F-CHART

User's Manual

Windows Version

F-Chart Software
Phone (608) 836-8531
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www.fchart.com

The authors make no guarantee that the program is free from errors or that the results produced with it will be free of errors, and they assume no responsibility or liability for the accuracy of the program or for the results which my come from its use.

Registration Number___________________________

ALL CORRESPONDENCE MUST INCLUDE THE REGISTRATION NUMBER

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CHAPTER 1

Getting Started

1.1 Overview

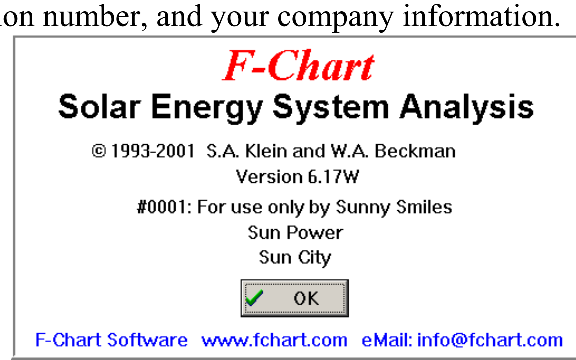
F-Chart is a computer program useful for the analysis and design of active and passive solar heating systems. The program is an implementation of methods developed at the University of Wisconsin Solar Energy Laboratory to estimate the long-term average performance of:

- Domestic Water Heating Systems
- Pebble Bed Storage Space and Domestic Water Heating Systems
- Water Storage Space and Domestic Water Heating Systems
- Active Collection with Building Storage Space Heating Systems
- Direct-Gain Passive Systems
- Collector-Storage Wall Passive Systems
- Pool Heating Systems
- General Solar Heating Systems (e.g., process heating systems)
- Integral Collector-Storage Domestic Water Heating Systems

Weather data for hundreds of North American locations, the 16 California climate zones and numerous other locations are included with the program. The user can add new weather data.

The easiest way to become acquainted with **F-Chart** is to try an example problem using the default parameters supplied with the program. **F-Chart** conforms to the Windows standard interface and can be run with a minimum of instructions. After you have become familiar with the program, you may wish to review the detailed program instruction set in Chapter 2 and the collector, system and economic parameter set descriptions in Chapters 3, 4, and 5.

When you start **F-Chart** (click on the file FCHART.EXE), a header will appear showing the version number, registration number, and your company information. To proceed, click OK.



After clicking the mouse button, the header will disappear and three windows containing the collector, system and economic parameters of the default system will appear. The default system is a pebble bed space and domestic water heating system with a flat-plate collector. (It is possible to change the default system to your specifications, as described with the *Save as* command in the next chapter.) Before changing any of the values, let's look at the available commands.

Commands are distributed among nine pull-down menus. Detailed descriptions of each of the commands can be found in the next chapter. A brief summary follows.

The **File** menu provides commands for loading and saving work files and printing information.

The **Edit** menu provides for the usual Windows Cut, Copy and Paste commands as well as providing for the specification of multiple (e.g., monthly) values of highlighted parameters.

The **Preferences** menu commands allow specification of the unit system (English or SI) and the visibility of the economics parameter window.

The **System** menu contains the commands to select the type of solar system that is to be analyzed.

The **Collector** menu allows specification of the type of solar collector array.

The **Data** menu shows the locations for which weather data are available as well as commands to view, change, or add weather data.

The **Run/Plot** menu contains commands to run a specific system or to run multiple calculations for a range of values of a specific parameter. Plotting capabilities are also provided.

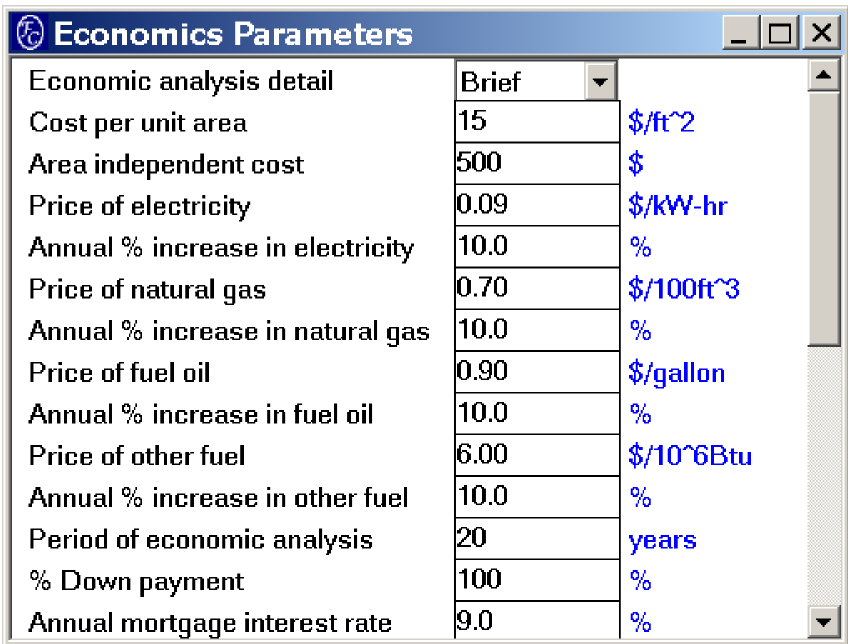
The **Window** menu brings selected windows to the front and determines how windows are arranged.

The **Help** menu provides on-line help as well as access to the manual. Help is available for most menus, commands and parameters by highlighting the object and pressing F1.

To select a command, place the cursor on the desired menu title, press the mouse button, and while holding the button down, slide the cursor to the command you wish to execute; then let up the mouse button. Help is available for all commands in the **Help** menu. Many of the menu commands have keyboard equivalents that are indicated in the menus. For example, the *Print* command in the **File** menu, which prints all information for the work session, can be issued by entering Ctrl+P. Menus (or commands within a menu) that are not presently accessible are dimmed. Dimmed items cannot be selected.

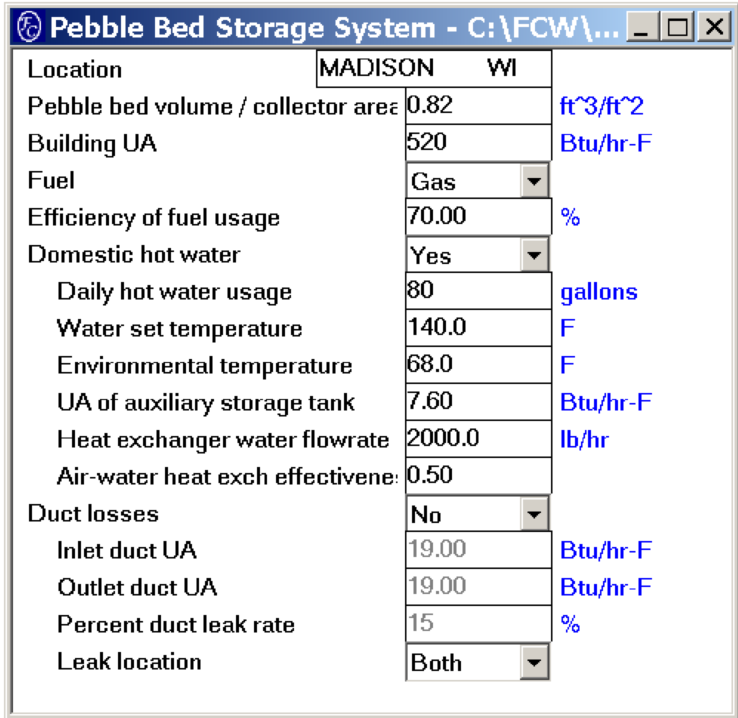
1.2 Example

Each system is described using three sets of parameters: the collector, the system and the economics sets. All three sets are shown at the start of the program. The economics parameter set will be in front and it will appear as follows:



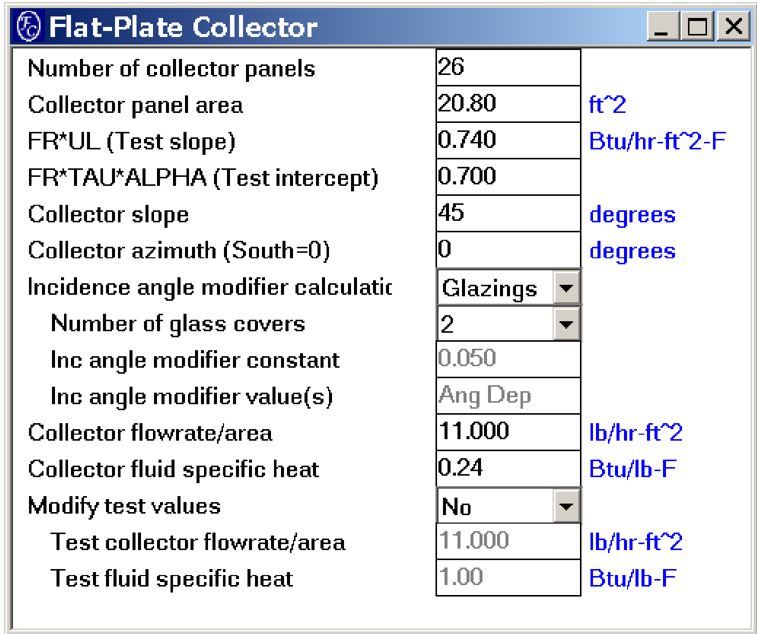
Depending on the screen size, the entire economics window may or may not fit on the screen. When the entire window cannot be displayed, the window will be provided with a scroll bar along the right hand side, as indicated above. Use of the scroll bar is needed to view the entire window. The operation of the scroll bars is the same as in any Windows application. The indicator, represented by the sliding box, can be controlled in three ways. It can be moved incrementally in either direction by clicking on the arrows. Holding the mouse button down while the cursor is positioned over the arrows causes a continuous slow scroll. The indicator can be moved up and down in large discrete amounts by clicking in the gray area above or below the indicator box. By placing the cursor on the indicator box and holding the mouse button down, the indicator can be dragged to any desired position.

Move the cursor to any exposed position on the Pebble-Bed Storage system window and click the mouse button to bring this window to the front. The default system parameters for the pebble bed system are:



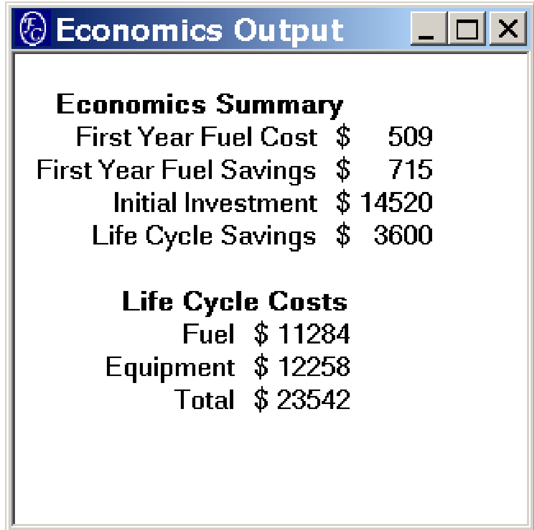
Note that the rectangular boxes for the last four parameter values are filled in with shading and no values are displayed. These four parameters are applicable only if Duct losses are considered in the calculation. Clicking the mouse in the box for Duct losses toggles the display from No to Yes and will uncover the duct loss parameters.

To move the collector parameter window to the front, place the cursor anywhere on the collector window and click the mouse button (or issue the *Collector Parameters* command from the **Window** menu). The default flat-plate collector parameter window will appear as:



There are several other window controls that you should be aware of. The title bar at the top of the window displays a title indicating the window's contents. When the window is active (i.e., the front window) the title bar will be displayed in color. The title bar serves as a handle should you wish to move the window. Move the cursor to a position within the title bar and press and hold the mouse button while dragging the window to a new position. At the right corner of the title bar is a small box with an X referred to as the 'go-away' box. Clicking the mouse button while the cursor is positioned in the go-away box will cause the window to be removed from view. The other two small boxes will minimize or maximize the window. The vertical size of any of the windows can be changed by moving the cursor to the lower right corner of the window and holding the mouse button down while dragging the mouse up or down to make the window longer or shorter.

Select *Calculate* from the **Run/Plot** menu (or enter F2) to initiate the calculations for this system in Madison, Wisconsin. When the calculations are completed, two new windows will appear showing the performance and economics results. The economics output window will be in front and by default, it will display a summary of the economic calculations. More detailed economic results, including a year-by-year cash flow analysis, can be obtained by changing the first parameter in the economics window.


Economics Output

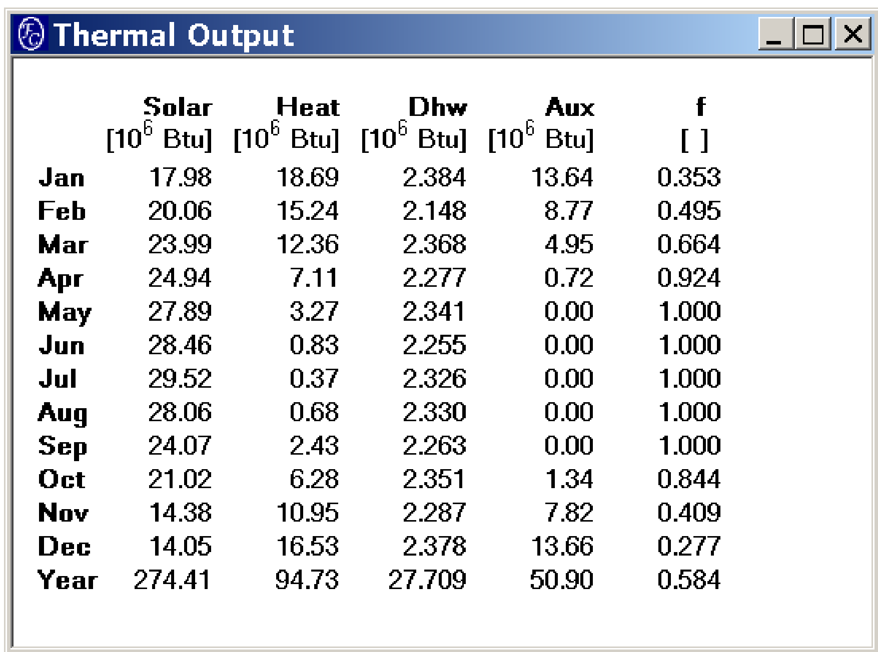
Economics Summary

First Year Fuel Cost	$ 509
First Year Fuel Savings	$ 715
Initial Investment	$ 14520
Life Cycle Savings	$ 3600

Life Cycle Costs

Fuel	$ 11284
Equipment	$ 12258
Total	$ 23542

Move the cursor to an exposed portion of the Thermal Output window to bring it to the front.


Thermal Output

	Solar [10^6 Btu]	Heat [10^6 Btu]	Dhw [10^6 Btu]	Aux [10^6 Btu]	f [ ]
Jan	17.98	18.69	2.384	13.64	0.353
Feb	20.06	15.24	2.148	8.77	0.495
Mar	23.99	12.36	2.368	4.95	0.664
Apr	24.94	7.11	2.277	0.72	0.924
May	27.89	3.27	2.341	0.00	1.000
Jun	28.46	0.83	2.255	0.00	1.000
Jul	29.52	0.37	2.326	0.00	1.000
Aug	28.06	0.68	2.330	0.00	1.000
Sep	24.07	2.43	2.263	0.00	1.000
Oct	21.02	6.28	2.351	1.34	0.844
Nov	14.38	10.95	2.287	7.82	0.409
Dec	14.05	16.53	2.378	13.66	0.277
Year	274.41	94.73	27.709	50.90	0.584

The system or economics parameters can easily be changed to determine the effect of alternative designs. For example, let's determine the performance for an array of 40 collector panels. Click on an exposed portion of the collector parameter window to bring it to the front. You may first want to use the *Stack* command in the **Edit** menu to organize the windows on the screen so that all of the title bars are visible. Now move the mouse to position the cursor just after the 6 in the edit box for the Number of collector panels and double-click the mouse. The line for which changes are being made will now be highlighted (i.e. displayed in inverse).

Flat-Plate Collector

Number of collector panels	26	
Collector panel area	20.80	ft^2
FR*UL (Test slope)	0.740	Btu/hr-ft^2-F
FR*TAU*ALPHA (Test intercept)	0.700	
Collector slope	45	degrees
Collector azimuth (South=0)	0	degrees
Incidence angle modifier calculatic	Glazings	
Number of glass covers	2	
Inc angle modifier constant	0.050	
Inc angle modifier value(s)	Ang Dep	
Collector flowrate/area	11.000	lb/hr-ft^2
Collector fluid specific heat	0.24	Btu/lb-F
Modify test values	No	
Test collector flowrate/area	11.000	lb/hr-ft^2
Test fluid specific heat	1.00	Btu/lb-F

Now enter 40 for the number of collector panels.

Number of collector panels	40

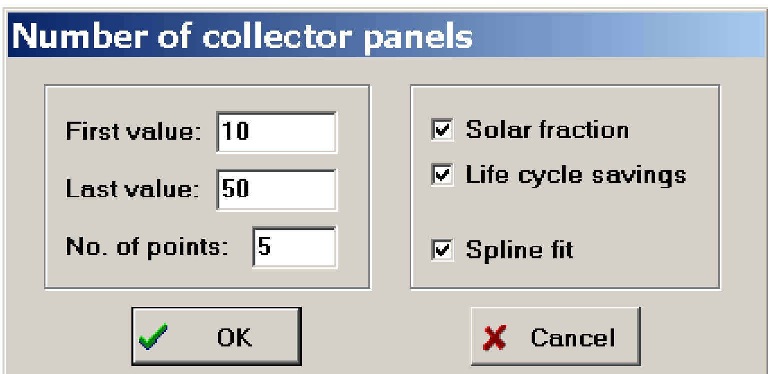
Select the *Calculate* command to repeat the calculations. Both the Thermal and Economic Output windows will be updated. The Thermal Output window will now appear like this:

Thermal Output

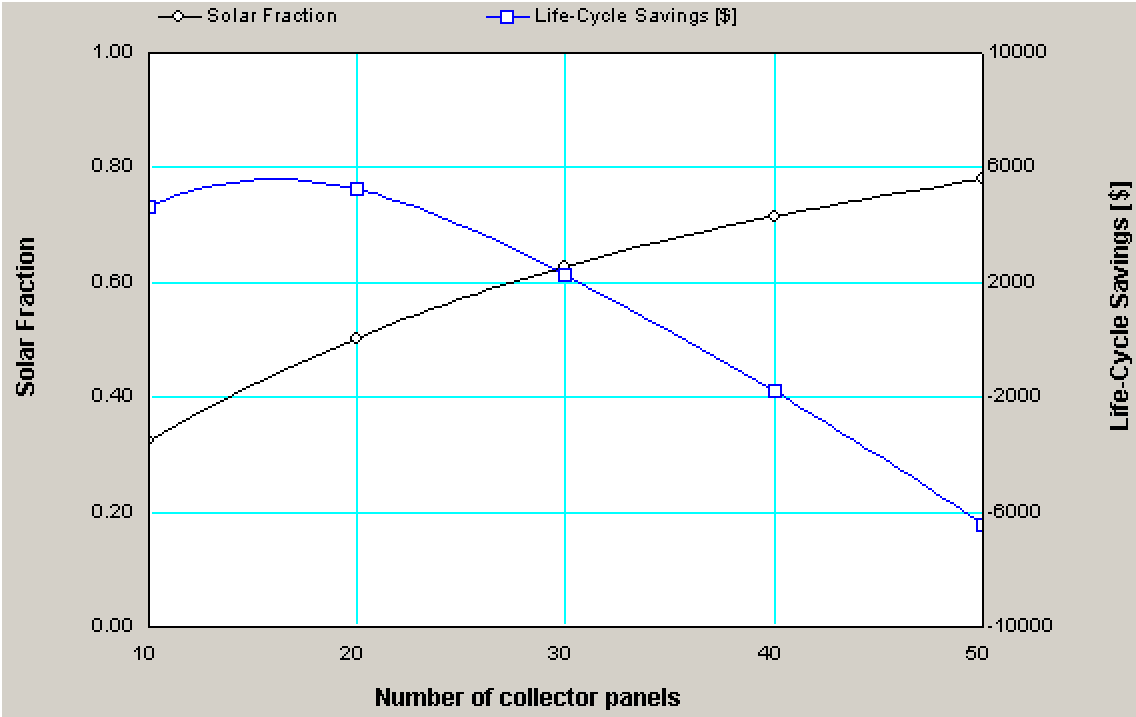
	Solar $[10^6$ Btu]	Heat $[10^6$ Btu]	Dhw $[10^6$ Btu]	Aux $[10^6$ Btu]	f [ ]
Jan	27.66	18.69	2.384	10.35	0.509
Feb	30.86	15.24	2.148	5.36	0.692
Mar	36.91	12.36	2.368	1.82	0.877
Apr	38.36	7.11	2.277	0.18	0.981
May	42.91	3.27	2.341	0.00	1.000
Jun	43.78	0.83	2.255	0.00	1.000
Jul	45.41	0.37	2.326	0.00	1.000
Aug	43.16	0.68	2.330	0.00	1.000
Sep	37.03	2.43	2.263	0.00	1.000
Oct	32.34	6.28	2.351	0.34	0.961
Nov	22.13	10.95	2.287	5.57	0.579
Dec	21.62	16.53	2.378	11.22	0.406
Year	422.17	94.73	27.709	34.83	0.715

Notice the non-intuitive results. Although the array area was increased by 54% from 26 to 40 panels, the fraction of the load supplied directly by the system increased only from 58.4% to 71.5%!

There is another way to examine the effect of a parameter such as array area on the system performance and economics. The *Parametric Plot* command in the **Run/Plot** menu produces a plot of the solar fraction and/or the life-cycle savings as a function of many of the parameters. For example, let's plot of solar fraction and life-cycle savings as a function of number of collector panels. We need to bring the collector parameters window to the front; but there are so many windows on the screen, it is difficult to see the collector parameters window. An easy way to bring the window to the front is to select *Collector Parameters* from the **Window** menu. Clicking on Number of collector panels in the collector window will cause the cursor to flash on this parameter. Now select *Parametric plot* from the **Run/Plot** menu. A dialog box will appear in which you enter low and high values for the Number of collector panels and the number of points for which calculations are to be made. Enter 10 and 50 respectively with No. of points equal to five. The dialog box should now appear like this.

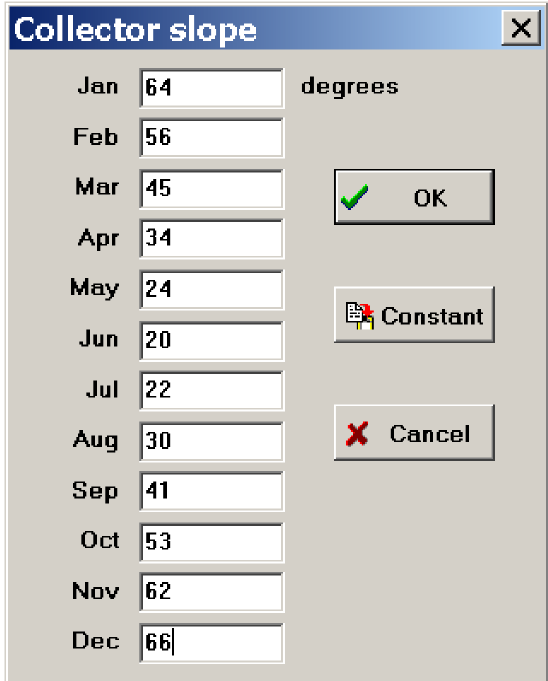


When the Ok button is clicked, **F-Chart** will initiate calculations using five values of Number of collector panels ranging between 10 and 50 (in this case, 10, 20, 30, 40, and 50 panels). If the Smooth Curves box is checked, a spline curve will be fit through the points. A check in the Life-Cycle Savings box will result in a plot of the savings as well as the solar fraction. When the calculations are completed, the plot will appear in a separate window on the screen. It is clear from the plot that the maximum life-cycle savings occurs with about 17 panels and the corresponding solar fraction is about 43%.



