# Chapter Four
# Sizing and Engineering

## 4.1 Collector

Once the type of collector, wall or roof, has been decided upon, the size is largely determined by the building. On conventional buildings the collector will usually use almost all available space. Wall collectors will probably be limited to 200 $ft^2$ or less, and roof collectors will use the entire available roof area, perhaps 350 to 500 $ft^2$. A standard rule-of-thumb is that the collector area should equal 1/5 to 1/4 the floor area in southern climates and 1/4 to 1/3 the floor area in the north.

From a performance standpoint, the optimum area for a full size installation depends upon the heating load of the house, collector performance, the collector cost, and the cost of the air-handling system, controls, and storage. Whereas the cost of the collector is fairly proportional to area, the cost of the remainder of the system contains a large fixed-cost base. A system with a smaller collector area requires almost the same expenditures for the air-handler as a system with a larger collector area. Thus, the total system cost per square foot of collector is higher for a small system. However, if the collector area is too large, it supplies more heat than can be used effectively to meet the building load.

If a more exact calculation of the optimum collector size or the expected performance is desired, a more sophisticated method can be used.

Solar Heating Design by the F-Chart Method, by Klein, Beckman, and Duffie, describes one of the best available methods for performance calculations. F-Chart calculates the useful output of the collector system given the heating load, climate, and basic characteristics of the collector arrangement. The book explains how to do a hand calculation of the performance. A computer calculation and a more detailed analysis can be obtained by contracting a solar engineering consulting firm. There are a number of such companies, including TEA, who will provide this service.

AIR FLOW RATE: The efficiency of air solar heating systems depends on the air flow rate through the collector. As the air flow rate through a collector is increased, the collector efficiency increases. This increase in the collector efficiency results from two factors: 1) an increase in air velocity which increases the heat transfer rate from the absorber plate to the air and 2) a decrease in the average air temperature in the collector. Increasing the air flow rate through the collector also increases the pressure drop through the collector, the air distribution system, and the rock storage bed as a direct result of increased air velocities. This requires larger air blowers. Although this energy is converted to useful heat, it increases operating costs if the cost of electricity is greater than the cost of fuel used for auxiliary heating.

For any system there is an optimum air flow rate at which the net energy savings is maximized. This flow rate depends on the climate, the length of the absorber plate, the size of the flow channels, and the design of the air distribution system and rockbed. The optimum flow rate for the MODEL-TEA is approximately 2.5 CFM per square foot of collector. Table 4.1 gives air flow rates along with other basic sizing information for collector areas from 200 to 500 $ft^2$.

MANIFOLD PAN SIZING. The manifolds must be designed to handle the air flow rate through the collector without an excessive pressure drop. It is recommended that the velocity of air in the manifold should not exceed 1000 FPM. The minimum manifold cross-sectional area is determined by dividing the total air flow rate between two manifolds by 1000; the minimum width of the manifold pans is determined by dividing the cross-sectional area by the depth of the manifolds.

Example 1: Determine the size of the manifold pans for a roof collector 20 feet long, 16 feet high, with manifolds located at each end of the collector. The collector area is 320 $ft^2$, so the total air flow rate would be 2.5 $CFM/ft^2 \times 320\ ft^2 = 800$ CFM. The minimum manifold cross-sectional area is therefore 800 CFM ÷ 1000 FPM = 0.80 $ft^2$ or 115 square inches.

The cross-sectional area equals the depth of the pan times the width of the pan. The depth of the pan depends on the depth of the rafters, and on the amount of rigid insulation installed behind the pan.

For example, if the rafters were 2x10's (actual depth 9-1/4 inches) and a minimum of 1 in. of rigid insulation is called for behind the pan, the pan depth would be 8-1/4 inches. Divide 8-1/4 inches into the cross-sectional area of the pan, 115 square inches. The result would be the width of the pan, in this case 14 inches. If 2 inches of rigid insulation were used behind the pan, the pan depth would be 7-1/4 inches, and the pan width would be approximately 16 inches.

Example 2: Determine the manifold pan size for a wall collector 20 feet long and 8 feet high. The collector area is 160 $ft^2$, so the total air flow rate from Table 4.1 is approximately 500 CFM (for a small wall collector, without storage, a flow rate of 3 $CFM/ft^2$ is better than $2.5 CFM/ft^2$). The minimum manifold cross-sectional area is therefore 500 CFM ÷ 1000 FPM = 0.50 $ft^2$, or 72 $in.^2$

If the wall studs are 2x6's (actual depth 5-1/2 in.) and 1 in. of rigid insulation were used behind the pan, the pan depth would be 4-1/2 in. Dividing this depth into the cross-sectional area, 72 $in.^2$, yields 16 in. If 2 in. of rigid insulation were used, a preferred approach, the pan depth would be 3-1/2 in., yielding a minimum pan width of 20-1/2 in.

*Rock Bin Storage*

## 4.2 Storage

The two major engineering concerns when sizing a rock bin are the volume of rocks, and the pressure drop of the air as it flows through the rocks. A rule-of-thumb for rock bin volume is to provide roughly 3/4 cubic feet of rocks for each square foot of collector area. This rule is flexible, some designers use slightly less and others use slightly more. The optimum size depends to a large extent on the volumetric flow rate of collector air through the rock bin. Too small a rock bin coupled with too much volumetric air flow would mean that the collector heat would be quickly "washed" through the rock bin, eliminating stratification and raising average collector temperatures (reducing efficiency) since the outlet of the rock bin is the inlet to the collectors. The rule-of-thumb for the MODEL-TEA volumetric air flow rate is to provide 2.5 CFM of air per square foot of collector area. The above two rules-of-thumb should provide satisfactory rock bin stratification and solar energy storage, hence insuring good system performance.

Pressure drop is the other main concern; too much pressure drop means excessive fan power is required to force air through the rocks, and too little pressure drop might mean that the air will channel through the bin creating hotspots, rather than spreading across the face of the rocks in the plenum and then flowing evenly through the bin. The pressure drop is a function of rock size, how tightly the rocks are packed (% voids), the velocity of air through the rocks (face velocity), and the length of the path presented to air flow. The rock size should be roughly 3/4 in. to 1-1/2 in. in diameter; it is not required that they be perfect spheres, irregularities such as found in crushed rock are acceptable.

