.534	.302	.082	.189	.549	.336	3.228	.187	.549	.350
New Orleans	LA	29.6	33238	.098	.276	.527	.288	.093	.224	.544	.326	3.896	.225	.542	.336
Shreveport	LA	32.3	52415	.136	.255	.532	.294	.128	.209	.550	.333	3.407	.204	.546	.343
Amherst	MA	42.2	157825	.379	.370	.516	.255	.357	.302	.528	.287	4.277	.323	.528	.308
8lue Hill	MA	42.1	152809	.310	.320	.523	.276	.293	.257	.539	.316	3.956	.299	.532	.316
8oston	MA	42.2	135215	.321	.342	.521	.269	.304	.278	.538	.310	4.198	.302	.531	.314
Lynn	MA	42.3	135215	.341	.370	.516	.255	.322	.303	.528	.289	4.277	.310	.527	.304
Natick	MA	42.2	147455	.303	.307	.522	.275	.286	.248	.537	.313	3.890	.285	.533	.317
Annapolis	MO	38.6	109146	.239	.292	.522	.278	.225	.239	.538	.317	3.675	.256	.538	.327
8altimore	MO	39.1	113491	.246	.287	.523	.280	.232	.235	.539	.318	3.643	.252	.539	.329
Silver Hill	MD	38.5	101064	.227	.280	.524	.280	.215	.225	.542	.319	3.596	.244	.540	.332
Caribou	ME	46.5	234406	.385	.309	.521	.272	.362	.249	.533	.303	3.805	.320	.529	.309
Portland	ME	43.4	175462	.285	.281	.525	.282	.268	.226	.539	.318	3.505	.275	.535	.321
Detroit	MI	42.1	154049	.361	.351	.517	.254	.340	.291	.532	.291	3.928	.294	.529	.309
East Lansing	MI	42.4	165697	.385	.365	.517	.253	.363	.298	.529	.286	4.071	.313	.527	.305
Lansing	MI	42.5	165685	.368	.347	.519	.260	.348	.284	.533	.296	3.954	.301	.529	.309
Sault St. Marie	MI	46.3	217151	.363	.319	.517	.261	.343	.256	.528	.291	3.763	.317	.527	.304
Columbia	MO	38.6	121103	.245	.275	.524	.276	.230	.225	.539	.312	3.359	.236	.540	.331
Kansas City	MO	39.2	123859	.257	.274	.525	.277	.243	.220	.541	.314	3.357	.234	.541	.332
St. Louis	MO	38.5	113993	.253	.285	.522	.271	.240	.232	.540	.308	3.505	.240	.539	.330
Springfield	MO	37.1	109672	.175	.249	.526	.226	.167	.207	.536	.248	2.951	.215	.546	.302
Duluth	MN	46.5	234136	.397	.323	.518	.264	.374	.260	.529	.297	3.749	.315	.530	.312
Minn. St. Paul	MN	44.5	195807	.398	.325	.519	.263	.376	.265	.535	.302	3.765	.298	.532	.316
St. Cloud	MN	45.3	212831	.349	.274	.525	.284	.328	.223	.539	.317	3.415	.277	.535	.321
Jackson	MS	32.2	55195	.139	.257	.530	.286	.131	.210	.547	.322	3.395	.204	.546	.343
Billings	MT	45.5	174353	.259	.256	.527	.289	.245	.204	.540	.322	3.139	.245	.539	.329
Glasgow	MT	48.1	215906	.294	.237	.527	.287	.277	.192	.539	.316	2.952	.242	.540	.332

Table 8-5 (continued)