The look of the plot can easily be changed. Double click on the plot and you have access to and can change many of the plot attributes.

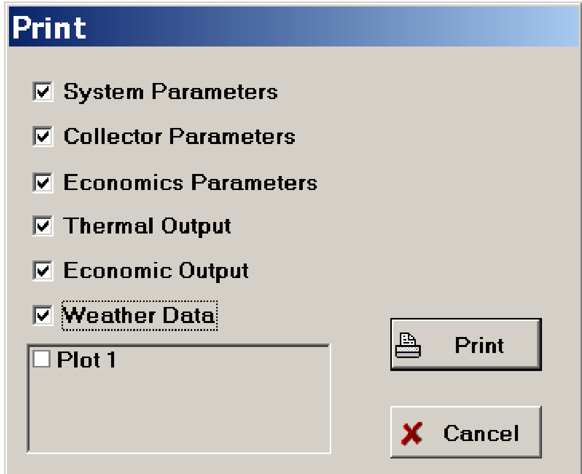
Most of the system parameters may assume monthly values. For example, suppose you wish to consider the advantage of adjusting the slope of the collector at monthly intervals. The optimum slope for any month will be the latitude plus the average solar declination for that month. (Average monthly declinations are given in Table 1.6.1 of Duffie and Beckman [1991].) To assign monthly values to the collector slope (or to change the values), place the cursor on the Collector slope parameter; and select *Monthly* from the **Edit** menu (or alternatively, press Ctrl+M) and a dialog box will appear showing the monthly values which, by default, are all equal to 45 degrees. Enter the following optimum values.



Click the Ok button when the values are entered. The dialog box will disappear and the system parameter window will be in front. The edit box for Collector slope now contains the word "Monthly" to indicate that this parameter has monthly values. You can change or view the values at any time by clicking the mouse button when the cursor is on the parameter.

Now pull down *Calculate* from the **Run/Plot** menu (or enter F2) to determine the increase in performance resulting from monthly orientation changes.

The contents of a window can be on the Clipboard using the *Copy Window* command in the **Edit** menu (or enter Ctrl-A). Any of the output appearing on the screen can be printed. Select *Print* from the **File** menu (or enter Ctrl+P) to bring up the Print dialog box.



If a check appears in the box, the item following the checkbox will be printed. (A dimmed item cannot be printed because it does not exist) To select or unselect an item, move the cursor to the appropriate check box and click the mouse button. By default, the output will go to the printer. Click the Print button to initiate the printing process. Following the traditional Windows operating practice, different printers can be selected using the *Printer Setup* option in the **File** menu.

You have now seen how the program is structured, how to select a system, change parameters and do the calculations. Try running another example. Don't forget the help feature. Help is available for most menus, commands and parameters by highlighting the object and pressing F1. The manual often provides additional information.

CHAPTER 2

Commands

2.1 Working with Menus

Commands are distributed among nine pull-down menus appearing at the top of the screen. To select a command, place the cursor on the desired menu title, press the left mouse button, and while holding the button down, slide the cursor to the command you wish to execute; then let up the mouse button. Many of the menu items have command key equivalents. That is, they can be executed either by using the mouse or by pressing the Ctrl key followed by the appropriate letter or number as shown to the right of the command in the pull-down menus.

2.2 Changing Parameter Values

The information needed to describe a system is contained in the system, collector, and economic parameter windows. To change the values of these parameters, move the cursor to the rectangular box containing the value and left click the mouse button. The cursor will flash in the box to indicate that it is the active parameter. Use the backspace key or drag the cursor to erase characters to the left of the flashing cursor. Characters entered from the keyboard are placed to the right of the indicator. A double click within the edit box will cause all of the characters in the edit box to be highlighted (i.e., displayed in inverse video). Pressing any key will replace the highlighted field with the character being typed. All parameter values are checked after they are entered. **F-Chart** will immediately inform you of an improper parameter with an appropriate error message.

2.3 Dialog Boxes

Many of the menu commands such as *Change/View Load*, will produce a dialog box in which you must supply information. Information which you can change is enclosed within a small rectangular edit box. Default values, if available, will be displayed. Values can be changed in the same manner as described for parameter values. Click the Ok button to accept all of the changes. Click cancel to disregard all changes.

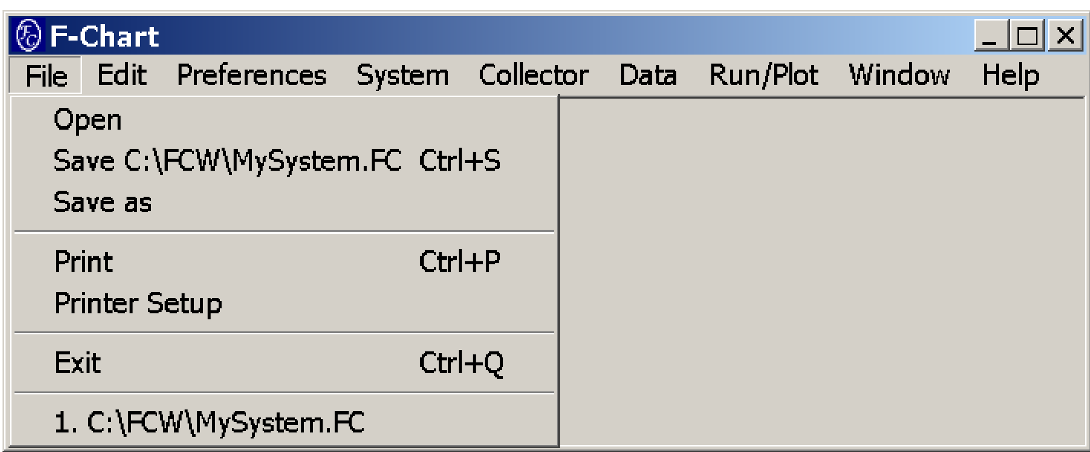
2.4 Using Scroll Bars

Many of the F-Chart windows are equipped with vertical and horizontal scroll bars that allow the contents of a window that is larger than the screen to be viewed. The operation of the scroll bars is as follows. The indicator position, represented by the small box, can be controlled in three ways. It can be moved either direction by clicking on the arrows. Holding the mouse button down while it is positioned over the arrows causes a continuous slow scroll. The indicator can be moved up and down in large discrete increments by clicking in the gray area above or below the indicator box. By placing the cursor on the indicator box and holding the mouse button down, the indicator can be dragged to any desired position.

2.5 Menu Command Descriptions

The remainder of this chapter provides detailed descriptions of each of the menu commands, Menu names will be shown in bold. Command names appearing in the menus will be shown in italics. All of the information presented here is available in the on-line **Help** menu.

2.5.1 The File Menu



Open will allow you to access and continue working on any file saved previously with the *Save* or *Save as* commands. After the confirmation for unsaved work, a dialog box will appear showing the names of all previously saved **F-Chart** files in the current folder. Other folders can be accessed in the normal Windows manner. Select a file by clicking the mouse button on the file name followed by a click on the Open button or alternatively, by double-clicking on the file name. When an old file is opened the screen will return to the state it was in when the file was saved. The nine most recently saved files are listed at the bottom and can be opened by double-clicking on the desired file.

Save will store all of the information in your work session on the disk with the same file name and on the same disk drive with which it was last saved. For a new work session, you will be prompted to supply a file name, just as if the *Save as* command were given. All information concerning the work session is saved on the disk, except the output. The stored information includes any changes you may have made to the meteorological data and the load. The *Save* menu item is deactivated (i.e., dimmed) after the save operation until a change is made.

Save as provides the same function as the *Save* command except that it will first prompt you to supply a file name. This command allows you to save the work session with another name or in another folder than used previously. A dialog box will appear in which you must supply a file name. Enter the file name of your choice in the box. The file name may have spaces, but should not contain a colon. The extension FC will be added automatically. Click the Save button when the name and drive are correct. Each time **F-Chart** is started, a default file called DEFAULTS.FC is brought up. If you wish, you can change this default file by setting up the parameters windows as you like and then saving it with the name DEFAULTS.FC in the folder where FCHART.EXE is located.

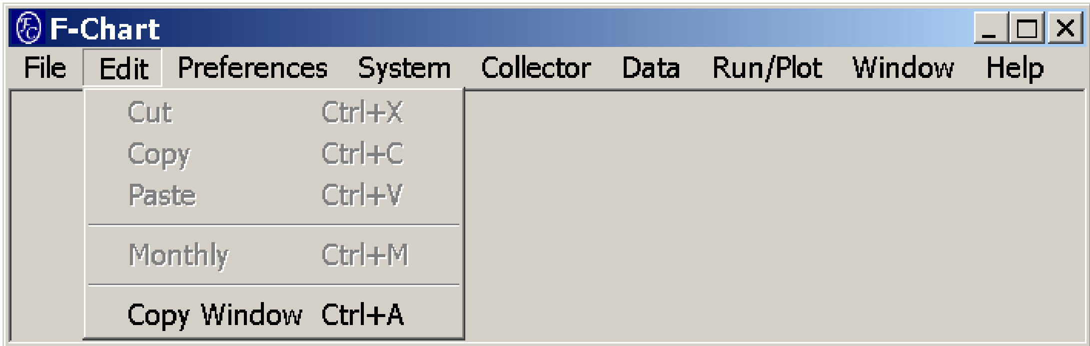
Print will allow printing of the contents of any window to a printer. A dialog box will appear with a number of check boxes on the left. If a box is checked, then the item it represents will be printed. To enter or remove a check mark, move the cursor to the box and click the mouse button. Dimmed items cannot be printed because they do not exist. Click Ok to start the print process.

To send output to a disk file rather than a printer, go to the Windows Start menu and select Settings and then Printers. Choose to add a printer. A dialog box will appear and choose local printer. When asked for the printer port, choose File and then use ‘Generic/Text only’ for the printer driver. In order to print to a text file, choose the ‘Generic/Text only’ printer in the *Printer Setup* command

Printer Setup brings up a dialog where you may choose your printer. This command need be given only once, provided that the same printer is used throughout the work session.

Quit command provides a graceful way to exit the program.

2.5.2 The Edit Menu

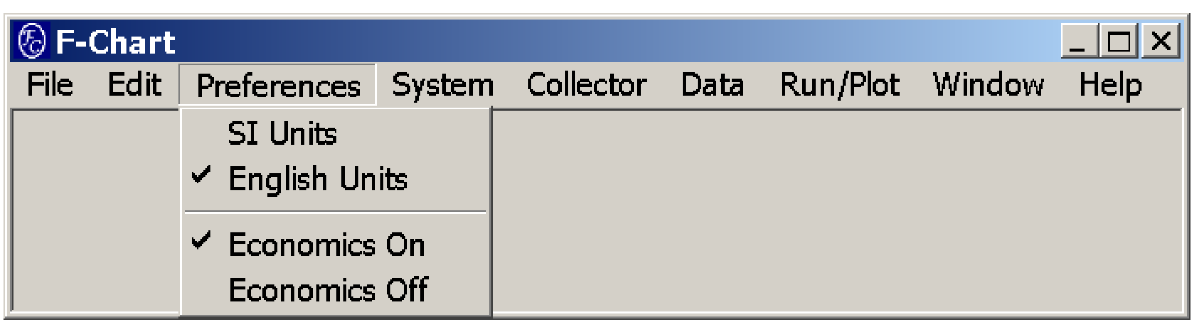


Cut, Copy and Paste perform the normal Windows functions.

Monthly allows a parameter to assume monthly values. To enter multiple values for a parameter, select the parameter by clicking the mouse button on the parameter value. If multiple values for this parameter are supported, the *Monthly* menu item in the **Edit** menu will be active (i.e., not dimmed). Select the *Monthly* item from the **Edit** menu (or use Ctrl+M). A dialog box will appear, showing the default values of the parameter. These values may be edited in the usual manner. The dialog box has three buttons. The Cancel button returns the program to the state it was in before the *Monthly* command was issued. The Constant button causes the parameter to assume a single constant value equal to the first value displayed, e.g., the January value. Pressing Ok will result in the parameter being associated with the displayed values. The word "Monthly" will be displayed in place of the parameter value. To edit multiple values, click on "Monthly". A maximum of seven monthly varying parameter values are allowed.

Copy Window places a copy of the active window on the clipboard. The clipboard information may be pasted into other programs such as word processors, spreadsheets or presentation software.

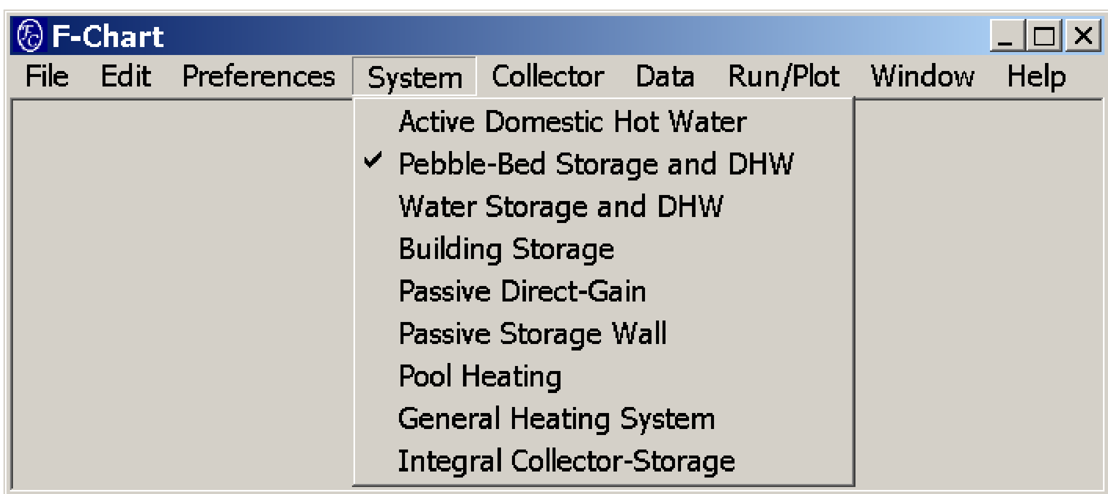
2.5.3 Preferences



SI and ***English*** control the unit system in which parameter values are entered. The currently selected unit system is indicated by a check mark in front of *SI Units* or *English Units* in the menu. The unit system can be changed at any point. All system information, including the weather data will be converted to the new unit system. You can use **F-Chart** to automatically do unit conversions by changing the unit system to that for which you know the parameter value, entering the value, and then changing back to the original unit system.

Economics On and ***Economics Off*** control the visibility of the economics parameter set. By default, the economics parameter window is visible. To remove the economics window from view and to thereby bypass the economic calculations, select *Economics Off*. To make the economics window visible (or to move it in front of all other windows), select *Economics On*. The economics parameters remain at their current values whether or not the economics window is visible. However, the economics calculations will be done only when the economics parameter window is visible.

2.5.4 System



Active Domestic Hot Water will open the parameter window for an active solar domestic hot water system. The system consists of a solar collector, optional freeze protection heat exchanger, and either one or two storage tanks. If a different system window is open at the time this command is issued, it will be closed and removed from view (with its parameters values retained). If the active domestic hot water window is already open, this command will cause the active domestic hot water system window to be moved in front of all other windows.

Pebble-Bed Storage Space & DHW will open the parameter window for a pebble-bed system. The pebble bed system is a space heating system (using air or liquid solar collectors) in which thermal energy is stored in heated pebbles. A combined space and domestic hot water system can be analyzed. If a different system window is open at the time this command is issued, it will be closed and removed from view (with its parameters values retained). If the pebble-bed window is already open, this command will cause the pebble-bed system window to be moved in front of all other windows.

Water Storage Space & DHW will open the parameter window for a solar space and domestic water heating system in which thermal energy is stored in a water tank. The system can be configured for just domestic water heating by setting the building UA to 0. If a different system window is open at the time this command is issued, it will be closed and removed from view (with its parameters values retained). If the water storage window is already open, this command will cause the water storage system window to be moved in front of all other windows.

Building Storage will open the parameter window for a solar space heating system that does not have its own thermal storage unit. When sufficient solar energy is available, energy is stored in the building structure by raising the indoor temperature above the low thermostat set temperature. A combined space and domestic hot water system can be analyzed. In this case, the presence of a water storage preheat tank is assumed. If a different system window is open at the time this command is issued, it will be closed and removed from view (with its parameters values retained). If the building storage window is already open, this command will cause the building storage system window to be moved in front of all other windows.

Passive Direct Gain will open the parameter window for a direct-gain passive solar space heating system. A direct gain system is essentially a window that allows solar energy to enter and be stored with the building structure by raising the indoor temperature above the low thermostat set temperature. If a different system window is open at the time this command is issued, it will be closed and removed from view (with its parameters values retained). If the direct gain window is already open, this command will cause the direct gain system window to be moved in front of all other windows.

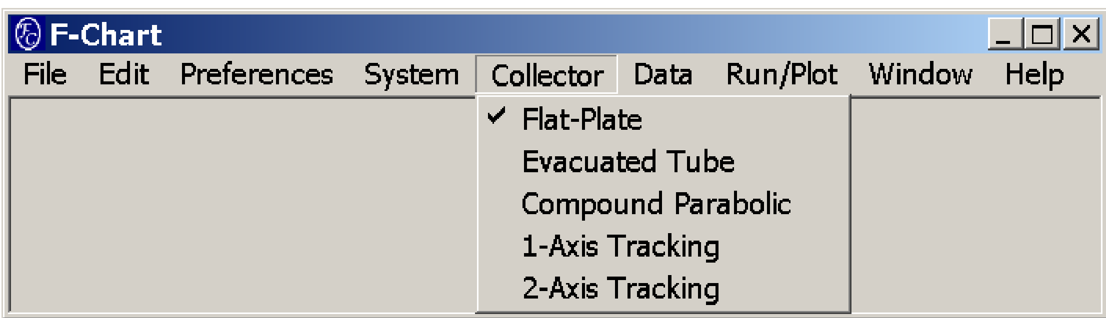
Passive Storage Wall will open the parameter window for a collector-storage wall passive solar space heating system. In this system a masonry wall is used to absorb and store incident solar radiation that is later released within the building. If a different system window is open at the time this command is issued, it will be closed and removed from view (with its parameters values retained). If the collector-storage window is already open, this command will cause the collector-storage system window to be moved in front of all other windows.

Pool Heating will open the parameter window for a solar pool heating system. Both indoor and outdoor pools can be analyzed. If a different system window is open at the time this command is issued, it will be closed and removed from view (with its parameters values retained). If the pool system window is already open, this command will cause it to be moved in front of all other windows.

General Heating System will open the parameter window for a general solar energy system. The general solar energy system can be either a closed or open-loop solar energy designed to supply thermal energy above a specified temperature. It can represent a space heating water heating, absorption air conditioning, or process heating system. If a different system window is open at the time this command is issued, it will be closed and removed from view (with its parameters values retained). If the general system window is already open, this command will cause it to be moved in front of all other windows.

Integral Collector-Storage will open the parameter window for an integral collector-storage (ICS) domestic water heating system. The ICS system combines the collector with the water storage unit. The analysis method requires test data from the SRCC test method. If a different system window is open at the time this command is issued, it will be closed and removed from view (with its parameters values retained). If the ICS system window is already open, this command will cause it to be moved in front of all other windows.

2.5.5 Collector



The **Collector** menu can be accessed only after a system type has been chosen. The passive direct gain, collector storage wall and ICS systems do not require a collector specification. The currently selected collector type is indicated by a check mark in the **Collector** menu. If a different collector window is open at the time when a **Collector** menu command is issued, it will be closed and removed from view (with its parameters values retained) and replaced by a new window with the selected collector type. If the same collector type is selected, the command will cause the collector window to be moved in front of all other windows.

Flat-Plate will open the parameter window for a flat-plate solar collector. The collector may be used with air or liquid. Collector performance is described using ASHRAE 93-77 test results.

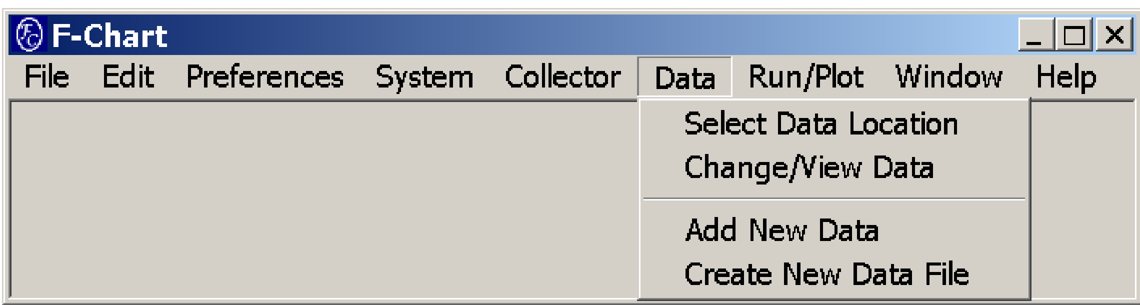
Evacuated Tube will open the parameter window for an evacuated tube collector. Evacuated tubes are modeled in the same manner as flat-plate collectors, with the exception that incidence angle modifiers may be specified for the planes parallel and perpendicular to the tube axis. The collector may be used with air or liquid.

Compound Parabolic will open the parameter window for a compound parabolic concentrating (CPC) solar collector. The collector may be used with air or liquid. CPC collectors are modeled in a manner similar to evacuated tubes except that beam radiation can be utilized only if it is within the collector acceptance angle.

1-Axis Tracking will open the parameter window for a solar collector that can track the solar position by rotation about a single axis. The axis may be horizontal (as in east-west and north-south orientations) or tilted as in a polar axis orientation. The tracking collector may a flat-plate or a concentrator.

2-Axis Tracking will open the parameter window for a solar collector that can track the solar position by rotation about two axes so that the collector plane is always normal to the solar position. The collector may a flat-plate or a concentrator using air or liquid.

2.5.6 Data



Select Data Location is used to first select a file of weather data and then to select the city from the file. When searching for a particular city, select a city and then press the first letter in the name of the desired city. There is a check box to the calculations for all cities in a file rather than one at a time. When "all cities" is selected, a dialog box appears asking for the name of a file where data will be sent. Information in this file can be later manipulated.

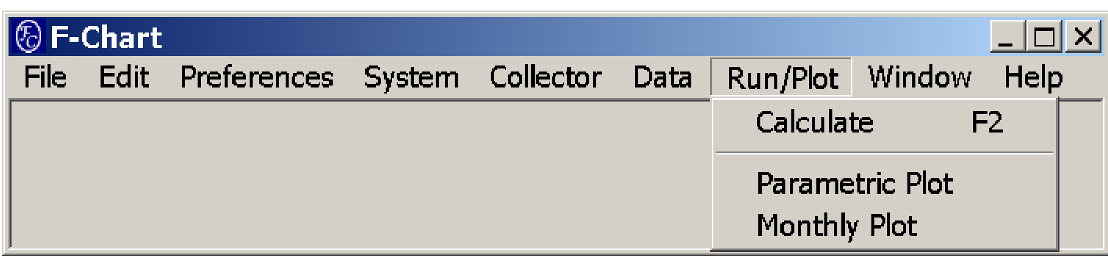
Weather data for the 16 California climate zones have been supplied by the California Energy Commission. The data for those cities that are in both the original **F-Chart** database and the CEC database are not the same. The **F-Chart** database, USA_Old, comes from a 1978 DOE report, Input Data for Solar Systems by V. Cinquemani, J.R. Owenby, Jr. and R.G. Baldwin (prepared under interagency agreement no E(49-26)-1041). The **F-Chart** database USA_New comes from the National Solar Radiation DataBase (NSRDB) created by the National Renewable Energy Laboratory (NREL).

