Do It Yourself Solar Water Heater

The following manual will give you the plans that will enable you to build your own solar water heater. These plans will focus on passive systems as these are the cheapest and easiest to build.

I have included an overview of all types of solar water heaters for your review. At the end of that overview, you will find specific plans to build your very own solar water heater.

The first section describes and illustrates the main types of solar water heating systems, along with variations of each type, as well as various freeze protection strategies and designs.

The second section details the principal components of solar water heating systems and their individual function.

System Types

I. System Types

This module describes the most common types of solar water heating systems. Factors that influence the selection of a specific system type include the amount of water that needs to be heated, relative cost and efficiency, simplicity of operation, and climate conditions in which the system will be used.

Solar water heating systems fall into two general categories:

- active systems, which use a pump to control water flow, and
- passive systems, which use no pump.

Both active and passive systems can be either direct or indirect (Figure 1).

- In a direct system, the potable water circulates from the storage tank to the collector and back to the storage tank. Thus, the heat collecting fluid is the same potable water that is in the water heater.

- In an indirect system, the fluid that circulates through the collector may be water or it may be another heat transfer fluid. This heat-collecting fluid never comes in contact with the potable water in the storage tank. Instead, it transfers heat to the potable water through a heat exchanger.

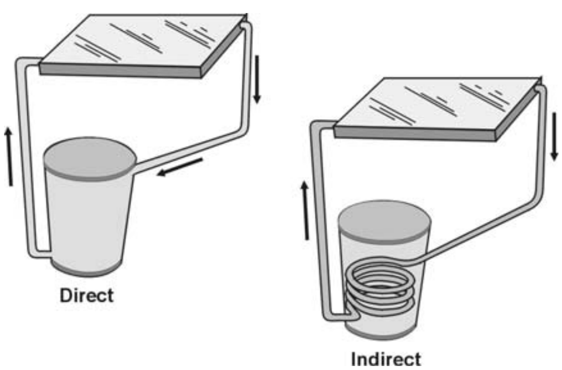


Figure 1 Direct and indirect solar water heating systems

Once again, there are two types of solar water heating systems – active and passive – and each has two categories – direct and indirect.

Active	**Passive**
Direct	Direct
Indirect	Indirect

The following pages will discuss the most common system types and their subcategories. Several design variations exist in each system type. The types and variations include:

1. Active Direct Systems
   - Active direct systems that use different types of controllers

2. Active Indirect Systems
    - Active indirect systems that use different types of controllers, heat collecting fluids, and heat exchange mechanisms

3. Passive Direct and Indirect Systems
    - Passive direct systems in which the collector and storage are one and the same
    - Passive systems that circulate water through thermosiphoning action and can be direct or indirect

1. Active Direct Systems

Active direct systems incorporate the following components:

- Water storage tank
- Solar collector
- Controller to regulate pump operation
- A pump or circulator to transfer water from the storage tank to the collector

Several additional components ensure proper system operation. Each of these components, listed below and in Figure 2, are discussed in detail in Section 2, Module: System Components.

1. Check valves prevent thermosiphoning action.
2. Isolation valves isolate subsystem components for service.
3. Pressure relief valves relieve high pressure.
4. Temperature and pressure relief valves relieve high temperatures and pressures.
5. Air vents release air that could cause air locks in the system.
6. Vacuum breakers allow proper collector loop drainage.
7. Drain valves drain the collector loop and tank or other subsystem components.
8. Freeze valves and sensors help to protect the collector from being damaged by freezing temperatures.
9. Optional temperature indicators and flow meters monitor components.

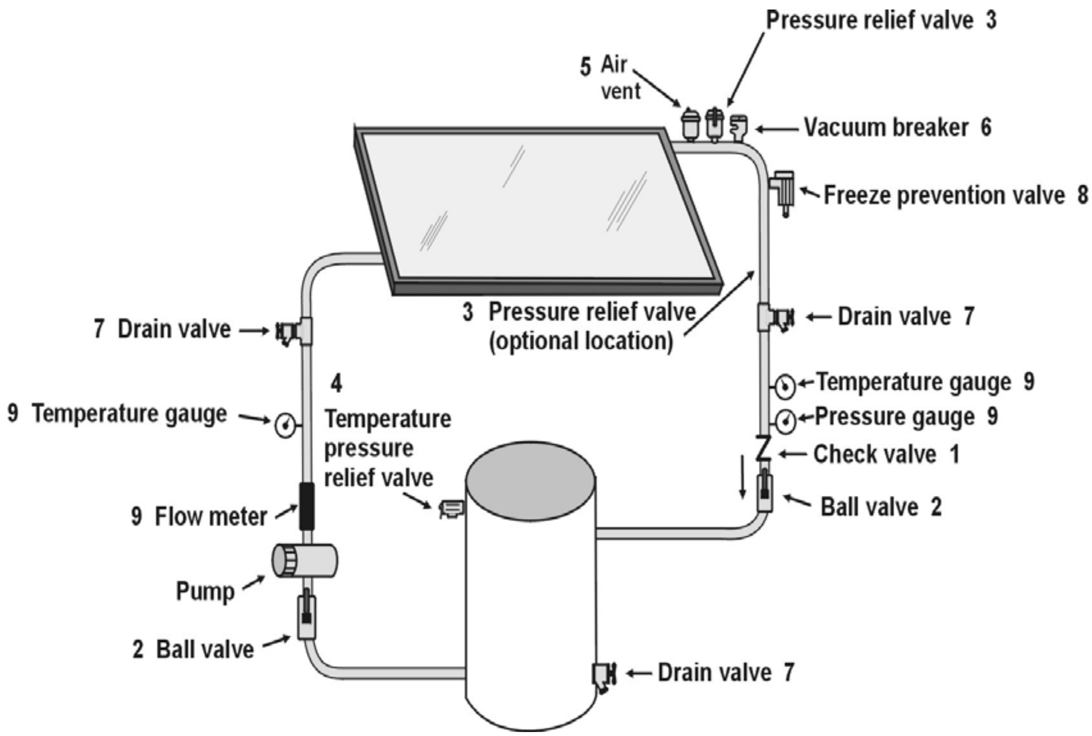


Figure 2 Additional system components

Active direct systems are principally differentiated by their pump control or freeze protection scheme. Following are descriptions and illustrations of four active direct systems based on their method of pump control.

Differential Controlled

In a differential controlled system (Figure 3), the circulating pump operates when sensors located at the top of the collector (hottest point) and bottom of the storage tank (coldest point) indicate a 5-20^{o} F temperature difference. Thereby, the water always gains heat from the collector when the pump operates. When the temperature difference drops to about 3-5^{o}F, the pump switches off. During the course of the day, the controller is constantly comparing the two sensor temperatures. In this way, water circulates through the collector only when sufficient solar energy is available to increase the water temperature.

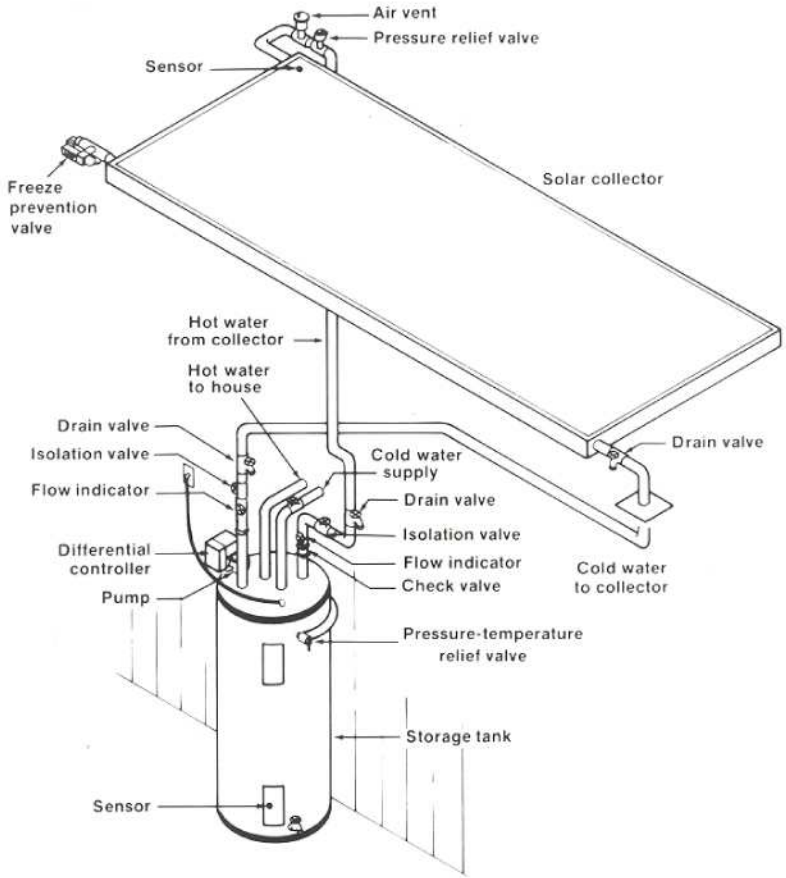


Figure 3 Active direct system with differential controller

Photovoltaic Controlled

Whereas the differential controlled active system uses a differential controller and sensors to regulate pump operation and heat collection, the photovoltaic (PV) controlled system (Figure 4) uses a PV module to perform these functions. Photovoltaics modules are semiconductor materials that convert sunlight directly to direct current (DC) electricity. In a photovoltaic controlled-system, a photovoltaic module generates power for a DC pump that circulates water through the collector and back into the storage tank. In a direct-coupled system, the module and pump are sized and properly matched to ensure that the pump will begin operating when sufficient solar energy for heating water is available and will stop operating when solar energy diminishes.

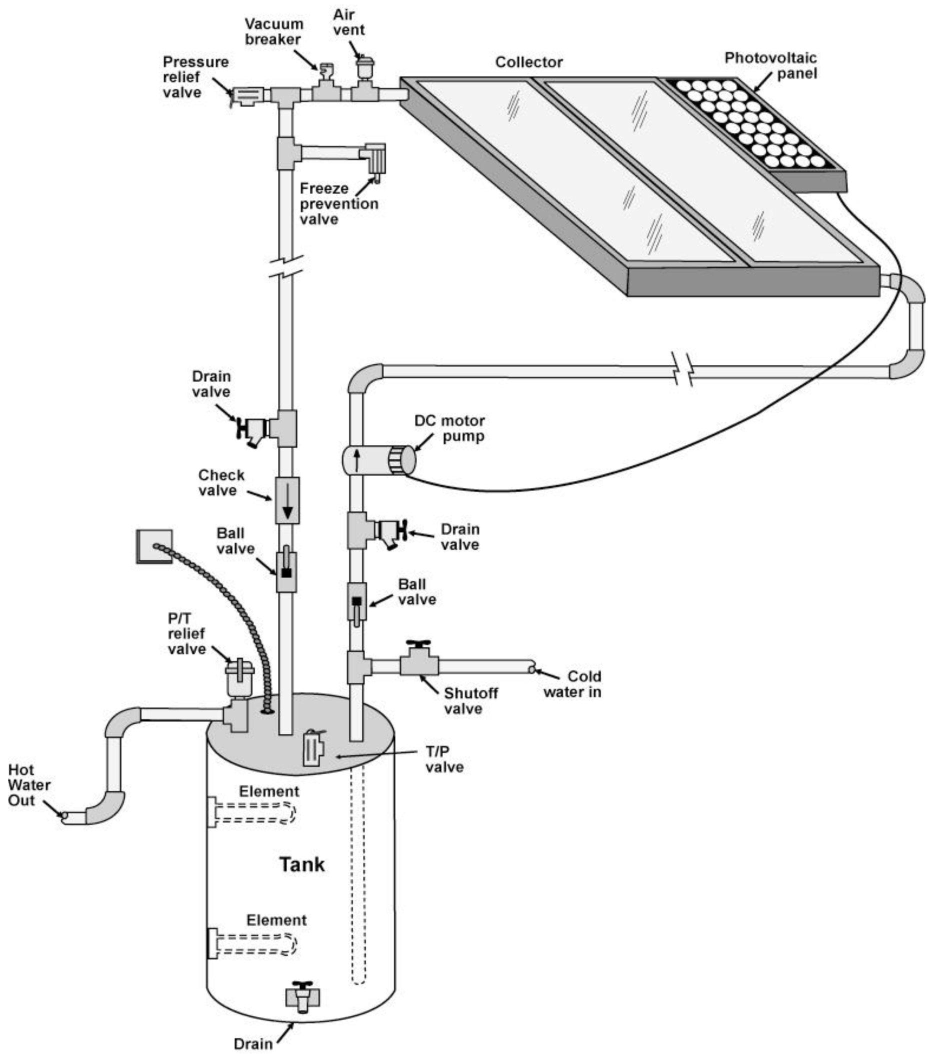


Figure 4 Active direct system with photovoltaic control

Timer Controlled

This control method is used in tropical climates where temperatures are mild year-round and significant amounts of solar energy are available almost every day. In a timer controlled system (Figure 5), a timer turns on a pump in mid morning and switches it off in late afternoon. To ensure that the heated water stratifies at the top of the storage tank, the system uses a very small (1/100-1/250 h.p.) pump. The collector feed and return lines are both connected through the use of a special valve at the bottom of the storage tank so only the coldest water from the tank flows through the solar collector.

Timer controlled systems could conceivably operate during rain or overcast conditions, so care must be taken to ensure the supply and return lines to the collector are located near the bottom of the storage tank. Therefore, if the pump operates during a cloudy day, only a small amount of the water at the very bottom of the tank will be circulated through the collector. This prevents potential major tank heat loss.

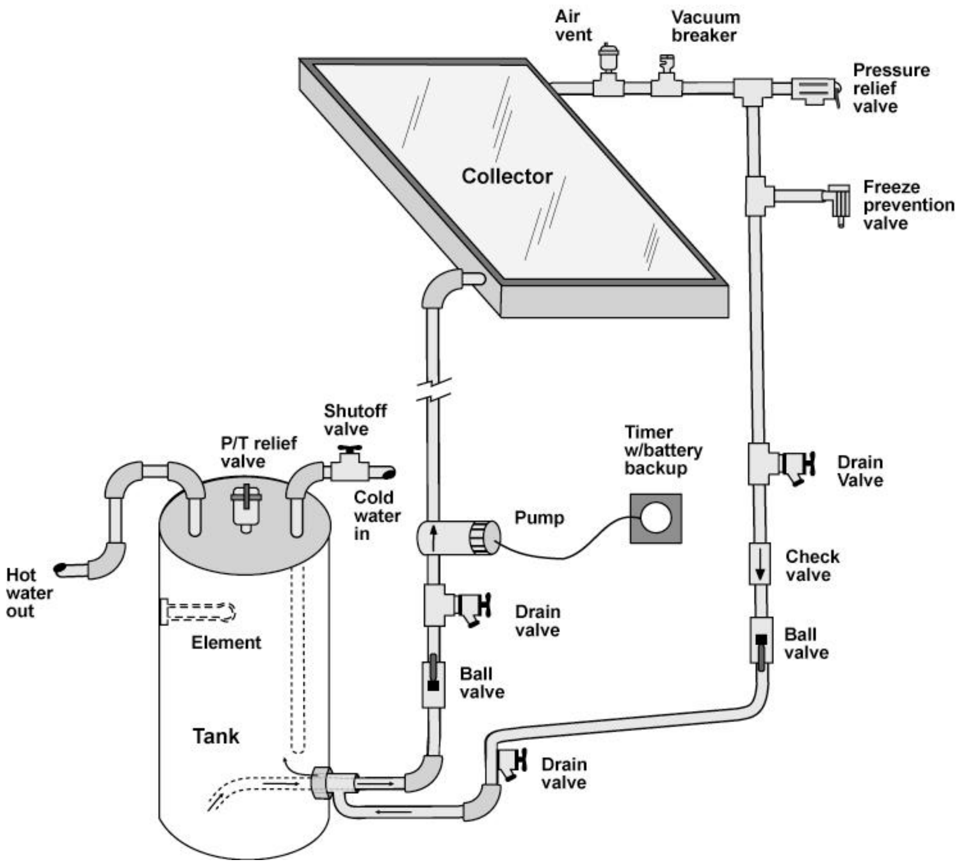


Figure 5 Active direct system with timer control

2. Active Indirect Systems

Indirect systems are typically used in areas of freezing temperatures or areas that have water that is very high in mineral content. The combination of high dissolved minerals and high temperatures produced by the solar system can accelerate scale buildup in system piping, fittings, and valves.

Like direct systems, active indirect systems employ a solar collector, a circulating pump, a potable water storage tank and a variety of ancillary valves. Unlike direct systems, indirect systems also incorporate a heat exchange mechanism that transfers heat from the freeze-proof heat-collecting fluid to the potable water in the storage tank. Active indirect systems are differentiated principally by the type of heat exchanger, controller, and heat collection fluid used.

Indirect Pressurized System

In an indirect pressurized system (Figure 6), the heat transfer fluid provides freeze protection at low temperatures. A differential or PV controller activates the circulator to move the fluid through the collector. A heat exchanger transfers the heat from the heat transfer medium to the potable water. The heat exchanger may be external to the storage tank, coiled around the outside lower half of the tank, or immersed inside the tank. A double wall heat exchanger is always used in systems that use toxic heat transfer fluids.

For systems using non-toxic heat transfer fluids, a single wall heat exchanger is acceptable. An expansion tank on the solar loop compensates for the heat transfer fluid's expansion and contraction. In addition, these systems require fill and drain valves for adding and servicing heat transfer fluids.