				LIQUID SYSTEM				AIR SYSTEM				DOMESTIC HOT WATER ONLY			
CITY	ST	LAT. (DEG.)	D-H (FHR/YR)	A_s $\left(\frac{°F\cdot ft^2\cdot Hr}{Btu}\right)$	Z	C_1	C_2	A_s $\left(\frac{°F\cdot ft^2\cdot Hr}{Btu}\right)$	Z	C_1	C_2	A_D $\frac{ft^2\cdot D}{°F\ kgal}$	Z $\left(\frac{°F\cdot ft^2\cdot Hr}{Btu}\right)$	C_1	C_2
Great Falls	MT	47.3	186001	.268	.259	.524	.283	.251	.211	.536	.313	3.202	.252	.537	.326
Summit	MT	48.2	255070	.393	.349	.513	.255	.367	.282	.521	.287	4.009	.348	.524	.299
Ashville	NC	35.3	101681	.177	.243	.527	.289	.166	.196	.539	.322	3.203	.221	.544	.340
Cape Hattaras	NC	35.2	65545	.117	.208	.531	.298	.111	.167	.543	.325	2.863	.183	.551	.354
Charlotte	NC	35.1	77225	.159	.229	.532	.293	.150	.190	.550	.327	3.178	.205	.547	.346
Greensboro	NC	36.1	91801	.189	.252	.525	.284	.179	.207	.544	.321	3.393	.229	.543	.338
Grnvle-Sptnbrg	NC	34.5	75907	.162	.237	.531	.289	.153	.195	.548	.323	3.243	.209	.546	.344
Raleigh	NC	35.5	84335	.161	.231	.530	.300	.152	.184	.545	.334	3.306	.216	.546	.343
Raleigh-Durham	NC	35.5	84333	.173	.241	.526	.291	.164	.198	.545	.326	3.388	.221	.545	.341
Bismarck	ND	46.5	217056	.327	.260	.524	.281	.307	.211	.537	.314	3.149	.260	.538	.327
Fargo	ND	46.5	222497	.415	.319	.519	.264	.391	.257	.530	.300	3.657	.300	.533	.317
Lincoln	NE	40.5	140806	.256	.257	.527	.285	.242	.212	.545	.323	3.328	.242	.540	.332
North Omaha	NE	41.2	158687	.263	.249	.528	.292	.249	.199	.543	.328	3.231	.237	.542	.335
Atlantic City	NJ	39.3	112629	.218	.261	.525	.287	.206	.213	.541	.320	3.449	.242	.540	.332
Trenton	NJ	40.1	118727	.243	.276	.523	.282	.229	.227	.541	.320	3.562	.253	.539	.329
Albuquerque	NM	35.0	103006	.133	.167	.538	.318	.125	.136	.549	.344	2.332	.164	.554	.360
Ely	NV	39.2	185590	.197	.191	.534	.310	.186	.156	.546	.336	2.536	.206	.547	.345
Las Vegas	NV	36.1	65015	.102	.163	.539	.312	.096	.133	.550	.334	2.377	.144	.557	.365
Reno	NV	39.3	144521	.158	.189	.533	.303	.149	.154	.543	.328	2.511	.192	.548	.348
Albany	NY	42.4	165311	.328	.322	.512	.256	.307	.255	.519	.282	3.829	.292	.531	.313
Binghampton	NY	42.1	174835	.371	.351	.517	.256	.351	.286	.530	.292	3.987	.309	.529	.309
Ithaca	NY	42.3	169246	.407	.387	.518	.251	.385	.319	.529	.282	4.281	.332	.525	.301
New York	NY	40.5	115462	.326	.369	.520	.266	.306	.304	.533	.301	4.503	.310	.530	.311
Rochester	NY	43.1	161249	.348	.338	.518	.259	.329	.275	.532	.297	3.853	.292	.530	.311
Schenectady	NY	42.5	163610	.409	.385	.521	.265	.386	.317	.531	.298	4.646	.344	.530	.311
Syracuse	NY	43.1	160264	.386	.371	.519	.256	.364	.304	.530	.290	4.126	.313	.527	.304
Cleveland	OH	41.2	147697	.367	.372	.516	.247	.346	.307	.526	.279	4.059	.301	.526	.303
Columbus	OH	40.0	135840	.326	.348	.515	.252	.307	.286	.530	.290	3.903	.284	.530	.310
Dayton	OH	39.5	135377	.294	.306	.520	.266	.277	.252	.536	.304	3.580	.259	.535	.321
Put-In-Bay	OH	41.4	142030	.376	.369	.519	.254	.354	.303	.532	.289	3.946	.288	.526	.303
Oklahoma City	OK	35.2	88676	.159	.206	.535	.304	.151	.169	.552	.336	2.885	.190	.549	.349
Stillwater	OK	36.1	87143	.180	.237	.529	.290	.170	.194	.546	.322	3.173	.207	.545	.342
Tulsa	OK	36.1	88315	.196	.250	.529	.291	.186	.204	.548	.327	3.320	.214	.544	.340
Astoria	OR	46.1	127078	.222	.359	.509	.242	.208	.291	.518	.274	4.422	.333	.521	.293
Corvallis	OR	44.3	116497	.242	.378	.508	.224	.228	.302	.513	.253	4.033	.301	.518	.286
Medford	OR	42.2	118319	.235	.331	.505	.229	.220	.264	.512	.260	3.500	.256	.525	.300
Portland	OR	45.4	115001	.269	.401	.517	.243	.253	.324	.521	.270	4.645	.334	.522	.295
Philadelphia	PA	39.5	116755	.247	.283	.523	.279	.232	.232	.539	.317	3.610	.253	.539	.329
Pittsburgh	PA	40.3	126665	.278	.306	.519	.268	.262	.252	.536	.306	3.700	.262	.535	.322
State College	PA	40.5	147169	.352	.357	.518	.257	.332	.293	.532	.293	4.095	.304	.529	.310
Newport	RI	41.3	139294	.258	.295	.524	.281	.243	.239	.540	.322	3.741	.275	.535	.321
