SECTION 5

LESSONS LEARNED

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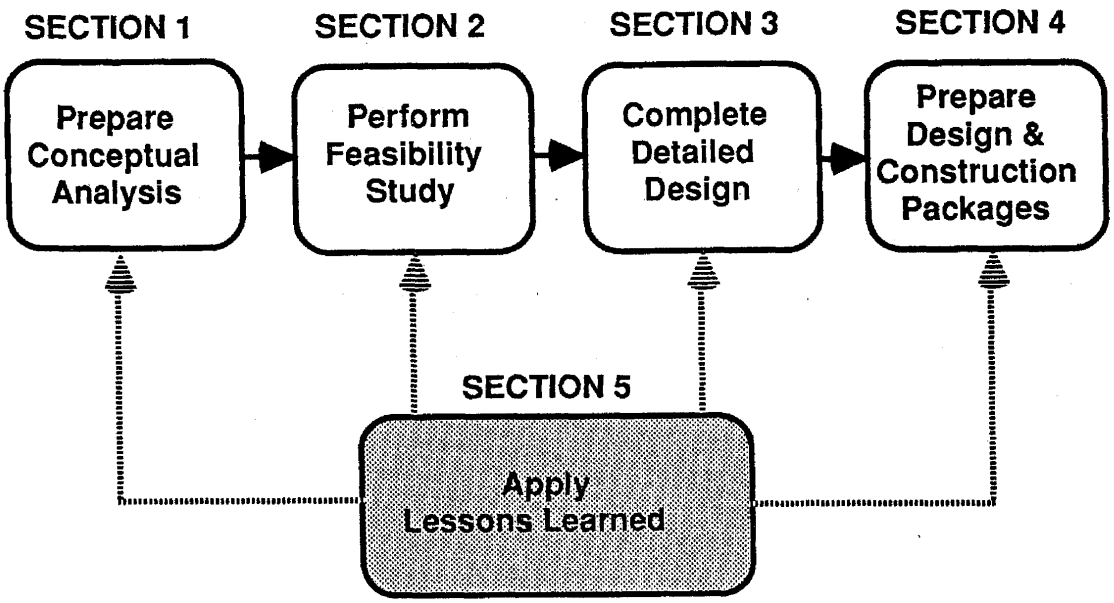
5.1 OVERVIEW



This section lists problems commonly found in solar systems that can be attributed to design errors or less-than-optimum design decisions. Where problems found in construction, operation, or maintenance of solar systems have been attributed to design errors, they are also included. The potential harmful effects of the problems on solar system operation are described, and solutions are given.

This section provides a quick reference by specific component for design problems commonly found that must be avoided; these lessons have already been incorporated in the manual's design procedures. Review of this section can prevent the inadvertent inclusion of a design procedure that has been shown by accumulated field experience to be dysfunctional.

5.2 SYSTEM SIZING

5.2.1 Oversizing

Problem:

- Overestimating load.
- Improper seasonal load design.
- Wrong inputs to computer simulation program.
- Designing for too high an annual solar fraction.

Effect:

- Unneeded capital cost, making the operational project less cost-effective.
- Collector stagnation, reducing collector life.
- In severe cases, heat dump must be retrofitted, increasing capital cost and parasitic power use.
- Faster glycol degradation (where used), increasing operating costs and possibility of collector plugging and system leaks.

Solution:

- Determine the load for the proposed system carefully; use actual water/fuel consumption figures when available for that building or for a similarly occupied building in that city.
- For a new building, remember that fossil fuel heating systems are not as capital-intensive as solar and are frequently oversized; use actual data from a similar building rather than fossil fuel design data.
- For seasonal designs where the load is significantly lower in one season (space heating in winter only with low service water heating load in summer is the usual example), optimize the design for high performance in the operating season (adjust collector tilt) and check for severity of overheating in off season. Consider draining system (save parasitic power) or deactivating a fraction of the system (cover the collectors) in the off season. Look for unusual uses of the extra solar heat in the off season that would pay for the parasitic power to run the system.
- Where overheating remains a significant problem (high cost of heat dump, parasitic power), consider reducing system size until problem disappears, then reevaluate cost-effectiveness.
- Select input for the example simulation computer program carefully, using actual values for the proposed site or from a similar operating solar system instead of default values. For systems large enough to support the extra cost, confirm these predictions with a second more detailed computer simulation.

- Do not try to couple an annual solar fraction above 80% with an uneven or uncertain load; design for high annual solar fractions only when the size and use pattern of the load are firmly established.