Change/View data is used to examine or modify any of the meteorological data for the currently selected city indicated in the menu title. A dialog box will appear showing monthly values of the solar radiation, ambient temperature and ground reflectance. Click the cancel button if you are just viewing the data. Any of these values can be changed. Click the OK button after making the desired changes. These changes will be stored along with other specific system information when the *Save or Save as* command is used. It is also possible to permanently store the data, independent of the system description, by clicking the Archive button. The Archive process permanently alters the master data file, so be sure that you have a backup copy.

Add New Data allows the user to enter meteorological data for a new location. A dialog box will appear with rectangular boxes in which the city name, latitude, and monthly-average values of the solar radiation, ambient temperature and ground reflectance. Click the Ok button to save the data. The city name will not be placed on a map, but will appear in the list of cities shown with the Cites Not on Map command. This command will permanently alter the master data file. It is not possible to delete a city. Be sure that you have a backup copy of the original program.

Create new Data File allows the user to select data from individual cities in any of the city files and construct a new city file.

2.5.7 Run/Plot



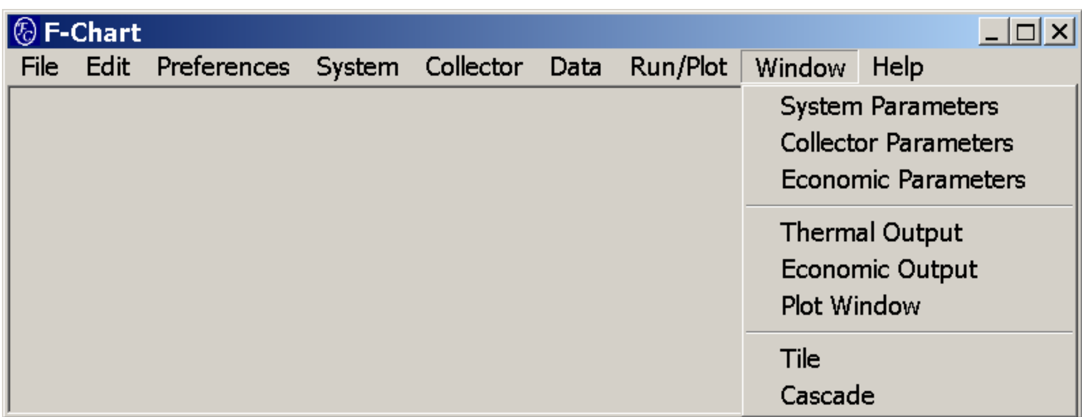
Calculate initiates the calculations for the system described by the parameter values in the system and economics windows. A dialog box will appear showing the progress of the calculations. The *Run* command generates a performance output window and, if the economics parameter window is open, an economics output window. Click the mouse button on the window you wish to view to bring it to the front. These output windows can be output to a printer, a disk file using the *Print* command.

Parametric Plot produces a plot of solar fraction and/or live-cycle savings versus any of the parameters that can have continuous values. Place the cursor on a parameter in the system, collector or economics parameters. If the *Parametric Plot* command is available for the selected parameter then executing this command will bring up a dialog window where the range of the parameter is selected along with the number of calculations to make within that range. A spline interpolation is done between points if the box in front of Spline fit is checked. The plot may be copied to the Clipboard using the *Copy Window* command in the **Edit** menu.

Double-clicking on any plot provides a means to change the character of the plot. Any of the plotting attributes can be changed but pleasing plots will be obtained with the plot default settings. The number of divisions, axis font size, plotted range, the presence or absence of grid lines and linear or logarithmic scales can be selected and changed.

Monthly Plot plots monthly values of the calculated thermal performance parameters such as solar fraction, incident solar energy and others as well as weather data. These plots can only be generated after the calculate command has been issued. When the *Monthly Plot* command is issued a dialog box appears. First select either the Calculated performance or Weather data radio button and then select the quantity to be plotted. The minimum and maximum values of the selected quantity will be displayed in the display format currently selected.

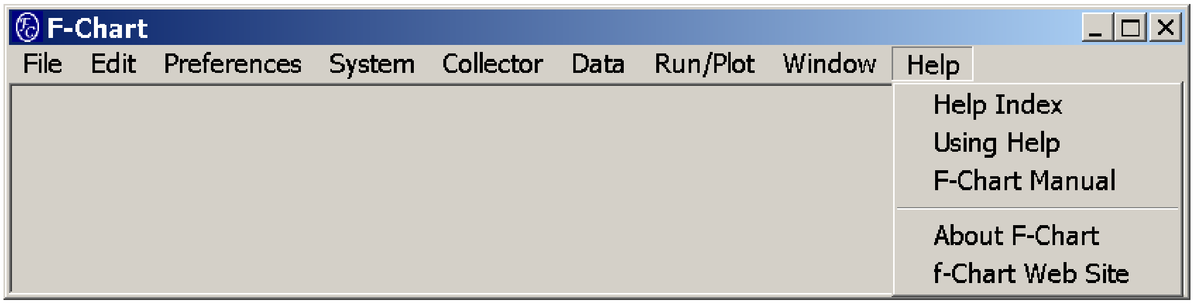
2.5.8 Window



System Parameters or any of the other windows can be moved to the front by selecting it.

Tile and Cascade organizes the open windows on the screen. The *Tile* command will place all windows side by side in two columns. The *Cascade* command places the window currently being edited in front and all other windows are positioned so that only their title bars are showing. These commands only affect the visual display.

2.5.9 Help



Help Index will activate the help processor that provides specific information on the use to **F-Chart**. Help for any parameter is available by selecting the parameter and then either selecting *Help Index* or by pressing the F1 key. Help on commands is obtained by dragging the cursor to the command of interest and pressing F1 or by selecting the command after issuing the *Help Index* command.

Using Help provides instructions on how to move around in the help processor.

F-Chart Manual starts Adobe Acrobat and displays an electronic version of this manual.

About F-Chart displays the window that comes up when the **F-Chart** program is started. This window lists the program version number and the registered owner. This information must be supplied when making inquiries about the program.

f-Chart Web Site opens the default browser program and sets the URL to the f-Chart web site. The program developers can be contacted by e-mail through the web site.

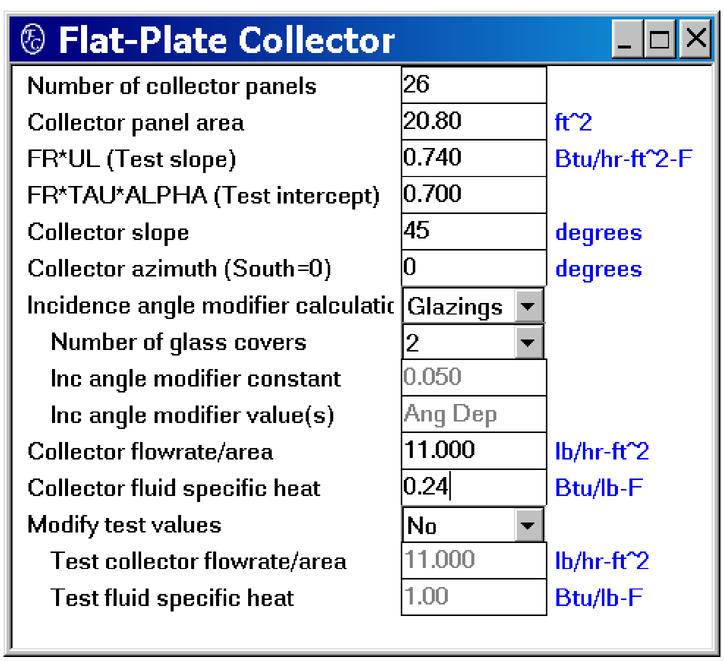
CHAPTER 3

Collector Parameter Sets

Five types of solar collectors may be evaluated by **F-Chart** for use with any of the active solar systems. The collector type is chosen from the collector menu. The basic equation relating the useful energy gain of the collector to meteorological variables has the same form for all five collector types, as shown in Duffie and Beckman [1991]. In each case, the performance of the collector is described in terms of FR*TAU*ALPHA ($F_R(\tau\alpha)$) and FR*UL ($F_R U_L$). FR*TAU*ALPHA (also call the optical efficiency) is the efficiency the solar collector would have if the collector inlet temperature were equal to the ambient temperature. FR*UL accounts for thermal losses. These parameters can be determined theoretically (Duffie and Beckman [1991]) or experimentally from the ASHRAE 93-77 collector test procedure [1977]. Provision is made in the parameter set for each collector type to modify the test values of the collector parameters to account for incidence angle effects and changes in the collector fluid flow rate from the test value.

In the following sections of this chapter, the parameter sets for each of the five solar collector types are displayed, along with their default settings in English units. A short description of each parameter is provided.

3.1 Flat-Plate Solar Collector



Number of collector panels is multiplied by the area of a single collector panel to determine the total array area.

Collector panel area is either the gross or net aperture area of each collector panel. The same (gross or net) aperture area that was used to determine FR*TAU*ALPHA and FR*UL must be used for this parameter. The ASHRAE Standard 93-77 [1977] collector test recommends the use of gross area.

FR*UL (Test Slope) is the product of the collector heat removal factor, FR, and the collector overall heat loss factor, UL. FR*UL is the negative of the slope of the straight-line efficiency plot obtained from the ASHRAE Standard 93-77 [1977] collector test.

FR*TAU*ALPHA (Test Intercept) is the product of the collector heat removal factor, FR, and the transmittance-absorptance product, TAU*ALPHA, at normal incidence. This parameter is also known as the optical efficiency. It is the Y-intercept of the straight-line efficiency plot obtained from the ASHRAE Standard 93-77 [1977] collector test.

Collector slope is the angle between the plane of the collector aperture and the horizontal. This parameter may have monthly values. The angle is measured in a vertical plane that is perpendicular to the line formed by the intersection of the plane of the collector aperture and the horizontal plane.

Collector azimuth (South=0) is the angle between the projection into the horizontal plane of the normal to the collector aperture and the local meridian with the zero point directly facing the equator, west positive, and east negative. The azimuth of a horizontal collector can have any value. The azimuth of a collector facing the sun at noon in the southern hemisphere (i.e. north facing) is 180. This parameter may have monthly values.

Incidence angle modifier calculation cycles through 'Glazings', 'Constant', and 'Value(s)' to indicate which of three possible methods is to be used to calculate the effect of incidence angle on FR*TAU*ALPHA. One of the next three parameters will be available depending upon the selection; the other two will be hidden. If 'Glazings' is selected, the Fresnel equations are used with nominal glass properties and the number of glazings will have to be selected. If 'Constant' is selected, the ASHRAE incident angle modifier constant will be required. If 'Value(s)' is selected, either a single incidence angle modifier or the incident angle modifier value for every 10 degrees will be required. If Value(s) is selected, then select ‘Ang Dep’ to enter either a single value or a value every 10 degrees in the dialog window.

Number of glazings can be 1 to 4. Values of the monthly-average incidence angle modifier are calculated using the Fresnel equations with glass properties and the method described in Duffie and Beckman [1991].

Inc angle modifier constant, b, is the parameter which provides the best fit in the equation K(t) = 1.0 - b (1/cos(t) - 1.0) where K(t) is the ratio of the transmittance-absorptance product at incidence angle t to the normal incidence transmittance-absorptance product. The constant, b, is determined experimentally as described in the ASHRAE Standard 93-77 collector test procedure [1977]. This parameter is active only if 'Constant' was chosen for the incidence angle modifier type.

Inc angle modifier value(s) are the value(s) of the collector incidence angle modifier, K(t) as determined by the ASHRAE Standard 93-77 collector test procedure [1977]. If a single value is used for this parameter, then the incidence angle modifier is taken to be that constant value independent of solar incidence angle. Alternatively, values of this parameter may be specified for incidence angles between 0 and 90 degrees in 10-degree increments. The incidence angle value(s) are used only if 'Value(s)' was chosen for the incidence angle modifier type.

Collector flow rate/area is the total mass flow rate of collector fluid through the collector array divided by the total collector array area. This flow rate may be different from the flow rate at which the collector was tested. Typical values of this flow rate are 11 lb/hr-ft^2 or 0.015 kg/s-m^2 for liquids and 9 lb/hr-ft^2 or 0.012 kg/s-m^2 for air.

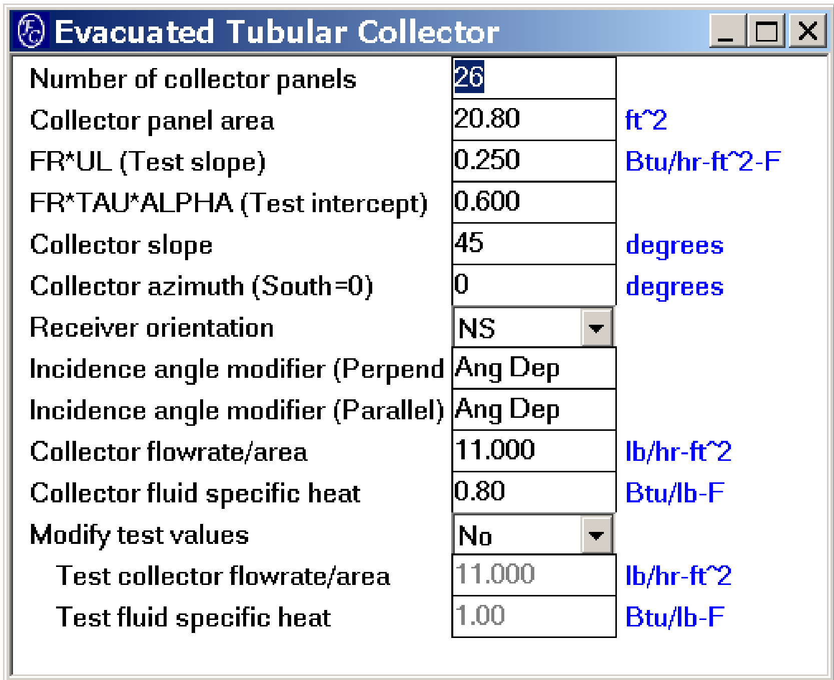
Collector fluid specific heat is the specific heat of the fluid flowing through the collectors. Properties can be found in the ASHRAE handbook of Fundamentals [1985] or in any heat transfer textbook. For water, use 1.0 Btu/lb-F or 4.19 kJ/kg-K. For air use 1.0 kJ/kg-K or 0.24 Btu/lb-F.

Modify Test Values (Yes/No) toggles to indicate if the next two parameters should be used to account for differences in the collector parameters due to differences in the actual and test fluid flow rates and series-parallel fluid flow circuit arrangements. If this parameter is set to No, the following two parameters are ignored.

Test collector flow rate/area is the ratio of the collector fluid flow rate used in the collector test to the array area of the collector tested. Usually, a single collector panel is tested. In this case, this parameter is the ratio of the test collector fluid flow rate to the collector panel area. This parameter is used only if Yes has been selected for 'modify test values'.

Test fluid specific heat is the specific heat of the fluid used in the collector test. Properties of common materials can be found in the ASHRAE Handbook of Fundamentals [1985] or in any heat transfer textbook. This parameter is used if Yes is selected for 'modify test values'.

3.2 Evacuated Tube Collectors



Number of collector panels is multiplied by the area of a single collector panel to determine the total array area.

Collector panel area is either the gross or net aperture area of each collector panel. The same (gross or net) aperture area that was used to determine FR*TAU*ALPHA and FR*UL must be used for this parameter. The ASHRAE Standard 93-77 [1977] collector test recommends the use of gross area.

FR*UL (Test Slope) is the product of the collector heat removal factor, FR, and the collector overall heat loss factor, UL. FR*UL is the negative of the slope of the straight line efficiency plot obtained from the ASHRAE Standard 93-77 [1977] collector test.

FR*TAU*ALPHA (Test Intercept) is the product of the collector heat removal factor, FR, and the transmittance-absorptance product, TAU*ALPHA, at normal incidence. This parameter is also known as the optical efficiency. It is the Y-intercept of the straight line efficiency plot obtained from the ASHRAE Standard 93-77 [1977] collector test.

Collector slope is the angle between the plane of the collector aperture and the horizontal. This parameter may have monthly values. The angle is measured in a vertical plane that is perpendicular to the line formed by the intersection of the plane of the collector aperture and the horizontal plane.

Collector azimuth (South=0) is the angle between the projection into the horizontal plane of the normal to the collector aperture and the local meridian with the zero point directly facing the equator, west positive, and east negative. The azimuth of a horizontal collector can have any value. The azimuth of a collector facing the sun at noon in the southern hemisphere (i.e. north facing) is 180¡ . This parameter may have monthly values.

Receiver orientation (EW,NS) toggles to indicate the axis orientation of the evacuated tubes. Specify NS if the collectors are mounted vertically with the tube pointing up and down.

Incidence angle modifier (Perpendicular) values(s) are the incidence angle modifiers for the plane perpendicular to the tube axis (i.e., the transverse plane). The incidence angle modifier is the ratio of the transmittance-absorptance product at an off-normal incidence angle in the transverse plane to the normal incidence transmittance-absorptance product. This parameter may have either one or ten values. A single value indicates that the incidence angle modifier is independent of solar incidence angle. The ten values, as shown above for the default parameter set, correspond to the incidence angle modifier values between 0 and 90 degrees in 10-degree increments.

Incidence angle modifier (Parallel) value(s) are the incidence angle modifiers for the plane parallel to the tube axis (i.e., the longitudinal plane). The incidence angle modifier is the ratio of the transmittance-absorptance product at an off-normal incidence angle in the longitudinal plane to the normal incidence transmittance-absorptance product. This parameter may have either one or ten values. A single value indicates that the incidence angle modifier is independent of solar incidence angle. The ten values, as shown above for the default parameter set, correspond to the incidence angle modifier values between 0 and 90 degrees in 10-degree increments.

Collector flow rate/area is the total mass flow rate of collector fluid through the collector array divided by the total collector array area. This flow rate may be different from the flow rate at which the collector was tested. Typical values of this flow rate are 11 lb/hr-ft^2 or 0.015 kg/s-m^2 for liquids and 9 lb/hr-ft^2 or 0.012 kg/s-m^2 for air.

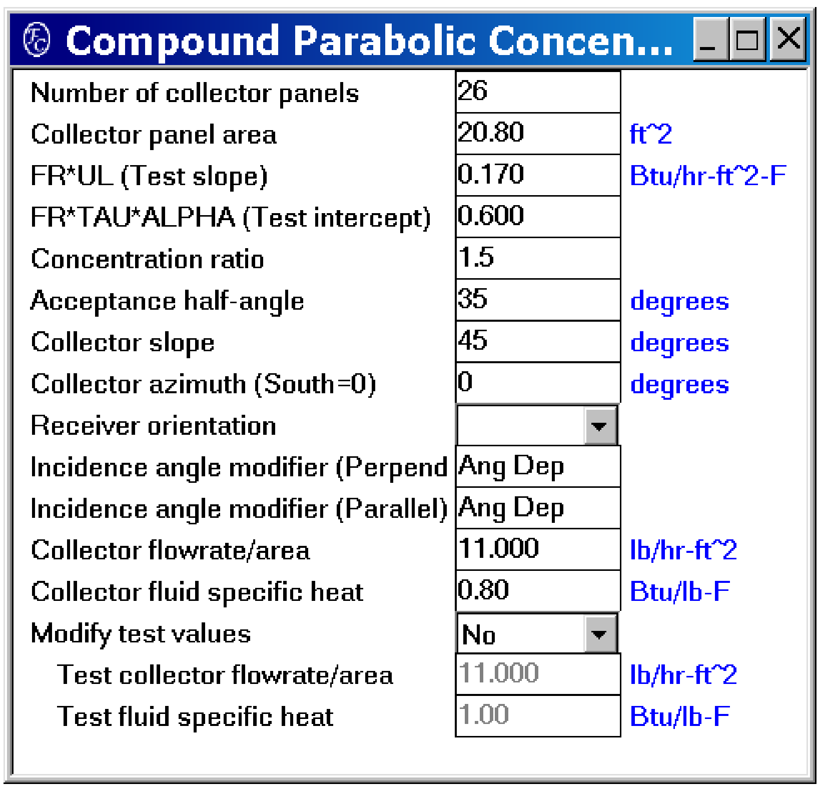
Collector fluid specific heat is the specific heat of the fluid flowing through the collectors. Properties can be found in the ASHRAE handbook of Fundamentals [1985] or in any heat transfer textbook. For water, use 1.0 Btu/lb-F or 4.19 kJ/kg-K. For air use 1.0 kJ/kg-K or 0.24 Btu/lb-F.

Modify Test Values (Yes/No) toggles to indicate if the next two parameters should be used to account for differences in the collector parameters due to differences in the actual and test fluid flow rates and series-parallel fluid flow circuit arrangements. If this parameter is set to No, the following three parameters are ignored.

Test collector flow rate/area is the ratio of the collector fluid flow rate used in the collector test to the array area of the collector tested. Usually, a single collector panel is tested. In this case, this parameter is the ratio of the test collector fluid flow rate to the collector panel area. This parameter is used only if Yes has been selected for 'modify test values'.

Test fluid specific heat is the specific heat of the fluid used in the collector test. Properties of common materials can be found in the ASHRAE Handbook of Fundamentals [1985] or in any heat transfer textbook. This parameter is used only if Yes is selected for 'modify test values'.

3.3 Compound Parabolic Concentrating Collector



Number of collector panels is multiplied by the area of a single collector panel to determine the total array area.

Collector panel area is either the gross or net aperture area of each collector panel. The same (gross or net) aperture area that was used to determine FR*TAU*ALPHA and FR*UL must be used for this parameter. The ASHRAE Standard 93-77 [1977] collector test recommends the use of gross area.

FR*UL (Test Slope) is the product of the collector heat removal factor, FR, and the collector overall heat loss factor, UL. FR*UL is the negative of the slope of the straight-line efficiency plot obtained from the ASHRAE Standard 93-77 [1977] collector test.

FR*TAU*ALPHA (Test Intercept) is the product of the collector heat removal factor, FR, and the transmittance-absorptance product, TAU*ALPHA, at normal incidence. This parameter, also known as the optical efficiency, is the Y-intercept of the straight-line efficiency plot obtained from the ASHRAE Standard 93-77 [1977] collector test.

Concentration ratio is the ratio of the collector aperture area to the receiver area.

Acceptance half-angle is the maximum angle measured from the axis of the CPC for which incident beam solar radiation will strike the absorber.

Collector slope is the angle between the plane of the collector aperture and the horizontal. This parameter may have monthly values. The angle is measured in a vertical plane that is perpendicular to the line formed by the intersection of the plane of the collector aperture and the horizontal plane.

Collector azimuth (South=0) is the angle between the projection into the horizontal plane of the normal to the collector aperture and the local meridian with the zero point directly facing the equator, west positive, and east negative. The azimuth of a horizontal collector can have any value. The azimuth of a collector facing the sun at noon in the southern hemisphere (i.e. north facing) is 180°. This parameter may have monthly values.

Receiver orientation (EW, NS) toggles to indicate the axis orientation of the evacuated tubes. Specify NS if the collectors are mounted vertically with the tube pointing up and down.

Incidence angle modifier (Perpendicular) values(s) are the incidence angle modifiers for the plane perpendicular to the tube axis (i.e., the transverse plane). The incidence angle modifier is the ratio of the transmittance-absorptance product at an off-normal incidence angle in the transverse plane to the normal incidence transmittance-absorptance product. This parameter may have either one or ten values. A single value indicates that the incidence angle modifier is independent of solar incidence angle. The ten values, as shown above for the default parameter set, correspond to the incidence angle modifier values between 0 and 90 degrees in 10 degree increments.