Charleston	SC	32.5	48792	.112	.221	.537	.305	.105	.181	.554	.339	3.243	.195	.549	.350
Rapid City	SD	44.1	176279	.233	.225	.532	.300	.218	.182	.543	.331	2.917	.225	.543	.338
Chattanooga	TN	35.0	84117	.195	.267	.526	.279	.185	.221	.547	.320	3.474	.226	.542	.336
Memphis	TN	35.0	77443	.188	.265	.528	.280	.177	.218	.546	.317	3.342	.211	.544	.338
Nashville	TN	36.1	88703	.232	.301	.522	.266	.219	.248	.542	.305	3.626	.239	.538	.327
Oak Ridge	TN	36.0	94658	.233	.300	.520	.265	.221	.249	.541	.305	3.709	.248	.537	.326
Abilene	TX	32.3	62634	.120	.198	.537	.307	.113	.163	.553	.337	2.867	.174	.552	.356
Amarillo	TX	35.1	100385	.143	.183	.536	.313	.134	.150	.549	.341	2.611	.176	.552	.356
Big Spring	TX	32.2	62182	.121	.200	.537	.305	.114	.163	.552	.336	2.899	.179	.550	.352
Brownsville	TX	25.6	15600	.046	.219	.533	.307	.043	.179	.548	.342	3.182	.168	.552	.355
Corpus Christi	TX	27.5	22318	.061	.240	.527	.301	.057	.191	.535	.331	3.147	.170	.551	.353
Dallas	TX	32.5	54952	.132	.235	.534	.298	.124	.193	.549	.331	3.219	.189	.548	.348
El Paso	TX	31.5	64798	.097	.155	.541	.316	.092	.127	.551	.337	2.330	.145	.557	.366
Fort Worth	TX	32.5	57720	.119	.209	.535	.303	.112	.172	.549	.333	2.927	.176	.551	.352
Houston	TX	29.6	34412	.092	.245	.530	.295	.086	.198	.542	.327	3.260	.183	.549	.349
Midland	TX	31.6	62182	.115	.190	.537	.308	.108	.156	.551	.335	2.753	.172	.553	.357
Port Arthur	TX	29.6	36428	.099	.255	.530	.291	.093	.207	.545	.326	3.447	.196	.547	.346
San Antonio	TX	29.3	37103	.084	.211	.538	.309	.079	.173	.552	.339	3.042	.174	.551	.353
Salt Lake City	UT	40.5	143591	.246	.271	.519	.269	.231	.218	.530	.301	3.244	.237	.538	.328
Mt. Weather	VA	39.0	136034	.257	.280	.525	.285	.242	.226	.541	.324	3.636	.266	.537	.326
Norfolk	VA	36.5	83707	.175	.254	.527	.289	.166	.205	.544	.325	3.397	.225	.544	.339
Richmond	VA	37.5	94530	.206	.267	.523	.280	.195	.219	.542	.317	3.502	.234	.542	.335
Prusser	WA	46.2	134578	.235	.291	.510	.240	.219	.232	.515	.266	3.149	.237	.532	.316
Pullman	WA	46.4	158974	.261	.303	.516	.252	.245	.244	.524	.283	3.398	.266	.529	.310
Richland	WA	46.2	117406	.268	.349	.504	.224	.251	.281	.511	.255	3.644	.262	.526	.303
Seattle	WA	47.3	106178	.251	.413	.509	.221	.235	.335	.510	.243	4.551	.333	.517	.285
Spokane	WA	47.4	164039	.295	.310	.513	.249	.277	.251	.526	.282	3.505	.272	.527	.305
Green Bay	WI	44.3	194344	.387	.336	.519	.260	.364	.272	.530	.296	3.882	.308	.531	.313
Madison	WI	43.1	185520	.348	.310	.522	.270	.329	.248	.534	.306	3.658	.286	.533	.318
Milwaukee	WI	42.6	178649	.350	.325	.518	.261	.331	.262	.532	.298	3.723	.290	.532	.315
Parkersburg	WV	39.2	115601	.301	.352	.519	.258	.286	.285	.533	.296	3.996	.278	.531	.313
Lander	WY	42.5	188879	.211	.193	.536	.313	.198	.157	.547	.340	2.565	.205	.547	.346
Laramie	WY	41.2	212137	.243	.221	.534	.309	.230	.177	.549	.342	2.907	.240	.541	.334
Edmonton	AT	53.3	246430	.376	.300	.517	.267	.355	.238	.528	.297	3.632	.313	.531	.313
Lethbridge	AT	49.4	207455	.300	.274	.520	.273	.283	.221	.532	.303	3.316	.275	.534	.319
Vancouver	BC	48.6	132357	.354	.477	.533	.257	.333	.404	.515	.244	5.347	.403	.526	.299
Churchill	MA	58.5	401471	.542	.322	.517	.276	.508	.262	.530	.309	3.735	.383	.530	.308
Winnipeg	MA	49.5	256296	.405	.286	.522	.276	.382	.231	.534	.307	3.446	.301	.532	.315
Moncton	NB	46.1	209447	.431	.385	.516	.251	.407	.310	.522	.279	4.484	.366	.530	.312
St. Johns	NF	47.3	215785	.472	.442	.525	.268	.445	.365	.520	.276	5.414	.434	.548	.341
Kapuskasing	OT	49.3	277727	.538	.376	.517	.262	.504	.310	.526	.290	4.410	.389	.535	.320
Ottawa	OT	45.3	209638	.391	.316	.522	.269	.368	.258	.536	.304	3.747	.310	.530	.312
Toronto	OT	43.4	163844	.391	.382	.518	.256	.368	.312	.526	.287	4.321	.336	.526	.304
Montreal	QU	45.3	196871	.471	.398	.514	.244	.440	.326	.516	.268	4.368	.354	.526	.302