When placed in the bin, the rocks should have approximately 40% to 50% voids, meaning that on the average every cubic foot is roughly 1/2 solid rock and 1/2 air space by volume. This can be tested by filling a 55 gallon drum with rocks and then measuring how much water can be added before overflow occurs. If 22 gallons of water can be added, then this implies 40% voids. If 27-1/2 gallons can be added, this implies 50% voids. With 3/4 in. to 1-1/2 in. diameter rock and 40-50% voids, it is desirable to limit air velocities through the rocks to 20-30 FPM face velocities to avoid excessive pressure drops. This number is the volumetric air flow rate divided by the cross-sectional area of rocks presented to the air flow. The pressure drop in the rock bin is directly proportional to the path length of the air flow through the rocks; twice the path length implies twice the total pressure drop.

The MODEL-TEA System incorporates a U-shaped rock bin since that is an effective way to permit both the inlet and outlet duct connections to be made at the top of the rock bin and to limit the overall height. The height of the rock bin can be limited to 6'-6" overall if the rock height in each half of the bin is limited to 3'-8".

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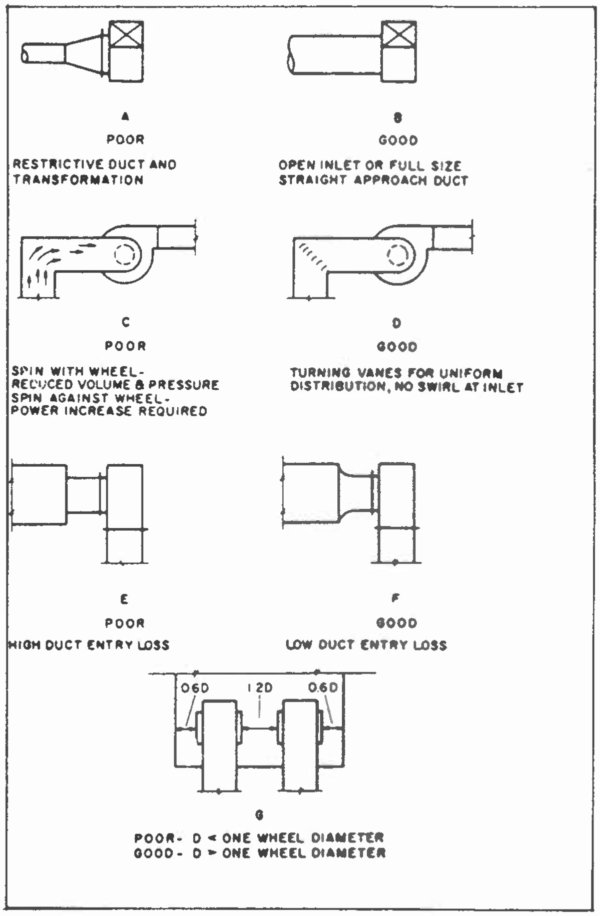

Figure 4.1 Fan Inlet Connections

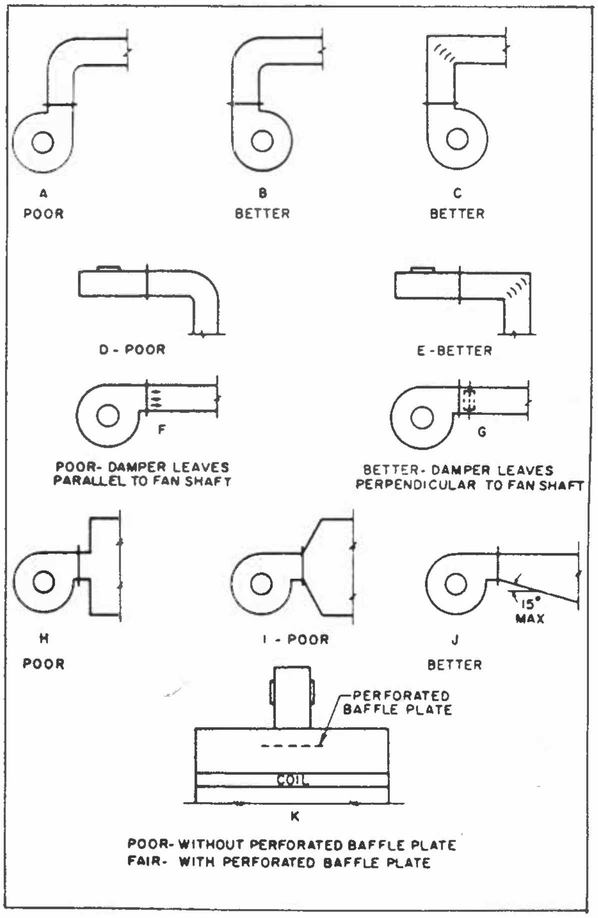

Figure 4.2 Fan Outlet Connections

Using 3/4 $ft^3$ of rocks per square foot collector, 3/4 in. to 1-1/2 in. diameter rocks with 40% to 50% voids, 2.5 CFM per square foot collector, and a path length of 2 x 3'-8" (7.3 feet) will result in a rock bed with a satisfactory volume and pressure drop (roughly .15" $H_2O$). Table 4.1 gives rock bin volumes for collector areas from 200 to 500 $ft^2$. Dividing the rock bin volume by 3.67 ft (height) will yield the cross-sectional area of rocks, and using this area the two horizontal dimensions can be determined.