5.2.2 Undersizing

Problem:

- Underestimating load.
- Wrong inputs to computer simulation.
- Designing too low an annual solar fraction.

Effect:

- Less efficient use of solar resource at that size, making project less cost-effective where economies of scale are possible for an expanded project.
- Less replacement of fossil fuel by solar energy.

Solution:

- As above, determine system load carefully.
- As above, select inputs for the example simulation program carefully and check with more detailed computer simulation whenever possible.
- After preliminary sizing estimates are made, determine if economies of scale are possible (cost per unit area is lower for added area than for the original design) and then design for the highest annual solar fraction possible without harmful overheating.

5.3 SYSTEM PROTECTION

5.3.1 Freeze Protection

Freeze protection is inherent in the design of drainback and glycol systems; only recirculation systems need a backup protection mode. However, all systems must be checked for design errors that can keep the protection mode from operating as designed.

5.3.1.1 Drainback System

Problem:

- System fails to drain completely.

Effect:

- Broken pipes, damaged collectors.
- Loss of use of system while repairs are made.

Solution:

- Install all piping runs to design slope and verify slope when construction is complete.
- Do not use nondrainable bellows expansion joints in horizontal runs.
- Install valves in a position that will permit complete draining of the piping.
- Support piping adequately so it will not sag to produce nondraining pockets.
- Prevent overfilling of drainback tank with level alarm and sight glass.
- Use an oversized return line with a vent line from the top of the drainback tank to the return line at a point inside the building. Do not insulate the top 3 ft (914.4 mm) of the vent line to ensure condensation of any water vapor that may rise to that point.

5.3.1.2 Glycol System

Problem:

- Nonglycol piping/components freeze.
- Glycol is diluted.

Effect:

- Broken pipes, damaged collectors, components.
- Loss of use of system while repairs are made.

Solution: (Non-glycol components)

- Install all water lines and water-containing components inside a heated building in an above-freezing environment.

- Do not circulate cold glycol through the heat exchanger at system startup; the glycol may be below 32°F (0°C) and could freeze the water side, damaging the heat exchanger. Install a freezestat in the collector outlet manifold that will stop pump operation until the glycol temperature is above 40°F (4.4°C) steady state.

Solution: (Diluted Glycol)

- Check glycol concentration every fall before cold weather starts. If concentration is low, drain some fluid from the loop and add enough undiluted glycol to raise the concentration to the original fill concentration.
- After every loss of fluid from the loop by leaks, draining, etc., add makeup fluid to the glycol loop manually, using the same glycol concentration as the original fill. Do not use automatic makeup; the glycol can become diluted, without the system operator's knowledge, to a concentration that will freeze in normal winter weather.

5.3.1.3 Recirculation System

Problem:

- Primary protection mode (recirculation) fails to operate.
- Secondary protection mode (flush) fails to operate or fails to perform according to design.

Effect:

- Broken pipes, damaged collectors.
- Loss of use of system while repairs are made.

Solution (Recirculation Mode):

- Mount freeze sensor on absorber plate.
- Dedicate separate temperature sensors for freeze protection; use several sensors at different locations in the field.
- Set sensors at 50°F (10°C).
- Give the freeze protection mode its own circuitry and fuse so that problems in the other control circuits do not disable the freeze protection.
- Do not use a timeclock as the collector system ON/OFF control. Although the timeclock works well in the summer, it may be left by oversight to continue operating in the winter when it will lock out the recirculation pump just when it is needed.

Solution (Flush Mode):

- Verify the supply pressure and quantity of makeup water available at the site in normal winter weather.

- Verify that makeup water supply line to the site will not freeze, even under the coldest expected winter conditions.
- Where the quantity of flush water available is in doubt, thermally activated "dribble" valves may be used to reduce and control the amount of flush water used. The cost of using enough of these valves to protect a large system must be judged against the cost of using a drainback or glycol system for freeze protection.

5.3.2 Overtemperature

Problem:

- No overtemperature protection mode provided in design.
- Overtemperature mode fails to operate.
- Collector loop pump shutdown occurs during high insolation time.

Effect:

- Storage tank temperature exceeds upper limit, tank lining (if any) may be damaged.
- Solar energy lost through relief valve activating.
- Thermal shock damage of stagnating collectors when pump restarts.
- Thermal degradation of glycol in glycol systems, leading to plugged collectors.