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Worksheet A
Sheet 1 of 2
AIR 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}

Worksheet A
Sheet 2 of 2
AIR SYSTEMS

11. Collector Fluid:

(a) Composition: ______________________________

(b) Flow rate G __________ ft^3/min

Storage Data

12. Storage medium ______________________________

13. Unit volume __________ ft^3/ft^2

14. Total volume (item 5 x 13) __________ ft^3

Auxiliary Furnace/Boiler

Type ______________________________

Manufacturer ______________________________

Rated Capacity __________ Btu/hr

Auxiliary energy source __________

Auxiliary DHW Unit

Size __________ gal

Auxiliary energy source __________

Hot water set temperature __________ °F

Worksheet B
AIR SYSTEMS

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 temperature

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

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
AIR SYSTEMS

COLLECTOR COMBINED PERFORMANCE CHARACTERISTICS, $F_R(\overline{\tau\alpha})$, F_RU_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 = ________________ ft^2

4. Collector volumetric flow rate (Worksheet A, 11(d))

________________ 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: $F_R(\tau\alpha)_n = F_R\ \tau\alpha \times \left[\dfrac{1}{1 + \dfrac{F_RU_L\ A_c}{2\ C_c}}\right]$ = _________________

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

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

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: $F_R(\tau\alpha)_n = F_R(\tau\alpha)_n \times \left[\dfrac{1}{1 + \dfrac{F_RU_L\ A_c}{C_c}}\right]$ = _______________

$F_RU_L = F_RU_L \times \left[\dfrac{1}{1 + \dfrac{F_RU_L\ A_c}{C_c}}\right]$ = _______________

Incident Angle Modifier, $\dfrac{F_R(\overline{\tau\alpha})}{F_R(\tau\alpha)_n} = \left\{\begin{matrix}.91, \text{ for two cover plates}\\ .90, \text{ for one cover plate}\end{matrix}\right.$

8. $F_R(\overline{\tau\alpha})$ = ____ x ____ = ____

CORRECTION FACTORS, K_1, K_2

PROJECT________________________

Collector Flow Factor, K_1

1. Air Flow Rate (Worksheet A, line 11(b)) = ________________cfm
2. A_c (from Worksheet A, line 5) = ________________ft^2
3. $\frac{\text{Air Flow Rate}}{A_c}$ = ________________cfm/ft^2
4. K_1 = (from Figure 8-7) = ________________