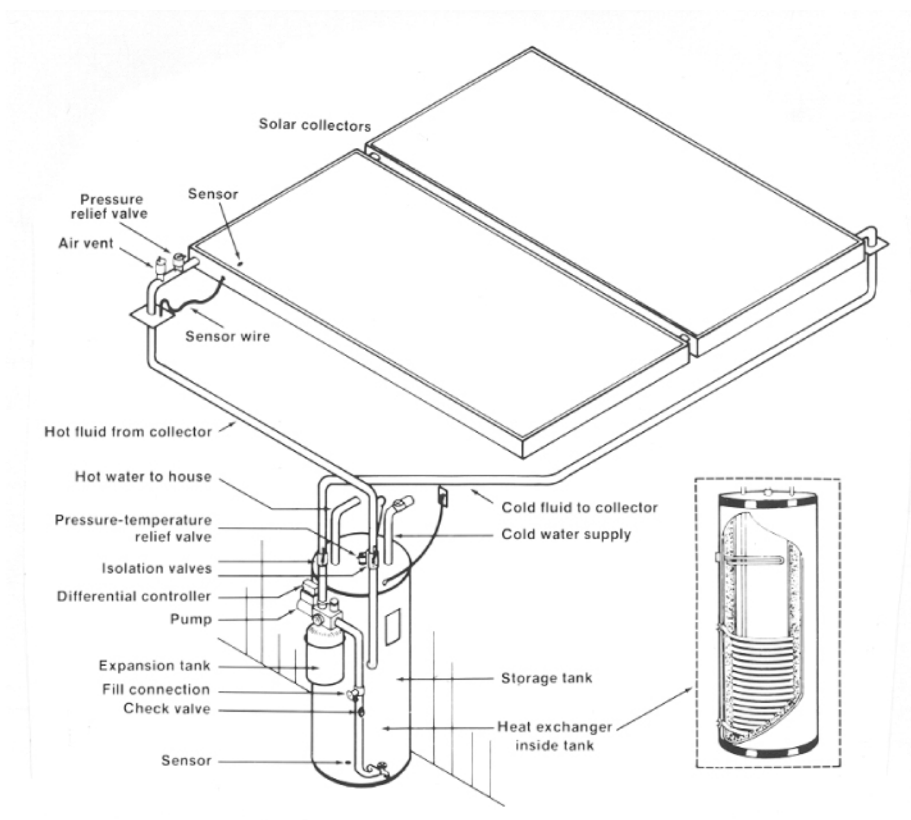


Figure 6 Active indirect system with tank internal heat exchanger

Drainback System

Drainback systems offer freeze protection and high-limit protection because the collectors empty by gravity when the system pump is not operating. Since these differentially controlled systems often use distilled water as the heat collection fluid, they offer improved heat transfer to the potable water. (This is because water has better heat transfer capabilities than other heat transfer fluids such as glycols or hydrocarbons.)

When installed correctly, these system also provide a fail-safe method for protecting the collectors and piping from freeze damage. Each time the differentially controlled pump shuts off, all fluid in the slightly tilted collector and pipes drains into an insulated reservoir tank located in the building's interior. In some systems, the heat exchanger is incorporated in the drainback reservoir; in others, the heat exchanger may be external or inside the storage tank. This system does not require air vents or vacuum breakers; instead, the piping contains air that should not be added or released.

Drainback systems have a measured amount of air and a measured amount of water in the system. The air is transferred to the reservoir when the pump is running and the water fills the collector. The pump is never without water since water is returning from the collector loop. When the pump shuts off, the air in the reservoir is forced up and into the top of the collector by the water draining back into the reservoir from the bottom of the collector.

Several other special characteristics of drainback systems include:

- Pumps must be sized correctly to overcome gravity and friction losses
- Since the system is not pressurized, expansion tanks, check valves or fill and drain valves are not required
- Collectors and pipe drains must be installed to allow proper and unimpeded drainage back to the drainback reservoir

3. Passive Direct and Indirect Systems

Passive systems use no pumps or controllers. Instead, they rely on convection either to move water between the collector and storage tank in a thermosiphon system or to stratify heated water within an integral collector system. Most passive systems are direct; that is, the potable water directly collects the sun's heat in the collector. However, a few passive systems employ a heat exchanger. Following are descriptions of the most common types of passive systems.

Thermosiphon System, Direct or Indirect

In a thermosiphon system (Figure 7) the water storage tank is located above the collector. Cold water from the bottom of the thermosiphon system's tank flows through a pipe to the bottom of the solar collector. As the sun shines on the collector, the heated water expands slightly and becomes lighter than the cold water. Heavier, denser cold water from the tank flows into the collector inlet, which pushes the lighter, heated water through the collector outlet and up into the top half of the storage tank. This process of displacement provides a tank full of hot water at the end of the day. The solar heated water is drawn from the elevated tank either directly to the hot water service or to an interior auxiliary tank. Some thermosiphon systems (Figure 8) include a heat exchanger in or around the tank and an antifreeze solution to avoid freeze problems.

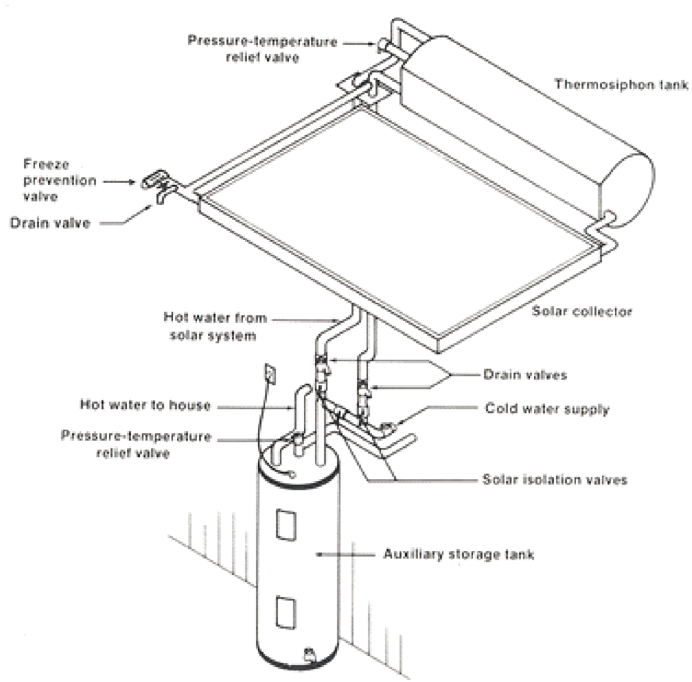


Figure 7 Direct thermosiphon system

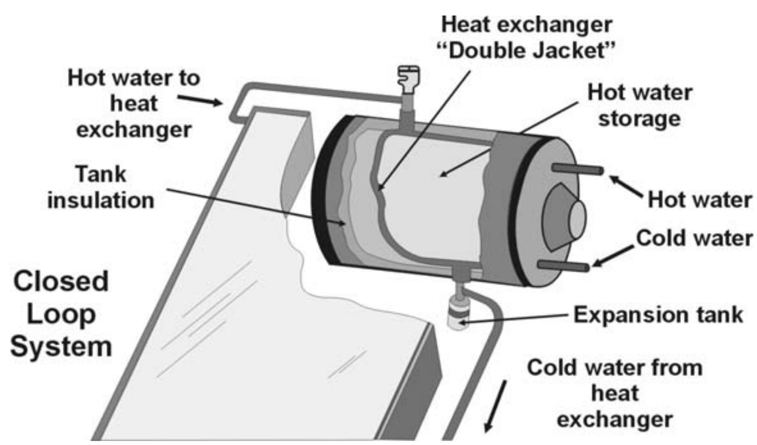


Figure 8 Indirect thermosiphon system

Integral Collector Storage (ICS) System

In other solar water heating systems the collector and storage tank are separate components. In an integral collector storage system, (Figure 9 and 10) both collection and solar storage are combined within a single unit. Most ICS systems store potable water inside several tanks within the collector unit. The entire unit is exposed to solar energy throughout the day. The resulting water is drawn off either directly to the service location or as replacement hot water to an auxiliary storage tank as water is drawn for use.

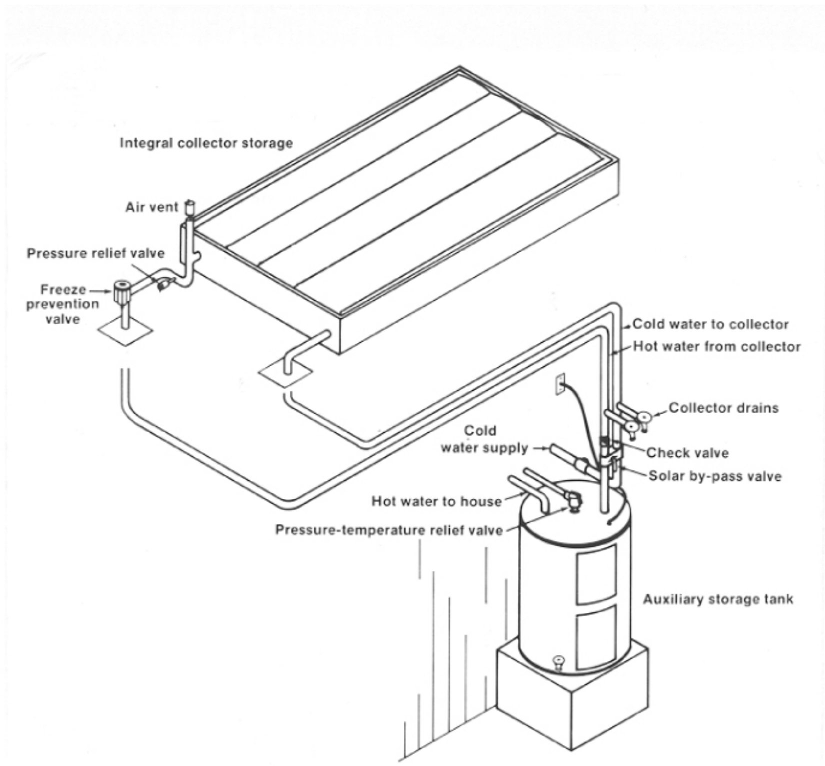


Figure 9 Integral collector storage (ICS) system

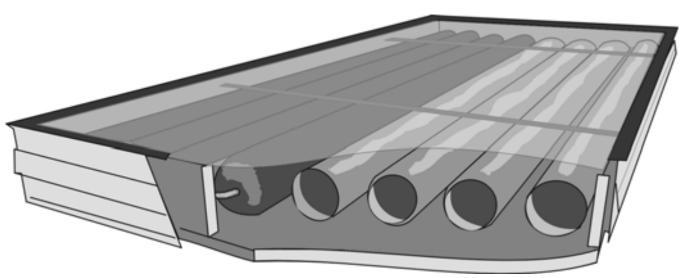


Figure 10 Cutaway of an ICS system

Batch System

The simplest of all solar water heating systems is a batch system (Figure 11). It is simply one or several storage tanks coated with a black, solar-absorbing material in an enclosure with glazing across the top and insulation around the other sides. It is the simplest solar system to make and is quite popular with do-it-yourselfers. When exposed to direct sun during the day, the tank transfers the heat it absorbs to the water it holds. The heated water can be drawn for service directly from the tank or it can replace hot water that is drawn from an interior tank inside the residence.

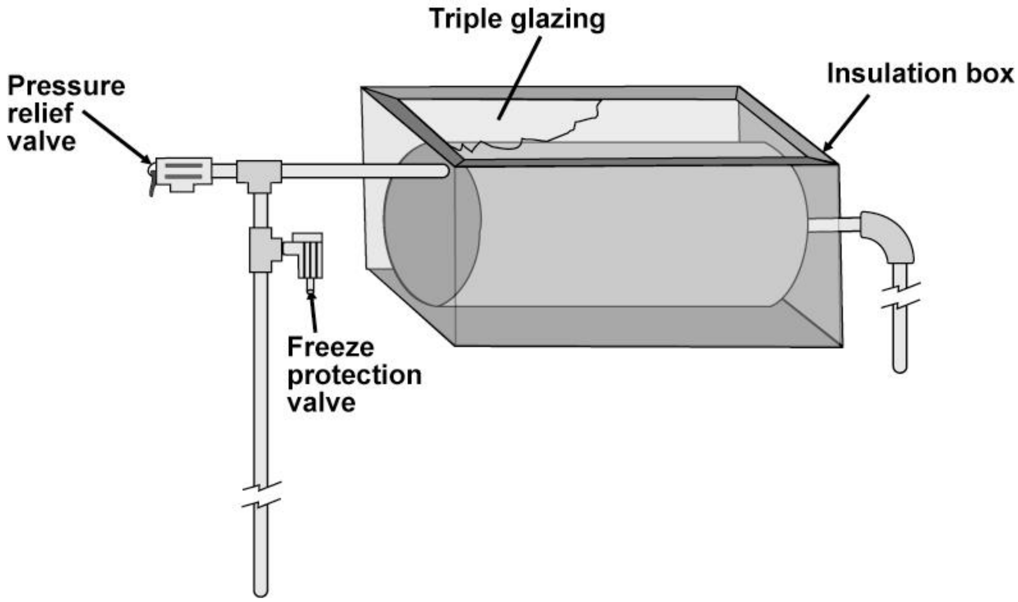


Figure 11 Batch solar water heater

II. FREEZE PROTECTION

Freeze protection mechanisms prevent freeze damage to system components. There are four basic methods used to prevent freezing. These include:

1. Indirect Antifreeze Fluid Circulation
2. Draining
3. Water Flow
4. Thermal Mass
5. Auxiliary heater

Except for solar systems in the tropics, all systems require some type of freeze protection method. The following examples are some of the more common methods used to prevent freezing. Systems may employ one or more of the following methods of freeze protection.

1. Indirect antifreeze fluid circulation

Indirect heat exchange systems, which are frequently used in cold climates, use a heat- transfer fluid that provides freeze protection in very low temperatures. The antifreeze solution circulates in a closed loop through the collector and heat exchanger. This provides protection to the collector and exterior piping during freezing temperatures.

2. Draining

Direct systems can be protected from freezing by removing all the water from the collector and the exposed piping. This can be done manually or automatically by one of two methods: drain down or drain back.

a. **Automatic Drain-down**

In a drain down system (Figure 12), sensors and a controller activate one or more automatic valves that isolate the collector loop from the tank. The automatic valve should be installed to allow collector loop drainage when power to the electrically operated valve is interrupted. The collectors and piping for these systems must be installed so that no gravity traps or low spots occur so that the collector loop fluid will drain totally by gravity.

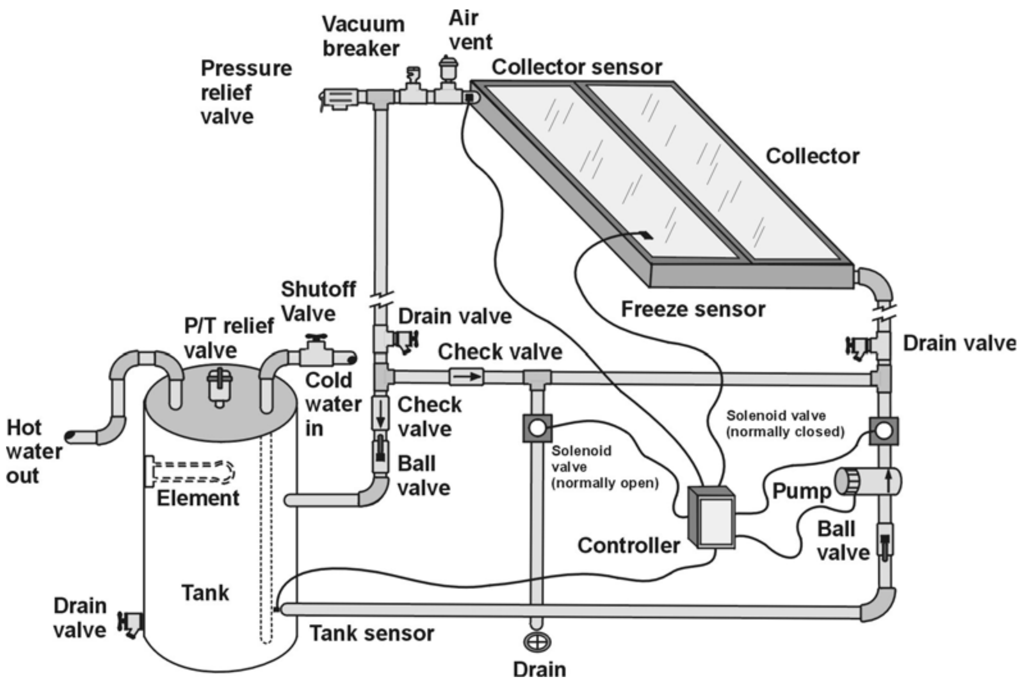


Figure 12 Drain-down system configuration b.

Manual Drain-down

Systems can also be designed to be manually drained. The system must have isolation valves between the collector and the storage tank and drain valves on the supply and return lines. The manual draining operation must include shut off of any system controller and circulating pump. It is best to keep the drain valves open when the collectors are drained. A leak or failure of the isolation valve can provide a path for water to flow back to the solar collector and result in freeze damage.

Complete draining requires both properly sloped piping and a means for air to enter the system. The use of a vacuum breaker will ensure that the collector loop drains properly. In turn, refilling after draining requires a method to allow air to escape at the high point of the system. A properly installed air vent will provide a means of allowing air to be purged automatically from the system.

c. **Drain-back**

In drain-back systems (Figure 13), a reservoir collects the heat-transfer fluid (usually distilled water) that drains from the collector loop each time the pump turns off. When the pump turns on, it recirculates this same fluid. Generally, a drain back system uses a heat exchanger to transfer heat from the collector fluid to the potable water.

The pump used in these drain-back systems must be capable of overcoming fairly large static heads, since the collector may be mounted several stories above the pump. The pump must be installed in such a way that it is below the low-water mark when liquid is not circulating. As in drain down systems, the collectors and piping for drain back systems must be installed in a way that allows no gravity traps or low spots to prevent the drain back of the heat-transfer fluid.

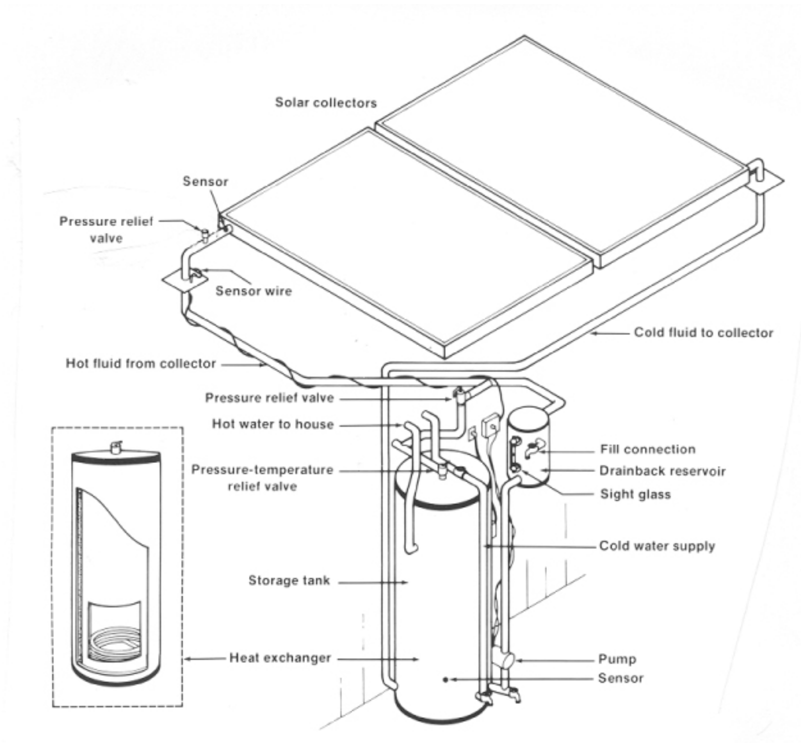


Figure 13 Drain-back system with internal tank heat exchanger

3. Water flow

Freeze prevention may be provided by moving warm water from the bottom of the tank through the collector. This movement can be accomplished by recirculation or use of freeze-protection valves.

a. Recirculation

In direct systems, recirculation may be used where the threat of freeze damage is infrequent. For recirculation, a freeze sensor is connected to the controller to turn on the pump whenever the collector temperature approaches freezing. For systems that use a separate freeze sensor, the freeze sensor should be placed on the collector plate at the middle or bottom of the collector (away from the collector inlet) so that it will sense the coldest temperature of the collector. Another option is to turn the pump on manually during freeze conditions.