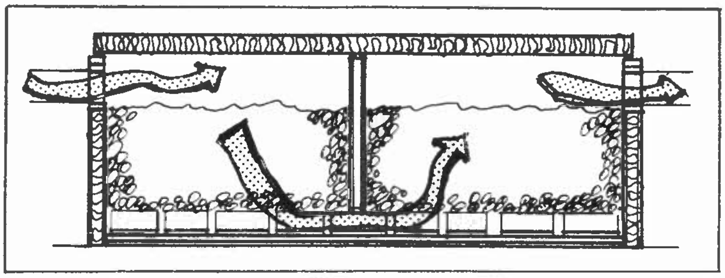

*Figure 4.3 Air Flow Through a U-Shaped Rock Bin*

## 4.3 Air-Handling

The air-handling system should be installed by someone experienced in this type of work. A heating contractor or experienced solar installer should be able to easily site-build the system using the information in this manual. The necessary engineering information has been developed according to collector area and is presented in the Pre-engineered Systems subsection. That discussion and the accompanying Tables 4.1, 4.2, and 4.3 present all the important sizing information. The following sub-sections on Air Supply, Blowers, and Ductwork provide important background information and the reasoning behind some of the engineering decisions.

PRE-ENGINEERED SYSTEMS. Once the collector area is known, these tables can be used to size the rock bin and to specify the collector and house blowers, the DHW coil if used, the main ductwork dimensions, and the required supply register free-outlet area. These tables were created by assuming three different collector areas of 200, 300, and 400 $ft^2$ and specifying the other system components to be compatible at these collector areas. The required length of ductwork for these systems was determined using an assumed retrofit system on a two story house (see Figure 1.1). For determining blower requirements the ductwork pressure drop was allowed to vary from 1/2 to 2 x the calculated value, since actual ductwork layouts can be expected to vary considerably. The collector, rock bin, and coil pressure drops remained constant as these are not a function of duct length.

As the collector area is decreased from the largest size in each of the given ranges in the chart, the following adjustments should be made in the system components:

SYSTEM AIR FLOW RATE: This should be adjusted to remain at 2.5 $CFM/SF_C$ for both the collector loop and house loop air flow rates.

ROCK BIN VOLUME: This should be adjusted to remain at 3/4 cubic feet of rock per $SF_C$ (square foot of collector). The plan cross-sectional area of rocks in the rock bin can be obtained by dividing the volume by 3.67 feet. The height of the rocks in the rock bin should remain constant at 3'-8" to give an overall rock bin height of 6'-6".

COLLECTOR BLOWER: The blower will remain as called out in Table 4.2. The speed of the blower should be field-adjusted with the adjustable pulleys, in order to reach the desired air flow rate delivery with the existing ductwork. This should be done by a mechanical heating/cooling contractor. The horsepower draw of the blower should be checked at the same time with an amp-probe.

HOUSE BLOWER: The operating conditions will change for this blower too as the air flow rate to the house decreases with decreasing collector area. The same comments apply to the house blower as for the collector blower.

DHW COIL: This is reduced in size as specified in the table; the face area is reduced to maintain a constant air velocity through the coil of approximately 300-350 FPM. The exception to this rule-of-thumb is a limit on the coil size on the 400-500 $SF_C$ systems to not larger than 18" x 24". In all cases the nearest equivalent standard size coil should be used since hot water preheating performance is not very sensitive to the coil size. Solaron, for example, uses a 15 in. x 18 in. coil for air flow rates up to 1300 CFM.

DUCTWORK: This should be adjusted according to Table 4.1 If other than round or 8 in. sizes are desired, go to Table 4.3 with the round duct size, then read off the two size rectangular duct dimensions. It is important to adjust the duct size to save costs and facilitate integration of the ductwork into the building space.

SUPPLY REGISTER FREE AREA: This should be adjusted by dividing the system air flow rate in CFM by 100 FPM (the outlet velocity to minimize drafty conditions at supply air temperatures down to 85°F). CFM System/100 FPM = Free Area ($ft^2$). The free area is not the total grille area, but must be found for each grille in the manufacturer's literature.

AIR SUPPLY TO THE HOUSE. The three most significant factors that determine what portion of house heating needs will be met with solar in a given climate are the collector size, storage size, and the house insulation level. Another factor of importance is the rate of air delivery to the house from the rock bin or collector. In order to maintain comfortable house temperatures, the energy losses from the house to the ambient have to be replaced by an equivalent amount of energy from the solar system or auxiliary. The important point here is that the rate of heat supply has to equal the rate of heat losses or the house temperature will drop. The rate of heat supply from any hot air heating system, including solar, depends greatly on the volumetric air flow rate (CFM) and the temperature of the supply air. The energy delivered by a small amount of hot air can be equalled by a larger amount of warm air.

If the rate of air delivery, from the solar system to the house, and the rock bed temperature are both too low to meet the house heat requirement, then the second stage of the thermostat will be activated as the house temperature drops and will in turn engage the backup auxiliary heating system. The energy delivered by the backup system is replacing energy that could perhaps have been supplied by solar; this decreases the solar system utilization and reduces the cost-effectiveness. The penalty would be greatest for large solar systems on tight houses since these solar systems would be capable of meeting the heating requirements of the house most of the time if the air delivery rate to the house were sufficient. Small systems would not be penalized since most of the time there would not be enough energy available to meet the heating load and auxiliary backup heating would have been required in any case. The point of this dicussion is that if solar energy is available it should be used as much as possible to prevent excessive backup heating. The MODEL-TEA control system reflects this desire, since on a call for heat the solar-heated air is used whenever it is hot enough to be comfortably supplied to the house without creating cool drafts. If further heating is required, then the auxiliary backup is turned on to augment the solar-heated air.

Supplying too much air to the house creates other problems such as requiring larger, more costly ductwork, a larger house blower, and in particular, more and larger supply registers. More and larger registers are needed to reduce the drafty feeling resulting from supplying a large amount of relatively cool air to a living area. Warm-air furnaces normally deliver air at 140°F which permits relatively high velocities at the supply registers. For solar-heated supply air at temperatures as low as 85°F, it is necessary to limit register face velocities to roughly 100-150 FPM , with 100 FPM being preferable. If 1000 CFM were being delivered to the house, sufficient registers would have to be specified to equal 10 SF of free outlet area (1000 CFM/100 FPM = 10 SF).

As a compromise between excessive system costs and system performance, the air supply to the house is chosen here to be such that the same ductwork size as used in the rest of the system can be utilized. This is a good compromise, since the larger systems will have a large air supply rate to the house, which is needed, and the smaller systems will have a small air supply rate to the house, which will not really penalize these systems because less solar energy is available for distribution. The appropriate air supply rates, ductwork size, and register free outlet areas are included in the pre-engineered systems sizing chart in Table 4.1.