Solution:

- Dedicate redundant temperature sensors in solar storage tank for overtemperature protection.
- Give the overtemperature protection mode its own circuitry and fuse so that problems in the other control circuits do not disable it.
- For water-cooled collector loops, either have the overtemperature shut down the collector loop pump or drain hot water from the solar storage tank, replacing it with makeup water (draining hot water wastes energy but keeps the pump running, avoiding thermal shock potential).
- For glycol-cooled collector loops, the second of the above modes may be used, or a heat rejection device may be added; the added cost of such a component must be justified against the expected cost of degraded glycol and system downtime and the expected frequency of need for overtemperature protection.
- Provide stagnation lockout to prevent pump restart while collectors are stagnating.
- Avoid designing too high an annual solar fraction into the system to reduce the frequency of possible overheat episodes.

- If a tank lining is necessary, use one that will operate above the stagnation temperature of the collectors used in the system.
- Provide a filter upstream of the collector loop pump to remove glycol degradation products and check/clean the filter after every overtemperature incident.

5.3.3 Overpressure

Problem:

- Lack of pressure relief valve (PRV) on component or piping run that can be isolated and heated.

Effect:

- Component/piping failure.

Solution:

- Install PRV on every component and piping loop that can be isolated and heated. The obvious requirements — solar storage tank, collector array — are usually taken care of, but the complete piping loops must be searched for less obvious requirements: collector rows with isolation valves, heat exchanger with isolation valves on both sides.
- Set PRVs to relieve below the design pressure of the component they are protecting.
- Direct PRV discharge into open container (if glycol) or drain (if water).

5.3.4 Corrosion

Problem:

- Dissimilar metals corrode at interface.
- Poor water quality causes corrosion of steel tanks.
- Glycol reacts with incompatible materials.
- Degraded glycol causes corrosion of copper components.

Effect:

- Leaking joints, failed components.
- Corrosion products foul balance of system.
- Storage tank life shortened.

Solution:

- Use dielectric unions on all copper/steel interfaces.
- Use treated water in closed loops; in open systems, treat the entire water supply.
- Line steel tanks where water treatment is too expensive.

- Monitor glycol quality frequently, especially after overtemperature incidents and change as often as necessary to maintain manufacturer's standards.
- Specify glycol-compatible materials for all components (seals, piping gaskets, valve seats, expansion tank diaphragms) that may contact the glycol.

5.3.5 Lightning

Problem:

- Lightning strike on or near the solar system.

Effect:

- Damaged collectors, piping.
- Damaged control components.

Solution:

- Provide complete lightning protection of collector system, whether roof or ground mounted, whether higher structures are close or not. Integration with the building's lightning protection system (for roof-mounted collectors) is recommended.
- Lightning protection systems should meet the requirements of ANSI/NFPA-78, Lightning Protection Code, and LPI-175, Installation Standard.
- Provide surge suppression in control system power supplies.

5.4 COMPONENTS

5.4.1 Collectors

Problem:
- Unequal flow through all collectors in one bank.

Effect:
- Lower collector efficiency for the low-flow units.

Solution:
- Use collector manufacturer's recommended flow rate as minimum.
- Limit number of collectors in one bank to eight.
- Install flow balancing valve at exit of outlet header of each bank to assure equal flow through each bank in the array for glycol and recirculation systems (for drainback systems, the balancing valve is installed in the inlet headers).
- Plumb outlet header in the reverse-return configuration.
- Flush piping system thoroughly before connecting to collectors.
- Install filter in collector loop to keep foreign material out of collectors.
- Size collector loop pump properly.

Problem:
- Collector performance degrades during operation.

Effect:
- Lower collector efficiency reduces system cost-effectiveness.

Solution:
- Specify collector with post-stagnation performance curve certified in accordance with ASHRAE Standard 93-77 (or later version 93-86).
- Specify insulation layer closest to absorber plate to be fiberglass without binder to prevent outgassing.
- Specify glazing/frame and absorber/frame seals to be EPDM rubber to maintain leak-tightness.
- Specify "floating" absorber plate to prevent thermal expansion damage.
- Specify frame coating suitable for the environment of the proposed site, e.g., baked enamel for seacoast sites.

Problem: - Evacuated collector with heat pipes shuts down because of "choking."

Effect: - Loss of energy collection capability.

Solution: - In the process called "choking," the heat pipe fluid condenses at the top and is not permitted to return to the bottom due to pressure exerted by the vapor below. This occurs with heat pipes using hydrocarbons as the heat transfer fluid and is avoided in heat pipes with water as the heat transfer fluid. Systems using evacuated collectors with heat pipes will avoid this situation by selecting appropriate heat pipe collectors, providing better heat transfer fluid for the collector loop, or designing the system for lower temperature collector operation.