Because the pump requires electric power, this method will fail when a power outage and freeze occur simultaneously. At such a time, the collector must be drained manually.

b. Freeze protection valves

A freeze protection valve (Figure 14), set to open before freezing temperatures, is installed on the collector return plumbing line just beyond where the line penetrates the roof. When the valve registers a set temperature, it opens and warm water bleeds through the collector and out the valve to protect the collector and collector loop piping from freezing. Once the valve registers warmer temperatures (from the tank water being circulated through the valve), it closes. This action is repeated throughout the freezing conditions. The valve may be controlled by a spring-loaded thermostat or a bimetallic switch. Figure 15 shows where a freeze-protection valve is typically located on a solar DHW system.

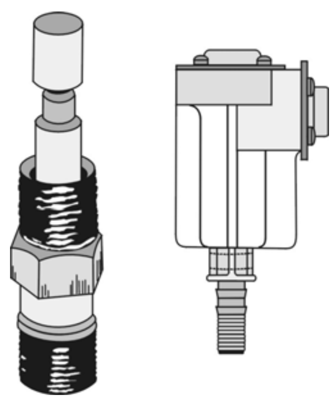


Figure 14 Freeze protection valves

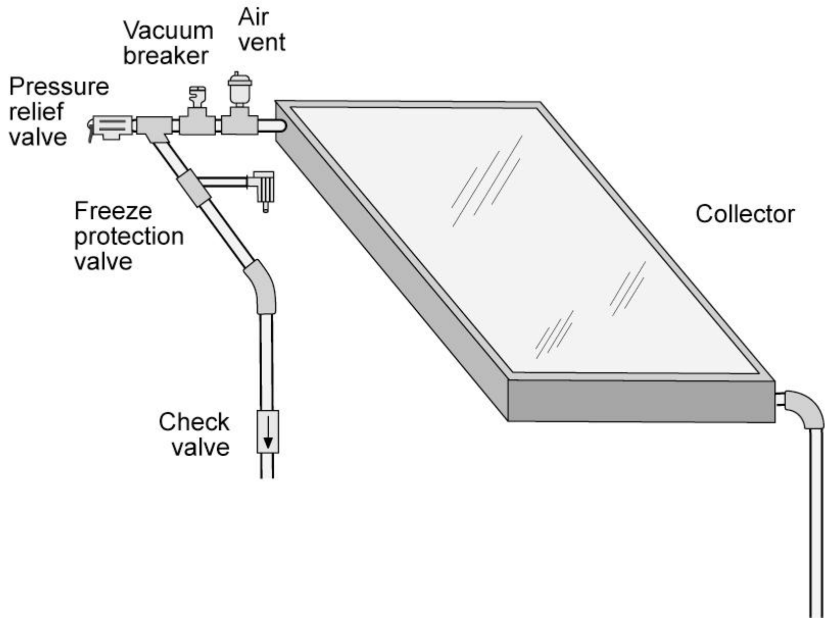


Figure 15 Location for freeze protection valve

Freeze-protection valves require water pressure to force water through the valve (and in turn through the collector and associated piping) when activated. If these valves are installed on well water or cistern systems, low-pressure relief valves should also be installed on the system. The valve will open and drain the collector and collector loop when power outages create low pressures.

A check valve must be used in all systems with freeze-protection valves. They are installed in the collector loop return line (See Figure 15). To protect the absorber plate, water must flow through all the pipes. The check valve prevents tank water from flowing straight from the tank to the freeze valve by way of the return line, thus bypassing flow through the collector.

4. Thermal mass

When used in milder climates, integral collector storage and batch type solar systems are protected from freezing by the large thermal mass in their collectors. Nevertheless, special care must be taken to protect exterior and attic collector loop piping. Any thermal mass protected system can eventually lose heat and freeze. The size of the collector tanks, the climatic and geographical location, local winter temperatures, and the length of the freeze all play a factor in determining how effective thermal mass will be as a freeze protection option.

5. Auxilliary heating

A less commonly used freeze-protection option is to use heat tape or electrical devices that are incorporated in the collector and collector loop piping. During freezing periods, these are activated to provide warmth to the collector and piping. As in recirculation, this relies on the continued availability of electric power during freezes.

Section 2
System Components

INTRODUCTION

Solar water heating systems have components for heat collection, heat storage, heat delivery and freeze protection. Active systems need controls for pump operation and valves for safety and proper operation. Passive systems utilize many of the same components but in some cases for different reasons. This chapter describes the following system components.

- Collectors - collect and convert the sun's energy to heat.
- Tanks - store solar heated water and heat transfer fluids.
- Heat delivery components - include piping, heat-transfer fluids and heat exchangers.
- Freeze protection mechanisms - prevent collectors and pipes from freezing.
- Isolation, check, relief and safety valves are used to valve fluid flow.
- Gauges and meters are used for system monitoring

COLLECTORS

Solar collectors capture the sun's electromagnetic energy and convert it to heat energy. While most direct and indirect active systems use flat-plate collectors, some systems employ evacuated tube collectors, or use collectors that incorporate one or more storage tanks.

Flat-Plate Collector

Flat plate collectors are designed to heat water to medium temperatures (approximately 140º F. As shown in Figure 1, flat-plate collectors typically include the following components:

- Enclosure: A box or frame that holds all the components together. The material is chosen for its environmental durability as well as its structural characteristics.

- Glazing: A transparent cover over the enclosure that allows the sun's rays to pass through to the absorber. Most glazing is glass but some designs use clear plastic. In general, the sun's heat energy passes quite easily through the glazing as short waves. Heat energy that re-radiates from the collector absorber is in long waves. Glass glazing prevents long waves from passing back through the glazing.

Glazing also blocks air motion across the absorber, thereby reducing heat loss through convection. The glazing also servers as a transparent insulation that can be single or multiple layers. The more the layers the greater the insulation value, but multiple layers also decrease the amount of light that is transmitted through the layers of glazing.

- Glazing frame: Attaches the glazing to the enclosure. Glazing gaskets prevent leakage around the glazing frame and allow for contraction and expansion.

- Insulation: Material between the absorber and the surfaces it touches that blocks heat loss by conduction thereby reducing the heat loss from the collector enclosure. The insulation must be able to withstand extremely high temperatures, so insulations like Styrofoam are not suitable.

- Absorber: A flat, usually metal surface inside the enclosure that, because of its physical properties, can absorb and transfer high levels of solar energy. The absorber material may be painted black with a semi-selective coating or it may be electroplated or chemically coated with a spectrally selective material (selective surface) that increases its solar absorption capacity by preventing heat from re-radiating from the absorber.

- Flow tubes: Highly conductive metal tubes across the absorber through which fluid flows, transferring heat from the absorber to the fluid. The heat transfer fluid tubes remove heat from the absorber. The collector may also incorporate headers, which are the fluid inlet and outlet tubes.

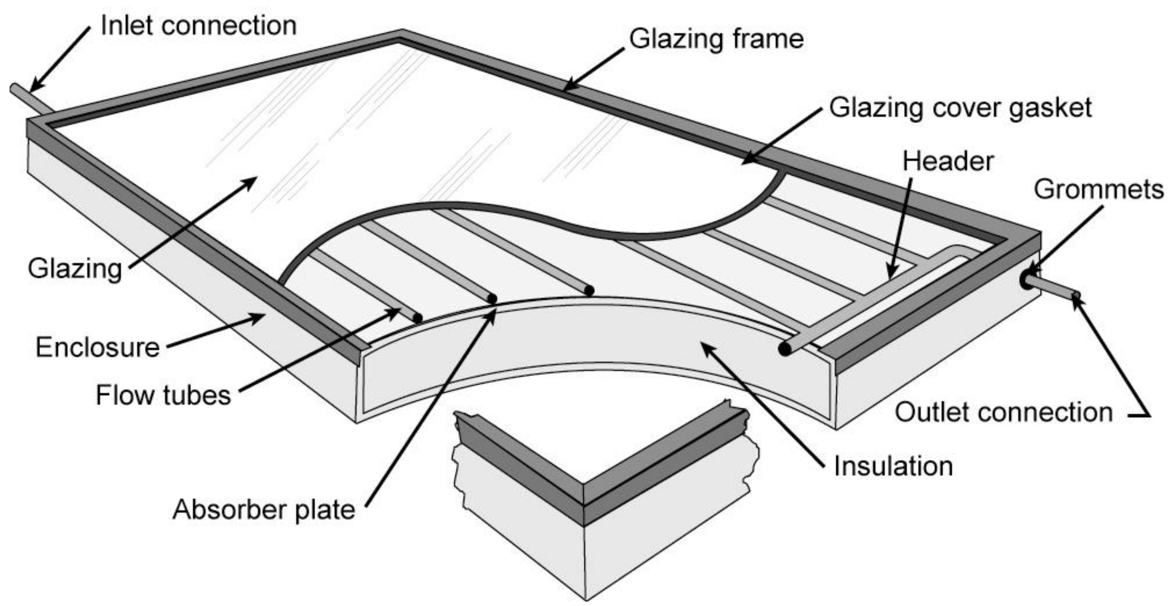


Figure 1 Flat plate collector

Evacuated-tube collectors

Evacuated-tube collectors generally have a smaller solar collecting surface because this surface must be encased by an evacuated glass tube. They are designed to deliver higher temperatures (approximately 300^{o}F). The tubes themselves comprise the following elements:

- Highly tempered glass vacuum tubes, which function as both glazing and insulation.
- An absorber surface inside the vacuum tube. The absorber is surrounded by a vacuum that greatly reduces heat losses.

In "flooded" evacuated-tube collectors (Figure 2) the absorber itself forms a tube through which the heat collection fluid is pumped. Flooded evacuated-tubes are typically used in passive thermosyphon systems.

In a "heat pipe" evacuated-tube collector (Figure 3), a flat absorber plate running the length of the tube covers a heat pipe filled with a fluid that evaporates at relatively low temperatures. As the fluid is heated, it evaporates and rises to the top of the tube. There it transfers the heat to water in a manifold. The condensed heat-collection fluid then returns by gravity to the bottom of the heat pipe. These systems can be active or passive.

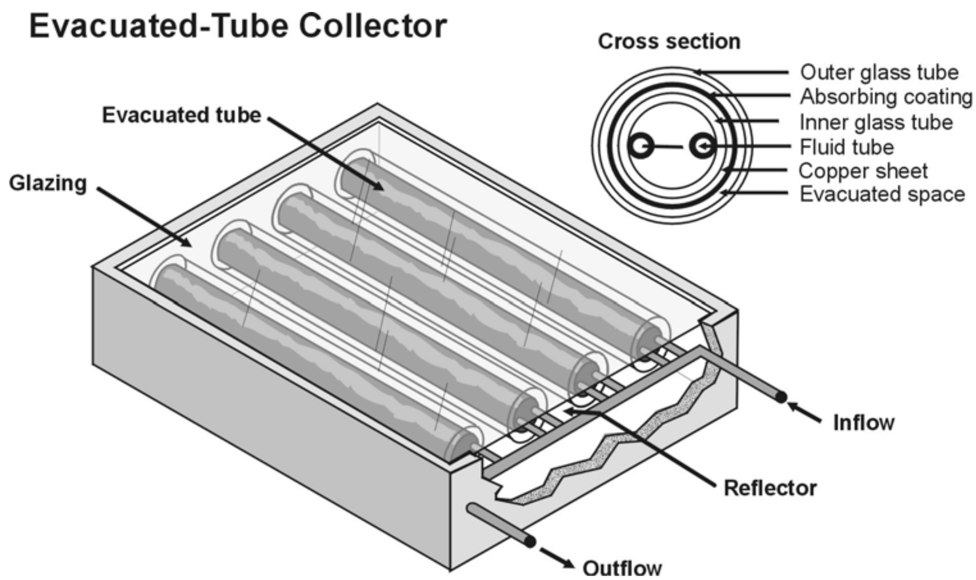


Figure 2 Flooded evacuated-tube collector

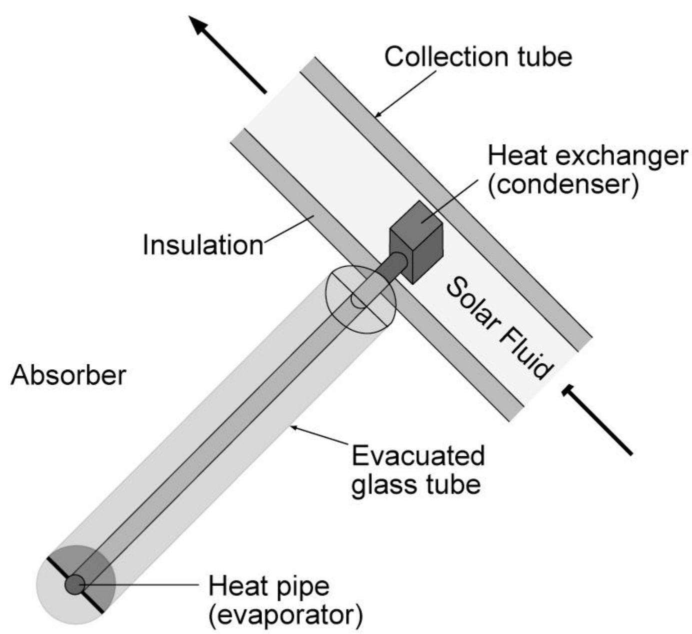


Figure 3 Heat pipe evacuated-tube collector

Integral Collectors

In integral collector storage (ICS) and batch solar water-heating systems, the collector functions as both solar absorber and water storage.

ICS collectors (Figure 4) generally incorporate 4" or larger diameter horizontal metal tanks connected in series by piping from a water inlet at the bottom of the tank to an outlet at the top. The tanks, which are coated with either a selective or moderately selective absorber finish, are enclosed in a highly insulated box covered with multiple glazing layers. The multiple glazing layers and selective coatings are designed to reduce the heat loss of water stored in the absorber.

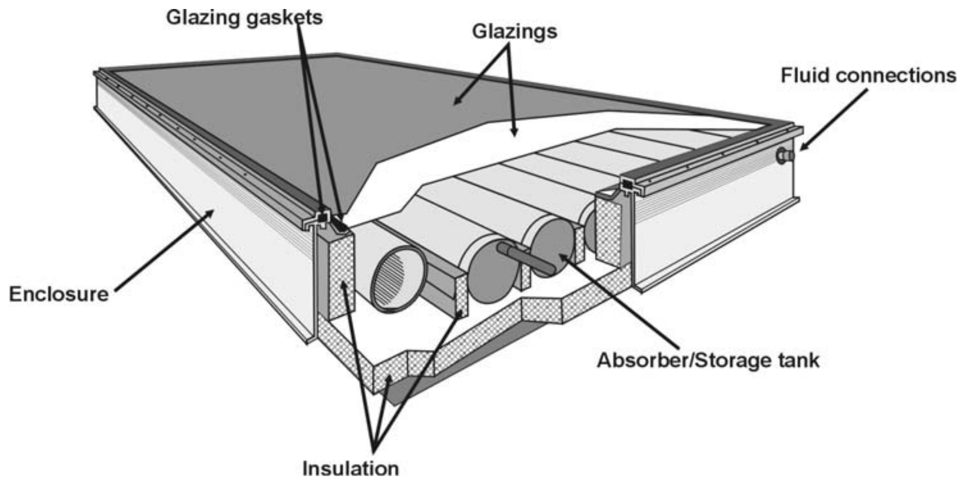


Figure 4 ICS collector

The simplest of all water-heating collectors, a batch collector (Figure 5) usually is made of just one black-painted metal tank inside an insulated enclosure covered with some type of glazing.

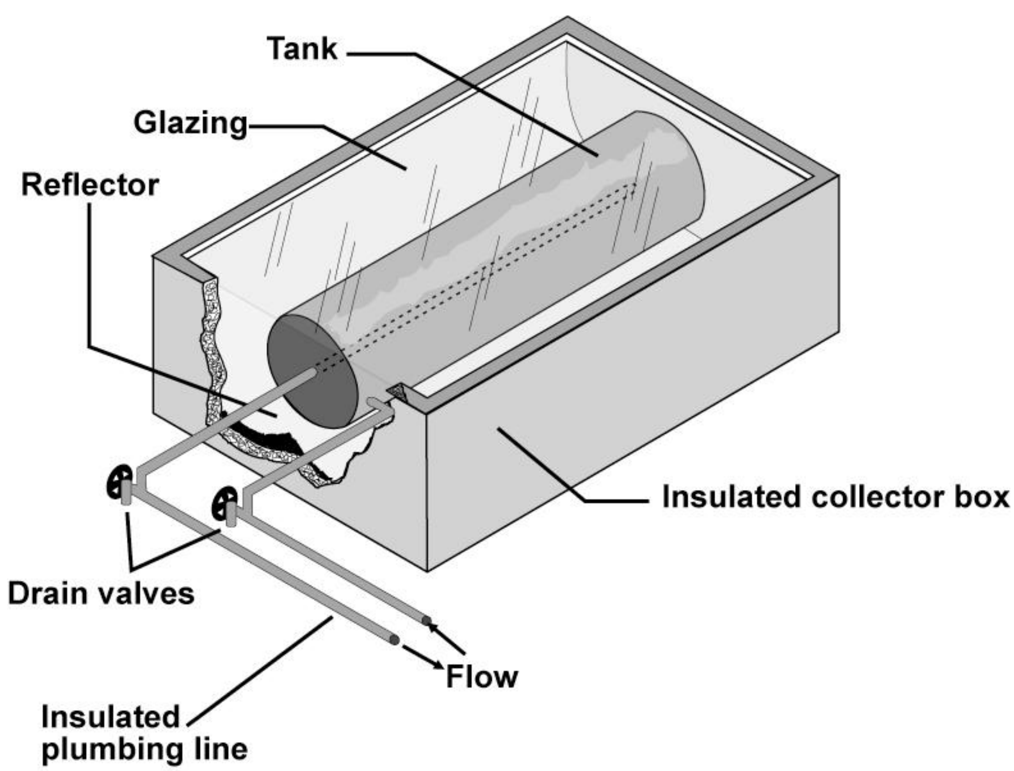


Figure 5 Batch collector

STORAGE TANKS

The storage tank holds the water that has been heated by the collector. The water can be stored in any vessel suitable for high temperatures. The tanks can be pressure rated depending on the application and whether or not a back-up heating system is used.