BLOWERS. Centrifugal blowers with forward-curved blades are normally used in residential heating and cooling equipment and are applicable to all but the smallest solar systems. If sized properly they can provide efficient and quiet air-moving. Centrifugal blowers with backward-inclined blades are less available and more costly than forward-curved blowers, but generally operate at higher efficiencies over a wider range of conditions. Backward-inclined blowers can be noisier than forward-curved blowers because they operate at higher speeds. An advantage of backward inclined centrifugal blowers is that they do not overload when system conditions change. For most applications of the MODEL-TEA System forward-curved blowers will be satisfactory.

Blowers are normally sized by specifying the CFM (volumetric air flow) and the system static pressure (usually in units of inches of water column). Careful attention should be given to insure that the outlet velocity of the air is reasonably low (not above 1700 FPM, preferably between 1000-1600 FPM), and that the blower horsepower requirements are minimized. Often several blowers will be acceptable, but the one that is operating most efficiently will require the least electrical cost to run. To learn more about blowers and duct design consult the ASHRAE EQUIPMENT VOLUME (1979), the ASHRAE HANDBOOK OF FUNDAMENTALS (1977), HVAC DUCT SYSTEM DESIGN by SMACNA (See Appendix C).

The suggested blowers for the MODEL-TEA air systems are the LAU FGP series, single inlet, four-way discharge, belt-driven blowers or the equivalent. These blowers are also sold under the Dayton label. If the four-way discharge option is not required the LAU BD series perform almost identically. Belt-driven blowers are preferable since the motor is not situated in the air stream, as is the case with direct drive blowers. With adjustable pulleys, the blowers will accommodate a wide range of operating conditions. Suggested blowers are specified in the pre-engineered system sizing chart in Table 4.2

Blower outlets should be connected to the system ductwork by gradual transitions (See Figure 4.1 and 4.2 from the ASHRAE FUNDAMENTALS and EQUIPMENT VOLUMES), with not greater than a $7^{o}$ slope of elements for diverging and not greater than $15^{o}$ slope for converging transitions. Fan inlet and

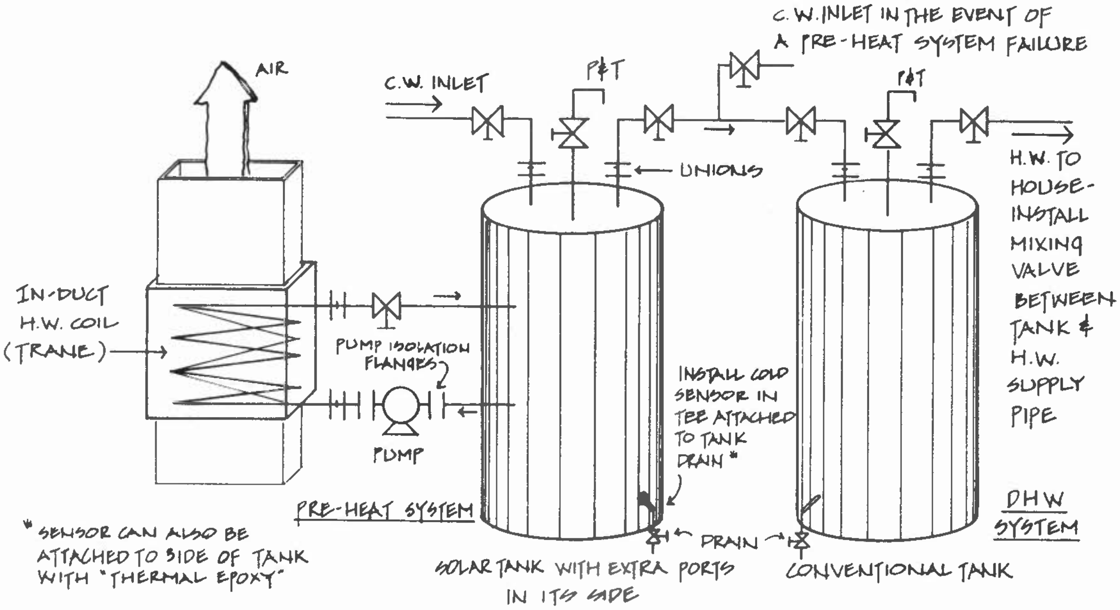

Figure 4.4 Solar Tank/Conventional Tank DHW System

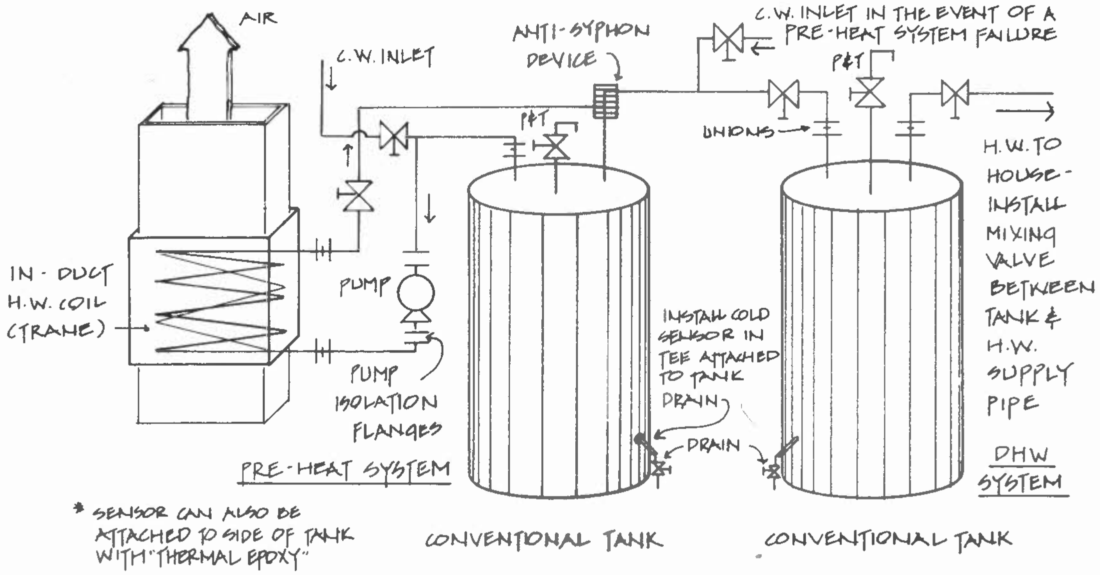

Figure 4.5 Two Conventional Tank DHW System

outlet ducts should be as straight as possible. Inlets should have a full size straight approach duct if possible, and outlet ducts should be straight (or a gradual transition) for a length of at least 2½ duct diameters. The blower should be connected to the system duct work by unpainted canvas (or other flexible material) flexible connectors (See Appendix A). The flexible canvas connector reduces vibration noise.