Problem: - Collectors installed on sleepers but sleepers secured only to roof and not to building structure.

Effect: - Windstorm blew collector/sleeper assembly off of roof leaving holes in the roof. The windstorm toppled collector/sleeper assembly over and onto flat roof destroying piping and damaging the collectors.

Solution: - Secure sleepers to building structural members with through-bolts (lag screws are not reliable), and seal sleeper to the roof.

Problem: - Collector support piers sink into the ground.

Effect: - Pipe lines become distorted and leak.

Solution: - Install concrete bearing pad below each pier sufficient to spread the load so that existing soil conditions will support the load. Soil properties should be tested and determined to provide reliable data before ground-mounted collector supports are designed.

Problem: - Soil in ground-mounting location is contaminated.

Effect: - Construction personnel cannot work in the area.

Solution: - Remove and dispose of contaminated soil, pave over construction area. If soil contamination is suspected, be sure soil quality is tested and reliable data is provided in time to permit selection of a alternate site without delays to the project.

5.4.2 Storage Tank

Problem:	- "Short circuiting" flow from inlet to outlet.
Effect:	- Much of tank volume never changes temperature.
Solution:	- Use vertical tank wherever possible.
	- Install inlet and outlet at opposite ends and elevations of the tank.
	- Provide baffles in tank to lengthen flow path, increase holdup time.
	- Provide a distribution header for each inlet stream.
Problem:	- Corrosion at water/air interface.
Effect:	- Corrosion products migrate through system; tank life shortened.
Solution:	- Use lined tank (but lining must be capable of operating at high temperature if collectors stagnate).
	- Use fiberglass tank if it need not be pressurized.
	- Filter all outlet lines from tank to trap corrosion products.
Problem:	- Fiberglass tank collapsed over support when charged with hot water.
Solution:	- Fiberglass tanks must stand on or be suspended from supports designed or approved by the tank manufacturer.
	- Fiberglass tank operating temperature capability must be above the design operating temperature of the system.
Problem:	- Optimum tank design will not fit available space or building entrance.
Solution:	- Use two or more tanks to give the required storage volume.
	- Specify identical tanks for economy in buying them.
	- Install in series to give "stratification" effect.
	- Install tanks close together to reduce insulation cost and keep thermal losses to a minimum.

5.4.3 Heat Exchanger

Problem:

- Heat exchanger does not transfer heat from the collector loop as fast as the collectors supply it; heat exchanger is undersized for the system.

Effect:

- Collector loop must work with higher temperature inlet fluid; therefore, collector efficiency is less than optimum.

Solution:

- Use realistic effectiveness factors when designing the heat exchanger. In-tank heat exchangers operate at about 0.15 effectiveness in the typical solar system, shell-and-tube heat exchangers at 0.6. Plate-and-frame heat exchangers can provide an effectiveness of 0.85.

- Where the facility layout permits, use either shell-and-tube or plate-and-frame heat exchanger; make a cost-effectiveness study of both models, balancing initial capital cost with change in collector performance.

- Use design conditions that will be found in the actual system.

- Size the heat exchanger for the average collection rate during the 2-hour period around solar noon in the highest insolation month.

5.4.4 Pumps

Problem:

- Pump does not circulate design flow; pump is undersized.

Effect:

- Collectors operate below manufacturer's recommended flow rate, at less than optimum efficiency.

Solution:

- Calculate the pressure drop around the piping loop carefully; be sure the as-built system will not be different from the design plan/elevation drawings.

- Add 5% to calculated flow and head requirements to allow for pump wear over time.

- Select a pump with required operating point at or close to its maximum efficiency.

- If available without excessive cost penalty, select a multispeed pump that will allow for increasing flow by increasing speed.

- Collector manufacturer's recommended flow rate is for water. If glycol is the heat transfer fluid, be sure its properties are used in the pump sizing calculations. A higher collector flow rate for glycol systems is required to give the same heat removal rate as water.

- Install pump in cold leg to lengthen its life.

Problem: - Pump runs but no fluid circulates; pump motor is wired backwards.

Effect: - No heat is collected, but casual inspection may indicate system is operating.

Solution: - Perform phase rotation check on motor after installation and after every power disconnection and reconnection; rewire motor correctly.

5.4.5 Piping

Problem: - Not sloped to drain.

Effect: - Inadequate drainage in drainback systems will cause freezing and damage to piping and/or collector. Problems filling and flushing systems will reduce collector efficiency in glycol and recirculation systems.