In subtropical and tropical climates, solar water heating systems usually have a single solar storage tank. This tank usually incorporates an electric heating element. Gas water heaters are not usually used for solar storage. The reason for this is that the gas burner is at the bottom of the tank. As cold water enters the tank and activates the gas burner, the whole tank is heated and the gas heat reduces the contribution from the solar system. When gas water heaters are used for back-up, a thermosyphon or ICS system that preheats water entering the gas back-up heater may be used. Or, a two-tank system may be used where the solar tank preheats the water for the gas back-up tank.

In colder regions and industrial applications, two tanks may be required to store sufficient solar-heated water over very cold or cloudy periods. In these cases a solar storage tank, to which the solar loop is plumbed, is connected in a series to an auxiliary water heater or boiler that has "back-up" electric or gas heating. This auxiliary tank or boiler provides hot water in the event there is insufficient solar-heated water. Solar thermal systems that supply heated water for applications other than potable domestic water, such as space heating, may employ more than one storage tank.

The most popular tanks are made of steel with an inner glass, stone or epoxy lining to protect the steel from galvanic corrosion caused by the water's chemistry. (Dissolved oxygen in the water becomes corrosive to untreated steel). Steel tanks also have an internal aluminum or magnesium "sacrificial" anode rod to attract the oxygen away from the steel. Stone-lined tanks and stainless steel or copper tanks normally do not require anode rods.

Where hard or highly conductive water will be stored in the tank, the anode rod should be replaced periodically. Even in areas with good quality water supplies, the solar storage (and auxiliary) tank should be drained periodically to remove sediment build-up.

Solar storage tanks should be well insulated, especially if they are installed in an air conditioned space. If they are installed outside a building, they should also be well protected from environmental conditions and corrosion, including ultraviolet degradation, by an ultraviolet (UV) resistant plastic, stainless steel or aluminum jacket. Painted steel or powder coated steel jacket materials on storage tanks require continuous maintenance in coastal or high moisture areas. If the system design requires that tanks be buried below ground, they should have additional insulation and accessible ports for valves and wiring connections. Heat loss from buried storage tanks is accelerated by high water tables or wet ground. Ground conditions should be considered in heat loss calculations.

Single Tank Systems

The design of conventional water heater tanks encourages mixing water in the tank, producing a tank full of water at the highest selected temperature. For this reason, natural gas and propane system burners are located at the bottom of the tank and conventional electric units have heating elements located in both the top and bottom third of the tank.

Electric

Solar systems with single tanks (Figure 6) are designed to encourage temperature stratification so that when water is drawn for service, it is supplied from the hottest stratum in the tank (top of tank). While a solar system tank in the U.S. normally contains a heating element, the element is deliberately located at the upper third of the tank. The electric element functions as back-up when solar energy is not available or when hot water demand exceeds the solar-heated supply. To further encourage stratification of cold and hot water in a storage tank, the cold supply water inlet is located at the bottom of the tank, as is the opening of the collector feed tube. In addition, the collector return tube opens below the heating element, returning the solar heated water to the hottest stratum.

Gas

Gas back-up systems may use passive (thermosyphon or ICS) solar preheating plumbed in series for proper operation. Or two separate tanks may be used for active solar systems with gas back-up heating systems. The solar storage tank is piped in series to the auxiliary tank sending the hottest solar preheated water to the gas back-up tank. (See Figures 8a and 8b.)

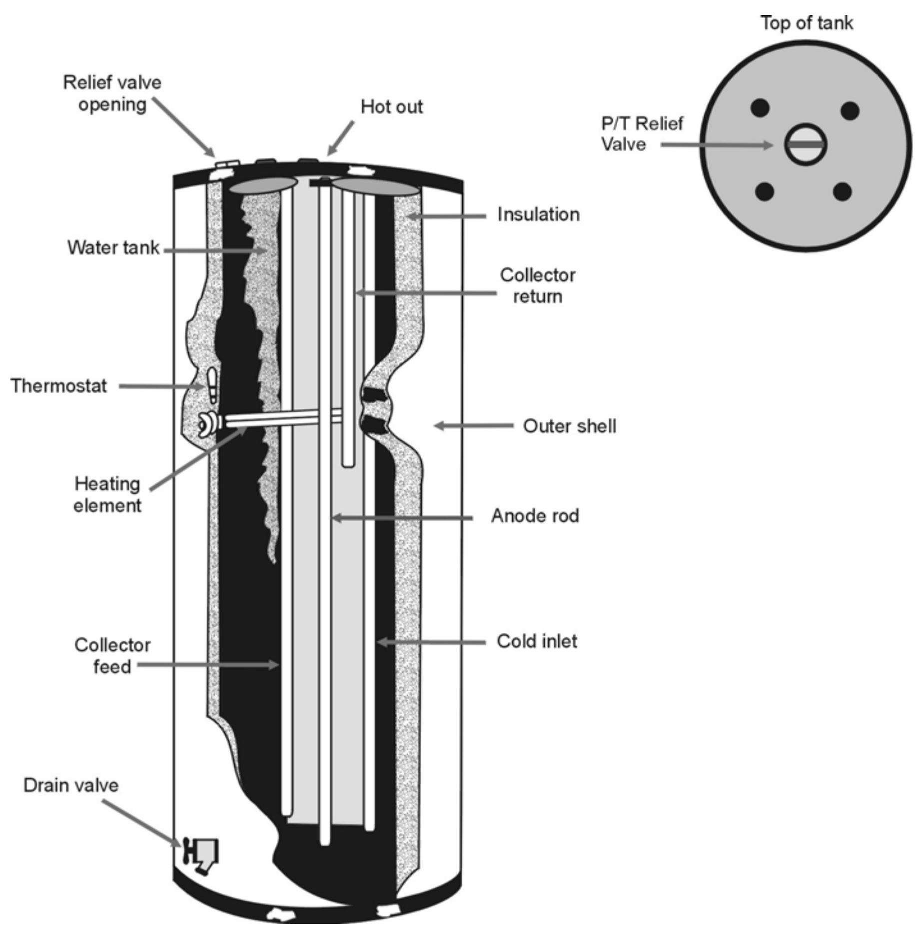
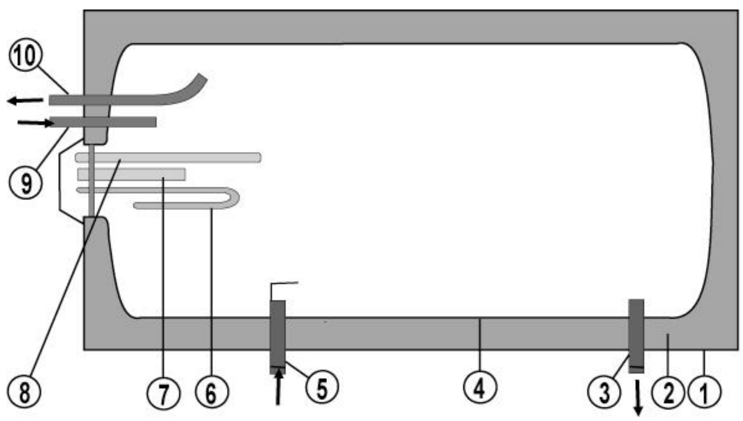


Figure 6 Vertical solar storage tank

Depending on the system design, solar tanks may be vertical, as shown in Figure 6, or horizontal as shown in Figure 7. Stratification is generally better in a vertical tank than in a horizontal tank. Yet, aesthetics and mounting considerations favor the horizontal tank design if the tank is mounted on the roof as in a thermosiphon roof-mounted system.

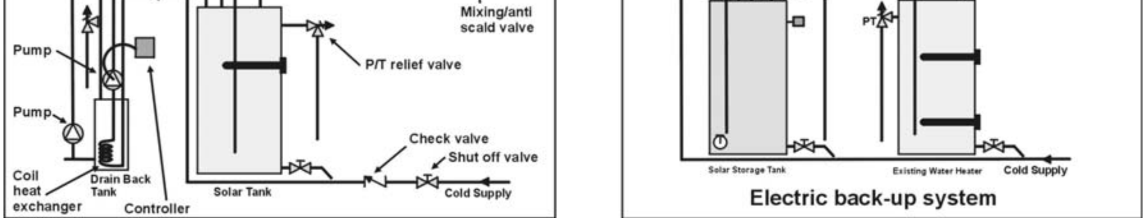


1. Tank jacket
2. Insulation
3. Cold to collector
4. Tank
5. Cold supply
6. Electric heater
7. P/T valve
8. Anode rod
9. Hot from collector
10. Hot supply

Multiple-Tank Systems

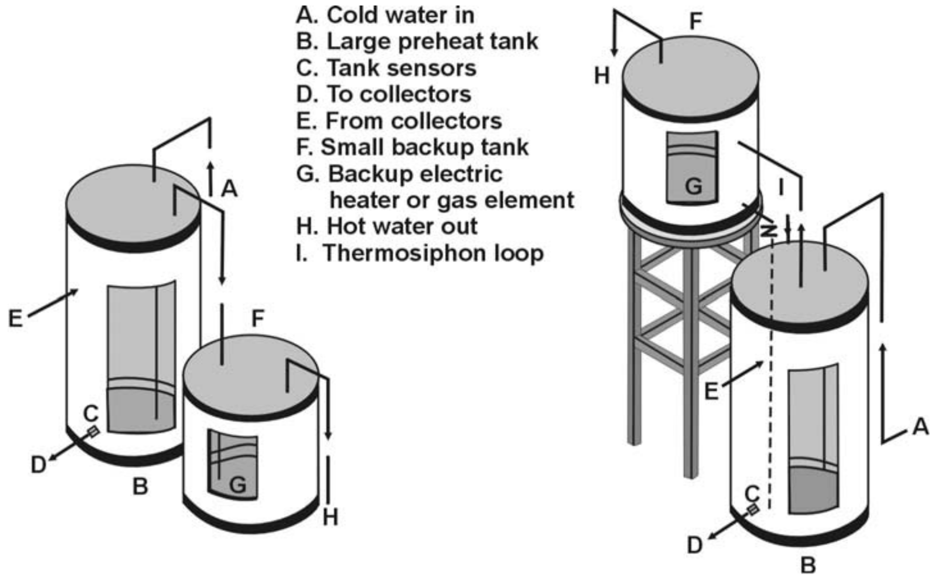
In two-tank systems (Figures 8a and 8b), one tank provides storage for solar-heated water. It is plumbed directly to the solar collector and does not contain any back-up heating source. This solar storage tank is plumbed to a second tank, which contains an auxiliary power source that can be used when no solar energy is available. This type of configuration is most commonly used in residential and light commercial applications.

Larger commercial and industrial solar system storage tank strategies can incorporate a single large solar storage tank or multiple smaller solar storage tanks. In these systems, all the tanks are typically plumbed in parallel, thereby acting as a single storage mechanism. The fluid flow is balanced so an equal amount of water enters each of the tanks as hot water is drawn for service. These storage tanks supply hot water directly to the back-up (auxiliary) heater or conventional commercial boiler. In certain situations, multiple tank storage systems use parallel piping between most of the tanks and series piping to a single tank with back-up capabilities.



Gas back-up **Electric back-up**

Figure 8a Two-tank solar water heater storage



Gas back-up **Electric back-up**

Figure 8b Two-tank solar water heater storage

PUMPS

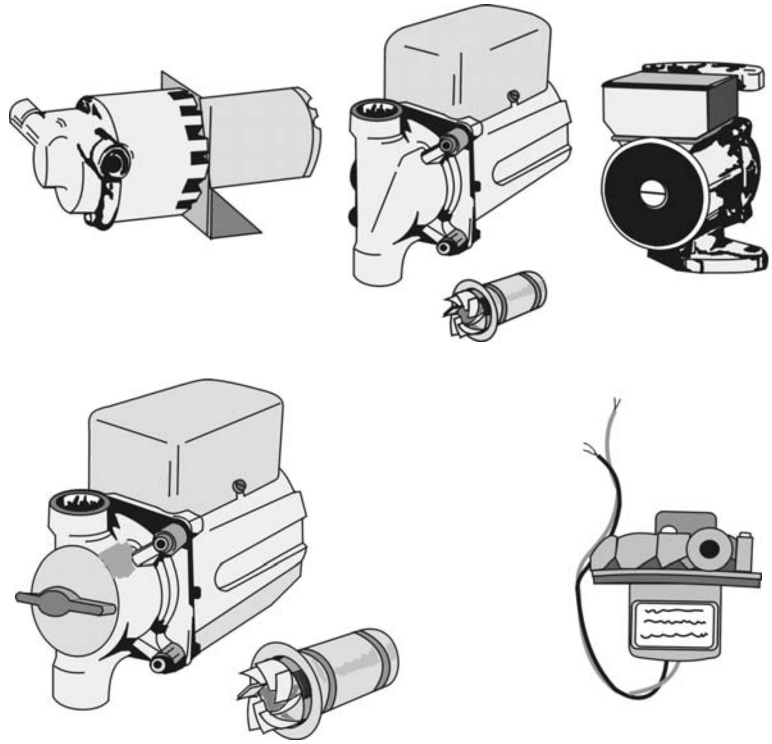
An active system uses a pump or circulator (Figure 8a) to move the heat transfer fluid from the storage tank to the collector. In pressurized systems, the system is full of fluid and a circulator is used to move hot water or heat transfer fluid from the collector to the tank. Pumps are sized to overcome static and head pressure requirements in order to meet specific system design and performance flow rates. (It is advisable to refer the pump manufacturer's pump curve to determine the proper pump size.)

Drain-back and other unpressurized solar water heating systems require a high head pump to lift the water from the storage vessel to the collector and force the air out of the collector or collector array. This requires a centrifugal pump or other pump that will provide adequate pressure.

Most active solar systems use centrifugal pumps. Pump selection depends on the following factors:

- System type (direct or indirect)
- Heat collection fluid
- Operating temperatures
- Required fluid flow rates
- Head or vertical lift requirements
- Friction losses

The most common pump (circulator) used in solar systems is the “wet rotor” type in which the moving part of the pump, the rotor, is surrounded by liquid. The liquid acts as a lubricant during pump operation, negating the need for manual lubrication.



AC Pump DC Pump

Figure 10 Pumps used in solar water heating systems

Pumps used on active direct systems must have bronze or stainless steel housings and impellers to prevent corrosion from water chemistry. Simply put, using cast iron pumps in systems in which the potable water comes into contact with the pump will cause the cast iron to rust. Cast iron pumps can be used with certain heat transfer fluids used in indirect systems. Table 1 lists pump options for various applications.

Application	Pump type and size
Potable water, pressurized, direct active system	Bronze or stainless steel, low head
Potable water, pressurized, direct active drain-	Bronze or stainless steel, low to medium head
Potable fluids, unpressurized, drain-back	Bronze or stainless steel, low to high
Glycol fluids, pressurized	Cast iron, low head
Glycol fluids, unpressurized	Cast iron, medium to high head

Table 1 Pump Applications

PIPING

Piping provides the path for fluid transport in the system. The piping must be compatible with system temperatures, pressures and other components. Most systems use copper piping because of its durability, resistance to corrosion and ability to withstand very high temperatures. Type L, K or M is commonly used, depending on the application, local codes and traditions.

Copper, brass, and bronze are normally the only materials that should be used in active direct solar systems using potable water. In cases where galvanized piping already exists, it should either be replaced, or dielectric unions should be used to isolate the different metals.

Pipe hangers
When installing-long system piping runs, pipe hangers are commonly used for support. The piping, depending on the type, may be pliable due to high temperatures and therefore, must be supported.

Since the slope of the piping must be maintained for proper operation and drainage of many systems, pipe hangers are also required to properly orient the pipe runs.

Solder
Solder used in system piping is normally 95/5 tin/antimony or 95/4 tin/silver, depending on the material to be soldered. Leaded solder should not be used in potable water system piping.

Incompatible materials
Corrosion caused by the contact between dissimilar metals is called galvanic corrosion. Such corrosion usually results in an accelerated rate of attack on only one of several dissimilar metals. In the language of the corrosion expert, the protected material – the one that remains virtually unattacked – is called the cathode. The material that is attacked is called the anode.

Metals can be listed in a galvanic series that is useful in predicting which metals are acceptable for use in contact with one another and which materials are likely to be corroded. The following is a simplified galvanic table that can be used as a reference source.

CORRODED END - ANODIC
- Magnesium
- Zinc, Galvanized Steel
- Aluminum
- Mild Steel, Cast Iron
- Lead, Tin
- *Brass, Copper, Bronze
- *Nickel-Silver, Copper-Nickel Alloys
- *Monel
- Stainless Steel

PROTECTED END - CATHODIC
The coupling of two metals from different groups will result in accelerated corrosion of the metal higher in the series. The farther apart the metals are in the series, the greater the galvanic corrosion tendency. Material groups marked with an asterisk (*) have no strong tendency to produce galvanic action and from a practical standpoint are safe to use in contact with one another.

Pipe insulation

The most common type of pipe insulation used in solar systems is the closed cell flexible elastomeric foam type (rubber), commonly marketed as Rubatex and Armaflex (Figure 11). Plastic insulation such as polystyrene or polyethylene should never be used due to their low operating temperatures (Figure 12). All exterior piping insulation must be protected from environmental and ultraviolet ray degradation by using special ultraviolet ray resistant coatings, paints or shielded wraps.

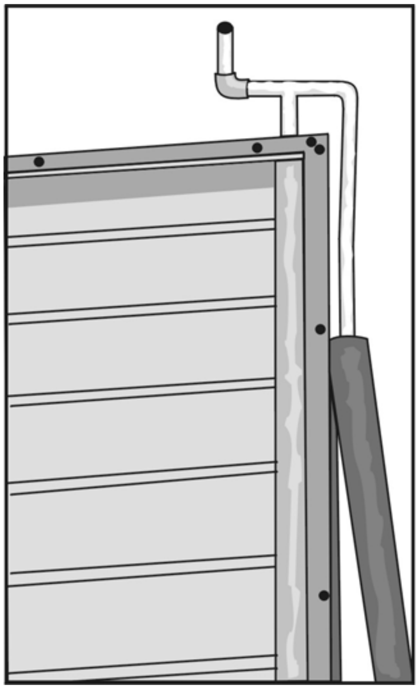


Figure 11 Rubber insulation being installed

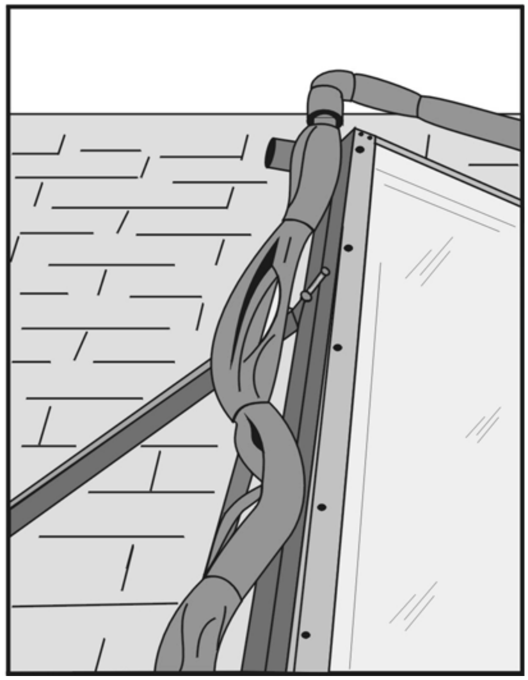


Figure 12 Plastic insulation should not be used in high temperature

CONTROLLERS

In active solar water-heating systems, the controller acts as the "brains" of the system. When the controller determines that sufficient solar energy is available at the collector, it activates the pump to circulate water to the collector and back to the storage tank. The most frequently used types of controllers include differential, photovoltaic and timer.