Incidence angle modifier (Parallel) value(s) are the incidence angle modifiers for the plane parallel to the tube axis (i.e., the longitudinal plane). The incidence angle modifier is the ratio of the transmittance-absorptance product at an off-normal incidence angle in the longitudinal plane to the normal incidence transmittance-absorptance product. This parameter may have either one or ten values. A single value indicates that the incidence angle modifier is independent of solar incidence angle. The ten values, as shown above for the default parameter set, correspond to the incidence angle modifier values between 0 and 90 degrees in 10 degree increments.

Collector flow rate/area is the total mass flow rate of collector fluid through the collector array divided by the total collector array area. This flow rate may be different from the flow rate at which the collector was tested. Typical values of this flow rate are 11 lb/hr-ft^2 or 0.015 kg/s-m^2 for liquids and 9 lb/hr-ft^2 or 0.012 kg/s-m^2 for air.

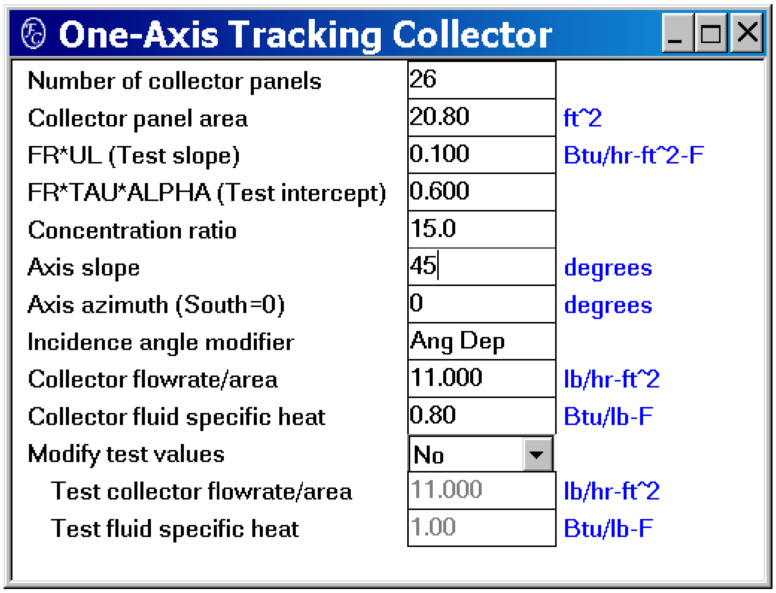
Collector fluid specific heat is the specific heat of the fluid flowing through the collectors. Properties can be found in the ASHRAE handbook of Fundamentals [1985] or in any heat transfer textbook. For water, use 1.0 Btu/lb-F or 4.19 kJ/kg-K. For air use 1.0 kJ/kg-K or 0.24 Btu/lb-F.

Modify Test Values (Yes/No) toggles to indicate if the next two parameters should be used to account for differences in the collector parameters due to differences in the actual and test fluid flow rates and series-parallel fluid flow circuit arrangements. If this parameter is set to No, the following three parameters are ignored.

Test collector flow rate/area is the ratio of the collector fluid flow rate used in the collector test to the array area of the collector tested. Usually, a single collector panel is tested. In this case, this parameter is the ratio of the test collector fluid flow rate to the collector panel area. This parameter is used only if Yes has been selected for 'modify test values'.

Test fluid specific heat is the specific heat of the fluid used in the collector test. Properties of common materials can be found in the ASHRAE Handbook of Fundamentals [1985] or in any heat transfer textbook. This parameter is used only if Yes is selected for 'modify test values'.

3.4 One-Axis Tracking Collector



Number of collector panels is multiplied by the area of a single collector panel to determine the total array area.

Collector panel area is either the gross or net aperture area of each collector panel. The same (gross or net) aperture area that was used to determine FR*TAU*ALPHA and FR*UL must be used for this parameter. The ASHRAE Standard 93-77 [1977] collector test recommends the use of gross area.

FR*UL (Test Slope) is the product of the collector heat removal factor, FR, and the collector overall heat loss factor, UL. FR*UL is the negative of the slope of the straight line efficiency plot obtained from the ASHRAE Standard 93-77 [1977] collector test.

FR*TAU*ALPHA (Test Intercept) is the product of the collector heat removal factor, FR, and the transmittance-absorptance product, TAU*ALPHA, at normal incidence. This parameter, also known as the optical efficiency, is the Y-intercept of the straight line efficiency plot obtained from the ASHRAE Standard 93-77 [1977] collector test.

Concentration ratio is the ratio of the collector aperture area to the receiver area.

Axis slope is the angle between the axis and the projection of the axis into the horizontal plane. This parameter may have monthly values.

Axis azimuth (South = 0) is the angle between the projection of the axis into the horizontal plane and the local meridian. An east-west axis orientation will have an axis azimuth of 90°.

Incidence angle modifier are the value(s) of the collector incidence angle modifier, K(t) as determined by the ASHRAE Standard 93-77 collector test procedure [1977]. If a single value is used for this parameter, then the incidence angle modifier is taken to be that constant value independent of solar incidence angle. Alternatively, values of this parameter may be specified for incidence angles between 0 and 90 degrees in 10-degree increments. The incidence angle value(s) are used only if 'Value(s)' was chosen for the incidence angle modifier type.

Collector flow rate/area is the total mass flow rate of collector fluid through the collector array divided by the total collector array area. This flow rate may be different from the flow rate at which the collector was tested. Typical values of this flow rate are 11 lb/hr-ft^2 or 0.015 kg/s-m^2 for liquids and 9 lb/hr-ft^2 or 0.012 kg/s-m^2 for air.

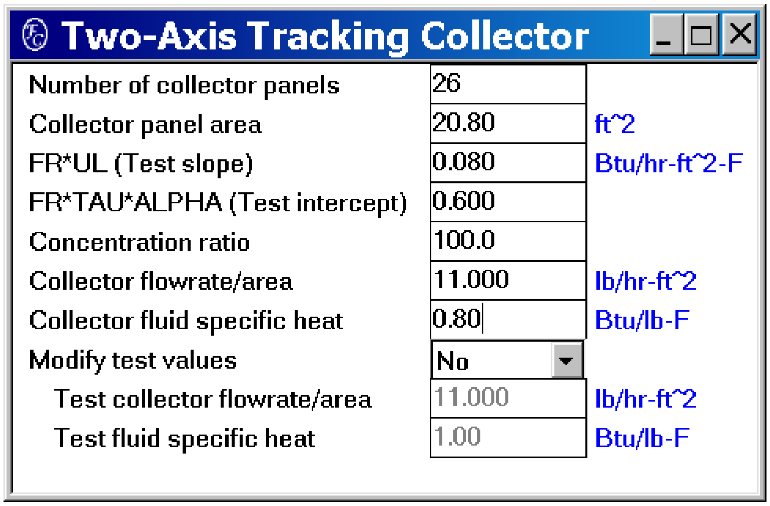
Collector fluid specific heat is the specific heat of the fluid flowing through the collectors. Properties can be found in the ASHRAE handbook of Fundamentals [1985] or in any heat transfer textbook. For water, use 1.0 Btu/lb-F or 4.19 kJ/kg-K. For air use 1.0 kJ/kg-K or 0.24 Btu/lb-F.

Modify Test Values (Yes/No) toggles to indicate if the next two parameters should be used to account for differences in the collector parameters due to differences in the actual and test fluid flow rates and series-parallel fluid flow circuit arrangements. If this parameter is set to No, the following three parameters are ignored.

Test collector flow rate/area is the ratio of the collector fluid flow rate used in the collector test to the array area of the collector tested. Usually, a single collector panel is tested. In this case, this parameter is the ratio of the test collector fluid flow rate to the collector panel area. This parameter is used only if Yes has been selected for 'modify test values'.

Test fluid specific heat is the specific heat of the fluid used in the collector test. Properties of common materials can be found in the ASHRAE Handbook of Fundamentals [1985] or in any heat transfer textbook. This parameter is used only if Yes is selected for 'modify test values'.

3.5 Two-Axis Tracking Collector



Number of collector panels is multiplied by the area of a single collector panel to determine the total array area.

Collector panel area is either the gross or net aperture area of each collector panel. The same (gross or net) aperture area that was used to determine FR*TAU*ALPHA and FR*UL must be used for this parameter. The ASHRAE Standard 93-77 [1977] collector test recommends the use of gross area.

FR*UL (Test Slope) is the product of the collector heat removal factor, FR, and the collector overall heat loss factor, UL. FR*UL is the negative of the slope of the straight line efficiency plot obtained from the ASHRAE Standard 93-77 [1977] collector test.

FR*TAU*ALPHA (Test Intercept) is the product of the collector heat removal factor, FR, and the transmittance-absorptance product, TAU*ALPHA, at normal incidence. This parameter is also known as the optical efficiency. It is the Y-intercept of the straight line efficiency plot obtained from the ASHRAE Standard 93-77 [1977] collector test.

Concentration ratio is the ratio of the collector aperture area to the receiver area.

Collector flow rate/area is the total mass flow rate of collector fluid through the collector array divided by the total collector array area. This flow rate may be different from the flow rate at which the collector was tested. Typical values of this flow rate are 11 lb/hr-ft^2 or 0.015 kg/s-m^2 for liquids and 9 lb/hr-ft^2 or 0.012 kg/s-m^2 for air.

Collector fluid specific heat is the specific heat of the fluid flowing through the collectors.

Properties can be found in the ASHRAE handbook of Fundamentals [1985] or in any heat transfer textbook. For water, use 1.0 Btu/lb-F or 4.19 kJ/kg-K. For air use 1.0 kJ/kg-K or 0.24 Btu/lb-F.

Modify Test Values (Yes/No) toggles to indicate if the next two parameters should be used to account for differences in the collector parameters due to differences in the actual and test fluid flow rates and series-parallel fluid flow circuit arrangements. If this parameter is set to No, the following three parameters are ignored.

Test collector flow rate/area is the ratio of the collector fluid flow rate used in the collector test to the array area of the collector tested. Usually, a single collector panel is tested. In this case, this parameter is the ratio of the test collector fluid flow rate to the collector panel area. This parameter is used only if Yes has been selected for 'modify test values'.

Test fluid specific heat is the specific heat of the fluid used in the collector test. Properties of common materials can be found in the ASHRAE Handbook of Fundamentals [1985] or in any heat transfer textbook. This parameter is used only if Yes is selected for 'modify test values'.

CHAPTER 4

System and Output Descriptions

The **F-Chart** program can evaluate eight different solar energy system types. Each system has its own input parameter set and output format. A description of each system is provided in the following eight sections, along with a description of its parameter set, an example calculation and an explanation of the program output. The economic parameters and output are the same for all systems and are described in Chapter 5.

The algorithms used to calculate the thermal and economic performance of the systems can be found in the cited references following Chapter 5. The monthly-average solar radiation on tilted surfaces is calculated for all systems from the horizontal solar radiation data by summing the long-term average hourly values calculated using the isotropic sky model in the manner described in Section 2.15 of Duffie and Beckman [1991]. The monthly diffuse fraction is estimated using the correlation developed by Erbs et al. [1982].

4.1 Active Domestic Hot Water System

A common configuration of a solar domestic water heating system is the two-tank system shown in Figure 4.1. The collector may heat either air or liquid. The collected energy is transferred directly or via a heat exchanger to a domestic water preheat tank which supplies solar-heated water to a conventional auxiliary water heater. The water is further heated to the desired temperature by the conventional water heater. The f-Chart method for domestic water heating was originally developed for two-tank systems. However, it is shown by Buckles et al. [1980] that the f-Chart method can also be used for single-tank systems in which auxiliary energy is supplied to the upper portion of the solar preheat tank.

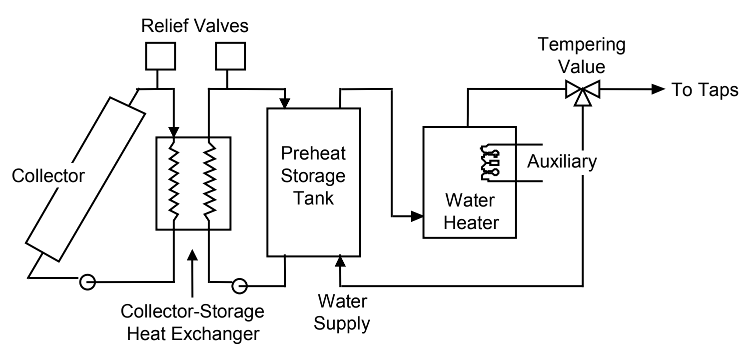
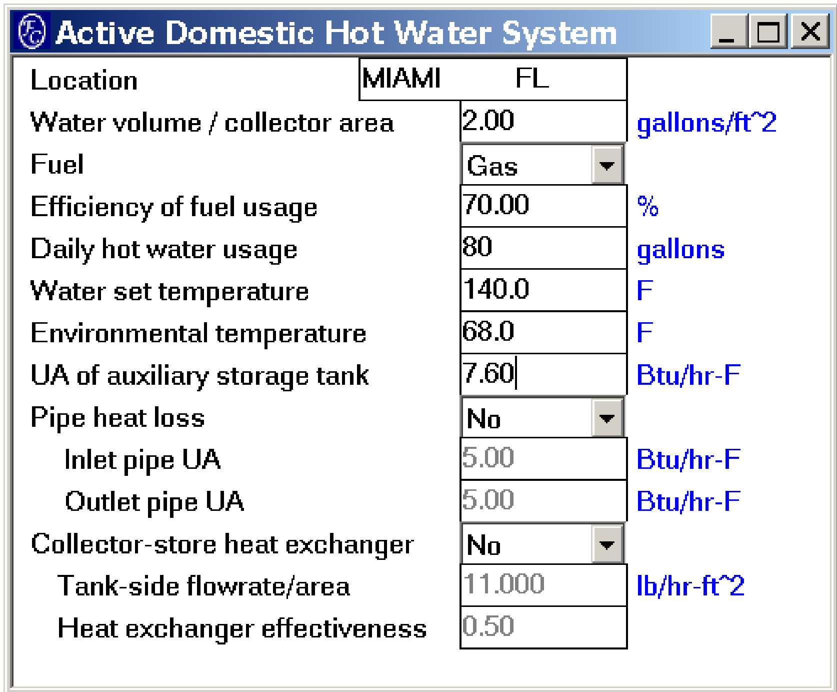


Figure 4.1: Two-Tank Domestic Water Heating System

The parameters for the active domestic hot water system are listed below along with their default values in English units. A description of each parameter follows the parameter listing.



Location is the location where the system is located. Existing city data can be viewed or changed or data for a new city added from the **Data** pull down menu.

Water storage volume / collector area is multiplied by the number of collector panels and the panel area to determine the volume of stored water used for thermal storage. In a single tank system, use the volume below the heating element thermostat.

Fuel cycles through the four possibilities of the back-up fuel (Elecricity, Gas, Oil, Other) where 'Other' represents, for example, wood. This parameter is used only in the economic evaluation.

Efficiency of fuel usage represents the average furnace efficiency of the back-up (conventional) fuel. This parameter is used in the economics calculations and it may vary monthly.

Daily hot water usage is the average amount of hot water per day required at the set temperature. Monthly values are allowed.

Water set temperature is the temperature to which domestic water is to be heated. Monthly values are allowed.

Environment temperature is the temperature of the surroundings of the domestic water storage tank to which heat losses occur. Monthly values are allowed.

UA of auxiliary storage tank is the product of the energy loss coefficient and surface area for the auxiliary tank in the solar domestic water heating system. In a single tank system, use the tank surface area above the heating element thermostat.

Pipe heat loss toggles between Yes and No to indicate if the following two parameters are to be used to calculate the effect of pipe heat losses. If No is selected, the following two parameters are ignored.

Inlet pipe UA is the overall loss coefficient-pipe area product for the pipe carrying fluid to the collector. This parameter is used only if Yes has been selected for pipe heat loss.

Outlet pipe UA is the overall loss coefficient-pipe area product for the pipe carrying fluid from the collector array. This parameter is used only if Yes has been selected for pipe heat loss.

Collector-store heat exchanger toggles between Yes and No to indicate if the following two parameters should be used to account for the performance penalty resulting from the heat exchanger between the collector array and the storage tank. If No is specified, the following two parameters are ignored.

Tank side flow rate/area is the mass flow rate of water from the storage tank through the collector-storage heat exchanger divided by the total array area. Set this parameter to a value that is larger than collector flow rate/area (in the collector parameter set) for an internal heat exchanger.

Heat exchanger effectiveness is the ratio of the actual to maximum possible heat transfer rates for heat exchanger located between the collector and the storage unit. This parameter is used only if Yes is selected for the collector-storage heat exchanger.

The thermal performance is calculated on a monthly basis. Shown below is the output for the default parameter set in English units with three flat-plate solar panels in Miami FL.

Thermal Output

	Solar [10^6 Btu]	Dhw [10^6 Btu]	Aux [10^6 Btu]	f [ ]
Jan	2.873	1.748	0.695	0.603
Feb	2.767	1.577	0.568	0.640
Mar	3.221	1.742	0.575	0.670
Apr	3.105	1.683	0.560	0.667
May	2.841	1.735	0.716	0.587
Jun	2.492	1.677	0.796	0.526
Jul	2.739	1.731	0.744	0.570
Aug	2.874	1.731	0.670	0.613
Sep	2.782	1.677	0.643	0.617
Oct	3.000	1.735	0.616	0.645
Nov	2.782	1.685	0.649	0.615
Dec	2.756	1.746	0.730	0.582
Year	34.232	20.470	7.960	0.611

Heat is the monthly total space heating demand.

Dhw is the monthly total water heating demand.

Aux is the monthly total auxiliary energy required to supply the space and domestic water heating demands.

f is the fraction of the space and domestic water heating demands which is supplied by the solar energy system. The remaining fraction must be met by an auxiliary source.

4.2 Pebble Bed Storage Space and Domestic Water Heating Systems

A common configuration of a solar heating system using a pebble bed for thermal is shown in Figure 4.2. Other arrangements of fans and dampers can be devised to result in an equivalent flow circuit. Air is heated in the flat-plate solar collector and circulated to either the house or to the pebble bed. Energy is stored in the pebble bed by heating the pebbles with the circulating hot air. At night, or in cloudy weather when the available solar energy is insufficient to meet the heating load directly, air is warmed as it is circulated through the pebble bed and is then delivered to the house. Auxiliary energy is supplied from the furnace when the energy stored in the pebble bed is depleted. Energy required for domestic hot water is provided in some systems by heat exchange with the hot air leaving the collector.

The thermal performance of the pebble bed storage system is estimated using the f-Chart method as described by Beckman, Klein and Duffie [1977] and in Duffie and Beckman [1991]. Note that the thermal performance of a domestic water heating system alone (without space heating) should be evaluated using the active domestic hot water system described above, even if air heaters are used.

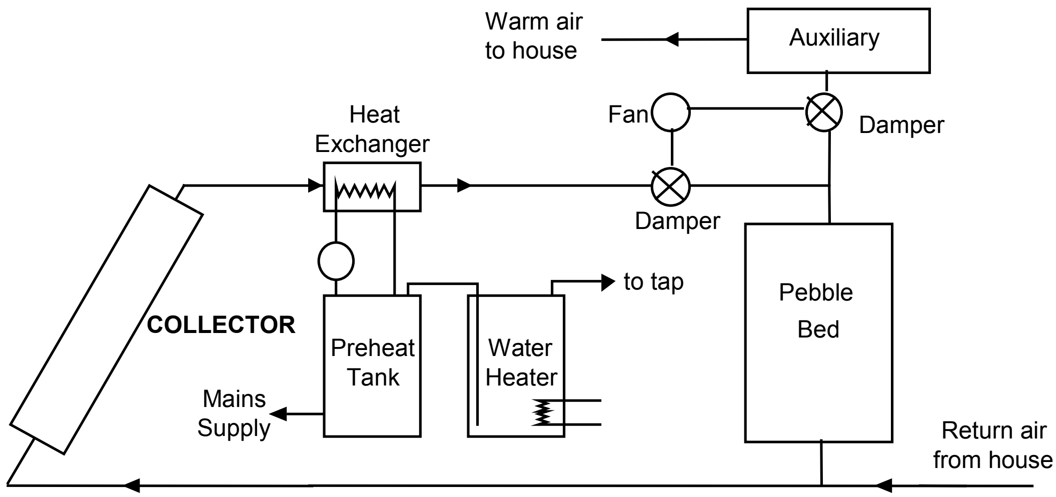
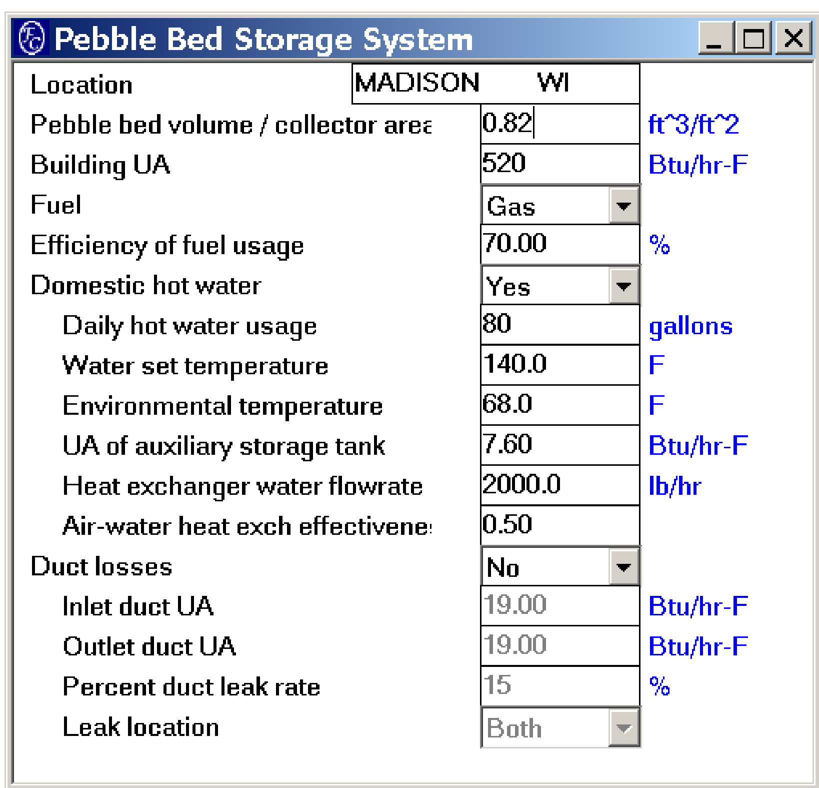


Figure 4.2: Pebble Bed Storage Space and Water Heating System

The parameters for the pebble bed storage system are listed below along with their default values in English units. A description of each parameter follows the parameter listing.



Pebble Bed Storage System

Location	MADISON WI	
Pebble bed volume / collector area	0.82	ft^3/ft^2
Building UA	520	Btu/hr-F
Fuel	Gas	
Efficiency of fuel usage	70.00	%
Domestic hot water	Yes	
Daily hot water usage	80	gallons
Water set temperature	140.0	F
Environmental temperature	68.0	F
UA of auxiliary storage tank	7.60	Btu/hr-F
Heat exchanger water flowrate	2000.0	lb/hr
Air-water heat exch effectivene:	0.50	
Duct losses	No	
Inlet duct UA	19.00	Btu/hr-F
Outlet duct UA	19.00	Btu/hr-F
Percent duct leak rate	15	%
Leak location	Both	

Location is the location where the system is located. Existing city data can be viewed or changed or data for a new city added from the **Data** pull down menu.

Volume of pebble bed / collector area is multiplied by the number of collector panels and the panel area to determine the total volume occupied by the pebbles including voids.