Solution: - Slope piping 1/4 in./ft (21 mm/m). If not required to drain completely for freeze protection, provide drain valves at all low points for filling/flushing glycol and recirculation systems.

Problem: - Piping sized for fluid velocity greater than 6 ft/s (1.8 m/s).

Effect: - Erosion of the pipe.

Solution: - Calculate the pipe size using design flow rates that yield a fluid velocity of 4 to 6 ft/s (1.2 to 1.8 m/s).

Velocity (ft/sec) =

$$[\text{Flow rate (gpm)} \times (1\ \text{ft}^3/7.48\ \text{gal}) \times (1\ \text{min}/60\ \text{sec})]/[\pi\{\text{Pipe I.D. (ft)}\}^2/4]$$

Velocity (m/s) =

$$\text{Flow rate (L/s)} \times (10^{-3}\ \text{m}^3/\text{L})/\ [\pi\{\text{Pipe I.D. (mm)}^2(10^{-6}\ \text{m}^2/\text{mm}^2)\}/4]$$

Problem: - Cold water makeup line not plumbed properly.

Effect: - System operates less efficiently because the coldest fluid in the system is not being circulated through the collector loop.

Solution: - Plumb the cold water makeup line to the cold inlet side of the heat exchanger (if used) or to the supply line to the collectors (if no heat exchanger is used).

Problem: - No initial fill lines provided.

Effect: - Difficult to fill, flush, and pressurize the system.

Solution: - In each loop provide two fill lines located 1 to 2 ft (305 to 610 mm) apart, separated by a block valve to allow the use of a high head, high flow fill pump or high pressure water supply to fill, flush, and pressurize the system at startup.

Problem: - No thermal expansion compensation.

Effect: - Damage to piping and possibly components.

Solution: - Provide expansion loop in each long piping run.

5.4.6 Insulation

Problem: - Insulation specification requirements not adequate.

Effect: - Poor installation and large heat losses.

Solution: - Locations for insulation should be identified, including the bottom side of thermal storage units, collector headers, etc., on installation drawings as well as in specifications. Proper sealing of insulation should be specified. Insulation should be specified by R and/or U value, not thickness. Rubber insulation should not be used. If fiberglass insulation is used, specify no binders. Specify inspection of insulation to look for thermal bridges, gaps, and compaction. Specify weatherproofing requirements and lap seams to shed water.

- Foamed-in-place component insulation, e.g., tanks, large pipelines, and heat exchangers, should be weatherproofed with a sprayed-on silcone membrane to form a seamless vapor barrier.

5.4.7 Valves

Problem: - No check valves for thermosiphon protection of anti-freeze and recirculation systems.

Effect: - Excessive heat loss at night through collectors and/or heat exchanger; freeze damage to heat exchanger in extreme cases.

Solution: - Install vertical, spring-loaded check valve on the array downcomer line and the hot inlet line to the storage tank. Specify a soft-seat check valve.

Problem:	- No backflow preventer on cold city water makeup line.
Effect:	- Contamination of city water system.
Solution:	- Install a backflow preventer on the cold water makeup line.
Problem:	- No drain valves on tanks.
Effect:	- Inability to flush sediment from tank.
Solution:	- Specify installation of drain valves on all tanks.
Problem:	- No balancing valves on collector banks.
Effect:	- Unbalanced flow through array with decreased energy collection.
Solution:	- Specify balancing valves on the outlet header of each collector bank in a glycol or recirculation system, and on the inlet header of a drainback system. Balancing valves with soft seats should be specified so banks can be isolated with the balancing valves, if necessary, and extra isolation (gate) valves are not needed.

5.4.8 System Controller

Problem:	- Control set points incorrectly specified.
Effect:	- Decrease in energy collection and/or system operation under nonoptimum conditions.
Solution:	- The turn-on, turnoff differentials on a differential temperature controller should be no greater than 20°F (11°C) or less than 8°F (4.4°C) for turn-on and between 3 and 5°F (1.7 and 2.8°C) for turnoff. Freeze protection set point temperature should be 50°F (10°C), and overtemperature protection set point temperature should not be above 205°F (96.1°C).
Problem:	- Control sensor location and attachment requirements not specified, sensors installed improperly.
Effect:	- Decrease in energy collection; system protection not activated correctly; system pumps run all the time.