Differential controller

Differential controllers (Figure 13) work in conjunction with two sensors (Figure 14) – one at or near the hottest point of the collector and another near the bottom of the storage tank. When the temperatures measured by the two sensors reach a preset difference of 5 to 20^{o}F, the controller starts the pump. On many controllers, the installer has the added option of selecting the differential setting. For instance, the installer can set the differential at 9, 12, 15 or 20^{o}F depending on the characteristics of the system. For systems with long pipe runs, it is suggested that higher temperature differentials be used, systems with short pipe runs can use smaller differentials.

When the temperature difference between the sensors falls to about 3 to 5^{o} F, the controller stops the pump. The off temperature differential is usually set at the factory and cannot be adjusted by the installer.

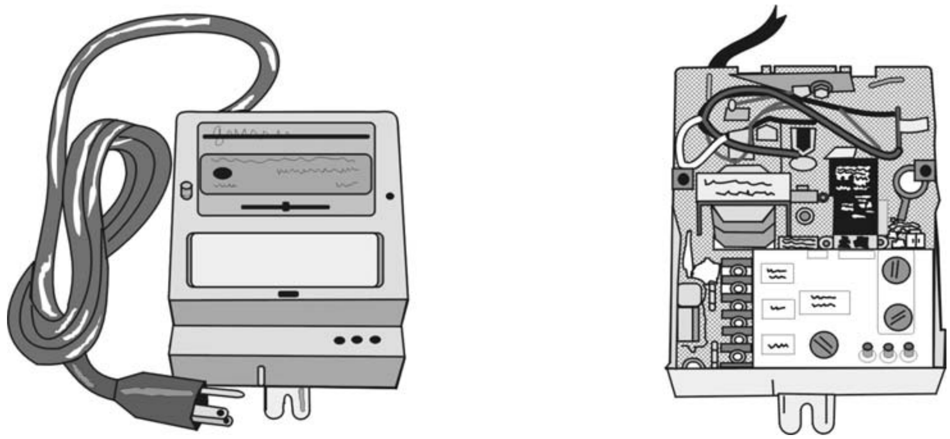


Figure 13 Differential controller

Differential controllers commonly have an on, off and auto position switch. In the on position, the sensor signals (and their interaction with the controller) are ignored and the controller operates the pump on a continuous basis. In the off position, the sensor signals are also ignored and the pump remains turned off. In the auto position, the sensors and controller interact to control the operation of the pump.

Many differential controllers also incorporate a freeze control to activate the pump during freezing conditions. A manual adjustment must be made by the installer to activate the freeze control option. Always check the manufacturers instructions when installing solar controllers. Installer selected features may be required to activate the controller functions designed into the unit.

Some differential controller models also incorporate high temperature limit settings that turn the pump off when a preset tank temperature has been reached. It is important to remember this is the temperature of the sensor at the bottom of the tank - the top of the tank may be even hotter.

Sensors

The sensors used with differential controllers are thermal resistors that change their electrical resistance with temperatures. They are commonly called thermistors. Understanding the relationship in a thermistor between electrical resistance and temperature is quite simple. It works in reverse. When the sensor's temperature increases, its resistance goes down. When its temperature decreases, its resistance increases.

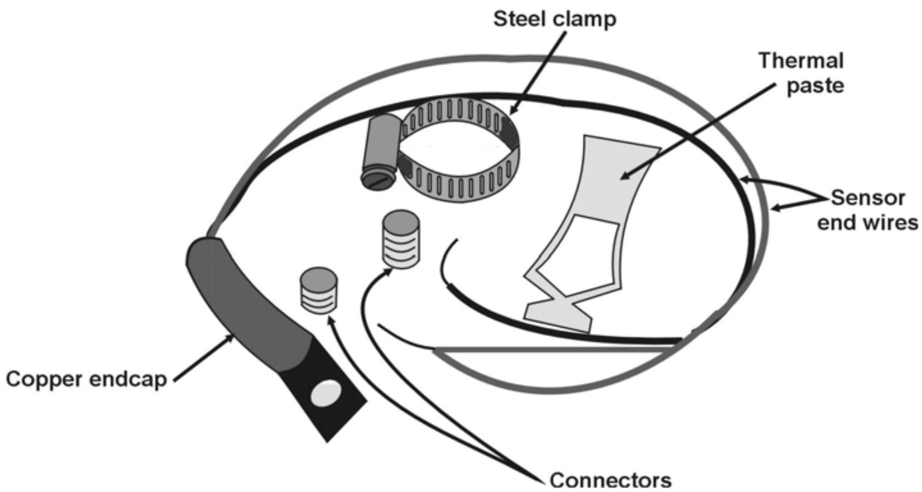


Figure 14 Sensors

Thermistors come in both 10K and 3K-ohm types (K=1,000). At 77º F, a 10K thermistor should have a 10,000 ohms resistance, while a 3K should have a 3,000 ohms resistance. Currently, most controller manufacturer use 10K thermistors. A few manufacturers have used more accurate resistance temperature detectors (RTDs), but, since they are more expensive than standard thermistors, they are not frequently used.

Special care must be made to avoid installing sensor wiring near sharp edges or close to 110V or 220V wiring as this could adversely affect the performance of the sensors and controller due to electrical interference. In addition, exterior runs of sensor wiring should also be protected from environmental degradation.

Photovoltaic (PV) Controller

In this control scheme, a photovoltaic module (Figure 15) is installed adjacent to the solar thermal collector and generates direct current (DC) electricity to power a DC pump motor. Because the PV module generates electricity only when the sun shines, the pump circulates water to the collector only when sufficient solar energy is available. To maximize solar collection, some systems also incorporate a pump activator (linear booster) that electronically assists pump start-up.

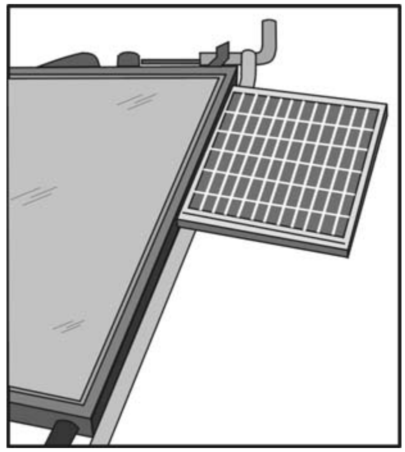


Figure 15 Photovoltaic module

The use of a photovoltaic controller offers increased heat collection efficiency, as the pump speed is proportional to the amount of power generated by the PV module. When more heat energy is available in the thermal collector due to increased solar radiation, the module also receives more solar radiation, which increases the pump speed sending more heat collecting fluid through the collector.

Timer Controller

A timer controller (Figure 16) turns the pump on only during the brightest portion of the day (from approximately 9 a.m. to 4:30 p.m.). To keep the system from losing energy in cloudy weather, the collector feed and return lines for timer-controlled systems are usually positioned at the bottom of the solar tank. Since both the feed and return lines are connected through a special valve installed in the tank's common drain port, special care must be taken to ensure the valve's feed and return ports do not accumulate a large amount of sediment and scale build-up which could eventually affect system performance. Routine maintenance of the feed and return valve should be observed.

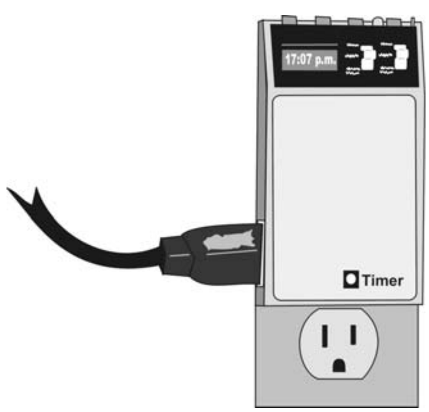


Figure 16 Timer

HEAT EXCHANGERS

Indirect systems have heat exchangers that transfer the energy collected in the heat-transfer fluid from the solar collector to the potable water. Heat exchangers can be either internal or external to the storage tank. Common heat exchanger designs are the tube-in-tube, shell-in-tube, coil-in-tank, wraparound-tube, wraparound-plate and side-arm designs. A technical discussion of the design and performance of these heat exchangers follows.

Tube in tube

This type of heat exchanger, as its name implies, consists of a tube within a tube (Figure 17). Heat transfer occurs when one fluid moves through the inner tube while a second fluid moves in a different direction through the space between the inner and outer tubes. These heat exchangers are most commonly used in smaller systems. For example, in an indirect system using a tube in tube heat exchanger, the collector heat-transfer solution would be in the inner tube, while the potable water would be in the space between the inner tub and the outer tube. The heat gained at the collector by the heat-transfer fluid would be transferred to the potable water passing over the inner tube.

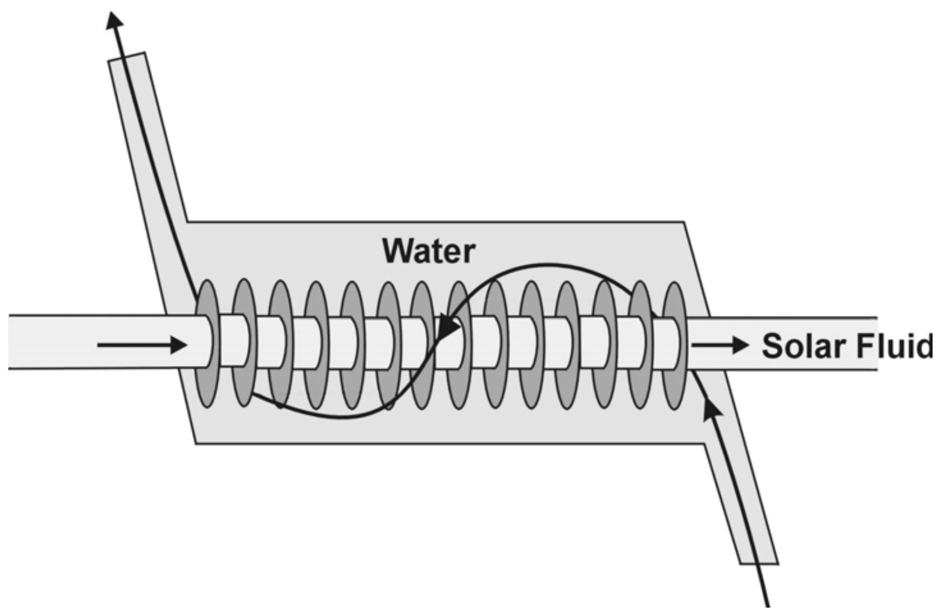


Figure 17 Tube-in-tube heat exchanger

Shell in tube

Similar to the tube-in-tube is the shell-in-tube heat exchanger (Figure 18) in which potable water flows through multiple tubes while the collector loop heat-transfer fluid passes over the tubes through the shell. This type of heat exchanger is used in numerous other technologies and available in single- or double-wall configurations.

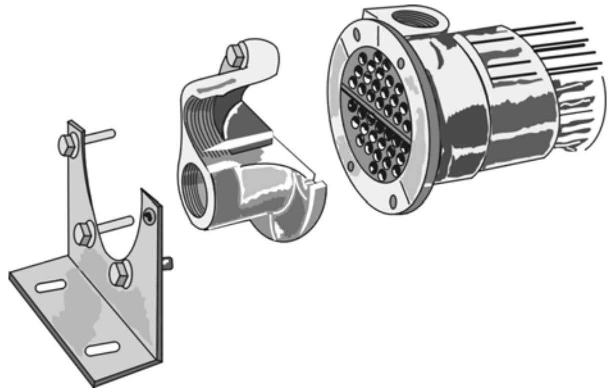


Figure 18 Shell-in-tube heat exchanger

The coil-in-tank heat exchanger (Figure 19) is immersed in the lower section of the storage tank. The wraparound-tube (Figure 20) heat exchanger uses tubes welded to the outside of the water vessel. It is located on the lower half of the storage tank. The wraparound-plate design (double jacket) is similar to the wraparound-tube but it uses a separate plate welded around the lower half of the storage tank.

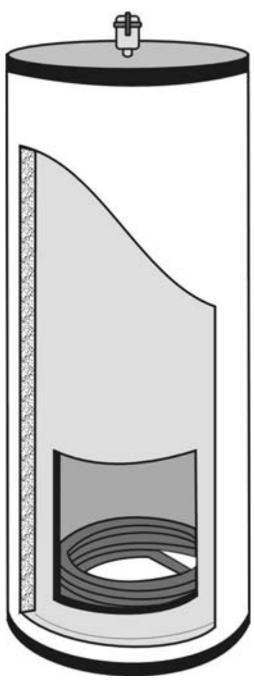


Figure 19 Coil-in-tank type heat exchanger

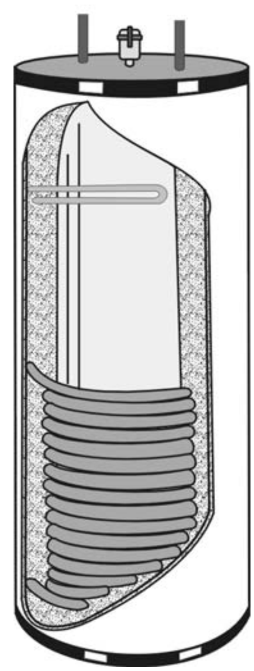


Figure 20 Wraparound type heat exchanger

A side-arm heat exchanger is a tube–in-shell design that can be installed on the side of the storage tank to allow thermosiphoning of the water from the storage tank through the heat exchanger. The heat transfer fluid in the solar loop side of the heat exchanger heats the water in the shell side of the heat exchanger and heat exchange initiates the thermosiphon action between the water storage (potable) and the heat exchanger.

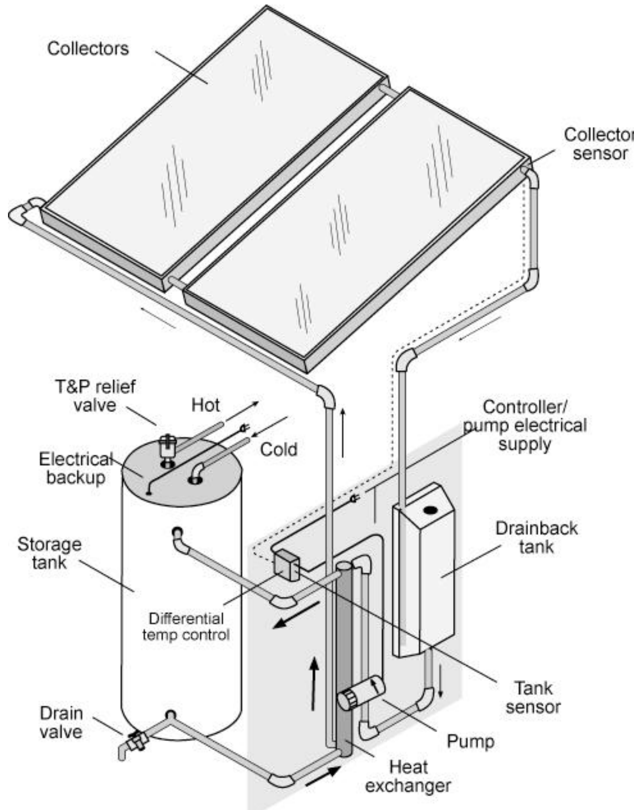


Figure 21 Side-arm heat exchanger

Single and double-wall heat exchangers

Heat exchangers may have one or two walls (Figure 22). Double-wall heat exchangers have two walls that separate the heat-transfer fluid from the potable water. Double-wall heat exchangers often incorporate small passageways between the two walls to provide leak detection. An area between the two walls allows leaking fluid to pass outside, thereby revealing any leaks. In the event a leak occurs, system owners or service personnel can visually see the fluid flowing out from these passageways.

Whether a single- or double-walled exchanger is used depends on the heat-transfer fluid used in the system. Nontoxic fluids such as propylene glycol can be used with a single-walled heat exchanger. But ethylene glycol, a toxic fluid, should be used only with a double-walled heat exchanger.

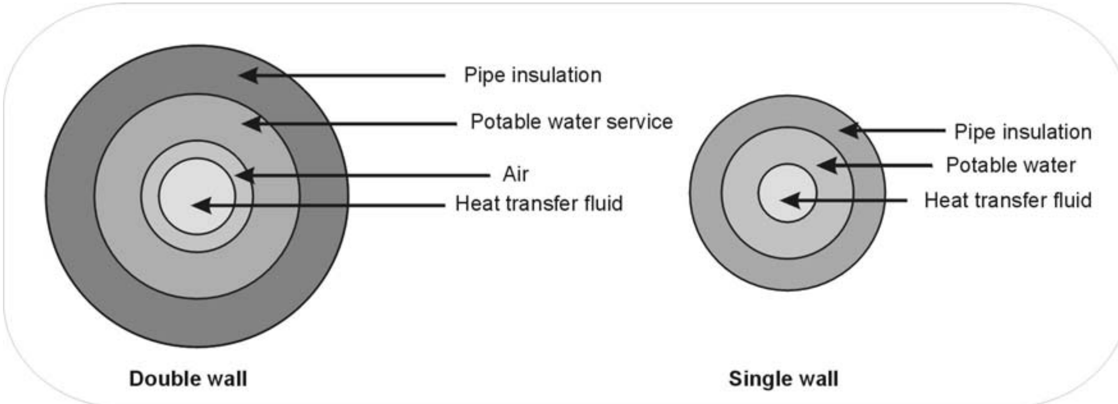


Figure 22 Single- and double-wall heat exchangers

Heat exchanger materials

Heat exchanger materials must be compatible with the system's fluid and piping. These materials can be steel, aluminum, bronze, stainless steel or cast iron, but copper is by far the most common. Copper prevents corrosion and also acts as a good thermal conductor. Alloys of copper and nickel may also be used for aggressive or hard water areas.

Heat exchanger efficiency

Systems with heat exchangers can experience a 10-20 percent loss in total efficiency in the transfer of heat from the collection loop to the stored water. However, economic savings and fail-safe freeze protection may offset that efficiency loss.