Building UA is the building overall energy loss coefficient-area product. See Chapter 25 of the ASHRAE Handbook of Fundamentals [1985] for additional information. This parameter may have monthly values. If the monthly loads are known, either from measurements or independent calculations, you may change the value of UA monthly so the program calculates the known monthly load. **F-Chart** will multiply the UA and the degree-days and either the number of hours in a day (English units) or seconds in a day (SI units) to determine the load. Consequently, the monthly value of UA must be calculated as [Monthly Load in BTUs] /[Degree-days in F-days]/24 for English units or as [Monthly Load in Joules]/[Degree-days in C-days]/ [24*3600] for SI units.

Fuel cycles through the four possibilities of the back-up fuel (Electricity, Gas, Oil, Other) where 'Other' represents, for example, wood. This parameter is used only in the economic evaluation of the system.

Efficiency of fuel usage represents the average furnace efficiency of the back-up (conventional) fuel. This parameter is used in the economics calculations and it may vary monthly.

Domestic hot water toggles between Yes and No to indicate whether a solar domestic water heating system is part of the heating system. If Yes is selected, a solar domestic hot water system is considered in addition to the space heating system. The following 6 parameters are then used to describe the domestic water system. If No is specified, the following 6 parameters are ignored. The liquid storage system should be selected if air collectors and a water-to-air heat exchanger are used to supply only domestic hot water.

Daily hot water usage is the average amount of hot water per day required at the set temperature. Monthly values are allowed. This parameter is visible only if Yes has been selected for domestic hot water parameter.

Water set temperature is the temperature to which domestic water is to be heated. Monthly values are allowed. This parameter is used only if Yes has been selected for domestic hot water.

Environment temperature is the temperature of the surroundings of the domestic water storage tank to which heat losses occur. Monthly values are allowed. This parameter is used only if Yes has been selected for domestic hot water.

UA of auxiliary storage tank is the product of the energy loss coefficient and surface area for the auxiliary tank in the solar domestic water heating system. In a single tank system, use the tank surface area above the heating element thermostat. This parameter is visible only if Yes has been selected for domestic hot water.

Heat exchanger water flow rate is the mass flow rate of water from the solar preheat tank to the air-water heat exchanger. This parameter is visible only if Yes has been selected for domestic hot water.

Air-water heat exch effectiveness is the ratio of the actual heat transfer rate to the maximum possible heat transfer rate for the air-to-water domestic hot water heat exchanger. This parameter is used only if Yes has been selected for domestic hot water.

Duct losses (Yes/No) toggles to indicate whether the following four parameters are to be used to calculate the effect of duct heat losses and air leaks. If No is specified, the following four parameters are ignored.

Inlet duct UA is the overall loss coefficient-duct area product for the duct carrying air to the collector array. This parameter is used only if Yes has been selected for duct losses.

Outlet duct UA is the overall loss coefficient-duct area product for the duct carrying air from the collector array. This parameter is used only if Yes has been selected for duct losses.

Percent duct leak rate is the percent of the collector outlet duct flow rate which is leakage. The collector is assumed to be under negative pressure, i.e., all leaks are into the ducts rather than out. This parameter is used only if Yes has been selected for duct losses.

Leak location (In, Out, Both) cycles through 'In', 'Out', and 'Both' to indicate the location of the duct air leakage. The total air leakage into the ducts as specified by the percent duct leak rate may be assumed to occur from the inlet duct, the outlet duct, or evenly from both the inlet and outlet ducts. This parameter is used only if Yes has been selected for duct losses.

The thermal performance is calculated on a monthly basis. The output (in English units) for the default parameter with a flat-plate collector appears below. (26 panels and cp=0.24)

Thermal Output

	Solar [10^6 Btu]	Heat [10^6 Btu]	Dhw [10^6 Btu]	Aux [10^6 Btu]	f [ ]
Jan	17.98	18.69	2.384	13.64	0.353
Feb	20.06	15.24	2.148	8.77	0.495
Mar	23.99	12.36	2.368	4.95	0.664
Apr	24.94	7.11	2.277	0.72	0.924
May	27.89	3.27	2.341	0.00	1.000
Jun	28.46	0.83	2.255	0.00	1.000
Jul	29.52	0.37	2.326	0.00	1.000
Aug	28.06	0.68	2.330	0.00	1.000
Sep	24.07	2.43	2.263	0.00	1.000
Oct	21.02	6.28	2.351	1.34	0.844
Nov	14.38	10.95	2.287	7.82	0.409
Dec	14.05	16.53	2.378	13.66	0.277
Year	274.41	94.73	27.709	50.90	0.584

Solar is the monthly total solar radiation incident on the collector surface.

Heat is the monthly total space heating demand.

Dhw is the monthly total water heating demand.

Aux is the monthly total auxiliary energy required to supply the space and domestic water heating demands.

f is the fraction of the space and domestic water heating demands which is supplied by the solar energy system. The remaining fraction must be met by an auxiliary source.

4.3 Water Storage Space and/or Domestic Water Heating Systems

The water storage solar heating systems considered here can supply space heat, domestic hot water, or both. A schematic diagram of a typical combined space and domestic water heating system is shown in Figure 4.3. This system uses an antifreeze solution as the heat transfer fluid in the collector loop. (Alternatively, water may be circulated directly through the collectors and drained at night or during periods of excessive cloudiness.) Energy is stored in the form of sensible heat in the water tank. A water-to-air load heat exchanger is used to transfer heat from the storage tank to the building. A liquid-to-liquid heat exchanger is used to transfer energy from the main storage tank to the domestic water preheat tank, which in turn, supplies solar heated water to a conventional water heater. (A single-tank arrangement in which auxiliary heat is supplied to the upper portion of the solar preheat tank can also be evaluated.) A conventional heating unit (e.g., a furnace, heat pump, or wood burner) is used to meet the space-heating load when the energy in the storage tank is depleted. The f-Chart method [Beckman, Klein and Duffie (1977)] is used to evaluate the monthly system performance.

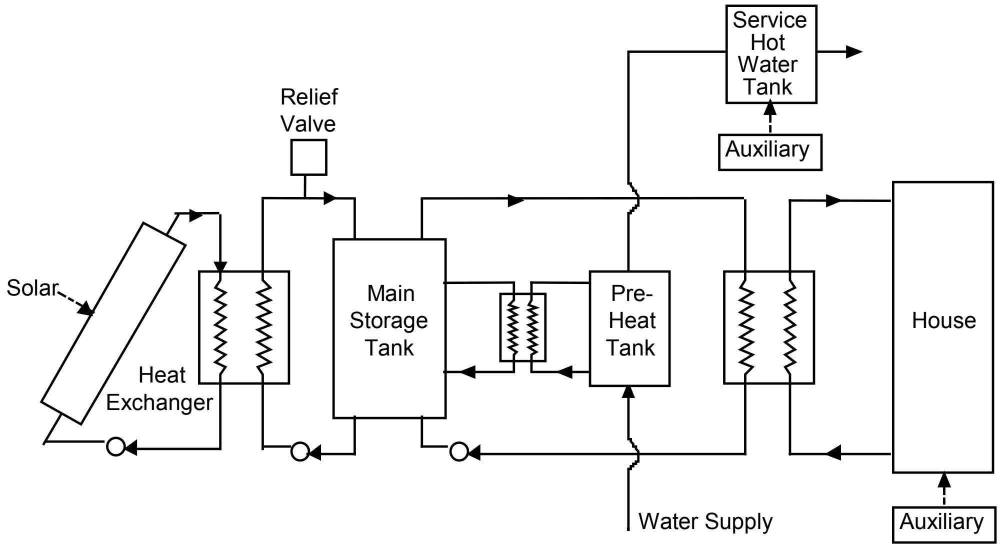
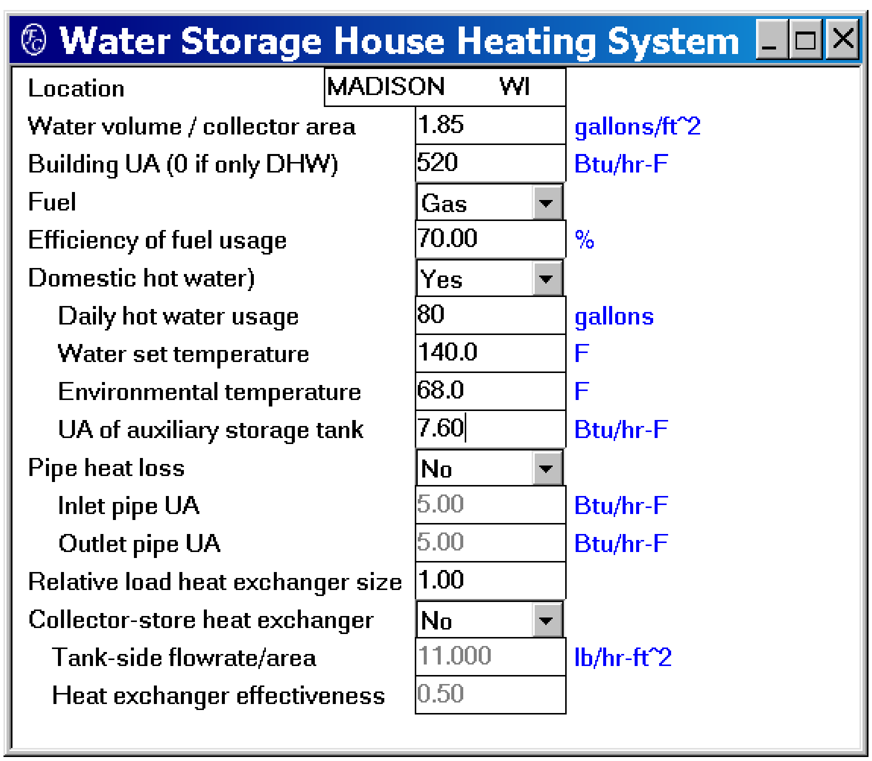


Figure 4.3: Water Storage Space and Water Heating System

The water storage system input parameters and their default values appear below in English units followed by the parameter descriptions.



Water Storage House Heating System

Location	MADISON WI	
Water volume / collector area	1.85	gallons/ft^2
Building UA (0 if only DHW)	520	Btu/hr-F
Fuel	Gas	
Efficiency of fuel usage	70.00	%
Domestic hot water)	Yes	
Daily hot water usage	80	gallons
Water set temperature	140.0	F
Environmental temperature	68.0	F
UA of auxiliary storage tank	7.60	Btu/hr-F
Pipe heat loss	No	
Inlet pipe UA	5.00	Btu/hr-F
Outlet pipe UA	5.00	Btu/hr-F
Relative load heat exchanger size	1.00	
Collector-store heat exchanger	No	
Tank-side flowrate/area	11.000	lb/hr-ft^2
Heat exchanger effectiveness	0.50	

Location is the location where the system is located. Existing city data can be viewed or changed or data for a new city added from the **Data** pull down menu.

Water storage volume / collector area is multiplied by the number of collector panels and the panel area to determine the volume of stored water used for thermal storage. If the building UA is set to zero, then calculations are done for solar domestic water heating only. In this case, this parameter should be the volume of the domestic water preheat tank divided by the total collector area. In a single tank system, use the volume below the heating element thermostat.

Building UA is the building overall energy loss coefficient-area product. See Chapter 25 of the ASHRAE Handbook of Fundamentals [1985] for additional information. If only domestic hot water is to be considered, this parameter should be set to zero. This parameter may have monthly values. If the monthly loads are known, either from measurements or independent calculations, you may change the value of UA monthly so the program calculates the the known monthly load. **F-Chart** will multiply the UA and the degree-days and either the number of hours in a day (English units) or seconds in a day (SI units) to determine the load. Consequently, the monthly value of UA must be calculated as [Monthly Load in BTUs] /[Degree-days in F-days]/24 for English units or as [Monthly Load in Joules]/[Degree-days in C-days]/ [24*3600] for SI units.

Fuel cycles through the four possibilities (Electricity, Gas, Oil, Other) of the back-up fuel where 'Other' represents, for example, wood. This parameter is used only in the economic evaluation.

Efficiency of fuel usage represents the average furnace efficiency of the back-up (conventional) fuel. This parameter is used in the economics calculations and it may vary monthly.

Domestic hot water (Yes/No) toggles to indicate whether a solar domestic water heating system is part of the heating system. If Yes is selected, a solar domestic hot water system is considered in addition to the space heating system. The following 6 parameters are then used to describe the domestic water system. If No is specified, the following 6 parameters are ignored. The liquid storage system should be selected if air collectors and a water-to-air heat exchanger are used to supply only domestic hot water.

Daily hot water usage is the average amount of hot water per day required at the set temperature. Monthly values are allowed. This parameter is visible only if Yes has been selected for domestic hot water parameter.

Water set temperature is the temperature to which domestic water is to be heated. Monthly values are allowed. This parameter is used only if Yes has been selected for domestic hot water.

Environment temperature is the temperature of the surroundings of the domestic water storage tank to which heat losses occur. Monthly values are allowed. This parameter is used only if Yes has been selected for domestic hot water.

UA of auxiliary storage tank is the product of the energy loss coefficient and surface area for the auxiliary tank in the solar domestic water heating system. In a single tank system, use the tank surface area above the heating element thermostat. This parameter is visible only if Yes has been selected for domestic hot water.

Pipe heat loss (Yes, No) toggles to indicate if the following two parameters are to be used to calculate the effect of pipe heat losses. If No is selected, the following two parameters are ignored.

Inlet pipe UA is the overall loss coefficient-pipe area product for the pipe carrying fluid to the collector. This parameter is used only if Yes has been selected for pipe heat loss.

Outlet pipe UA is the overall loss coefficient-pipe area product for the pipe carrying fluid from the collector array. This parameter is used only if Yes has been selected for pipe heat loss.

Relative load heat exchanger size is the ratio of the actual thermal size of the load heat exchanger to the standard value. The standard value is chosen such that the product of the load heat exchanger effectiveness and minimum capacitance rate (i.e., mass flow rate times specific heat) is equal to twice the value of the building UA. This parameter may have monthly values.

Collector-store heat exchanger (Yes, No) toggles to indicate if the following two parameters should be used to account for the performance penalty resulting from the heat exchanger between the collector array and the storage tank. If No is specified, the following two parameters are ignored.

Tank side flow rate/area is the mass flow rate of water from the storage tank through the collector-storage heat exchanger divided by the total array area. Set this parameter to a value which is larger than collector flow rate/area (in the collector parameter set) for an internal heat exchanger.

Heat exchanger effectiveness is the ratio of the actual to maximum possible heat transfer rates for heat exchanger located between the collector and the storage unit. This parameter is used only if Yes is selected for the collector-storage heat exchanger.

The thermal performance is calculated on a monthly basis. Shown below is the output for the default parameter set in English units with 26 flat-plate solar collectors and collector fluid specific heat equal to 0.8.

Thermal Output

	Solar [10^6 Btu]	Heat [10^6 Btu]	Dhw [10^6 Btu]	Aux [10^6 Btu]	f [ ]
Jan	17.98	18.69	2.384	13.90	0.340
Feb	20.06	15.24	2.148	9.18	0.472
Mar	23.99	12.36	2.368	5.51	0.626
Apr	24.94	7.11	2.277	1.23	0.869
May	27.89	3.27	2.341	0.00	1.000
Jun	28.46	0.83	2.255	0.00	1.000
Jul	29.52	0.37	2.326	0.00	1.000
Aug	28.06	0.68	2.330	0.00	1.000
Sep	24.07	2.43	2.263	0.00	1.000
Oct	21.02	6.28	2.351	1.73	0.799
Nov	14.38	10.95	2.287	8.02	0.394
Dec	14.05	16.53	2.378	13.80	0.270
Year	274.41	94.73	27.709	53.38	0.564

Solar is the monthly total solar radiation incident on the collector surface.

Heat is the monthly total space heating demand.

Dhw is the monthly total water heating demand.

Aux is the monthly total auxiliary energy required to supply the space and domestic water heating demands.

f is the fraction of the space and domestic water heating demands which is supplied by the solar energy system. The remaining fraction must be met by an auxiliary source.

4.4 Building Storage Systems

Shown in Figure 4.3 is a schematic of a simple solar space heating system which does not have a primary storage component. Solar energy is used to heat a fluid (usually air, but possibly a liquid) which is circulated through the collectors. The useful energy gain of the fluid is transferred either directly (for air) or via heat exchange (for liquids) to the building space. If the solar contribution is less than the instantaneous load, all of the energy entering the space at this time is useful in offsetting auxiliary energy use. If the solar gain exceeds the instantaneous load, the building temperature will rise, providing a means of energy storage. If the building temperature exceeds the maximum allowable value, the collector pump is turned off since the solar gain cannot be used or stored at this time. The algorithm used to do the monthly performance calculations for this system is presented by Evans and Klein [1983]. A domestic hot water heat exchanger can be installed in the line leading from the collector. In this case the monthly DHW solar contribution is calculated by the f-Chart method [Beckman, Klein and Duffie (1977)].

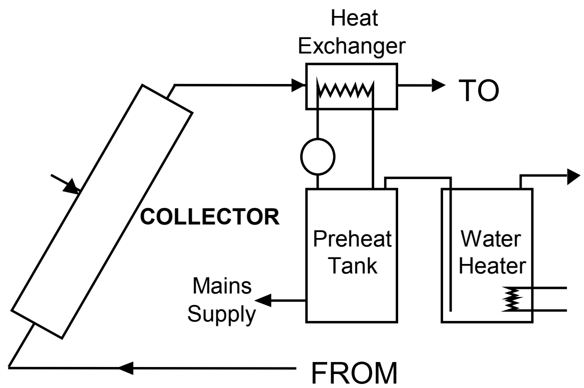
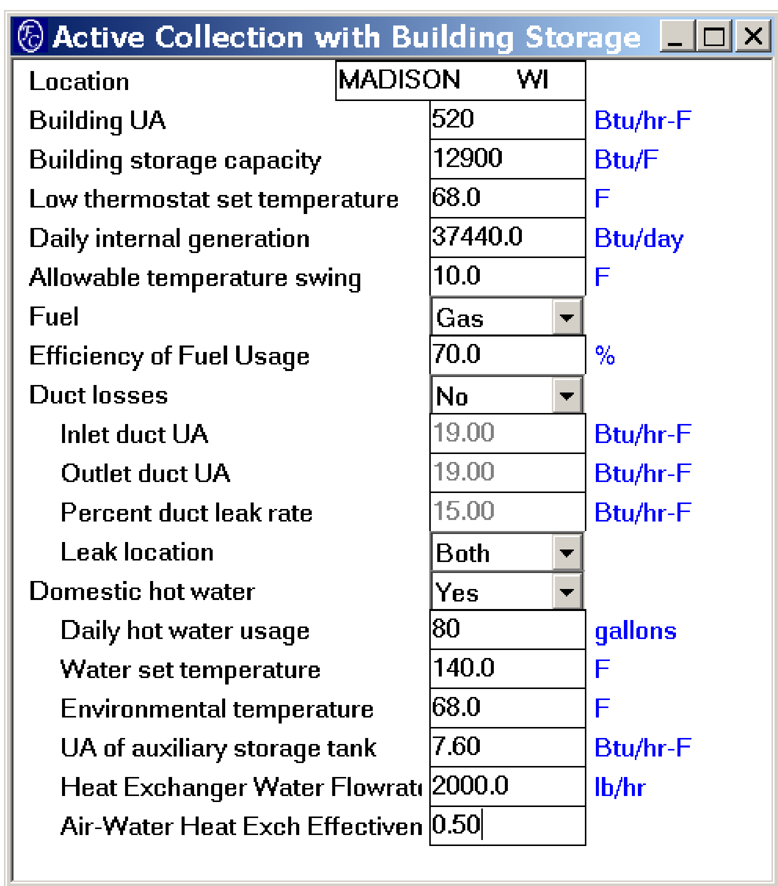


Figure 4.4: Active Collection with Building Storage System

The parameters for this system are listed below along with their default values and explanations.



Active Collection with Building Storage

Location	MADISON WI	
Building UA	520	Btu/hr-F
Building storage capacity	12900	Btu/F
Low thermostat set temperature	68.0	F
Daily internal generation	37440.0	Btu/day
Allowable temperature swing	10.0	F
Fuel	Gas	
Efficiency of Fuel Usage	70.0	%
Duct losses	No	
Inlet duct UA	19.00	Btu/hr-F
Outlet duct UA	19.00	Btu/hr-F
Percent duct leak rate	15.00	Btu/hr-F
Leak location	Both	
Domestic hot water	Yes	
Daily hot water usage	80	gallons
Water set temperature	140.0	F
Environmental temperature	68.0	F
UA of auxiliary storage tank	7.60	Btu/hr-F
Heat Exchanger Water Flowrat	2000.0	lb/hr
Air-Water Heat Exch Effectiven	0.50	

Location is the location where the system is located. Existing city data can be viewed or changed or data for a new city added from the **Data** pull down menu.

Building UA is the building overall energy loss coefficient-area product. See Chapter 25 of the ASHRAE Handbook of Fundamentals [1985] for additional information. This parameter may have monthly values. If the monthly loads are known, either from measurements or independent calculations, you may change the value of UA monthly so the program calculates the the known monthly load. **F-Chart** will multiply the UA and the degree-days and either the number of hours in a day (English units) or seconds in a day (SI units) to determine the load. Consequently, the monthly value of UA must be calculated as [Monthly Load in BTUs] /[Degree-days in F-days]/24 for English units or as [Monthly Load in Joules]/[Degree-days in C-days]/ [24*3600] for SI units.

Building storage capacity is the effective energy storage capacity of the building. A value of 6 BTU per square foot (123 KJ per square meter) of floor area is recommended for residential construction. This parameter may have monthly values.

Low thermostat set temperature is the temperature of the indoor space at which the auxiliary furnace turns on. This parameter may have monthly values.

Daily internal generation is the monthly-average daily energy generated within the building by appliances, lights, people, and solar gains other than those attributed to the solar collector system. This parameter may have monthly values.

Allowable temperature swing is the number of degrees above the low set point temperature which the indoor space may be heated to before the solar collector fluid flow is terminated. This parameter may have monthly values.

Fuel cycles through the four possibilities of the back-up fuel (Electricity, Gas, Oil, Other) where 'Other' represents, for example, wood. This parameter is used only in the economic evaluation of the system.

Efficiency of fuel usage represents the average furnace efficiency of the back-up (conventional) fuel. This parameter is used in the economics calculations and it may vary monthly.

Duct losses (Yes/No) toggles to indicate whether the following four parameters are to be used to calculate the effect of duct heat losses and air leaks. If No is specified, the following four parameters are ignored.

Inlet duct UA is the overall loss coefficient-duct area product for the duct carrying air to the collector array. This parameter is used only if Yes has been selected for duct losses.

Outlet duct UA is the overall loss coefficient-duct area product for the duct carrying air from the collector array. This parameter is used only if Yes has been selected for duct losses.

Percent duct leak rate is the percent of the collector outlet duct flow rate which is leakage. The collector is assumed to be under negative pressure, i.e., all leaks are into the ducts rather than out. This parameter is used only if Yes has been selected for duct losses.

Domestic hot water (Yes/No) toggles to indicate whether a solar domestic water heating system is part of the heating system. If Yes is selected, a solar domestic hot water system is considered in addition to the space heating system. The following 6 parameters are then used to describe the domestic water system. If No is specified, the following 6 parameters are ignored. The liquid storage system should be selected if air collectors and a water-to-air heat exchanger are used to supply only domestic hot water.

Daily hot water usage is the average amount of hot water per day required at the set temperature. Monthly values are allowed. This parameter is visible only if Yes has been selected for domestic hot water parameter.

Water set temperature is the temperature to which domestic water is to be heated. Monthly values are allowed. This parameter is used only if Yes has been selected for domestic hot water.

Environment temperature is the temperature of the surroundings of the domestic water storage tank to which heat losses occur. Monthly values are allowed. This parameter is used only if Yes has been selected for domestic hot water.

UA of auxiliary storage tank is the product of the energy loss coefficient and surface area for the auxiliary tank in the solar domestic water heating system. In a single tank system, use the tank surface area above the heating element thermostat. This parameter is visible only if Yes has been selected for domestic hot water.