Solution: - The collector temperature sensor should be either attached to the back of the absorber surface, one-third of the way from the top and in the center, or in a thermowell in the outlet header that places the sensor directly above a collector outlet. The storage temperature sensor should be firmly attached to the surface of the storage unit or preferably installed in a thermowell, near the bottom of the storage unit. A poorly installed storage sensor will read ambient temperature so that the controller will always sense a large differential temperature and keep the system running continuously.

Freeze protection temperature sensors or thermal switches should be in thermowells in the inlet and outlet headers, as close to the collector as possible. For system protection controls, redundant sensors, connected to operate independently, should be specified.

Sensors installed in thermowells must be in the flowing stream, not in a standoff that does not see changing temperatures.

Problem: - No operational mode checkout specified.

Effect: - Undetected system malfunctioning.

Solution: - A detailed operational mode checkout should be specified which simulates or verifies under actual conditions all the operational modes; the checkout must be completed successfully before the system is accepted. The checkout procedures are used later in troubleshooting a malfunctioning system.

Problem: - Use of proportional differential controller with components requiring fixed voltage inputs.

Effect: - Component damage.

Solution: - Specify controller outputs that match the inputs required by the controlled component.

5.4.9 Btu Meters

Problem: - Incorrectly located flowmeters and/or temperature sensors.

Effect: - Incorrect energy readings.

Solution: - Verify that the two temperature sensors "see" the same flow rate (i.e., no fluid is being added to or taken from the system between the locations of the flowmeter and temperature sensors). Install the temperature sensors in a thermowell immersed in the flowing stream, not in a standoff that does not see changing conditions.

5.4.10 Drainback Tank

Problem: - No sight glass/level gauge specified.

Effect: - Operating and/or drainback levels cannot be verified, possibly causing pump cavitation if operating level is too low or freezing if drainback level is too high.

Solution: - Specify a sight glass or level gauge on the drainback tank; mark operating and drainback levels on it clearly.

5.4.11 Fans in Air-Collector Systems

Problem: - Fan for the collector array is not large enough to supply the design air flow throughout the collector array with existing fan off.

Effect: - Failure to reach design collector efficiency, and a decrease in collected energy.

Solution: - Design controls so that when solar heat is being delivered to the load, usually the first stage of the thermostat, the existing blower is also turned on.

Problem: - Collector-storage loop installed without a fan, expecting existing fan to provide air circulation through collector and building.

Effect: - Overly complex and expensive duct system must be provided; design air flow through collector not achieved; decreased collector efficiency and collected energy result.

Solution: - Avoid single fan design; if in place, retrofit with a separate fan for collector-storage loop.

Problem: - Fan large enough for design air flow through large collector array provides higher flow than needed in building heating loop.

Effect: - Building may overheat, cycle solar loop on and off.

Solution: - Install motorized dampers to reduce air flow in building loop to design level and direct balance through storage; install separate smaller fan in building loop to provide design flow with auxiliary heat when solar loop is not operating.

Problem: - Air collectors not sealed tightly against leaks.

Effect: - Heated air leaks out, reducing collected energy.

Solution: - Install collector loop fan downstream from collector array so that collectors operate under negative pressure so collected energy is not lost.

5.4.12 Ducting in Air-Collector Systems

Problem: - Nonmetallic (e.g., sealed fiberglass) ducting specified.

Effect: - Personnel in the building complained of possible health hazards.

Solution: - Assess health hazard potential through independent authority during system design; use metal ducting if question of health hazard is raised.

5.4.13 Dampers

Problem: - "Open" and "closed" positions of damper not labeled.

Effect: - Maintenance personnel have difficulty assessing system operation. System operates poorly because dampers are left in wrong position.

Solution: - Label all dampers for "open," and "closed," positions and label to show direction of flow for all operating modes.

Problem: - Dampers do not seal off duct tightly.

Effect: - Design air flows through collectors and heating loop are not achieved; system operates below design efficiency.

Solution: - Use high quality tight sealing dampers with positive drive in both damper directions.

Problem:	- Dampers do not seal off collector loop duct tightly.
Effect:	- Cold air (below freezing) leaks past dampers and freezes water coil in duct used to heat domestic hot water.
Solution:	- Use high quality dampers and locate water coil in the duct between the collector loop fan and the warm end of the pebble storage bed (not between fan and collector).

5.4.14 Pebble Bed Storage Units

Problem:	- Pebble bed becomes damp from condensation.
Effect:	- Pebble bed supports bacteria growth, odors develop and are carried through building.
Solution:	- Install pebble bed in heated space of the building, not outdoors where condensation can occur or below grade where water table may rise and infiltrate the bed.