For example, heat exchange systems can use corrosion-inhibiting heat-transfer fluids that allow the use of less-expensive aluminum or steel in collectors, exchangers and piping. If aluminum is used anywhere in the system, no red metal (copper, brass or similar alloys) should be used unless the heat-transfer fluid is non-ionic or an ion trap is placed upstream of each aluminum component to reduce galvanic corrosion. Ion traps require periodic servicing.

Heat exchanger sizing

Heat exchangers are sized based on their heat-transfer capabilities, flow rates and the temperatures of incoming and outgoing fluids. For packaged and approved or certified systems, the manufacturers have sized the heat exchanger and matched its performance to the collector array and flow rates of the system. Under sizing the heat exchanger is a common mistake of home-built systems.

HEAT-TRANSFER FLUIDS

All solar systems use some types of heat-transfer fluid. Potable water is the heat-transfer fluid in active direct systems and is the most common. Indirect systems in cold climates use a non-potable solution that will freeze only at extremely low temperatures. The most common of these fluids are:

- Propylene glycol
- Ethylene glycol
- Hydrocarbon oils
- Synthetic oils such as silicone.

Some of these fluids are toxic (notably, ethylene glycol) and require double-wall heat exchangers.

Glycols are the most commonly used heat-transfer solutions for indirect systems. Special inhibitors are added to the glycol during the manufacturing process to prevent the fluid from becoming corrosive. Thus glycol fluids must be checked periodically (follow manufacturers instructions) to ensure they remain chemically stable. PH tests of the glycol can be conducted using either pH test strips or standard pH testing color charts.

When using glycol, materials, such as gaskets and seals used in the various system parts (pumps, valves, expansion tank, etc.), must be compatible. Glycol compatible materials include Teflon, Viton and EPDM. The use of certified systems will assure that all system components and materials are compatible.

In some cases, the glycol is mixed or diluted with distilled or demineralized water during the system charging process. As always, follow the manufacturer's recommendations. Some heat transfer fluids should not be diluted since dilution can change the level of freeze protection.

Synthetic and silicon oils have unique characteristics. Both have long lifetimes and require little maintenance. Their toxicity is also low. Nevertheless, the lower thermal conductivity and viscosity of these oils increase pump and heat exchanger requirements. As in the case of glycol, one must pay special attention to component material selection and their compatibility with the specific oils. The surface tension of the oils is very low so sometimes leaks can be a recurring problem. Special care must be taken to avoid mixing any water with the oils.

EXPANSION TANK

Most indirect systems that use a heat-transfer fluid other than water also incorporate an expansion tank (Figure 23). As the heat-transfer fluid temperature rises, it expands. The expansion tank provides room for this change in volume. Inside the expansion tank, a flexible bladder maintains a constant pressure on the fluid while allowing it to expand and contract as it heats and cools. The expansion tank prevents damage from over- pressurization and eliminates the potential creation of a vacuum inside the collector loop.

Expansion tanks are normally pre-charged by the manufacturer to a set psi. The system pressure-relief devices provide overpressure protection. The size of the expansion tank depends on the volume of fluid in the system and the rate of fluid expansion at higher temperatures. The higher the temperature the more the fluid expands. The size of the expansion tank must allow for the total potential expansion of the fluid or elevated pressures will be experienced causing the pressure relief valve to open and result in complete pressure loss in the solar loop. Some solar systems have an expansion tank on the cold water supply line when a check valve or back-flow prevention device is on the cold-water line.

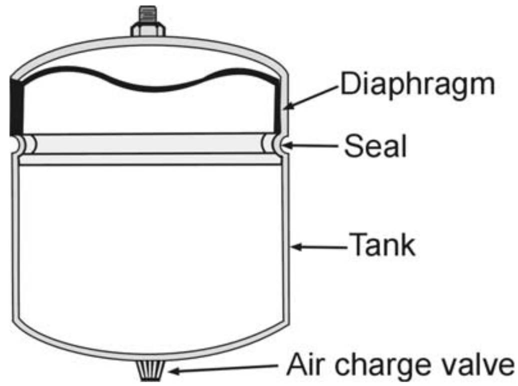


Figure 23 Expansion tank

VALVES, GAUGES AND METERS USED IN SOLAR SYSTEMS

As indicated in Figure 24, a variety of valves, gauges and meters can be incorporated as part of a solar system's design. These components serve to:

- Expel and vent air from the system (air vents)
- Safely limit excessive temperatures and pressures (pressure relief and temperature-pressure relief valves)
- Prevent vacuum locks during drainage (vacuum breakers)
- Isolate parts of the system (isolation valves)
- Prevent thermosiphon heat losses and maintain flow direction (check valves – mechanical and motorized)
- Provide freeze protection (freeze-prevention valve)
- Monitor the system (pressure gauges, temperature gauges and flow meters).

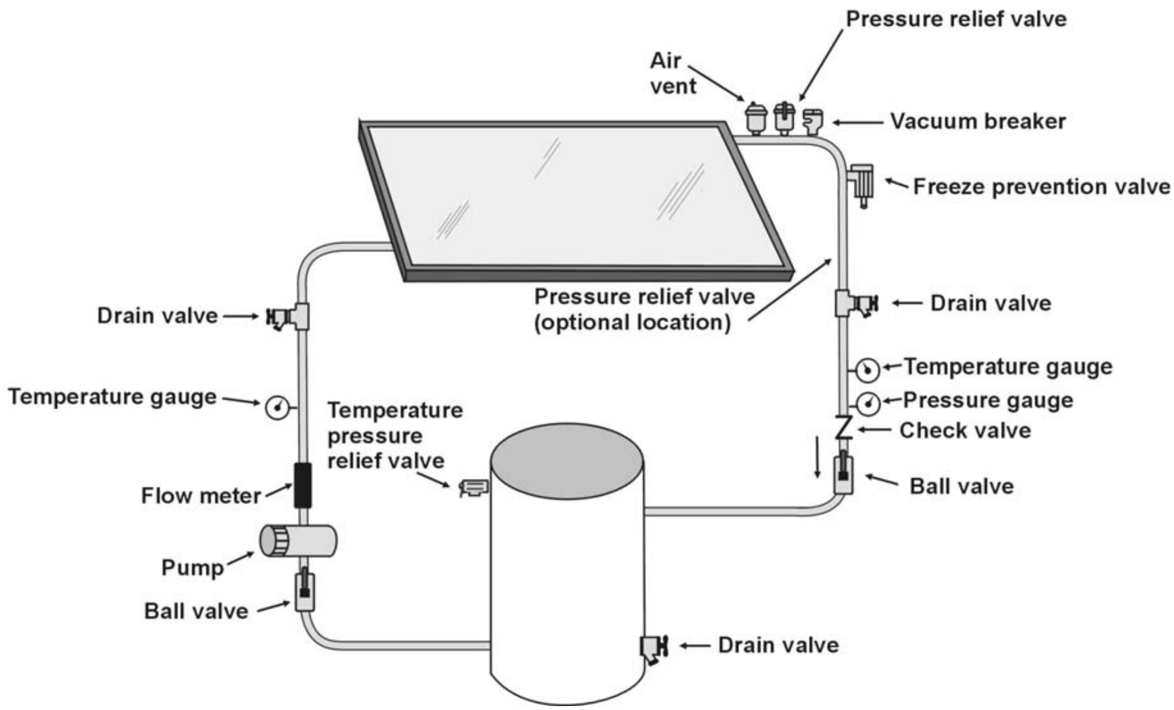


Figure 24 Solar water heating system valves and monitoring equipment

AIR VENT

This valve (Figure 25) allows air that has entered the system to escape, and in turn prevents air locks that would restrict flow of the heat-transfer fluid. An air vent must be positioned vertically and is usually installed at the uppermost part of the system. In active direct systems supplied by pressurized water, an air vent should be installed anywhere air could be trapped in pipes or collectors. Indirect systems that use glycol as the heat-transfer fluid use air vents to remove any dissolved air left in the system after it has been pressurized or charged with the heat-transfer fluid. (Once the air has been purged in these indirect systems, the air vent mechanism is manually closed.)

A popular option to using a separate air vent and vacuum breaker, when both are required, is a combination air vent and vacuum breaker valve.

Manual air vents should be used in indirect systems to avoid any loss of heat-transfer fluid, which would affect the system's pressurization. Using a manual air vent that the installer opens during charging to relieve trapped air in the loop will not only vent trapped air, but once the air has been expelled and the installer then closes the vent, it will in turn prevent any additional venting from the system. If an automatic, instead of manual air vent is used, the dissolved air bubbles that had accumulated during the charging process will eventually vent through the automatic air vent causing the system loop to lose pressure. Some automatic air vents have a dust cap that can be closed to prevent additional venting or loss of pressure.

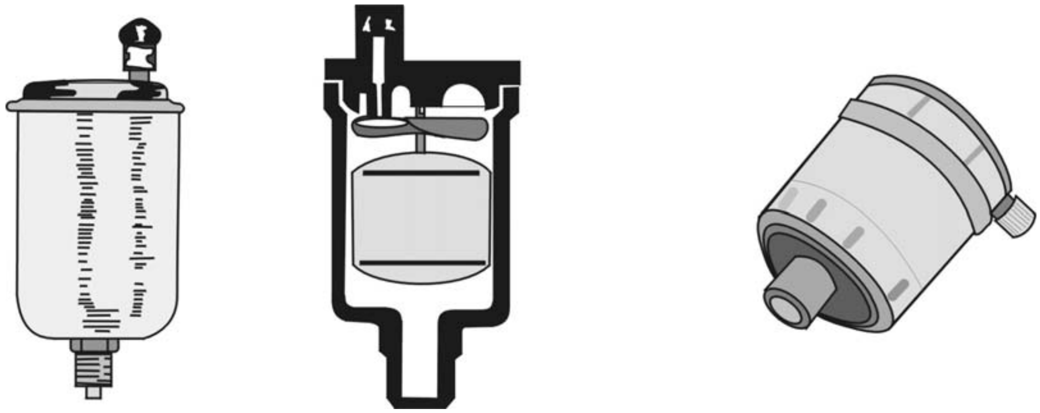


Figure 25 Air vent

TEMPERATURE-PRESSURE RELIEF VALVE

A temperature-pressure relief valve is also called a pressure-temperature relief valve or P&T valve or T&P valve. These names are used interchangeably in the industry. This valve (Figure 26) protects system components from excessive pressures and temperatures. A pressure-temperature relief valve is always plumbed to the solar storage (as well as auxiliary) tank. In thermosiphon and ICS systems, where the solar tanks are located on a roof, these tanks may also be equipped with a temperature-pressure relief valve since they are in some jurisdictions considered storage vessels. These valves are usually set by the manufacturer at 150 psi and 210° F. Since temperature pressure relief valves open at temperatures below typical collector loop operating conditions, they are not commonly installed in collector loops. (See pressure relief valves below.) Temperature-pressure relief valves located inside a building must drain to the outside. If uncertain, follow local code requirements.

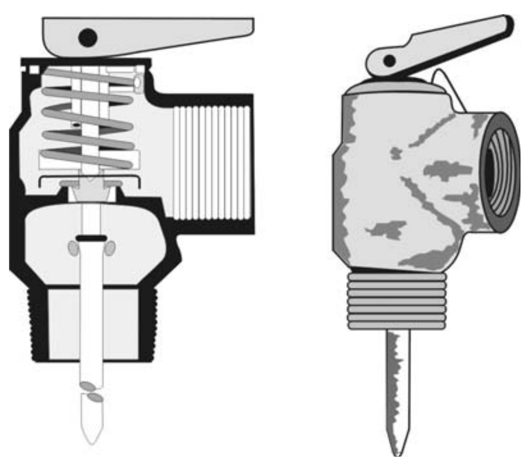


Figure 26 Pressure-temperature relief valve

PRESSURE RELIEF VALVE

A pressure relief valve (Figure 27) protects components from excessive pressures that may build up in system plumbing. In any system where the collector loop can be isolated from the storage tank, a pressure relief valve must be installed on the collector loop. The pressure rating of the valve (typically 125 psi) must be lower than the pressure rating of all other system components, which it is installed to protect.

The pressure relief valve is usually installed at the collector. Because it opens only with high pressure, it operates less frequently than does a temperature-pressure relief valve.
For this reason, it offers a higher degree of reliability and is the valve of choice for protecting the solar collector. Indirect systems typically use pressure-relief valves with
even lower psi settings. Pressure relief valves located inside a building should be piped to discharge to a safe location.

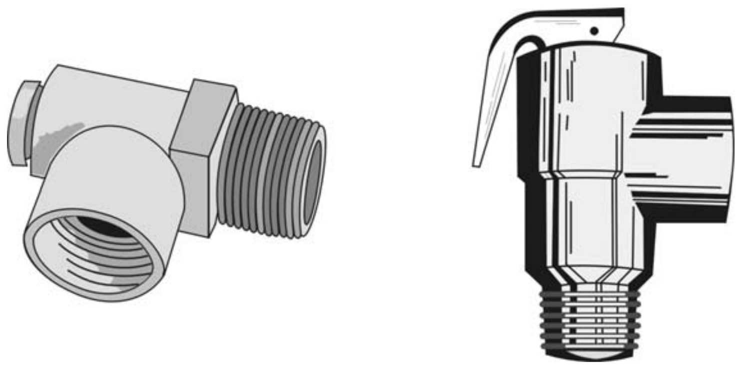


Figure 27 Pressure relief valve

PRESSURE GAUGE

A pressure gauge (Figure 28) is used in indirect systems to monitor pressure within the fluid loop. In both direct and indirect systems, such gauges can readily indicate if a leak has occurred in the system plumbing.

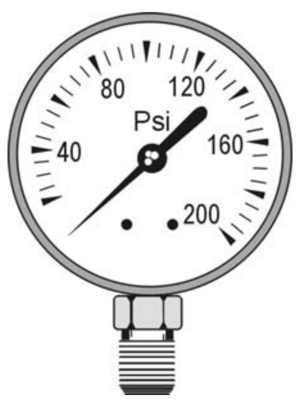


Figure 28 Pressure gauge

VACUUM BREAKER

A vacuum breaker (Figure 29) admits atmospheric pressure into system piping, which allows the system to drain. This valve is usually located at the collector outlet plumbing but also may be installed anywhere on the collector return line. The vacuum breaker ensures proper drainage of the collector loop plumbing when it is either manually or automatically drained. A valve that incorporates both air vent and vacuum breaker capabilities is also available.

Figure 29 Vacuum breaker

ISOLATION VALVES

These valves are used to manually isolate various subsystems. Their primary use is to isolate the collectors or other components before servicing. Two common types of isolation valves are ball valves (Figure 30) and gate valves (Figure 31).

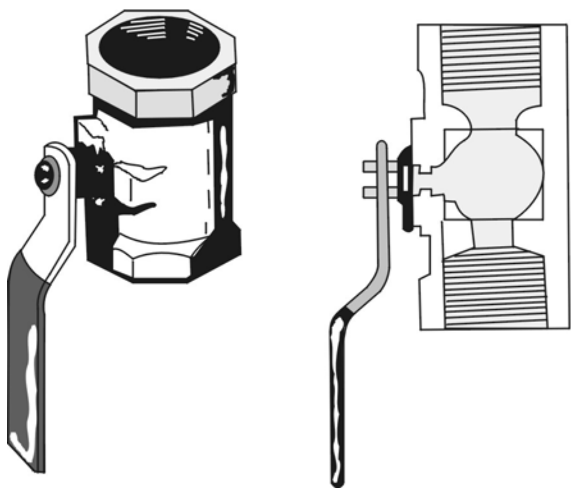


Figure 30 Ball valve

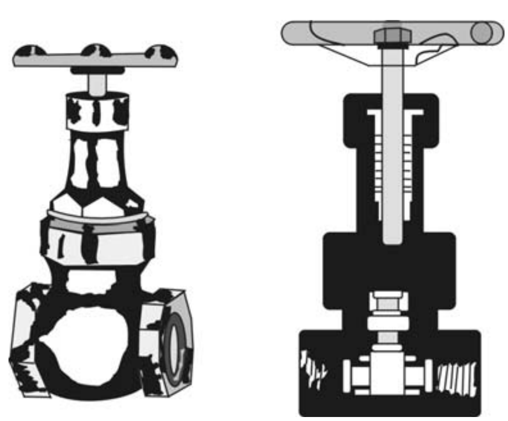


Figure 31 Gate valve

Ball valves provide a complete flow barrier and are less likely than gate valves to leak, corrode or stick. Ball valves may also be used as flow balancing valves in multiple collector arrays. Three-way ball valves may be used for both isolation and draining at the collector loop. An isolation valve is also required in the cold-water service line in the event water flow to the storage tank and system must be stopped.

DRAIN VALVES

These valves (Figure 32) are used to drain the collector loop, the storage tank and, in some systems, the heat exchanger or drain-back reservoir. In indirect systems, they are also used as fill valves. The most common drain valve is the standard boiler drain or hose bib.

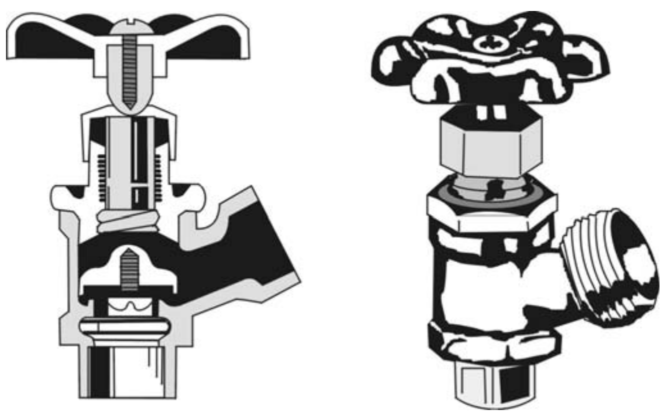


Figure 32 Drain valve

CHECK VALVES

Check valves allow fluid to flow in only one direction. In solar systems, these valves prevent thermosiphoning action in the system plumbing. Without a check valve, water that cools in the elevated (roof-mounted) collector at night will fall by gravity to the storage tank, displacing lighter, warmer water out of the storage tank and up to the collector. Once begun, this thermosiphoning action can continue all night, continuously cooling all the water in the tank. In many cases, it may lead to the activation of the back-up-heating element, thereby causing the system to lose even more energy.

The various types of check valves include motorized, vertical and horizontal swing. A motorized check valve (Figure 33) is wired to the pump. When the pump is on, the valve opens; when the pump is off, the valve closes and forms a positive seal.