SYSTEM DUCTWORK: The paramount concern when designing and constructing system ductwork is to eliminate air leakage. Air leakage in some duct systems has been found to be as high as 40% of design flow. Needless to say, this has a devastating effect on performance. Strict industry procedures should be earnestly followed in making all ductwork connections. Leaks in liquids systems are physically destructive, but in air systems they are neither physically damaging nor easily detectable. However, air leakage does severely damage the performance of a solar system.

In general, round ducts are easier to make leak-tight than rectangular ducts. SMACNA's HVAC DUCT SYSTEM DESIGN MANUAL recommends that the fiberglass duct work be in conformance with SMACNA's FIBROUS GLASS DUCT MANUAL, but that the metal duct be sealed in conformance with the Medium Pressure Duct Standards at the very least. If low pressure duct work is used, all joints must be sealed very carefully with a high quality duct tape or equivalent.

Sizing the ductwork is important; ducts which are too small are noisy (since the air velocity is high) and require excessive blower power to move air through them. Standard rectangular sizes are 8 in. x 4 in. to 8 in. x 30 in. in two inch increments (8 in.x 4in., 6 in, 8 in., 10 in. ...30 in.). With rectangular duct work it is best to use "short way" angles ($45^{o}$ angle) and elbows ($90^{o}$ angle) with 4in. radius throats for all bends wherever possible. The pressure drop through these fittings is much less than through the "long way" fittings. Good design practices should be used to avoid excessive pressure drops and leakage in system duct work. Guidelines for duct work sizes are given in the pre-engineered systems sizing chart in Table 4.1.

DOMESTIC HOT WATER OPTION: Two schematics are shown in Figures 4.4 and 4.5 for alternative DHW installations. The first uses a specially designed solar tank as the preheat tank. Since this has two additional ports on the side, it enables a simpler plumbing arrangement to be used. The second method uses a conventional tank, similar to the one already employed for the conventional hot water system. This tank only has two ports inlet and outlet, located at the top. This arrangement necessitates the use of an anti-syphon device and a slightly more complex plumbing system. In addition to a tank and the coil, either system requires a pump, valves, and controls.

TABLE 4.1 PRE-ENGINEERED SYSTEMS SIZING

| COLLECTOR AREA* | SYSTEM CFM** | ROCKBIN VOLUME (ROCKS)*** | ROUND DUCT SIZE FOR EQUIV.**** | RECTANGULAR DUCT SIZE (ROUNDED UP TO NEAREST EVEN DIM) | at round equiv. | | TWO ROW DHW COIL FACE AREA | | FREE AREA SUPPLY REGISTER SIZE $(FT^2)$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | FPM | P/100' ("/$H_2O$) | $(ft^2)$ | P | |
| 200 | 500 | 150 | 11.0 | 8"x14" | 760 | .08 | 1.5 | .10 | 5 |
| 225 | 563 | 169 | 11.4 | 8"x14" | 780 | .08 | 2 | .10 | 5.6 |
| 250 | 625 | 188 | 11.9 | 8"x16" | 800 | .08 | 2 | .10 | 6.3 |
| 275 | 688 | 206 | 12.4 | 8"x18" | 830 | .08 | 2 | .11 | 6.9 |
| 300 | 750 | 225 | 12.8 | 8"x18" | 840 | .08 | 2.25 | .10 | 7.5 |
| 325 | 813 | 244 | 13.6 | 8"x22" | 800 | .07 | 2.5 | .10 | 8.1 |
| 350 | 875 | 263 | 14.0 | 8"x22" | 820 | .07 | 2.5 | .12 | 8.8 |
| 375 | 938 | 281 | 14.5 | 8"x24" | 820 | .07 | 3 | .10 | 9.4 |
| 400 | 1000 | 300 | 14.6 | 8"x24" | 850 | .07 | 3 | .10 | 10.0 |
| 425 | 1063 | 319 | 15.2 | 8"x26" | 850 | .07 | 3 | .12 | 10.1 |
| 450 | 1125 | 338 | 15.2 | 8"x26" | 900 | .08 | 3 | .13 | 11.3 |
| 475 | 1188 | 356 | 15.6 | 8"x28" | 900 | .08 | 3 | .15 | 11.9 |
| 500 | 1250 | 375 | 15.9 | 8"x30" | 900 | .07 | 3 | .16 | 12.5 |

* For intermediate collector areas go to next highest collector area

** At intermediate collector areas use collector area x 2.5

*** Divide RB volume by 3.67 ft. to get plan cross sectional area of rocks in rock bin

**** Other rectangular ducts which are equivalent can be found from Table 4.3 by entering with the round duct equivalents.