Heat exchanger water flow rate is the mass flow rate of water from the solar preheat tank to the air-water heat exchanger, used only if Yes has been selected for domestic hot water.

Air-water heat exch effectiveness is the ratio of the actual heat transfer rate to the maximum possible heat transfer rate for the air-to-water domestic hot water heat exchanger. This parameter is used only if Yes has been selected for domestic hot water.

The thermal performance is calculated on a monthly basis. The output (in English units) for the default parameters with 26 flat-plate collectors and cp =0.24 appears below.

Thermal Output

	Solar [10^6 Btu]	Heat [10^6 Btu]	Dhw [10^6 Btu]	Aux [10^6 Btu]	f [ ]
Jan	17.98	18.69	2.384	14.87	0.294
Feb	20.06	15.24	2.148	10.87	0.375
Mar	23.99	12.36	2.368	7.44	0.495
Apr	24.94	7.11	2.277	2.61	0.722
May	27.89	3.27	2.341	0.00	1.000
Jun	28.46	0.83	2.255	0.00	1.000
Jul	29.52	0.37	2.326	0.00	1.000
Aug	28.06	0.68	2.330	0.00	1.000
Sep	24.07	2.43	2.263	0.00	1.000
Oct	21.02	6.28	2.351	2.54	0.706
Nov	14.38	10.95	2.287	8.17	0.383
Dec	14.05	16.53	2.378	13.87	0.266
Year	274.41	94.73	27.709	60.37	0.507

Solar is the monthly total solar radiation incident on the collector surface.

Heat is the monthly total space heating demand.

Dhw is the monthly total water heating demand.

Aux is the monthly total auxiliary energy required to supply the space and domestic water heating demands.

f is the fraction of the space and domestic water heating demands which is supplied by the solar energy system. The remaining fraction must be met by an auxiliary source.

4.5 Passive Direct-Gain Systems

A schematic representation of a direct-gain system is shown in Figure 4.5. During the month, solar energy strikes the window surface and some of this energy is transmitted through the window and absorbed within the building space. The absorbed solar energy supplies some of the load, i.e., the energy required to maintain the building at the low thermostat set point temperature. The load is the sum of the energy losses back out the direct-gain window and the losses (including infiltration) occurring from the rest of the building. However, not all of the absorbed solar energy is useful in offsetting the load; some of the solar energy may be absorbed when the building space is at the high thermostat set point temperature. In this case, the excess energy will have to be removed to keep the building space from becoming uncomfortably warm. Alternatively, shades could be drawn to block the solar energy from entering the space. The thermal performance of direct-gain passive systems is calculated using the Un-utilizability method of Monsen, Klein, and Beckman [1981].

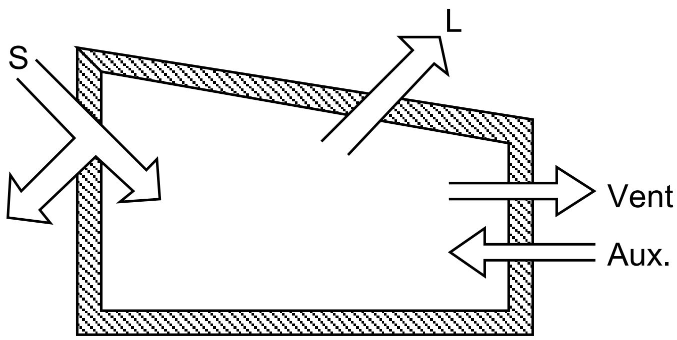
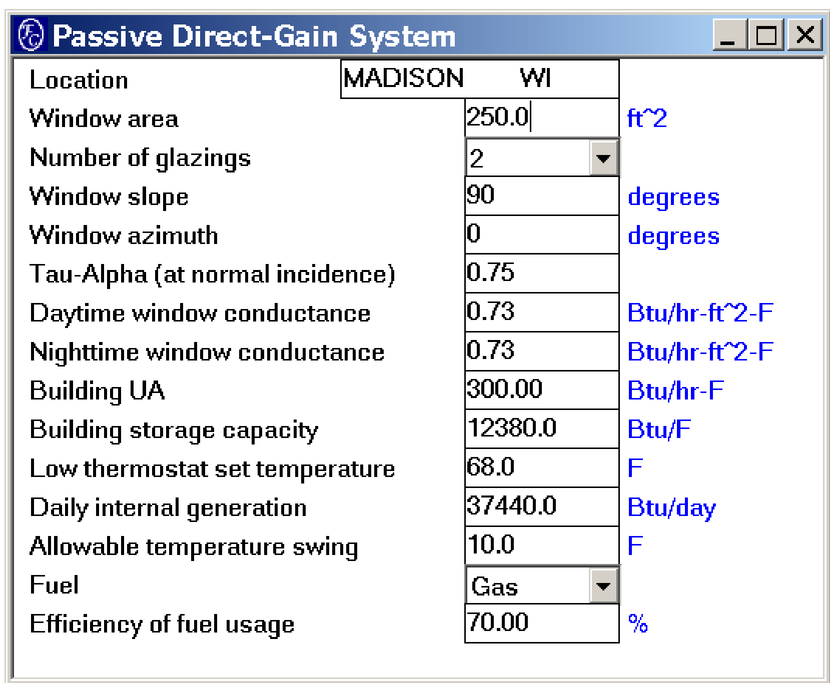


Figure 4.5: Passive Direct-Gain System

The thermal parameters for direct-gain systems are listed below followed by their descriptions.



Passive Direct-Gain System

Location	MADISON WI	
Window area	250.0	ft^2
Number of glazings	2	
Window slope	90	degrees
Window azimuth	0	degrees
Tau-Alpha (at normal incidence)	0.75	
Daytime window conductance	0.73	Btu/hr-ft^2-F
Nighttime window conductance	0.73	Btu/hr-ft^2-F
Building UA	300.00	Btu/hr-F
Building storage capacity	12380.0	Btu/F
Low thermostat set temperature	68.0	F
Daily internal generation	37440.0	Btu/day
Allowable temperature swing	10.0	F
Fuel	Gas	
Efficiency of fuel usage	70.00	%

Location is the location where the system is located. Existing city data can be viewed or changed or data for a new city added from the **Data** pull down menu.

Window area is the area of the direct-gain window.

Number of glazings cycles through 1 to 4 and is used to calculate the angular dependence of the transmittance of solar radiation.

Window slope is the angle between the plane of the glazing and the horizontal. A vertical window will have a 90° slope. Monthly values are permitted.

Window azimuth is the deviation of the normal to the direct-gain window from south. A due south orientation will have an azimuth of 0 degrees. Due west and due east will have values of 90 and -90, respectively. Monthly values are permitted. In the southern hemisphere a direct-gain window facing the sun at solar noon would have an azimuth angle of 180.

Tau-Alpha (at normal incidence) is the product of the glazing transmittance and room wall absorptance for solar radiation at normal incidence. Monthly values are permitted. The solar absorptance, Alpha, of the direct gain window and the room can be estimated from

$$\text{Alpha} = (1 - \rho)/(1 - \rho\ (1 - \tau\ \text{Area}_W/\text{Area}_R))$$

where

ρ is the room wall solar reflectance
τ is the diffuse solar transmittance of the window
Area_W is the window area
Area_R is the surface area of all walls, floors and ceilings in the room.

Daytime window conductance is the overall heat transfer coefficient per unit area between indoors through the glazing system to outdoors when night insulation is not in place. This is the reciprocal of the window overall resistance. Monthly values are permitted.

Nighttime window conductance is the overall heat transfer coefficient per unit area between indoors through the glazing system to outdoors when night insulation is in place. Insulation is assumed to be in place from sunset to sunrise. This is the reciprocal of the window overall resistance. Monthly values are permitted.

Building UA is the building overall energy loss coefficient-area product NOT including the contribution of the passive element. This parameter may have monthly values. See Chapter 25 of the ASHRAE Handbook of Fundamentals [1985] for additional information.

Building storage capacity is the effective energy storage capacity of the building. A value of 6 BTU per square foot (123 KJ per square meter) of floor area is recommended for residential construction. This parameter may have monthly values.

Low thermostat set temperature is the temperature of the indoor space at which the auxiliary furnace turns on. This parameter may have monthly values.

Daily internal generation is the monthly-average daily energy generated within the building by appliances, lights, people, and solar gains other than those attributed to the solar collector system. This parameter may have monthly values.

Allowable temperature swing is the number of degrees above the low set point temperature which the indoor space may be heated to before the solar collector fluid flow is terminated. This parameter may have monthly values.

Fuel cycles through the four possibilities of the back-up fuel (Electricity, Gas, Oil, Other) where 'Other' represents, for example, wood. This parameter is used only in the economic evaluation.

Efficiency of fuel usage represents the average furnace efficiency of the back-up (conventional) fuel. This parameter is used in the economics calculations and it may vary monthly.

An example of the output for the direct-gain system follows:

Thermal Output

	Solar [10^6 Btu]	Load [10^6 Btu]	Aux [10^6 Btu]	f [ ]
Jan	8.015	17.26	12.12	0.298
Feb	8.081	14.06	9.06	0.356
Mar	8.244	11.38	6.60	0.420
Apr	7.271	6.52	2.83	0.566
May	6.880	2.96	0.16	0.944
Jun	6.609	0.74	0.00	1.000
Jul	7.014	0.33	0.00	1.000
Aug	7.704	0.60	0.00	1.000
Sep	7.778	2.20	0.00	1.000
Oct	8.065	5.74	2.15	0.626
Nov	6.111	10.08	6.44	0.362
Dec	6.319	15.25	11.11	0.271
Year	88.091	87.14	50.47	0.421

Solar is the monthly total solar radiation incident on the exterior surface of the direct-gain window.

Load is the monthly total space heating demand.

Aux is the monthly total auxiliary energy required to maintain the indoor space above the low thermostat set point temperature

f is the fraction of the total load (including losses out the direct-gain window) which is supplied by the direct-gain system. The remaining fraction must be met by an auxiliary source.

4.6 Storage Wall Systems

The monthly energy flows occurring in a passive storage wall system are represented in Figure 4.6. During the month, solar energy is transmitted through the glazings and absorbed on the storage wall. The absorbed energy causes the outer wall temperature to rise and energy is then transmitted to the indoor space by conduction through the wall and via a convection loop through the gap between the wall and the glazings. As with the direct-gain system, not all of the energy which enters the space is useful in offsetting the auxiliary energy consumption; some of the energy may actually have to be removed to keep the space from becoming uncomfortably warm. The Un-utilizability method of Monsen, Klein, and Beckman [1982] is used to evaluate the performance of passive storage wall systems.

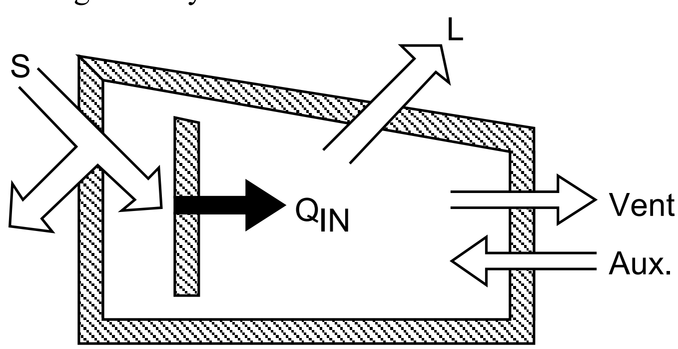
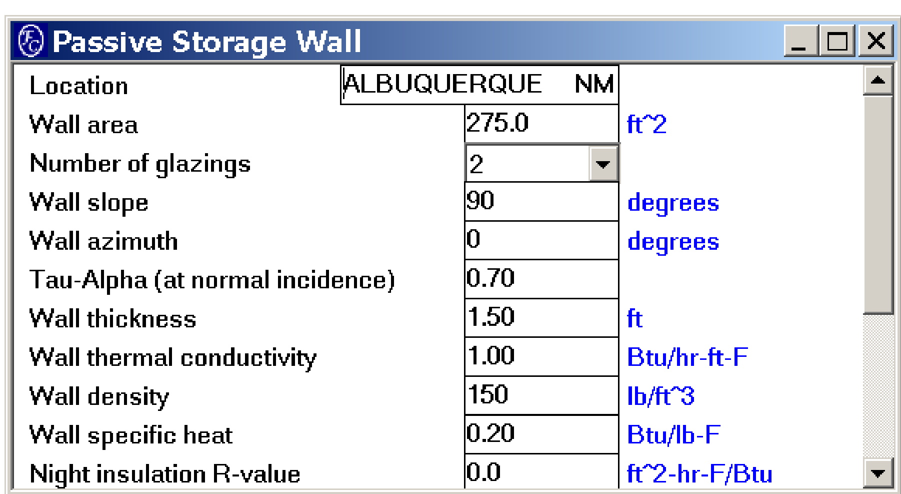
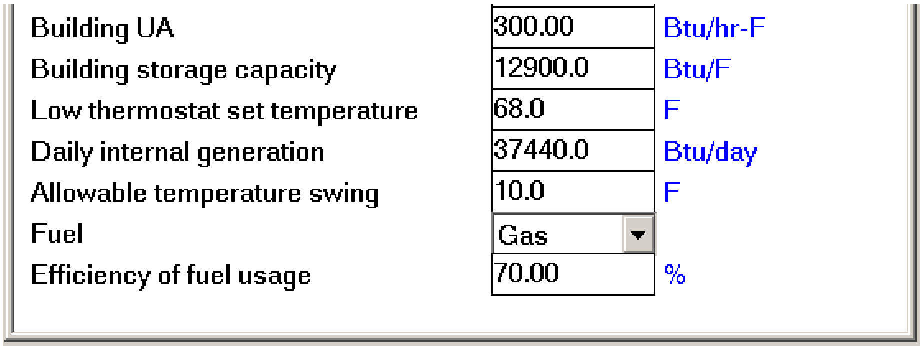


Figure 4.6: Passive Solar Wall System

The thermal parameters for the passive storage wall system are listed below, along with the default values. The parameter descriptions follow this list.





Location is the location where the system is located. Existing city data can be viewed or changed or data for a new city added from the **Data** pull down menu.

Wall area is the surface area of the passive storage wall upon which solar radiation is absorbed.

Number of glazings cycles through 1 to 4 and is used to calculate both the angular dependence of the transmittance of solar radiation and the resistance to heat transfer from the outdoors to the exterior surface of the passive storage wall. Monthly values are permitted.

Wall slope is the angle between the plane of the wall and the horizontal. A vertical wall will have a 90 degree slope.

Wall azimuth is the deviation of the normal to the storage wall from south. A due south orientation will have an azimuth of 0 degrees. Due west and due east will have values of 90 and -90, respectively. In the southern hemisphere a direct-gain window facing the sun at solar noon (i.e. facing north) would have an azimuth angle of 180.

Tau-Alpha (at normal incidence) is the product of the glazing transmittance and wall absorptance for solar radiation at normal incidence. Monthly values are permitted.

Wall thickness is the thickness of the solid portion of the passive storage wall (i.e., excluding the glazing or night insulation).

Wall thermal conductivity is the thermal conductivity of the passive storage wall material. Properties of common building materials can be found in the ASHRAE Handbook of Fundamentals [1985] or in any heat transfer textbook.

Wall density is the density of the passive storage wall material. Properties of common building materials can be found in the ASHRAE Handbook of Fundamentals [1985] or in any heat transfer textbook.

Wall specific heat is the specific heat of the passive storage wall material. Properties of common building materials can be found in the ASHRAE Handbook of Fundamentals [1985] or in any heat transfer textbook.

Night insulation R-value is the thermal resistance of night insulation applied between the passive storage wall and outdoors. This parameter may have monthly values.

Building UA is the building overall energy loss coefficient-area product NOT including the contribution of the passive element. This parameter may have monthly values. See Chapter 25 of the ASHRAE Handbook of Fundamentals [1985] for additional information.

Building storage capacity is the effective energy storage capacity of the building. A value of 6 BTU per square foot (123 KJ per square meter) of floor area is recommended for residential construction. This parameter may have monthly values.

Low thermostat set temperature is the temperature of the indoor space at which the auxiliary furnace turns on. This parameter may have monthly values.

Daily internal generation is the monthly-average daily energy generated within the building by appliances, lights, people, and solar gains other than those attributed to the solar collector system. This parameter may have monthly values.

Allowable temperature swing is the number of degrees above the low set point temperature which the indoor space may be heated to before the solar collector fluid flow is terminated. This parameter may have monthly values.

Fuel cycles through the four possibilities of the back-up fuel (Electricity, Gas, Oil, Other) where 'Other' represents, for example, wood. This parameter is used only in the economic evaluation of the system.

Efficiency of fuel usage represents the average furnace efficiency of the back-up (conventional) fuel. This parameter is used in the economics calculations and it may vary monthly.

The output for the default values in English unit is as follows.

Thermal Output

	Solar [10^6 Btu]	Load [10^6 Btu]	Aux [10^6 Btu]	f [ ]
Jan	13.00	8.072	4.216	0.478
Feb	11.62	5.884	2.635	0.552
Mar	11.55	4.667	1.730	0.629
Apr	9.60	2.328	0.263	0.887
May	7.61	0.720	0.000	1.000
Jun	6.65	0.064	0.000	1.000
Jul	7.13	0.000	0.000	1.000
Aug	8.70	0.064	0.000	1.000
Sep	10.59	0.358	0.000	1.000
Oct	13.44	2.164	0.000	1.000
Nov	12.74	5.201	1.743	0.665
Dec	12.40	7.831	4.139	0.471
Year	125.03	37.351	14.726	0.606

Solar is the monthly total solar radiation incident on the exterior glazing surface of the passive storage wall

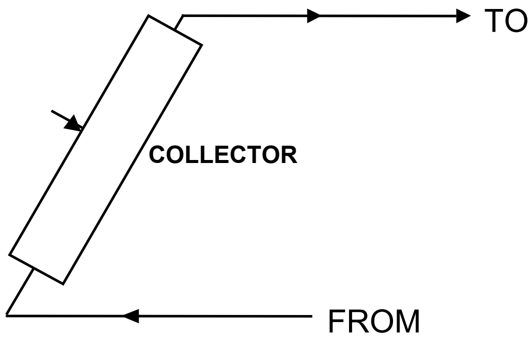
Load is the monthly total space heating demand

Aux is the monthly total auxiliary energy required to maintain the indoor space above the low thermostat set point temperature

f is the fraction of the total load (including losses out the storage wall) which is supplied by the solar system. The remaining fraction must be met by an auxiliary source.

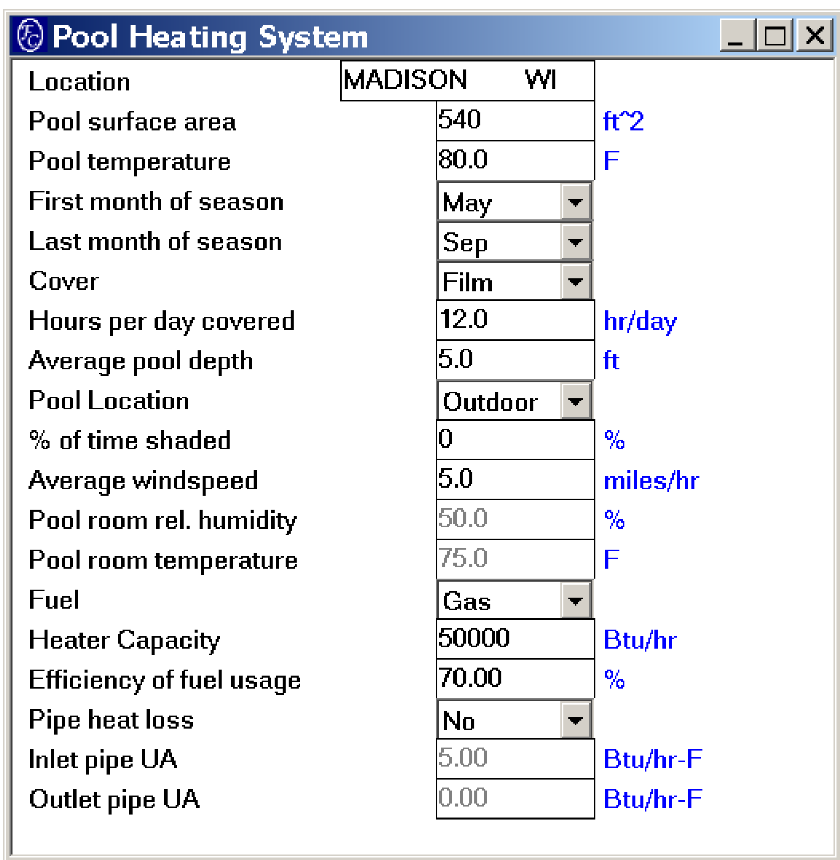
4.7 Pool Heating Systems

Pool solar heating calculations can be done for either indoor or outdoor pools as shown in Figure 4.7. The outdoor pool heating system can use solar energy in two ways. Solar energy is absorbed directly by the water in the pool and it can be supplied by an optional solar collector system. If a solar collector system is not being used, set Number of collector panels in the collector parameter set to 0. Energy is lost from the pool by evaporation, convection, thermal radiation, and conduction to the ground. The evaporation loss can be eliminated by a pool cover. The cover, however, reduces the amount of solar radiation absorbed by the pool. Convection losses are reduced when a bubble type cover is used. The covers are assumed to be transparent to infrared radiation, so that radiation heat losses are not affected by the cover. This pool heating system will provide estimates of the monthly energy loss from the pool based on the algorithms described by Sigworth et al. [1979]. If this information is already known from previous pool heating energy use, the general solar heating system of Section 4.7 is an alternative way to estimate the contribution from a solar collector system.



Figue 4.7: Pool Heating System

The thermal parameters for the pool heating system are listed below along with default values. The parameter descriptions follows.



Pool Heating System

Location	MADISON WI	
Pool surface area	540	ft^2
Pool temperature	80.0	F
First month of season	May	
Last month of season	Sep	
Cover	Film	
Hours per day covered	12.0	hr/day
Average pool depth	5.0	ft
Pool Location	Outdoor	
% of time shaded	0	%
Average windspeed	5.0	miles/hr
Pool room rel. humidity	50.0	%
Pool room temperature	75.0	F
Fuel	Gas	
Heater Capacity	50000	Btu/hr
Efficiency of fuel usage	70.00	%
Pipe heat loss	No	
Inlet pipe UA	5.00	Btu/hr-F
Outlet pipe UA	0.00	Btu/hr-F

Location is the location where the system is located. Existing city data can be viewed or changed or data for a new city added from the **Data** pull down menu.

Pool surface area is the surface area of the pool water.

Pool temperature is the monthly average desired pool temperature. It is assumed that the auxiliary pool heating system has sufficient capacity to maintain the pool at this temperature. This parameter can vary monthly.

First month of season can be cycled through all months of the year to select the month that pool usage (and heating) begins. It is assumed that heating begins on the first day of the selected month.

Last Month of Season can be cycled through all months of the year to select the month that pool usage (and heating) ends. It is assumed that pool heating ends on the last day of this month.

Cover cycles through 'None', 'Film' and 'Bubble' indicating the type of pool cover, if any. The fraction of the solar energy incident on the pool surface that is absorbed by the pool water when no cover is used is assumed to be 0.855. A film cover eliminates all evaporation losses when in place and has 0.837 of the incident solar radiation absorbed by the pool. A bubble-type pool cover eliminates evaporation and reduces convective losses. The fraction of the incident solar radiation absorbed by the pool when the bubble-type cover is in place is assumed to be 0.783. The R-value for the bubble-type cover is assumed to be 1.87 hr-ft2-F/Btu (0.33 m2-C/W).

Hours per day covered is the average number of hours per day that the pool cover is in place. This parameter can vary monthly.

Average pool depth is multiplied by the pool area to determine the pool volume.