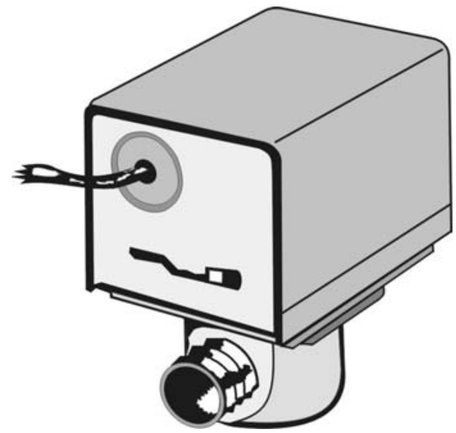


Figure 33 Motorized check valve

Vertical check valves (Figure 34) must open easily with activation of the low-flow, low- head PV-powered pumps used in some solar systems. The seat of these valves should resist scale and high temperatures.

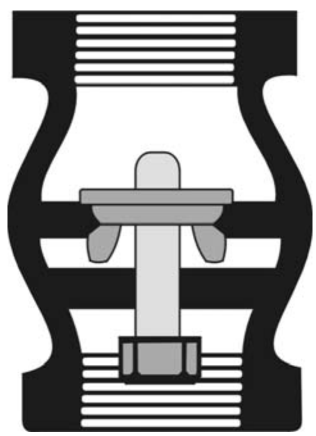


Figure 34 Vertical check valve

Horizontal swing check valves (Figure 35) must be installed horizontally because gravity and the flapper's weight close the valve.

Corrosion and scale may build up on the internal components of any (motorized, vertical or horizontal) check valve; therefore, a regular service schedule should be maintained. The chemical makeup of the local water supply is a major determinant in how scale build-up affects system components.

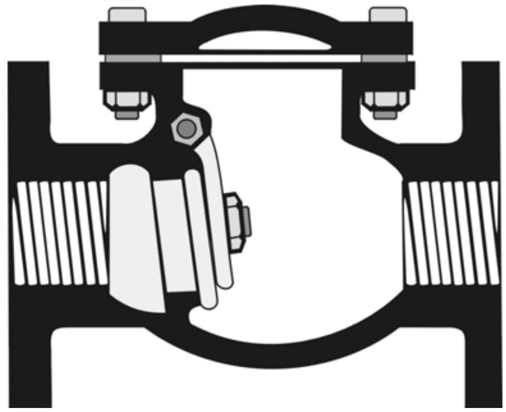


Figure 35 Horizontal swing check valve

MIXING OR TEMPERING VALVE

This valve will mix cold water with the hottest water from the storage tank, delivering water at a preset temperature. Such a valve increases the total amount of hot water available. The intended use of this valve is to conserve hot water – not as a safety device (Figure 36).

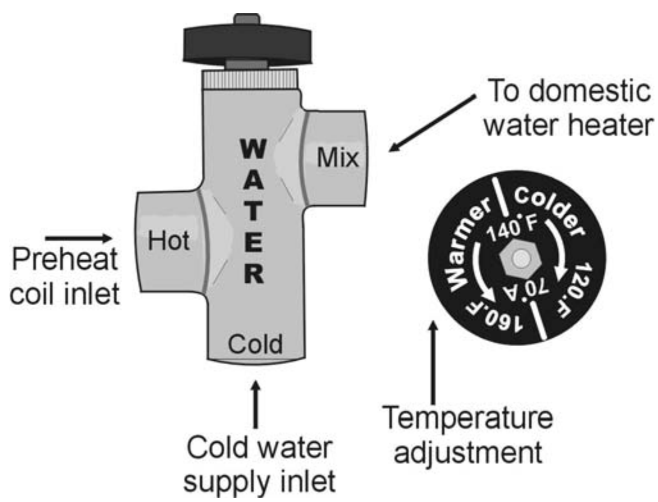


Figure 36 Tempering valve

ANTI-SCALD VALVE

An anti-scald valve (Figure 37) also mixes cooler water with hot water to deliver water at a preset temperature. However, unlike a mixing valve, an anti-scald valve also functions as a safety device, closing off the flow into the house if the hot or cold mixing supply fails.

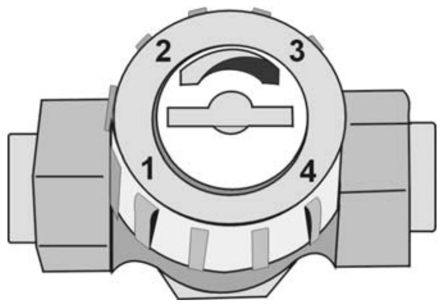


Figure 37 Anti-scald valve

FREEZE-PROTECTION VALVES

Freeze-protection valves (Figure 38), are set to open at near freezing temperatures, and are installed on the collector return line in a location close to where the line penetrates the roof. Warm water bleeds through the collector and out this valve to protect the collector and pipes from freezing. A spring-loaded thermostat or a bimetallic switch may control the valve. Figure 39 shows where a freeze-protection valve is typically located on a solar system.

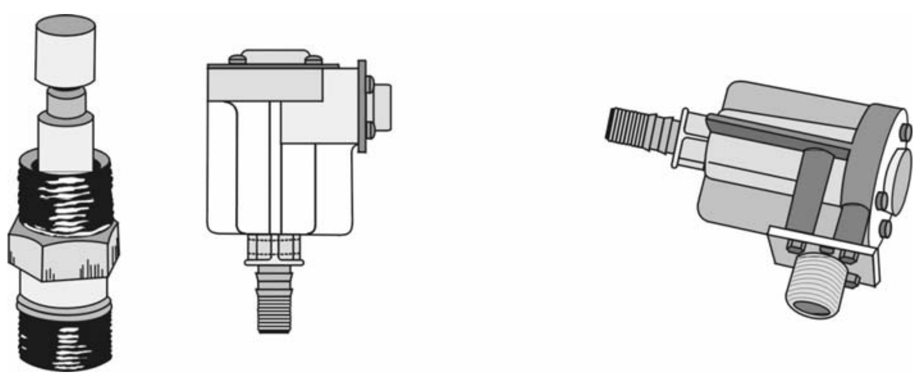


Figure 38 Freeze-protection valves

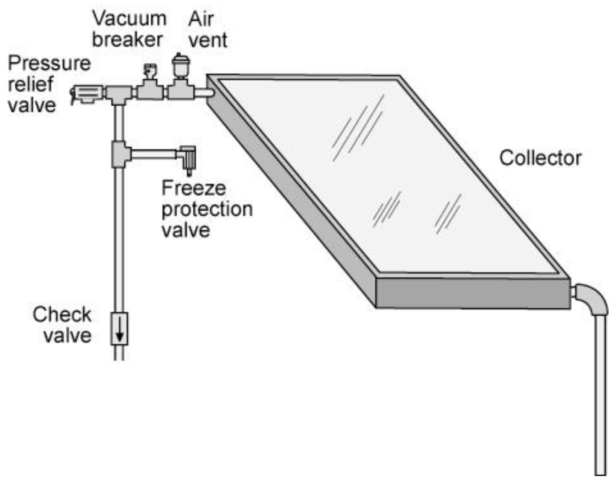


Figure 39 Location for freeze-protection valves

A check valve must be used in all systems with freeze-protection valves. This check valve prevents tank water from going straight from the tank to the freeze valve, thus bypassing flow through the collector.

If these valves are installed on well water or cistern systems, low-pressure valves should also be installed, which enable freeze protection to function when power outages create low pressures.

OTHER COMPONENTS

The following components are not as crucial to system operation as the previously listed valves, but they do provide the homeowner and service technician with important information.

TEMPERATURE GAUGES

These gauges (Figure 40) provide an indication of system fluid temperatures. A temperature gauge at the top of the storage tank indicates the temperature of the hottest water available for use. Temperature wells installed at several points in the system will allow the use of a single gauge in evaluating system operation.

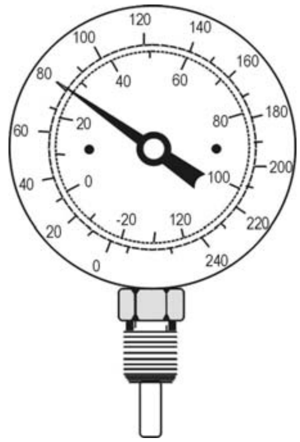


Figure 40 Temperature gauge

FLOW METERS

Flow meters (Figure 41) enable the owner and service person to determine if the pump is operating and, if so, at what flow rate. The flow meter is usually located in the collector feed line above the pump to protect the meter from extreme temperatures.

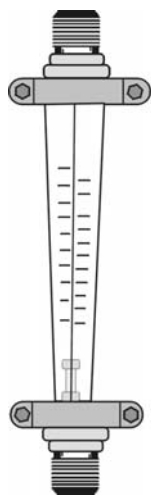


Figure 41 Flow meter

WATER SUPPLY

While not necessarily a component of a solar water heating system, the method for cold water supply to the system can influence both system selection and operation. Most solar water heating systems must operate under pressure. Pressure is supplied though the service water entering from the municipality, a pressure pump on the water system of the building (well, cistern), or pressurized by an elevated cold-water supply tank mounted above the solar system.

The Plans

I hope you enjoyed the overview of solar water heaters. The following pages will look into specific plans. As mentioned earlier, we will only be looking at passive solar water heater plans.

Specifically, we will take a look at several different batch water heater plans and also plans for a thermospin system.

Batch Water Heaters

Because batch heaters are so straightforward, you could probably build a serviceable unit with instructions as general as these: Build a south-facing, weatherproof, insulated wooden box; insert a black-painted water tank; add glazing; connect the tank to the supply line leading to your existing water heater; and install valves so you can fill and drain the system as needed. In fact, thousands of batch heaters have been built with instructions just that basic.

Thousands more have been assembled by handymen using only their common sense to guide them. On the other hand, with a little more attention to detail you can build a batch heater that will rank among the very best, and rival the performance of more complex systems costing two or three times as much. Surprisingly, only a handful of factors separate the winners from the also-rans.

The Water Tank

The water tank is the heart of any batch heater. Its size, shape, and positioning within the heater's enclosure determines how well it does its job. A useful rule of thumb for sizing batch heaters suggests that the tank should hold from one to two- and-one-quarter gallons of water for every square foot of glazing on the batch heater enclosure.

This insures that the tank is large enough to provide a reasonable amount of hot water, but not so large that it requires many hours of solar heating before reaching the desired temperature of 110 -- 120 Degrees F.

Preventing Heat Loss

If you used hot water only while the sun was shining, then you simply could insulate the walls of the batch heater's enclosure, and that would be that. But most families use large amounts of hot water twice a day: first around breakfast time, and again after supper. So a batch heater must be constructed to hold the day's solar heat through the evening and into the following morning.

At night (assuming the walls of the heater's enclosure are thoroughly insulated), the glazing will be the principal cause of heat loss. Because of this a batch heater should be double-glazed to minimize this loss. In cool climates, it's also a good idea to add some form of movable insulation (see Illustration A) that can be opened in the morning and closed at night. Movable insulation is highly effective, but it has a drawback because the owner must schedule twice-daily trips to the heater in order to operate it. If you forget to open the insulation, you'll get no heat for the day. Also, though the work involved in opening or closing insulation doors is hardly major, it's not really in keeping with the purely passive concept of batch heating. A more elegant solution is to use triple glazing on the enclosure to minimize convective heat loss, and a "selective surface" on the tank to minimize radiant heat losses. (A selective surface is a special product that absorbs large amounts of solar energy, but reradiates very little, keeping the heat inside where it belongs.) Together, triple glazing plus a selective surface work virtually as well as movable insulation, but without the bother.

Freezing is another heat-loss problem that affects batch heaters in the snow belt. Because water expands as it freezes, burst tanks and pipes are a very real danger.

There are two basic approaches to solving the problems of freezing. One is to mount the batch heater in a sheltered location such as a sunspace or a green- house. Because the sunspace or greenhouse provides both temperature moderation and weather-proofing, this type of batch heater can be simpler and less expensive than designs that must face the elements alone.

The second method of freeze proofing is for batch heaters in their own enclosures, whether freestanding or built as part of a home's exterior wall: You simply drain the tank in early winter, and let it stand idle during the coldest months. (A rule of thumb: batch heaters should be shut down during any month that racks up more than 1,000 degree- days in your area.) Winter clouds and cold temperatures mean that there isn't all that much solar energy to be had anyway, and winter shutdowns of, say, three months reduce the heater's annual Btu output by only 15 percent or so. **We feel winter shutdowns are the most practical solution to freeze proofing:**

Make sure your tank and all exterior plumbing can be drained completely.

Glazing

The best glazing material for batch heaters seems to be one of the specially designed solar plastics. (Kalwall, Filon, 7410, etc.) They're less expensive than glass, they're much easier to work with, they offer good resistance to breakage, and they have good optical and thermal properties.

Collection Efficiency

In the simplest batch heater designs, the entire inner surface of the enclosure is painted flat black to absorb solar heat. This technique works, but it's not ideal because using the box's inner surface as a collector raises the temperature of the box as a whole and increases heat loss. The resulting higher temperatures also may cause glues, plastics, or other heat-sensitive components to deteriorate. Better batch heaters use some sort of shiny surface to reflect the incoming sunlight onto the tank. For example, it's a simple matter to line the enclosure with aluminum foil or other shiny metal. And if the heater is equipped with movable insulating doors, the backs of the doors should also be covered with reflective materials so they can be angled during the day to reflect additional sunlight onto the tank.

Flat reflective surfaces like these help raise the collection efficiency of batch heaters, but have some built-in limitations. Hold a pencil up to a mirror (an excellent flat reflector) and you'll see why: The image of the pencil occupies only a small fraction of the mirror's surface, and you can see a reflected view of you and the room to either side of the pencil. A flat reflector in a batch heater works the same way. A large amount of the reflected solar energy simply misses the cylindrical water tank altogether and is bounced right back out through the glazing.

Proper Siting

In order to work properly, a batch heater needs a good location.First of all, it should be located as close as possible to your existing water heater to minimize heat losses from the connecting pipes. Second (and more obviously), it needs plenty of sunlight.

It's easy to find a good solar site. You start by determining where true or "solar" south is. (It's usually different from magnetic south as shown by a compass.) The fastest way to find true south is to drive a stake into the ground and observe its shadow at solar noon, when the shadow forms a precise north-south line. (South is toward the sun.) Solar noon is the time exactly halfway between sunrise and sunset, and may or may not coincide with 12 p.m. on the clock. You can find the times of sunrise and sunset in any almanac or daily newspaper.

Ideally, a solar heater should face due south. But if your home is off the mark, don't give up. Any location that lets you mount your batch heater so that it faces within about 20 degrees east or west of due south will provide upwards of 90 percent of the energy available at a due-south orientation, and that's still pretty decent performance.

Of course, shadows will ruin the performance of even a perfectly oriented solar system, so you need to be sure your south-facing location will remain essentially shade-free during the prime solar collection hours of 9 a.m. to 3 p.m. You can estimate sun and shadow at your site with an ingenious method developed by New York's Energy Task Force:

Stand where you want to place your collectors and face true south. Hold your left arm out straight, level with your eyes, and point at the horizon. Place your right hand, in a fist, on top of your left hand and "stack" your fists one on top of the other in succession, moving upward, the number of times listed in Table One. Do this three times, following the Table:

Table One Sighting Angles

Your Latitude	Due South	30° East and West Of Due South
28°N	4½ Fists	3 Fists
32°N	3½ Fists	2½ Fists
36°N	3 Fists	2¼ Fists
40°N	2½ Fists	2 Fists
44°N	2¼ Fists	1½ Fists
48°N	2 Fists	1½ Fists

From *No Heat, No Rent: An Urban and Energy Conservation Manual*, Energy Task Force, 519 East 11th Street, New York, NY 10009.

Once for true south, next for 30 degrees east of south, and last for 30 degrees west of south. Any object you can see above your fists in these directions will cast a shadow on your collectors; any object below your fists in these directions is of no concern.

You should now have a good understanding of not only solar water heaters in general but a better idea when it comes to batch water heaters as well.

We will now take a look at specific plans to build your own.

Batch Water Heater #1

The solar batch water heater is a fun project for the do-it-yourselfer and provides an inexpensive hot water source for the back yard workshop or weekend cabin. It is easy to construct, costs only about $70 to build and produces water temperatures as high as 150 degrees F.

Remember, the batch heater is not designed to operate with pressurized water systems and should not be connected to a city water supply. If you are looking for such a system, consider manufactured solar systems, which have been designed to meet strict standards and aesthetic considerations.

The solar batch heater is made with a steel drum. Since a standard 55-gallon drum cannot withstand city water pressure, but some pressure is needed to push water through the system, gravity flow is often used. This involves a second 55-gallon drum, filled with cold water and elevated above the batch heater drum. Gravity provides enough pressure to move water from the elevated drum (cold-water source) to the batch heater drum and finally to the hot water faucet in a sink, shower or other outlet.

Follow these simple instructions to build your own solar batch water heater.

LIST OF MATERIALS

- 55-gallon drum (Be sure the drum has not contained any toxic materials.)
- Flat-black paint (made to adhere to metal surfaces)
- 75 (approx.) concrete blocks for frame
- Foil-faced insulation, 2 - 4 ft. x 8 ft. sheets (Do not use polystyrene sheets --

they will melt. Use Thermax, Rmax or another isocyanurate insulation.)

- Reinforced garden hose or automotive heater hose, 3 sections (1/2-in. inside diameter)

    - a 3-ft. section for inside drum
    - a section leading to the cold water inlet valve*
    - a section leading to the hot water outlet valve*

- Hose clamps, 3

- 3/4-inch fitting, copper or CPVC**
  (3/4-in. thread x 1/2-in. sweat x 1/2-in. sweat)

- Pipe, copper or CPVC**
  (1 ft., 1/2-in. outside diameter)

- 5 ft. × 5 ft. sheet of window glass

- Duct tape or reflective tape (2 in. wide)

- "Rat tail" file, rotary grinder or other tool for grinding

- Solder

- Cement

- 4 sections of plywood or other wood 1 in. x 6 in. x 5 ft. each

- 4 pipe clamps or c clamps

* Hose lengths vary depending on distances from the system to the cold water inlet and the hot water outlet.