*Table 4.1 Pre-Engineered Systems Sizing*

TABLE 4.2 BLOWER SPECIFICATIONS

| COLLECTOR AREA (SF) | COLLECTOR BLOWER | HOUSE BLOWER | COMMENTS |
|---|---|---|---|
| 200-300 | FGP 10-6A**<br>BD 10-6A***<br>BC 122**** | FGP 10-6A<br>BD 10-6A<br>BC 122 | For new systems with series auxiliary, supply ductwork and house blower are determined from the auxiliary CFM and air temperature delivery requirements necessary to meet design heat loss conditions. |
| | 750 CFM@<br>1/2"-3/4" P<br>2/3"-2/3" P* | 750 CFM@<br>3/10"-6/10" P<br>1/5"-1/2" P* | |
| 301-400 | FGP 12-6A<br>BD 12-6A<br>BC 122 | FGP 12-6A<br>BD 12-6A<br>BC 122 | Example blower requirements for largest collector area in three ranges (300, 400, 500 SF) |
| | 1000 CFM@<br>3/5"-4/5" P<br>1/2"-3/4" P* | 1000 CFM@<br>1/4"-3/5" P<br>1/5"-1/2" P* | |
| 401-500 | FGP 12-6A<br>BD 12-6A<br>BC 150 | FGP 12-6A<br>BD 12-6A<br>BC 135 | Blower motors should have internal thermal cut-outs. |
| | 1250 CFM@<br>2/3"-1" P<br>1/2"-4/5" P* | 1250 CFM@<br>3/8"-7/16" P<br>1/5"-1/2" P* | |

* W.O. DHW COIL

** FGP LAU BLOWER (FORWARD CURVED)

*** BD LAU BLOWER (FORWARD CURVED)

**** BC BAYLEY BLOWER (BACKWARD INCLINED)

*Table 4.2 Blower Specifications*

EXAMPLE OF SYSTEM SIZING: This subsection presents an example of system sizing calculations. Assume a roof collector 16 ftx 24 ft with the DHW option (384 $ft^2$):

Falls within 301-400 $ft^2$ range, from pre-engineered systems sizing chart, Table 4.1, this implies:

a) Rockbin rock volume: 3/4 x 384= 288 CF, plan cross-sectional area @ 288 CF ÷ 3.67 ft = 78.47 SF

b) Collector blower: LAU #FGP 12-6A

c) House blower: LAU #FGP 12-6A

d) DHW COIL:

2 row, 18'' x 24'' (3$ft^2$ size as specified in chart)

e) Main system ductwork: 8'' x 24'' or the equivalent to 14.6'' (from Table 8.4 rounding up to 400 sf )

f) Roof collector implies power venting

g) Required supply register free area:

CFM system/100 FPM = 960 CFM/100 FPM = 9.6 $ft^2$

h) Return air grille and filter

at 300 FPM face velocity filter size is:
960 CFM ÷ 300 FPM = 3.2 $ft^2$ or 461 $in^2$

## Table 4.3 Circular Equivalent of Rectangular Ducts for Equal Friction and Capacity

Dimensions in Inches

| Side Rectangular Duct | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 9.0 | 10.0 | 11.0 | 12.0 | 13.0 | 14.0 | 15.0 | 16.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.0 | 3.8 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 4.9 | 5.1 | 5.2 | 5.5 | 5.7 | 6.0 | 6.2 | 6.4 | 6.6 | 6.8 | 7.0 |
| 3.5 | 4.1 | 4.3 | 4.6 | 4.8 | 5.0 | 5.2 | 5.3 | 5.5 | 5.7 | 6.0 | 6.3 | 6.5 | 6.8 | 7.0 | 7.2 | 7.4 | 7.6 |
| 4.0 | 4.4 | 4.6 | 4.9 | 5.1 | 5.3 | 5.5 | 5.7 | 5.9 | 6.1 | 6.4 | 6.8 | 7.1 | 7.3 | 7.6 | 7.8 | 8.1 | 8.3 |
| 4.5 | 4.6 | 4.9 | 5.2 | 5.4 | 5.6 | 5.9 | 6.1 | 6.3 | 6.5 | 6.9 | 7.2 | 7.5 | 7.8 | 8.1 | 8.4 | 8.6 | 8.9 |
| 5.0 | 4.9 | 5.2 | 5.5 | 5.7 | 6.0 | 6.2 | 6.4 | 6.7 | 6.9 | 7.3 | 7.6 | 8.0 | 8.3 | 8.6 | 8.9 | 9.1 | 9.4 |
| 5.5 | 5.1 | 5.4 | 5.7 | 6.0 | 6.3 | 6.5 | 6.8 | 7.0 | 7.2 | 7.6 | 8.0 | 8.4 | 8.7 | 9.0 | 9.4 | 9.6 | 9.8 |