Location (Indoor, Outdoor) toggles to specify the location of the pool. If the pool is indoors, then the humidity and temperature of the controlled indoor space must be specified. The pool calculations do not include energy to condition the indoor space.

% of time shaded (Outdoor) is the percentage of solar radiation incident on an unobstructed horizontal surface which is incident on the outdoor pool surface. This parameter can be used to estimate the effects of nearby buildings or trees or it can be used to modify the assumed cover transmittance and pool absorptance. This parameter can vary monthly.

Average wind speed (Outdoor) is the average wind speed at the outdoor pool surface. The wind speed at a local meteorological station is often significantly higher than the average wind speed at a pool surface. Sigworth et. al. [1979] recommend that, for a well-protected pool, the wind speed reported by the weather bureau be reduced by a factor of 10. For a moderately protected pool, they recommend a factor of 5. This parameter can vary monthly.

Pool room relative humidity is the average relative humidity of the conditioned space in which the indoor pool is located. Energy calculations for the pool system do not include energy to maintain the pool room conditions. This parameter can vary monthly.

Pool room temperature is the average temperature of the conditioned space in which the indoor pool is located. Energy calculations for the pool system do not include energy to maintain the pool room conditions. This parameter may have monthly values.

Fuel cycles through the four possibilities of the back-up fuel (Electricity, Gas, Oil, Other) where 'Other' represents, for example, wood. This parameter is used only in the economic evaluation of the system.

Efficiency of fuel usage represents the average furnace efficiency of the back-up (conventional) fuel. This parameter is used in the economics calculations and it may vary monthly.

Pipe heat loss (Yes, No) toggles to indicate if the following two parameters are to be used to calculate the effect of pipe heat losses. If No is selected, the following two parameters are ignored.

Inlet pipe UA is the overall loss coefficient-pipe area product for the pipe carrying fluid to the collector array. This parameter is used only if Yes has been selected for pipe heat loss.

Outlet pipe UA is the overall loss coefficient-pipe area product for the pipe carrying fluid from the collector array. This parameter is used only if Yes has been selected for pipe heat loss.

The output for the default values in English units is as follows.

Thermal Output

	Q Coll [10^6 Btu]	Q Pool [10^6 Btu]	Load [10^6 Btu]	Aux [10^6 Btu]	f [ ]	Pool T [F]
May	14.52	25.54	36.72	22.20	0.395	80.0
Jun	15.98	27.31	23.16	7.18	0.690	80.0
Jul	17.43	27.66	19.42	2.00	0.897	80.0
Aug	16.46	23.93	25.75	9.28	0.639	80.0
Sep	13.01	17.60	38.79	25.78	0.335	80.0
Year	77.40	122.04	143.84	66.44	0.538	

Q Coll is the monthly solar energy delivered by the solar collectors to the pool.

Q Pool is the monthly solar energy directly absorbed by the pool.

Load is the monthly energy loss from the pool by evaporation, convection, thermal radiation, and ground conduction minus the absorbed solar radiation (Qpool).

Aux is the monthly energy that must be supplied by the backup pool heater to maintain the pool temperature at the specified value.

f is the fraction of the pool heating demand which is supplied by the solar collector system. Direct absorption of solar radiation (for outdoor pools) is considered as a reduction to the pool heating load.

Pool T is the monthly average temperature of the pool. If the heater capacity is sufficiently large, then the pool temperature will be equal to the second parameter, the Pool temperature. If the heater capacity is not sufficient to maintain the pool temperature at the desired setting then the pool will reach an equilibrium temperature which balances the input energy from the sun and solar system with the pool losses.

4.8 General Solar Heating Systems

The solar energy system shown in Figures 4.2 and 4.8 represent the general classes of closed and open-loop solar energy systems which can be used for a variety of applications including space heating, absorption air conditioning, water heating and process heating. Solar energy is collected and stored as sensible heat in a liquid storage tank. The storage tank is assumed to be pressurized or filled with a liquid having a high boiling point so that energy dumping (i.e., energy loss through the pressure relief valve) does not occur. When required, the heated liquid is either pumped from storage through a heat exchanger to supply thermal energy to the load (closed-loop system) or the fluid is removed from the tank and replaced with cold fluid (open-loop system). The load is a demand for energy above a minimum useful temperature, TMIN. The value of TMIN depends on the application. For residential space heating, TMIN is the indoor temperature of the building, which is about 20 C. All energy above 20 C can be used for space heating. There are other space heating applications for which TMIN may be higher or lower than 20 C, as, for example, the solar heating of a warehouse which is to be maintained at 10 C. In a water heating system, TMIN will be the mains supply water temperature. TMIN for industrial processes or air conditioning applications will depend on the particular installation. Auxiliary energy is supplied if the solar energy is insufficient to meet the load.

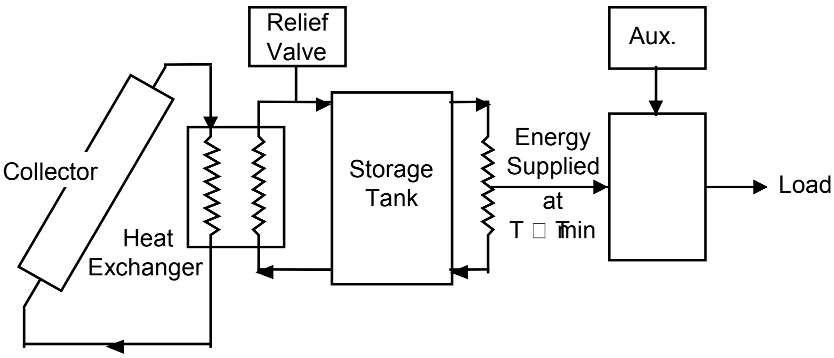
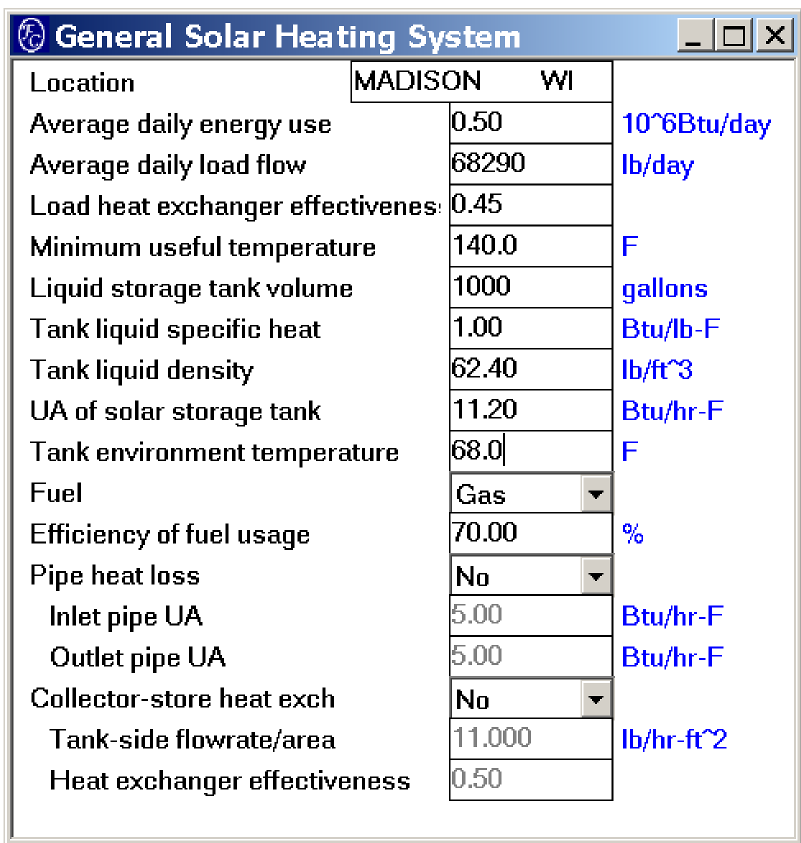


Figure 4.8: Closed-Loop Solar Energy System

The thermal performance of these general solar heating systems is calculated using the PHIBAR, f-Chart $(\bar{\phi}, f-chart)$ method of Klein and Beckman [1979] which has been extended to open-loop systems as described by Braun and Klein [1983]. The thermal parameters and default values are listed below followed by descriptions of the parameters.



General Solar Heating System

Location	MADISON WI	
Average daily energy use	0.50	10^6Btu/day
Average daily load flow	68290	lb/day
Load heat exchanger effectivenes:	0.45	
Minimum useful temperature	140.0	F
Liquid storage tank volume	1000	gallons
Tank liquid specific heat	1.00	Btu/lb-F
Tank liquid density	62.40	lb/ft^3
UA of solar storage tank	11.20	Btu/hr-F
Tank environment temperature	68.0	F
Fuel	Gas	
Efficiency of fuel usage	70.00	%
Pipe heat loss	No	
Inlet pipe UA	5.00	Btu/hr-F
Outlet pipe UA	5.00	Btu/hr-F
Collector-store heat exch	No	
Tank-side flowrate/area	11.000	lb/hr-ft^2
Heat exchanger effectiveness	0.50	

Location is the location where the system is located. Existing city data can be viewed or changed or data for a new city added from the **Data** pull down menu.

Average daily energy use is the monthly average daily energy demand of the process. This energy demand is met by a combination of solar energy and conventional energy. This parameter may have monthly values.

Average daily load flow is the average daily amount of stored fluid circulated (or removed) to supply the load. In a closed-loop system, this will be the product of the rate at which fluid is circulated through the load heat exchanger and the average number of hours per day in which there is a load. In an open-loop system, this is average daily amount of fluid removed from the tank. This parameter may have monthly values.

Load heat exchanger effectiveness is the ratio of the actual to maximum heat transfer rates in the heat exchanger between the solar storage tank and the load in a closed-loop system. For an open-loop system, a heat exchanger does not exist and this parameter should be set equal to 1.0.

Minimum useful temperature is the lowest temperature in which energy supplied to the load is useful. Monthly values are permitted.

Liquid storage tank volume is the volume of stored liquid used for sensible heat storage of collected solar energy.

Tank liquid specific heat is the specific heat of the liquid in the storage tank. Properties of common materials can be found in the ASHRAE Handbook of Fundamentals [1985] or in any heat transfer textbook. For water, use 1 Btu/lbm F or 4190 J/kg-K.

Tank liquid density is the density of the liquid in the storage tank. Properties of common materials can be found in the ASHRAE Handbook of Fundamentals [1985] or in any heat transfer textbook. For water use 62.4 lbm/ft^3 or 1000 kg/m^3.

UA of solar storage tank is the product of the energy loss coefficient and surface area for the solar storage tank.

Tank environment temperature is the temperature of the surroundings of the storage tank to which heat transfer losses occur. Monthly values are permitted.

Fuel cycles through the four possibilities (Electricity, Gas, Oil, Other) of the back-up fuel where 'Other' represents, for example, wood. This parameter is used only in the economic evaluation.

Efficiency of fuel usage represents the average furnace efficiency of the back-up (conventional) fuel. This parameter is used in the economics calculations and it may vary monthly.

Pipe heat loss toggles between Yes and No to indicate if the following two parameters are to be used to calculate the effect of pipe heat losses. If No is selected, the following two parameters are ignored.

Inlet pipe UA is the overall loss coefficient-pipe area product for the pipe carrying fluid to the collector array. This parameter is used only if Yes has been selected for pipe heat loss.

Outlet pipe UA is the overall loss coefficient-pipe area product for the pipe carrying fluid from the collector array. This parameter is used only if Yes has been selected for pipe heat loss.

Collector-store heat exch toggles between Yes and No to indicate if the following two parameters should be used to account for the performance penalty resulting from the heat exchanger between the collector array and the storage tank. If No is specified, the following two parameters are ignored.]

Tank side flow rate/area is the mass flow rate of water from the storage tank through the collector-storage heat exchanger divided by the total array area. Set this parameter to a value that is larger than collector flow rate/area for an internal heat exchanger. This parameter is used only if Yes is selected for the collector-storage heat exchanger.

Heat exchanger effectiveness is the ratio of the actual to maximum possible heat transfer rates for heat exchanger located between the collector and the storage unit. This parameter is used only if Yes is selected for the collector-storage heat exchanger.

The output for the default values (which represents a process heating system) in English units is:

Thermal Output

	Solar [10^6 Btu]	Load [10^6 Btu]	QTank [10^6 Btu]	Aux [10^6 Btu]	f [ ]
Jan	17.98	15.50	0.622	12.95	0.165
Feb	20.06	14.00	0.572	10.62	0.242
Mar	23.99	15.50	0.639	11.09	0.285
Apr	24.94	15.00	0.627	9.81	0.346
May	27.89	15.50	0.658	9.22	0.405
Jun	28.46	15.00	0.646	8.04	0.464
Jul	29.52	15.50	0.675	7.70	0.503
Aug	28.06	15.50	0.674	7.76	0.500
Sep	24.07	15.00	0.635	9.02	0.399
Oct	21.02	15.50	0.640	10.98	0.292
Nov	14.38	15.00	0.598	12.96	0.136
Dec	14.05	15.50	0.614	13.88	0.104
Year	274.41	182.50	7.601	124.02	0.320

Solar is the monthly total solar radiation incident on the collector surface.

Load is the monthly total thermal energy demand on the system at a temperature above the specified minimum useful temperature.

Q Tank is the monthly total energy loss from the storage tank.

Aux is the monthly total auxiliary energy which must be supplied in addition to the solar energy to meet the demand.

f is the fraction of the load supplied by the solar energy system. The remaining fraction is supplied by an auxiliary source.

4.9 Integral Collector-Storage Water Heating Systems

Integral collector-storage (ICS) units are passive solar water preheaters that combine solar collection with thermal storage. They are usually roof or ground mounted in series with a conventional domestic water heater and supplied by mains water. An ICS unit is basically a black tank in an enclosure with an optical cover system, as shown in Figure 4.8. There are many variations in design. Some units have several tanks plumbed in series within the enclosure. Others have internal reflector systems, non-flat covers or finned tanks. ICS solar water heaters usually cost less than active systems and are inherently simple to install and maintain. They often operate without heat exchangers, pumps or controllers. Auxiliary energy must be supplied if the solar energy collected by the ICS system is insufficient to meet the water heating load.

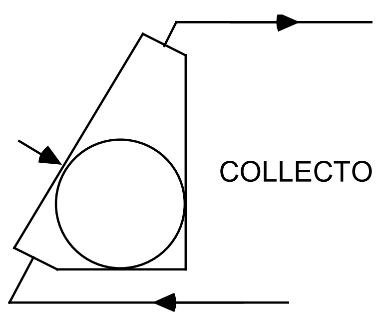
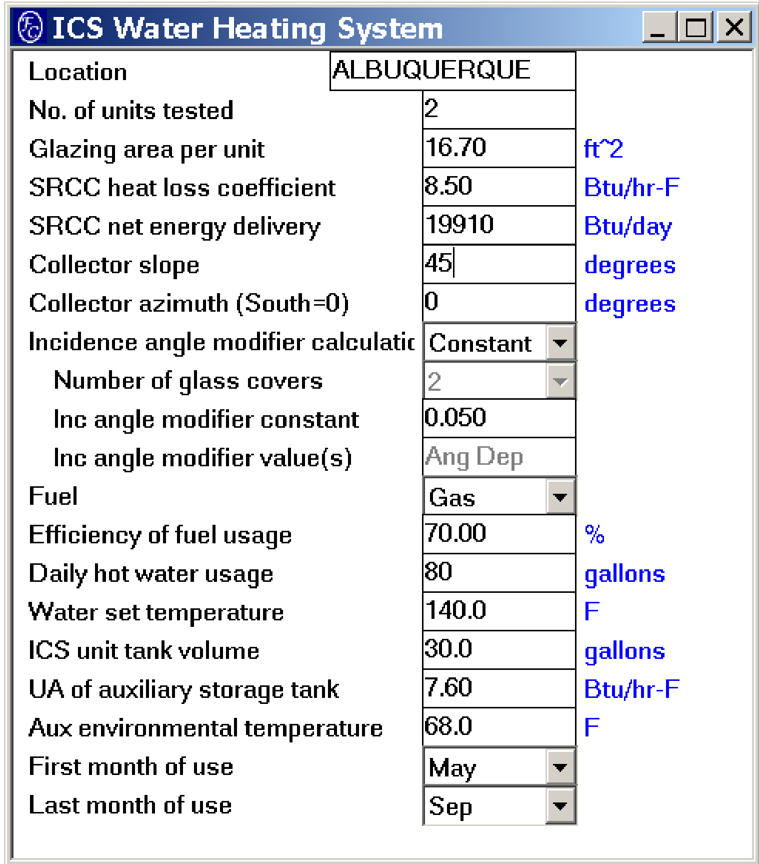


Figure 4.9: Integral Collector-Storage Solar Water Heater

The monthly performance of an ICS system is estimated using the method of Zollner et al. [1985]. The thermal parameters and default values in English units are listed below followed by descriptions of the parameters.



Location is the location where the system is located. Existing city data can be viewed or changed or data for a new city added from the **Data** pull down menu.

No. of units tested is the number of integral collector-storage units used in the SRCC test. NOTE: This parameter should not be changed without supplying modified values of the SRCC heat loss coefficient and SRCC net energy delivered.

Glazing area per unit is the aperture area of each ICS unit panel. NOTE: This parameter should not be changed without supplying modified values of the SRCC heat loss coefficient and the SRCC net energy delivery.

SRCC heat loss coefficient is the overall integral collector-storage unit heat loss coefficient resulting from the nighttime cool-down test as prescribed by SRCC Standard 200.

SRCC net energy delivery is the periodic steady value of the daily useful energy collected by the integral collector-storage system obtained from the ASHRAE 95-1981 test procedure under simulated environmental conditions as prescribed by SRCC Standard 200.

Collector slope is the angle between the plane of the collector aperture and the horizontal. This parameter may have monthly values. The angle is measured in a vertical plane that is perpendicular to the line formed by the intersection of the plane of the collector aperture and the horizontal plane.

Collector azimuth (South=0) is the angle between the projection into the horizontal plane of the normal to the collector aperture and the local meridian with the zero point directly facing the equator, west positive, and east negative. The azimuth of a horizontal collector can have any value. The azimuth of a collector facing the sun at noon in the southern hemisphere (i.e. north facing) is 180. This parameter may have monthly values.

Incidence angle modifier calculation cycles through 'Glazings', 'Constant', and 'Value(s)' to indicate which of three possible methods is to be used to calculate the effect of incidence angle on FR*TAU*ALPHA. One of the next three parameters will be available depending upon the selection; the other two will be hidden. If 'Glazings' is selected, the Fresnel equations are used with nominal glass properties and the number of glazings will have to be selected. If 'Constant' is selected, the ASHRAE incident angle modifier constant will be required. If 'Value(s)' is selected, either a single incidence angle modifier or the incident angle modifier value for every 10 degrees will be required.

Number of glazings cycles through 1 to 4 to indicate the number of glazings on the solar collector. Values of the monthly-average incidence angle modifier are calculated using the Fresnel equations with glass properties and the method described in Duffie and Beckman [1980].

Inc angle modifier constant, b, is the parameter which provides the best fit in the equation K(t) = 1.0 - b (1/cos(t) - 1.0) where K(t) is the ratio of the transmittance-absorptance product at incidence angle t to the normal incidence transmittance-absorptance product. The constant, b, is determined experimentally as described in the ASHRAE Standard 93-77 collector test procedure [1977]. This parameter is visible only if 'Constant' was chosen for the incidence angle modifier type.

Inc angle modifier value(s) are the the value(s) of the collector incidence angle modifier, K(t) as determined by the ASHRAE Standard 93-77 collector test procedure [1977]. If a single value is used for this parameter, then the incidence angle modifier is taken to be that constant value independent of solar incidence angle. Alternatively, values of this parameter may be specified for incidence angles between 0 and 90 degrees in 10 degree increments. The incidence angle value(s) are used only if 'Value(s)' was chosen for the incidence angle modifier type.

Fuel cycles through the four possibilities (Electricity, Gas, Oil, Other) of the back-up fuel where 'Other' represents, for example, wood. This parameter is used only in the economic evaluation.

Efficiency of fuel usage represents the average furnace efficiency of the back-up (conventional) fuel. This parameter is used in the economics calculations and it may vary monthly.

Daily hot water usage is the average amount of hot water per day required at the set temperature. Monthly values are allowed. This parameter is visible only if Yes has been selected for domestic hot water parameter.

Water set temperature is the temperature to which domestic water is to be heated. Monthly values are allowed. This parameter is used only if Yes has been selected for domestic hot water.

ICS unit tank volume is the volume of the integral collector-storage unit.

UA of auxiliary storage tank is the product of the energy loss coefficient and surface area for the auxiliary tank in the solar domestic water heating system. In a single tank system, use the tank surface area above the heating element thermostat.

Auxiliary environmental temperature is the temperature of the surroundings of the auxiliary water heater to which heat losses occur. Monthly values are allowed.

First month of use cycles through the 12 months to indicate the month of the year in which the integral collector-storage unit will be put into operation. It is assumed operation begins on the first day of the month.

Last month of use cycles through the 12 months to indicate the last month of the year in which the integral collector-storage unit will be operating. It is assumed operation stops on the last day of the month.

The thermal performance is calculated on a monthly basis. Shown below is the output for the default parameter set in English units.

Thermal Output

	Solar [10^6 Btu]	Load [10^6 Btu]	Loss [10^6 Btu]	Aux [10^6 Btu]	f [ ]
May	2.14	1.73	0.41	1.36	0.36
Jun	2.05	1.67	0.39	1.27	0.38
Jul	2.04	1.72	0.41	1.31	0.38
Aug	2.08	1.72	0.41	1.30	0.39
Sep	2.04	1.67	0.39	1.29	0.38
Year	10.34	8.51	2.01	6.54	0.38

Optical Efficiency = 0.48
Energy Loss Coefficient = 0.25

Solar is the monthly total solar radiation incident on the collector surface.

Load is the monthly domestic hot water energy demand.

Loss is the monthly energy loss from the auxiliary storage tank.

Aux is the monthly total auxiliary energy required to supply the domestic hot water demand.

f is the fraction of the hot water energy demand which is supplied by the ICS system.

Optical efficiency is the effective product of the glazing transmittance and tank absorptance.

Energy Loss Coefficient is the effective energy loss coefficienct of the ICS system to the ambient expressed per unit glazing area.

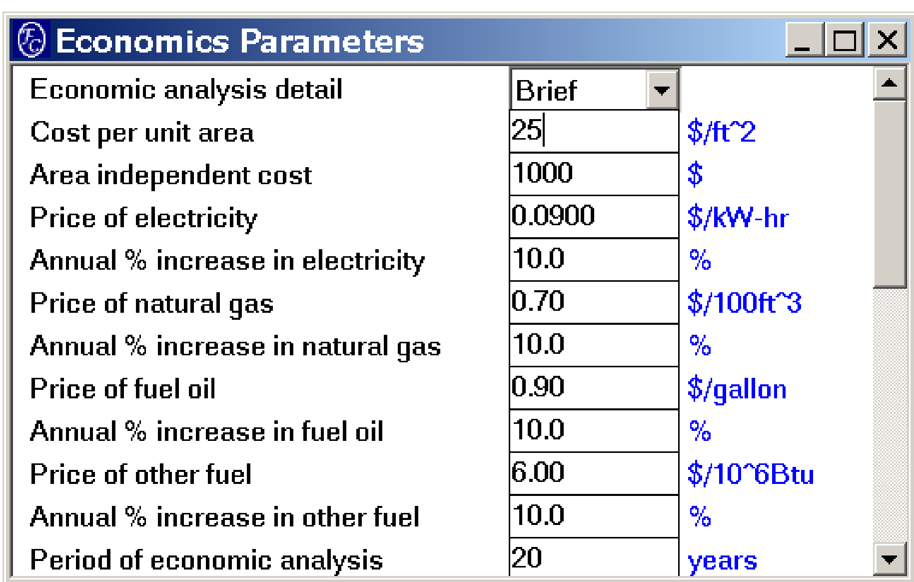
CHAPTER 5

Economics

The economic calculations done in **F-Chart** are first year costs, life cycle, life cycle savings and cash flow. Life cycle costs and savings are computed from present costs of energy from fuel and its anticipated inflation rate, market discount rate, an assumed period of economic analysis, owning costs and operating costs. The life-cycle costs of owning and operating the improvement includes such items as interest and principle payments on funds borrowed to pay for the improvement (e.g., on the incremental mortgage), income tax effects of incremental property taxes and interest payments, tax credits, resale value, depreciation, etc. In this chapter, we discuss the meaning of the economic output and discuss each of the economic parameters. The life cycle cost method as applied to solar energy systems can be found in Duffie and Beckman [1991].