Storage Mass Capacitance Factor K_2

5. Unit Volume (Worksheet A, line 13) = ________________ft^3/ft^2
6. K_2 = (from Figure 8-8) = ________________

Worksheet F
AIR SYSTEMS

SYSTEM PERFORMANCE PARAMETERS X, Y

PROJECT________________

LOCATION_______________

	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. $Y = \dfrac{A_c F_R(\overline{\tau\alpha})S}{L} = F_1 \cdot \dfrac{S}{L}$
5. From Table 5-5
8. $X = \dfrac{A_c F_R U_L (T_{ref} - T_a)\Delta time}{L} \times K_1 \times K_2$

$= F_2 \cdot [(6)\cdot(7)] \div (2)$

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)

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

$F_2 = A_c F_R U_L K_1 K_2$ = ____________

Worksheet G
AIR SYSTEMS

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

PROJECT ______________________

COLLECTOR AREA ____ ft^2
LOCATION ____________

	1	2	3	4	5
Month	Tot. Mo. Htg. Load $L \times 10^6$ Btu/mo.	System Parameters X	System Parameters Y	Solar Fraction/ mo. f	Actual Solar en/mo $E \times 10^5$ Btu/mo.
Jan.					
Feb.					
March					
April					
May					
June					
July					
Aug.					
Sept.					
Oct.					
Nov.					
Dec.					

$L_{tot} =$

$E_{tot} =$

$F_{Annual} = \frac{E_{tot}}{L_{tot}} = \underline{\quad\quad} = \underline{\quad\quad}$

1. From Worksheet B
2. From Worksheet F, Column 8
3. From Worksheet F, Column 4
4. From "f chart", Figure 8-6
5. E = f x L

SOLAR SYSTEM DATA
RELATIVE AREAS METHOD

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/($hr \cdot ft^2 \cdot °F$)
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/($hr \cdot ft^2 \cdot °F$)
   - (b) Case 2: $\frac{T_{in} + T_{out}}{2}$ (correction needed)

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

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

$$= \qquad \_\_\_\_ \text{ Btu/(hr} \cdot °F)$$

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

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

= __________ x __________ = __________

(ii) F_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) $x = \frac{C_c}{\varepsilon_{cs}C_{min}}$ = $\frac{\qquad\qquad}{(\qquad)(\qquad)}$ = ________

(e) $y = \frac{A_cF_RU_L}{C_c}$ = (______)(______) = ________

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

Corrections to Collector Parameters

10. Incident angle modifier

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

$= \underline{\hspace{2cm}} \times 0.91 = \underline{\hspace{2cm}}$

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

$= \underline{\hspace{2cm}} \times 0.93 = \underline{\hspace{2cm}}$

11. (a) $F_R'\overline{\tau\alpha} = \dfrac{\hspace{3cm}}{\text{line 10a or 10b}} \times \dfrac{\hspace{3cm}}{\text{line 8 or 9f}} = \underline{\hspace{2cm}}$

(b) $F_R'U_L = \dfrac{\hspace{3cm}}{\begin{array}{l}\text{line 7a(ii)}\\ \text{or 7b(ii)}\\ \text{or 7c(ii)}\end{array}} \times \dfrac{\hspace{3cm}}{\text{line 8 or 9f}} = \underline{\hspace{2cm}}$ Btu/(hr•°F)

List c_1, c_2, A_S, A_D, Z from Table 8-5

12. A_S or $A_D = \underline{\hspace{1.5cm}}$ $Z = \underline{\hspace{1.5cm}}$ $c_1 = \underline{\hspace{1.5cm}}$ $c_2 = \underline{\hspace{1.5cm}}$

For Solar Heating and DHW Systems:

13. $A_{50} = \dfrac{A_S(UA)_L}{F_R\overline{\tau\alpha} - F_RU_L(Z)}$ where $(UA)_L = \dfrac{\text{Design Heating Load}}{\text{Design Temp. Diff.}}$

$A_{50} = \dfrac{(\quad)(\quad)}{(\quad) - (\quad)(\quad)} = \underline{\hspace{1.5cm}}$ ft^2

14. $A_c/A_{50} = \underline{\hspace{3cm}} = \underline{\hspace{4cm}}$

15. $\log_e(A_c/A_{50}) = \underline{\hspace{4cm}}$

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

$= \underline{\hspace{1.5cm}} + \underline{(\hspace{1.5cm})(\hspace{1.5cm})} = \underline{\hspace{1.5cm}}$

17. $A_c/A_{50} = 150/138 = 1.09$

18. $\text{Log}_e(A_c/A_{50}) = 0.0834$

19. $F = \underline{\hspace{1.2cm}} + (\quad)(\quad) = \underline{\hspace{1.5cm}}$