| Side Rectangular Duct | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 22 | 24 | 26 | 28 | 30 | Side Rectangular Duct |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 6.6 | | | | | | | | | | | | | | | | | | | | 6 |
| 7 | 7.1 | 7.7 | | | | | | | | | | | | | | | | | | | 7 |
| 8 | 7.5 | 8.2 | 8.8 | | | | | | | | | | | | | | | | | | 8 |
| 9 | 8.0 | 8.6 | 9.3 | 9.9 | | | | | | | | | | | | | | | | | 9 |
| 10 | 8.4 | 9.1 | 9.8 | 10.4 | 10.9 | | | | | | | | | | | | | | | | 10 |
| 11 | 8.8 | 9.5 | 10.2 | 10.8 | 11.4 | 12.0 | | | | | | | | | | | | | | | 11 |
| 12 | 9.1 | 9.9 | 10.7 | 11.3 | 11.9 | 12.5 | 13.1 | | | | | | | | | | | | | | 12 |
| 13 | 9.5 | 10.3 | 11.1 | 11.8 | 12.4 | 13.0 | 13.6 | 14.2 | | | | | | | | | | | | | 13 |
| 14 | 9.8 | 10.7 | 11.5 | 12.2 | 12.9 | 13.5 | 14.2 | 14.7 | 15.3 | | | | | | | | | | | | 14 |
| 15 | 10.1 | 11.0 | 11.8 | 12.6 | 13.3 | 14.0 | 14.6 | 15.3 | 15.8 | 16.4 | | | | | | | | | | | 15 |
| 16 | 10.4 | 11.4 | 12.2 | 13.0 | 13.7 | 14.4 | 15.1 | 15.7 | 16.3 | 16.9 | 17.5 | | | | | | | | | | 16 |
| 17 | 10.7 | 11.7 | 12.5 | 13.4 | 14.1 | 14.9 | 15.5 | 16.1 | 16.8 | 17.4 | 18.0 | 18.6 | | | | | | | | | 17 |
| 18 | 11.0 | 11.9 | 12.9 | 13.7 | 14.5 | 15.3 | 16.0 | 16.6 | 17.3 | 17.9 | 18.5 | 19.1 | 19.7 | | | | | | | | 18 |
| 19 | 11.2 | 12.2 | 13.2 | 14.1 | 14.9 | 15.6 | 16.4 | 17.1 | 17.8 | 18.4 | 19.0 | 19.6 | 20.2 | 20.8 | | | | | | | 19 |
| 20 | 11.5 | 12.5 | 13.5 | 14.4 | 15.2 | 15.9 | 16.8 | 17.5 | 18.2 | 18.8 | 19.5 | 20.1 | 20.7 | 21.3 | 21.9 | | | | | | 20 |
| 22 | 12.0 | 13.1 | 14.1 | 15.0 | 15.9 | 16.7 | 17.6 | 18.3 | 19.1 | 19.7 | 20.4 | 21.0 | 21.7 | 22.3 | 22.9 | 24.1 | | | | | 22 |
| 24 | 12.4 | 13.6 | 14.6 | 15.6 | 16.6 | 17.5 | 18.3 | 19.1 | 19.8 | 20.6 | 21.3 | 21.9 | 22.6 | 23.2 | 23.9 | 25.1 | 26.2 | | | | 24 |
| 26 | 12.8 | 14.1 | 15.2 | 16.2 | 17.2 | 18.1 | 19.0 | 19.8 | 20.6 | 21.4 | 22.1 | 22.8 | 23.5 | 24.1 | 24.8 | 26.1 | 27.2 | 28.4 | | | 26 |
| 28 | 13.2 | 14.5 | 15.6 | 16.7 | 17.7 | 18.7 | 19.6 | 20.5 | 21.3 | 22.1 | 22.9 | 23.6 | 24.4 | 25.0 | 25.7 | 27.1 | 28.2 | 29.5 | 30.6 | | 28 |
| 30 | 13.6 | 14.9 | 16.1 | 17.2 | 18.3 | 19.3 | 20.2 | 21.1 | 22.0 | 22.9 | 23.7 | 24.4 | 25.2 | 25.9 | 26.7 | 28.0 | 29.3 | 30.5 | 31.6 | 32.8 | 30 |
| 32 | 14.0 | 15.3 | 16.5 | 17.7 | 18.8 | 19.8 | 20.8 | 21.8 | 22.7 | 23.6 | 24.4 | 25.2 | 26.0 | 26.7 | 27.5 | 28.9 | 30.1 | 31.4 | 32.6 | 33.8 | 32 |
| 34 | 14.4 | 15.7 | 17.0 | 18.2 | 19.3 | 20.4 | 21.4 | 22.4 | 23.3 | 24.2 | 25.1 | 25.9 | 26.7 | 27.5 | 28.3 | 29.7 | 31.0 | 32.3 | 33.6 | 34.8 | 34 |
| 36 | 14.7 | 16.1 | 17.4 | 18.6 | 19.8 | 20.9 | 21.9 | 23.0 | 23.9 | 24.8 | 25.8 | 26.6 | 27.4 | 28.3 | 29.0 | 30.5 | 32.0 | 33.0 | 34.6 | 35.8 | 36 |
| 38 | 15.0 | 16.4 | 17.8 | 19.0 | 20.3 | 21.4 | 22.5 | 23.5 | 24.5 | 25.4 | 26.4 | 27.3 | 28.1 | 29.0 | 29.8 | 31.4 | 32.8 | 34.2 | 35.5 | 36.7 | 38 |
| 40 | 15.3 | 16.8 | 18.2 | 19.4 | 20.7 | 21.9 | 23.0 | 24.0 | 25.1 | 26.0 | 27.0 | 27.9 | 28.8 | 29.7 | 30.5 | 32.1 | 33.6 | 35.1 | 36.4 | 37.6 | 40 |
| 42 | 15.6 | 17.1 | 18.5 | 19.8 | 21.1 | 22.3 | 23.4 | 24.5 | 25.6 | 26.6 | 27.6 | 28.5 | 29.4 | 30.4 | 31.2 | 32.8 | 34.4 | 35.9 | 37.3 | 38.6 | 42 |
| 44 | 15.9 | 17.5 | 18.9 | 20.2 | 21.5 | 22.7 | 23.9 | 25.0 | 26.1 | 27.2 | 28.2 | 29.1 | 30.0 | 31.0 | 31.9 | 33.5 | 35.2 | 36.7 | 38.1 | 39.5 | 44 |
| 46 | 16.2 | 17.8 | 19.2 | 20.6 | 21.9 | 23.2 | 24.3 | 25.5 | 26.7 | 27.7 | 28.7 | 29.7 | 30.6 | 31.6 | 32.5 | 34.2 | 35.9 | 37.4 | 38.9 | 40.3 | 46 |
| 48 | 16.5 | 18.1 | 19.6 | 20.9 | 22.3 | 23.6 | 24.8 | 26.0 | 27.2 | 28.2 | 29.2 | 30.2 | 31.2 | 32.2 | 33.1 | 34.9 | 36.6 | 38.2 | 39.7 | 41.2 | 48 |
| 50 | 16.8 | 18.4 | 19.9 | 21.3 | 22.7 | 24.0 | 25.2 | 26.4 | 27.6 | 28.7 | 29.8 | 30.8 | 31.8 | 32.8 | 33.7 | 35.5 | 37.3 | 38.9 | 40.4 | 42.0 | 50 |
| 52 | 17.0 | 18.7 | 20.2 | 21.6 | 23.1 | 24.4 | 25.6 | 26.8 | 28.1 | 29.2 | 30.3 | 31.4 | 32.4 | 33.4 | 34.3 | 36.2 | 38.0 | 39.6 | 41.2 | 42.8 | 52 |
| 54 | 17.3 | 19.0 | 20.5 | 22.0 | 23.4 | 24.8 | 26.1 | 27.3 | 28.5 | 29.7 | 30.8 | 31.9 | 32.9 | 33.9 | 34.9 | 36.8 | 38.7 | 40.3 | 42.0 | 43.6 | 54 |
| 56 | 17.6 | 19.3 | 20.9 | 22.4 | 23.8 | 25.2 | 26.5 | 27.7 | 28.9 | 30.1 | 31.2 | 32.4 | 33.4 | 34.5 | 35.5 | 37.4 | 39.3 | 41.0 | 42.7 | 44.3 | 56 |
| 58 | 17.8 | 19.5 | 21.1 | 22.7 | 24.2 | 25.5 | 26.9 | 28.2 | 29.3 | 30.5 | 31.7 | 32.9 | 33.9 | 35.0 | 36.0 | 38.0 | 39.8 | 41.7 | 43.4 | 45.0 | 58 |
| 60 | 18.1 | 19.8 | 21.4 | 23.0 | 24.5 | 25.8 | 27.3 | 28.7 | 29.8 | 31.0 | 32.2 | 33.4 | 34.5 | 35.5 | 36.5 | 38.6 | 40.4 | 42.3 | 44.0 | 45.8 | 60 |
| 62 | 18.3 | 20.1 | 21.7 | 23.3 | 24.8 | 26.2 | 27.6 | 29.0 | 30.2 | 31.4 | 32.6 | 33.8 | 35.0 | 36.0 | 37.1 | 39.2 | 41.0 | 42.9 | 44.7 | 46.5 | 62 |
| 64 | 18.6 | 20.3 | 22.0 | 23.6 | 25.2 | 26.5 | 27.9 | 29.3 | 30.6 | 31.8 | 33.1 | 34.2 | 35.5 | 36.5 | 37.6 | 39.7 | 41.6 | 43.5 | 45.4 | 47.2 | 64 |
| 66 | 18.8 | 20.6 | 22.3 | 23.9 | 25.5 | 26.9 | 28.3 | 29.7 | 31.0 | 32.2 | 33.5 | 34.7 | 35.9 | 37.0 | 38.1 | 40.2 | 42.2 | 44.1 | 46.0 | 47.8 | 66 |
| 68 | 19.0 | 20.8 | 22.5 | 24.2 | 25.8 | 27.3 | 28.7 | 30.1 | 31.4 | 32.6 | 33.9 | 35.1 | 36.3 | 37.5 | 38.6 | 40.7 | 42.8 | 44.7 | 46.6 | 48.4 | 68 |
| 70 | 19.2 | 21.0 | 22.8 | 24.5 | 26.1 | 27.6 | 29.1 | 30.4 | 31.8 | 33.1 | 34.3 | 35.6 | 36.8 | 37.9 | 39.1 | 41.3 | 43.3 | 45.3 | 47.2 | 49.0 | 70 |