5.1 Economic Parameters

The economic parameter list contains 28 parameters. Two additional economic parameters are contained in the system parameter list: the fuel type and the efficiency of fuel usage. These two parameters are explained in the appropriate places in Chapter 4. The economic parameter list and explanations of the parameters follow.



% Down payment	100	%
Annual mortgage interest rate	9.0	%
Term of mortgage	20	years
Annual market discount rate	8.0	%
% Extra insur. and maint. in year 1	0.0	%
Annual % increase in insur. and m	8.0	%
Eff Fed.+State income tax rate	20.0	%
True % property tax rate	3.0	%
Annual % increase in property tax	8.0	%
% Resale value	100.0	%
% Credit rate in tier 1	56.0	%
Maximum investment in tier 1	10000	$
% Credit rate in tier 2	0.0	%
Maximum investment in tier 2	10000	$
Commercial system?	No	
Commercial depreciation schedul	Schedule	%

Economic analysis detail cycles through "Brief", "Detailed", and "Cash Flow". The Brief selection gives economic information about the first year, the life cycle costs, and the life cycle savings. The Detailed option includes the information given under the Brief selection and, in addition, gives information on the breakdown of the life cycle economic costs. The Cash Flow option includes all of the above and gives the annual cash position.

Cost per unit area is the cost per square foot or square meter of the solar collection system including such items as the storage costs that increase with increasing collector area. If the total cost of the system is known, then set this parameter to zero and place the total cost into the "Area independent cost" parameter. For a passive system, this unit area cost should be only the incremental cost of the wall above the conventional wall. If this cost is less than a conventional wall then use a negative cost per unit area.

Area independent cost is the cost of fixed equipment such as pumps, controllers, piping, part of the storage, and other costs that are independent of collector area. If the total cost of the system is known, then set this parameter to the total cost and place a zero in the "Cost per unit area" parameter.

Price of electricity is the average purchase price per kilowatt-hour paid in the first year.

Annual % increase in electricity is the anticipated average yearly inflation rate of electricity during the period of the economic analysis. It is assumed that the average rate occurs each year of the analysis.

Price of natural gas is the average purchase price per 100 cubic feet (approximately per therm) or per cubic meter paid in the first year.

Annual % increase in nat. gas is the anticipated average yearly inflation rate of gas during the period of the economic analysis. It is assumed that the average rate occurs each year of the analysis.

Price of fuel oil is the average purchase price per gallon or per liter paid in the first year.

Annual % increase in fuel oil is the anticipated average yearly inflation rate of oil during the period of the economic analysis. It is assumed that the average rate occurs each year of the analysis.

Price of other fuel such as wood is the average purchase price per million BTU or per gigajoule paid in the first year.

Annual % increase in other fuel is the anticipated average yearly inflation rate of heating fuel such as wood during the period of the economic analysis. It is assumed that the average rate occurs each year of the analysis.

Period of economic analysis is the number of years over which the life cycle cost analysis is done. Often this is 20 years or the same as the term of the mortgage.

Percent down payment is the percentage of the incremental cost of the solar system which is paid out at the time of installation. The balance is paid for by a mortgage.

Annual mortgage interest rate is the yearly rate charged by the lender on funds borrowed, in percent.

Term of the mortgage is the number of years over which the funds borrowed must be repaid.

Annual market discount rate is the yearly rate of return from the solar system owner's best alternative investment, in percent. For a home owner, this is often the interest rate available at a bank, either the savings account rate or the rate for certificates of deposit (CD's). For a business, the internal rate of return of the company is often used.

% Extra insur. and maint. in year 1 is the first year's extra insurance, maintenance, and other non-fuel operating expenses attributable to the system, expressed as a percent of the initial investment.

Annual % increase in insur. and maint. is the average expected inflation rate of these expenses (previous parameter) over the period of the economic analysis.

Eff Fed.+State income tax rate is the effective combined federal and state income tax rate of the solar system owner. If tax laws do not permit deducting of state taxes on federal returns (e.g., if the owner uses standard deductions on his/her federal return) then this parameter is the sum of the federal and state brackets, in percent. If state taxes are deducted from federal income for tax purposes, then the effective rate is the sum of the federal and state rates minus their product.

True % property tax rate is the ratio of the increment in real estate taxes due to the solar system to the cost of the solar system (not the assessed tax value of the solar system), expressed as a percent. Some taxing districts specifically exempt solar systems in which case this parameter should be zero.

Annual % increase in property tax is the anticipated average yearly rate of inflation of property taxes over the period of the economic analysis, in percent. This is often set equal to the general inflation rate.

% Resale value is the anticipated resale or salvage value of the solar system at the end of the period of the economic analysis, as a percent of the initial solar system cost. If the solar system were added to a house and treated like any other part of the house, the percent resale value would be equal to the ratio of the house selling price at the end of the economic analysis divided by the house purchase price. If the solar system were worn out and needed replacement at the end of the economic period, then the resale value would be negative and equal to the removal cost divided by the initial solar system cost. These two limits probably bracket the actual situation. If the period of the economic analysis is long, say 20 years or more, then the resale value will have only a small effect on the life cycle cost.

% Credit Rate in tier 1
Maximum investment in tier 1
% Credit Rate in tier 2
Maximum investment in tier 2
These four parameters are provided to enter tax credits or government subsidies that effectively reduce the purchase price of the solar system. Since some solar systems may be subsidized by more than one government agency, provision has been made to consider credits from two agencies with different limits of eligibility. Consider a state government with a tax credit of 25% on the first $2000 of investment and a federal government with a 40% credit on the first $10000 of investment. The credit on the first $2000 would be 65% and the credit on the next

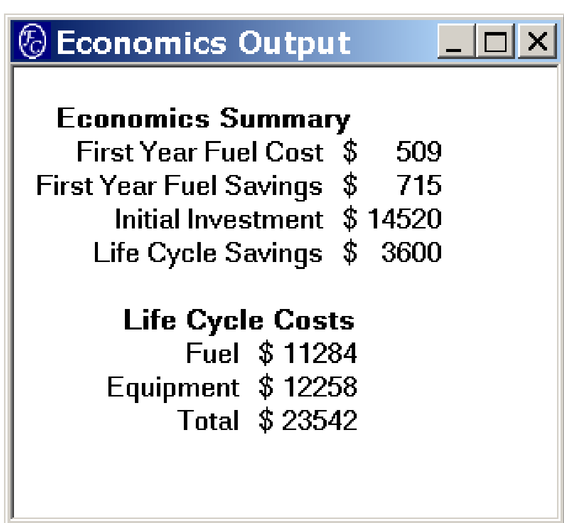
$8000 would be 40%. The percent credit rate in tier one is 65%. The maximum investment in tier one is $2000. The percent credit in tier two is 40%. The maximum investment in tier 2 is $10000.

Commercial system? toggles between "Yes" and "No" to indicate if the solar system can be depreciated for tax purposes and if fuel is deductible as a business expense. If this parameter is set to "Yes", then the depreciation schedule in the next parameter is used in calculating taxes and fuel is assumed to be deductible as a business expense. (For a business that makes a profit and pays taxes, the government subsidizes fuel). Consequently, commercial solar energy systems are harder to justify on economic grounds than residential or other non-profit solar systems.) If fuel is deductible, but depreciation is not allowed, set this parameter to "Yes" and set the depreciation schedule to zero. If depreciation is allowed but fuel is specifically not allowed as a business expense, set this parameter to "Yes" and artificially increase the fuel cost by the effective income tax bracket. For solar systems on private homes, this parameter should be set to "No".

Commercial depreciation schedule is applicable only if the commercial system parameter is set to "Yes". In this case, then you may enter 10 yearly depreciation values that effect the taxes paid. For a three-year depreciation schedule, the U.S. Government allows 25%, 38%, and 37%. For a five-year schedule, the rates are 15%, 22%, 21%, 21% and 21%. For a ten-year schedule, the rates are 8%, 14%, 12%, 10%, 10%, 10%, 9%, 9%, 9% and 9%.

5.2 Economics Output

The level of detail displayed for the economic calculations is controlled by the first parameter in the economic parameter window. The economics output resulting from the Brief setting is as follows: (Using the file DEFAULTS.FC)



First year fuel cost is calculated by multiplying the cost per unit of auxiliary energy by the annual auxiliary requirements determined in the thermal analysis and dividing this result by the fuel usage efficiency.

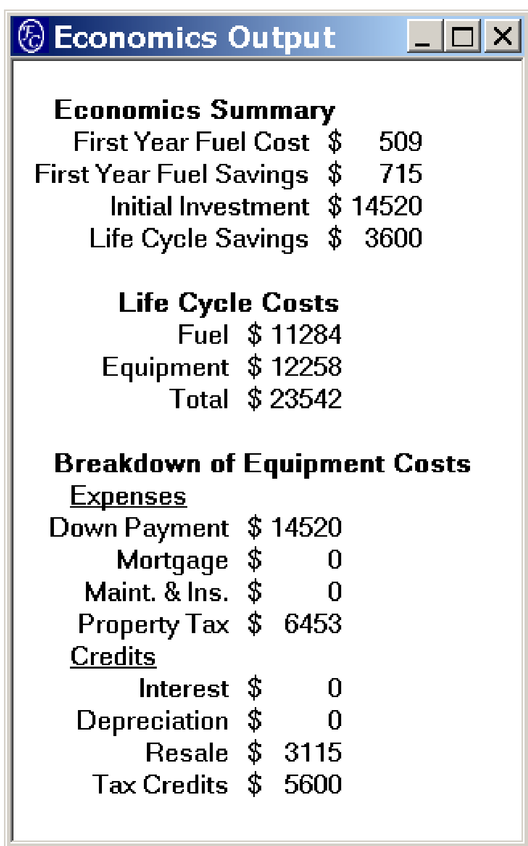
First year fuel savings plus the first year fuel cost is equal to the non-solar fuel cost.

Initial investment is calculated by multiplying the cost per unit area by the area and adding the fixed cost.

Life cycle savings are calculated by subtracting the present worth of the owning and operating costs from the present worth of the fuel savings, both calculated for the period of the economic analysis. This savings represents the economic advantage of the system over a fuel-only system.

Life cycle costs is the sum of the present worth of the fuel cost and the owning and operating cost. A breakdown of the life cycle costs is provided.

When the economics analysis detail is set to Detailed, all of the above information will be presented along with a breakdown of equipment costs into expenses and credits.



The **Down Payment** is assumed to be made at the beginning of the first year and is therefore not discounted. The **Mortgage** cost is the present worth of the sum of the annual mortgage payments. **Maintenance and insurance** costs are the sum of the present worth of the inflating annual payments. **Property taxes** are also calculated as the sum of the present worth of the inflating annual payments. However, property taxes are a net cost since income tax deductions have been included. **Interest** represents the tax benefit resulting from including the mortgage interest as a deduction on federal and state income tax forms. **Depreciation** is the present worth of the depreciation, calculated according the Commercial depreciation schedule, for income producing buildings. R**esale** is the present worth of the product, which is the % Resale value times the initial investment. For commercial property, the resale value is reduced by tax considerations. The **Tax credits** from federal and state governments are calculated if Consider Rebates is set to Yes.

Setting the economic analysis detail to Cash Flow provides, in addition to the outputs for the detailed setting, the annual cash position for each year of the economic analysis which appears as follows.

Annual Cash Position

Year	Maint & Ins [$]	Prop Tax [$]	Energy Cost [$]	Tax Savings [$]	Net Savings [$]	Present Worth [$]
0	0	0	0	5600	-8920	-8920
1	0	436	509	87	367	340
2	0	470	560	94	411	352
3	0	508	616	102	459	364
4	0	549	677	110	513	377
5	0	593	745	119	573	390
6	0	640	820	128	640	403
7	0	691	902	138	714	417
8	0	747	992	149	797	430
9	0	806	1091	161	888	444
10	0	871	1200	174	990	459
11	0	940	1320	188	1103	473
12	0	1016	1452	203	1228	488
13	0	1097	1597	219	1368	503
14	0	1185	1757	237	1522	518
15	0	1279	1933	256	1693	534
16	0	1382	2126	276	1883	550
17	0	1492	2339	298	2093	566
18	0	1612	2573	322	2326	582
19	0	1741	2830	348	2585	599
20	0	1880	3113	376	17391	3731
Tot	0	19934	29153	9587	30625	3600

Maint & Ins is the annual expense to maintain and insure the equipment.

Prop Tax is the annual property tax.

Energy Cost is the annual payment made for auxiliary fuel.

Tax Savings is the annual saving due to state and federal tax deductions. For non-commercial systems, this term includes property taxes and interest. For commercial systems, maintenance, insurance and fuel are tax deductible and these savings are included in this term. In year 0, this column includes any additional state and federal rebates.

Net Savings is the difference between the annual expenses incurred without a solar system and the expenses incurred with a solar system. In year 0, this term is the difference between the down payment and the tax rebates.

Present Worth is the present worth of the Net Savings column. The total of the Present Worth column is equal to the life cycle savings.

APPENDIX A
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APPENDIX B

UNIT CONVERSION TABLES

SI UNITS

Basic Units

meter	m	length
kilogram	kg	mass
second	s	time
Kelvin	K	temperature

Derived units

liter	l	volume	10-^3m^3
Newton	N	force	kg-m/s
Joule	J	energy	N-m
Watt	W	power	J/s
Hour	hr	time	3600 s

Decimal Multiples of Units

tera	T	10^{12}
giga	G	10^9
mega	M	10^6
kilo	k	10^3
micro	m	10^{-3}
nano	n	10^{-9}
pico	p	10^{-12}

UNIT CONVERSIONS

Length

1 ft	= 0.3048 m
1 mile	= 1.6093 m
1 inch	= 25.4 mm
1 yard	= 0.9144 m

Velocity

1 ft/min	= 0.00508 m/s
1 mile/hr	= 0.44704 m/s

Area

1 ft^2	= 0.092903 m^2
1 $mile^2$	= 2.58999 km^2
1 $inch^2$	= 0.000645 m^2

Volume

1 ft^3	= 28.3168 l
1 gal	= 3.78544 l
1 ft^3	= 7.48 gal
1 $yard^3$	= 0.7645 m^3

Volumetric Rate

1 cfm	= 0.47195 l/s
1 gal/min	= 0.06309 l/s
1 gal/min-ft^2	= 0.6791l/s-m^2
1 cfm/ft^2	= 0.1968 l/s-m^2

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Mass

1 lb	= 0.453492 kg
1 oz	= 28.3495 g

Mass Flow Rate

1 lb/hr	= 0.000126 kg/s
1 lb/hr-ft^2	= 0.001356 kg/s-m^2

Temperature Scales

F	= C x 1.8 + 32
C	= (F-32) x 5/9
K	= C + 273
R	= F + 460

Temperature Differences

1 F	= 0.55556 C
1 C	= 1.8 F

Energy

1 Btu	= 1.05506 kJ
1 Therm	= 105.506 MJ
1 cal	= 4.1868 J
1 kW-hr	= 3.6 MJ
1 langley	= 41.86 kJ/m^2

Power

1 Btu/hr	= 0.29307 W
1 ton (refg)	= 3.51685 kW
1 kcal/hr	= 1.163 W
1 hp	= 0.74570 kW

Energy Flux

1 Btu/hr-ft^2	= 3.15469 W/m^2
1 langley/hr	= 11.6277 W/m^2
1 cal/cm^2-min	= 697.4 W/m^2
1 Btu /hr-ft^2-F	= 5.67826 W/m^2-C
1 Btu /hr-ft-F	= 1.70307 W/m^2-C

NUMERICAL VALUES OF SOME PROPERTIES

Solar Constant = 1353 W/m^2
= 1.940 langleys/min
= 428 $Btu/hr\text{-}ft^2$

	Density		Specific Heat	
Air	1.204	kg/m^3	1012	J/kg-C
	0.07516	lb/ft^3	0.241	BTU/lb-F
Water	1000	kg/m^3	4190	J/kg-C
	62.4	lb/ft^3	1.00	BTU/lb-F
	8.34	lb/gal		
Rock	2400	kg/m^3	838	J/kg-C
	150	lb/ft^3	0.2	BTU/lb-F
Antifreeze	1065	kg/m^3	3350	J/kg-C
(50% Ethylene glycol-water)	66.5	lb/ft^3	0.80	BTU/lb-F

APPENDIX C

California Compliance Requirements

The state of California has special requirements for showing compliance with Title 24, Part 2, Chapter 2-53, Section 2-5351. This appendix has been prepared from the appropriate documents for **F-Chart** users in California.

When calculating solar domestic hot water performance, the *Water Storage Space & DHW* system should be selected from the **System** menu. The Building UA must be set to zero to turn off the house heating option and the Domestic hot water option must be set to Yes. Some of the **F-Chart** parameters and weather data have to be set according to the California code. The storage tank is initially assumed to be perfectly insulated so that UA of auxiliary tank must be set to zero. A special calculation method is used to estimate standby losses and is included in the calculation procedure outlined below. The Water set temperature must be set to 140 F. The Daily hot water usage must be set to 50 gal/day/unit for single family dwellings or to 35 gal/day/unit for multi-family dwellings.

Weather data for the 16 California climate zones have been added to the **F-Chart** database using data supplied by the California Energy Commission. The data for those cities that are in both the original **F-Chart** database and the CEC database are not the same. The **F-Chart** database, USA_Old, comes from a 1978 DOE report, Input Data for Solar Systems by V. Cinquemani, J.R. Owenby, Jr. and R.G. Baldwin (prepared under interagency agreement no E(49-26)-1041). The **F-Chart** database USA_New comes from the National Solar Radiation DataBase (NSRDB) created by the National Renewable Energy Laboratory (NREL).

The CEC calculation procedure for estimating the total water heating energy is reproduced here. The tables needed to fill in the worksheet are also provided. Table 1 lists the 16 climate zones, the **F-Chart** city number, the storage tank environment temperature for Parameter 9, the water mains temperature and the number of freeze days per year. The **F-Chart** *Chg/View Data* command in the **Weather** menu will have to be used to change the water mains temperatures to the values found in Table 1. Table 2 gives estimates of pump and controller annual energy use. Table 3 gives the standby loss adjustment.

CALCULATION OF ANNUAL WATER HEATING ENERGY

A. Equipment Data

1. Tank capacity	_______	Gal	From CEC Appliance Directory
2. Recovery efficiency	_______	Percent	From CEC Appliance Directory
3. Hourly input rate	_______	Btu/hr.	From CEC Appliance Directory
4. Pumping energy	_______	Watt-hr/yr	See Table 2.

B. Operating Data

1. Tank set temp.	140	F	Fixed input
2. Water main temp.	_______	F	See Table 1
3. Daily water load	_______	Gal/day	Single family=50 gal/day Multi-family =35 gal/day
4. Environment temp.	_______	F	See Table 1
5. Adj. standby loss	_______	Percent	See Table 3

C. Water Heating Energy

1. Annual recovery load	_______	KBtu/yr	B3 x 8.25 x (140-B2) x 365/1000
2. Energy from non-depletable resources	_______	KBtu/yr	F for yr x DHW load for yr from **F-Chart** output
3. Net annual recovery load	_______	KBtu/yr	C1-C2
4. Annual recovery energy	_______	KBtu/yr	C3/A2
5. Annual standby loss energy	_______	KBtu/yr	(24-(C4 x 1000)/(A3 x 365)) x 8.25 x A1 x B5 x 365 x (140-B4)/1000
6. Pumping energy	_______	KBtu/yr	A4 x 3.414 x 3/1000
7. Total water heating energy	_______	KBtu/yr	C4+C5+C6 Gas systems or ((C4+C5)x3)+C6 for all electric systems

TABLE 1.: California Climate Zone Modeling Variables

CEC Zone	City	Lat.	------Temperatures------ Environment	Water Mains	Number of Freeze Days
1	Arcata	41.0	52.1	60	5
2	Santa Rosa	38.5	57.9	65	16
3	Oakland	37.7	56.9	65	1
4	Sunnyvale	37.4	60.3	65	8
5	Santa Maria	34.9	60.3	65	24
6	Long Beach	33.8	63.5	70	1
7	San Diego	32.7	62.9	70	1
8	El Toro AFB	33.7	73.0	70	1
9	San Fernando	34.3	63.6	70	1
10	Riverside	33.9	63.3	70	14
11	Red Bluff	40.2	62.8	65	22
12	Sacramento	38.5	60.3	65	17
13	Fresno	36.8	62.3	65	28
14	China Lake AFB	35.7	55.9	65	124
15	El Centro	32.8	72.6	70	22
16	Mount Shasta	41.3	42.8	60	130

If a solar system is being installed, pump and control energy must be determined for the particular generic solar system type. This energy can be determined from the fixed values listed below. Other values are allowed if verification of pump and controller wattage is provided to the local building department.

TABLE 2. Determining Pumping Energy

System Type		Pump and Control Energy (Watt-hr/yr)
Open-loop (direct)		
Recirculation -	85W pump @ 6 hrs/day 5W controller @ 24 hrs/day	See * below
Draindown -	85W pump @ 6 hrs/day 5W controller @ 24 hrs/day 2W draindown valve @ 24 hrs/day	247, 470
Closed-loop (indirect)		
Drainback -	85W pump @ 6 hrs/day 70W pump @ 6 hrs/day 15W controller @ 24 hrs/day	470, 850
Anti-freeze -	85W pump @ 6 hrs/day 5W controller @ 24 hrs/day	229, 950
Oil -	185W pump @ 6 hrs/day 85W pump @ 6 hrs/day 15W controller @ 24 hrs/day	722, 700
Refrigerant- - phase change	85W pump @ 6 hrs/day 5W controller @ 24 hrs/day	229, 950
Air-	75W pump @ 6 hrs/day 5W controller @ 24 hrs/day	208, 050

* Pumping energy for recirculation solar systems is dependent upon the number of freeze days in each climate zone. Use the value found from the following equation to determine the pumping energy for recirculation systems:

(Pump energy, watts x 12 x (freeze days/yr +4)) +
(Pump energy, watts x pump operation time, hrs x remaining days in year) +
(Controller energy, watts x 24 hrs/day x 365)

Where the number of freeze days per year is found in Table 1.

The following Adjusted Standby Loss Factors were developed based on data contained in the Directory of Certified Water Heaters. The table's purpose is to provide an easy reference for determining the adjusted standby loss rate of a particular water heater that has been externally wrapped with an insulating blanket of R-12. Where blankets of lesser value are used in meeting the combined internal and external insulation level of R-16, as specified in Section 2-5352(i) of the regulations, the adjustment procedure provided in the Appendix to the regulations must be used. (This appendix is not included in this manual.) Multiply the standby loss percent from the Directory for the given water tank capacity by the factor given below.

TABLE 3. Standby Loss Adjustment

Tank Capacity (Gal.)	GAS	ELECTRIC
15-24	90	92
25-34	80	80
35-44	71	80
45-54	66	76
55-64	62	74
65-74	55	72
75-84	54	67
85-94	53	67
95 and up	50	59