FROM ASHRAE 1977 FUNDAMENTALS

## 4.4 Purchasing Materials and Scheduling Construction

A discussion of materials and a list of sources are given in Appendix A. All materials must be on hand before beginning construction, and certain materials may require special ordering and significant waiting periods. The following discussion presents purchasing information for each major material.

SHEET METAL COLLECTOR MANIFOLDS. The sheet metal manifolds must be ordered from a sheet metal shop, and formed to exact specifications. They should be ordered as early as possible since there may be significant delays, and the first work on the collector involves the manifolds.

CAULK. Urethane caulk is readily available at Sears stores and can also be ordered directly from manufacturers. GE Silicone caulk is available at many building supply stores. Caulk is required at the beginning of construction, and there should always be a sufficient quantity at the site so that it can be used liberally.

THERMO-PLY SHEATHING. If possible, the Super-grade (Blue) Thermo-ply should be used, rather than the Structural-grade (Red). Unfortunately, the "Structural" is much more available than the "Super." Many building supply stores carry the "Structural" and any that do can order the "Super." The problem is that they must order a minimum of 200 sheets and they may not have enough demand to justify that. If this difficulty does occur, it is possible to contact the manufacturer directly (See Appendix A) and locate the nearest supply. A lead time of six or eight weeks may be necessary.

ALUMINUM SIDING. The aluminum siding can be ordered from one of a number of distributors across the country. The rubber end closures should be ordered with the aluminum siding and must be ordered to fit the "inside" of the selected rib pattern. It is important to note that the 4-inch rib pattern is not completely symmetrical -- the flat valleys which are against the Thermo-ply are narrower than the flat raised sections. A minimum lead time of six to eight weeks may be necessary.

PAINT. If a standard flat black paint is used (such as Rustoleum #412), there will be no problem with availability. If an epoxy or selective paint is chosen, it will have to be ordered directly from the manufacturer, along with the appropriate primer and reducer.

PAINT SPRAYER. A paint sprayer and a protective face mask will be needed for painting the absorber. The painting should be done on a dry, windless, dustless day, and the paint should be allowed to dry thoroughly before it is sealed-over by the next layer of the collector. The absorber should be clean and dry when the glazing is installed; all surfaces should be as dust-free as possible

GLASS. Low-iron solar glass may be available from local glass distributors, or may have to be ordered directly from the manufacturer. If ordered from the manufacturer, several weeks should be allowed for delivery. Single glass is used for the roof collector, and double glass solar panels for the wall version. These panels are designed specifically for use in solar collectors. Regular double-glass patio door panels should not be used -- they are sealed with a different type of edge and will not withstand the stresses caused by extreme differential heating.

CRUSHED ROCK FOR ROCK BIN. The 3/4 in. to 1-1/2 in. rock should be readily available. It is important that the rock be clean, so it should be washed twice. If the rock supplier will not wash the rock a second time, the builder will have to wash the rock on-site. Since that is a difficult undertaking, every effort should be made to have the supplier do all the washing. The rock should be thoroughly dry before it is loaded into the storage bin.

SPECIAL SHEET METAL WORK. Custom sheet metal work may be required not only for the collector manifolds, but also for transitions to the blowers. If this is the case, a local sheet metal shop should be contacted to do the work, and there might be delays of up to two weeks. The slide-dampers and backdraft dampers should either be constructed by the builder or fabricated by a sheet metal shop.

AIR-HANDLING AND CONTROL EQUIPMENT. Most of the air-handling equipment is available through local heating contractors, or from local distributors. Some equipment, such as blowers, can also be ordered from a catalog supply house (e.g., W.W. Grainger).