** If you use plastic pipe instead of copper, be sure to get CPVC, not PVC. PVC cannot withstand as high temperatures as CPVC

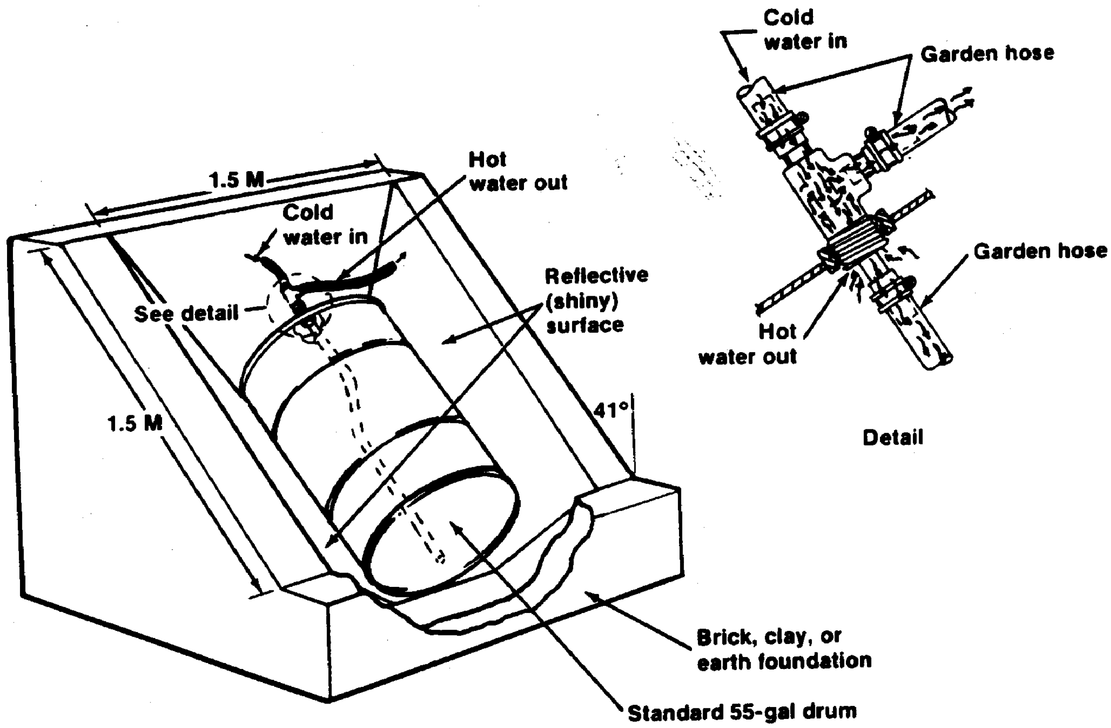


Figure 1. Solar batch heater

WASH AND PAINT THE DRUM

1. Wash the inside of the 50-gallon drum. Use a bleach/water solution to get rid of any mildew; then rinse thoroughly.

   A word of caution: do not use a drum that has contained any toxic materials. Some toxic substances cannot be washed away.

2. Once the drum is clean and dry, paint the exterior with a flat-black paint made to adhere to metal surfaces.

CONSTRUCT THE CONCRETE-BLOCK FRAME

1. Site your system where it can receive as much solar radiation as possible and is not shaded by trees or other structures. The drum itself should face due south and should be tilted. (See NOTE in step 12 for more about this).

2. To build the walls of the frame, mark off an area 5 foot x 5 foot square. For a secure

foundation, dig a trench three or four inches deep and lay the first square of blocks in the trench. You need to lay some blocks lengthwise and some crosswise to fit the dimensions. Pack the soil around them.

3. Add a second layer of blocks atop the first.

4. Set the third row of blocks on only three walls (west, north and east) to begin the incline of the west and east walls (see Figure 1).

   Starting on the west wall, set the first block about 1/2 block-length in from the south end. Continue setting blocks around the north and east walls, ending 1/2 block-length in from the south end.

5. Set a fourth row of blocks, decreasing another 1/2 block-length at the south end of the east and west walls, and so on, until the frame is seven blocks high.

6. At the sixth level, leave a space in the north wall (back) for the outlet hose and another space in the east wall for the inlet hose.

FINISH THE WEST AND EAST WALLS OF THE FRAME

The tops of the west and east walls have a step-like shape. To create a flat incline for the glass cover to rest on, fill in the "steps" with cement.

1. To make braces to support the cement while it dries, use 1 inch x 6 inch x 5 foot boards (plywood or other wood). Lay one board along the inside face and another along the outside face of one of the inclined walls (lining up the top edge of the board with the top of the wall).

2. Hold the boards in place with pipe clamps or c clamps -- one at the top of the incline and one at the bottom.

3. Make a second brace along the other inclined wall.

4. Use ready-mix cement, mortar or a cement/sand mixture to fill in the step-like spaces, forming a smooth surface along the tops of the inclined walls.

   The finished frame's east and west walls will have a 42-45 degree incline from top to bottom (north to south). (See Figure 1.)

NOTE: Depending on the latitude, you may want to adjust the walls' tilt so that the drum can be positioned to receive the maximum sunlight available. A good rule of thumb is to set the drum at an angle equal to the site latitude plus 15 degrees. In the example system, designed for Botswana, Africa (latitude 26 degrees), the drum has a 41-degree tilt (26 + 15 = 41 degrees).

CUT AND INSTALL FOIL-FACED INSULATION

Four sections of foil-faced insulation form a "dish" for the drum, sloping from the top of the block frame down into the center of the enclosure.

1. Cut two sections--mirror images of one another--to fit on either side of the drum as shown in Figure 2. Dimensions are: 4 ft. 11 in. x 2 ft. 6 in. x 3 ft. 5 in. x 2 ft. 11 in. Cut side A-D on an angle as shown.

2. Cut a third section of insulation to fit under the top of the drum as shown in Figure 3. Dimensions are:
   4 ft. 11 in. x 2 ft. 11 in. x 1 ft. 11 in. x 2 ft. 11 in. Cut sides A-B and C-D on an angle as shown.

3. Cut a fourth section of insulation to fit under the base of the drum as shown in Figure 3.
   Dimensions are: 1 ft. 10 in. x 4 ft. 11 in. x 1 ft. 10 in. x 3 ft. Again, cut sides A-B and C-D on an angle as shown.

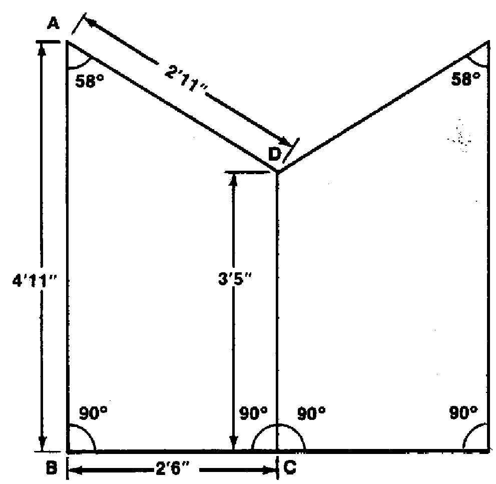


Figure 2. Insulation side sections.

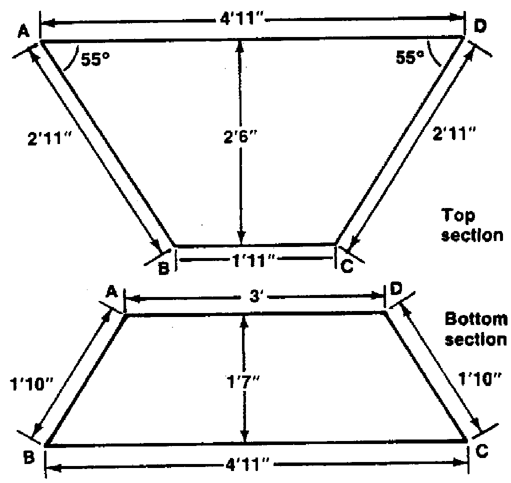


Figure 3. Insulation top and bottom sections.

4. Set the insulation inside the frame so that it slopes from the top of the blocks down into the center of the enclosure.

   You may need to add dirt or sand to support the insulation (and the drum, once it is in place). Remember, the drum must be lower than the concrete frame in order for the glass cover to fit on top.

5. Use duct tape or reflective tape to hold the sections of insulation together. Don't worry if they do not meet exactly at the center or overlap somewhat. The important thing is to form a curved "dish" to hold the drum.

CONNECT THE FITTING, PIPES AND HOSES

1. Cut a 7-inch section of pipe (to be inserted through the fitting so that it protrudes about 2 inches on either end).

   Before you can insert the pipe, you must use a "rat tail" file or rotary grinder to grind away the ridge inside the 1/2-inch sweat at the top of the fitting (opposite the threaded end).

2. Solder or sweat the pipe.and fitting at the top (1/2- inch) joint.

3. Cut a 3-inch section of pipe, insert it in the other (side) 1/2-inch opening and, again, solder the joint.

4. Use a hose clamp to attach a 3-foot length of garden hose to the pipe at the threaded end of the fitting.

5. Feed the hose into the drum's 3/4-inch hole and thread the fitting into the hole. (The drum will also have a 1-1/2-inch bung hole. This hole should be plugged.)

6. Use a hose clamp to attach a second section of garden hose to the pipe extending from the top of the fitting. This hose should be long enough to reach the inlet (cold) water supply.

7. Connect a third section of garden hose to the other (side) piece of 1/2-inch pipe.

This hose should be long enough to reach the outlet (hot) water valve.

POSITION THE DRUM AND COMPLETE THE INSTALLATION

1. Place the drum on top of the insulation so that the fitting and pipes are at the highest point of the drum. (The 1-1/2-inch bung hole should be at the lowest point on the top of the drum.)

2. Mark where the inlet and outlet hoses need to pass through the insulation and out of the concrete frame. Cut holes and feed the hoses through.

3. Connect the hose leading out the top pipe to the cold water inlet; connect the hose leading out the side pipe to the hot water outlet.

4. Open the cold water inlet valve and fill the drum with water. Check for leaks and tighten any clamps if necessary.

5. Place the glass cover over the frame.

OPERATING THE SYSTEM

Your solar batch heater is not under city water pressure, but does need some pressure to move water through it. If you use a second 55-gallon drum, filled with cold water and elevated above the batch heater drum, gravity provides that pressure.

As you open the outlet valve and draw hot water out of the batch heater drum, gravity draws cold water down from the elevated drum. When you close the outlet valve, the drum is sealed. Water in the batch heater drum prevents water in the elevated drum from continuing to flow down.

Since heat rises, the hottest water collects at the top of the drum. That is why the outlet hose extends only a few inches into the top of the drum -- to draw off the hottest water when you open the outlet valve. The inlet hose extends to the bottom of the drum, so that the cold water coming in does not mix with and cool the hot water at the top.

Try to schedule your hot water use for late afternoon and early evening when water in the batch heater will be hottest.

Batch Water Heater #2

To keep the cost of the system down these collectors were designed around recycled 52 gallon electric hot water heater tanks and a single pane patio glass. These two items dictated the size of the collector. A cradle supports the tank and legs made from 2x4's. A plywood box surrounds the cradle and tank and serves to hold the insulation and glazing in place. The collector was designed to avoid wasted material, and complicated cutting and assembly operations.

A sheet of selective surface such as "Sunsponge " is recommended on the upper face of the tanks to increase the performance of the collectors. You probably have to order the selective surface through the mail.

No freeze protection was added to the system, the water mass in the tank coupled with the use of insulated polybutlyene piping resulted in a freeze tolerant system. Under extreme cold conditions the polybutylene pipes between the collector and the heated portions of the house will freeze, but will not burst. When frozen pipes do occur, simple valving, shown in Figure 6 will allow bypassing the collectors until the pipes thaw. You may wish to bypass the system during December, January and February, to avoid freeze up situations using the same valving procedures

LOCATING THE COLLECTORS

The following three important factors have to be considered when locating the solar collectors:

1. The distance between the batch collectors and the existing hot water heater should be kept to a minimum.

2. Collectors should have minimal shading.

3. Collectors should be optionally oriented.

Ground Mounting and Short Pipe Runs

When considering different places to locate the collector, it is important to be aware of the distance between the collectors and the existing water heater. The longer the run the more heat will be lost from piping, even if the pupae are insulated.

Batch collectors are heavy; the ideal situation is to have them situated on the ground near the existing water heater. A short run of pipe to the collector is then possible.

Batch collectors can be roof mounted, but care must be taken to insure that the roof structure can support the load. Roof mounting should only be considered if all ground mounting possibilities have been exhausted. A structural engineer should be consulted before mounting batch collectors on a roof.

Optimal Collector Orientation

The collector should be orientated, as near to true south as possible, hue any orientation within 30 degrees of true south is suitable. Batch collectors lose more heat over night than active systems; this is especially the case in the winter. Because of this, the OSU batch collector is designed to take more advantage of the summer sun and warm conditions. The collector is sloped 30 degrees up from level, a low angle compared to most active solar collectors.

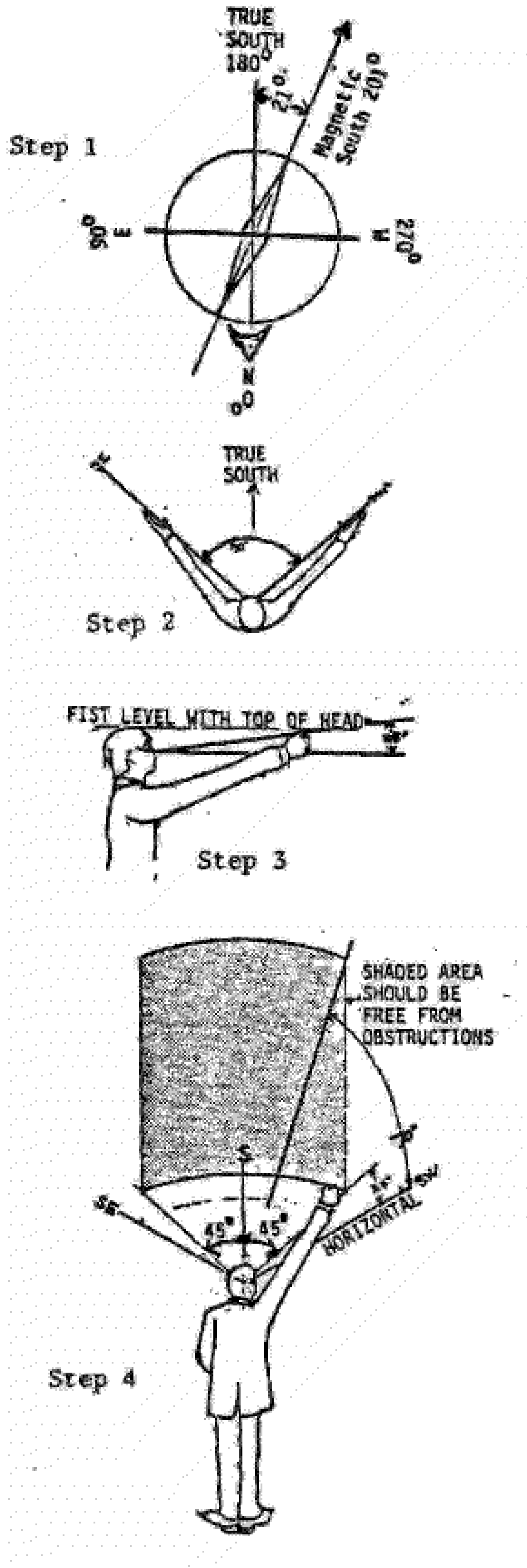
Having the collectors in the sun is by far the most important siting criteria. To do a quick check on whether or not the proposed location for the collectors is shaded see Figure 4. More accurate site analysis methods are described in Energy Notes "Plotting Skylines "and "Easy Skyline Plotters'.

MATERIALS AND TOOLS

After selecting the appropriate location for the collector, and dialing with the applicable building permits, you are ready to assemble tools and buy materials. See the tools and material lists on the last page for details. To save time and blisters, a variable speed electric drill with a bit to drive screws is a strongly recommended. Make sure the screw bit fits the screw head, which might be either a hex head and or a slotted head.

Figure 4checking for Shading

Step 1 To check for shading, stand where you plan to locate the collectors. Find true south on a compass by setting the south end of the magnetic needle on 20 degrees, true south will be at 180 degrees on the compass see Step 1 illustration).



Step 2 Facing south, hold your arms out so they are at right angle see Step 2 illustration) . Pick cut a reference point in line with each arm.

Step 3 Make a fist; raise the fist so that it is even with the top of your head see Step 3 illustration).

Step 4 keeping your fist at this angle, swing it from one reference point to the other. The area above your fist throughout this arc should be free from obstructions such as trees, buildings including your house) or steep hills. Utility poles and wires usually do not present a shading problem. If there are obstructions, try another location.

PREPARE WATER TANK

Remove drain valve, nipples, thermostat and wiring but not elements). Remove sheet metal shell and insulation. If a secondhand tank is being used, pressure teat it far leaks. To pressure teat do the following steps

1) Screw a 6" galvanized nipple into the drain at the bottom of the tank. Wrap Teflon tape around pipe threads. Screw a hose bib to nipple.

2) Plug the entire inlet holes at the top of the tank except one with ¾" galvanized plugs.

3) Connect garden hose to water supply and hose bib at the bottom of the tank. Fill tank with water until flowing out the top of the tank. Turn off water.

4) Plug remaining inlet hole with plug and turn water back on.

5) Look for leaks. Leaks around elements can sometimes be fixed with a new gasket. Leaks around the base of the unit are beyond repair. If there are no leaks drain tank and remove hose bib from drain nipple.

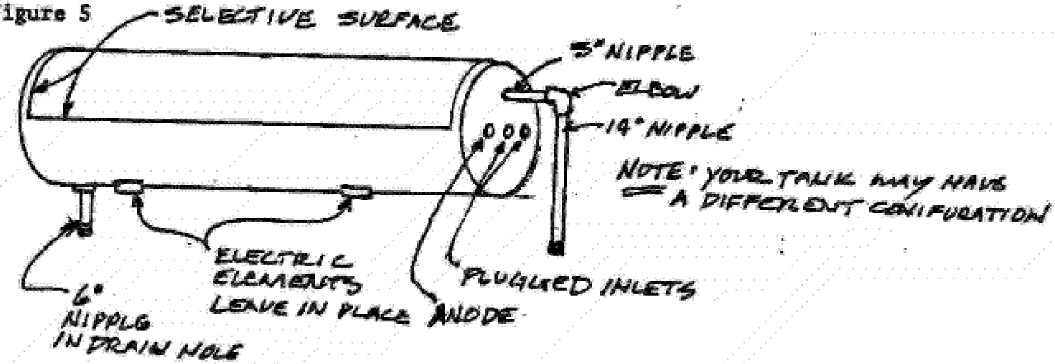
Unscrew anode rod at the top of the tank and cheek its condition, replace if necessary. Remove any rust on the tank with sandpaper. Spray tank with high temperature flat black stove paint.

Determine the inlet hole in the top of the tank. Select the inlet holes which is on the opposite side of the tank from the tank drain and screw into it a 6" galvanized nipple. Screw an elbow on the end of the nipple. Screw a 14" nipple into elbow and rotate until the nipple is in line with the tank's drain.

All the inlets at the top of the tank should plugged except for the one with the nipple See Figure 5.

Selective surface increases the collector's performance. It should be applied just before the tank is installed in the collector for the final time. This avoids damaging the selective surface while handling the tank during the construction of the collector. The selective surface should be applied to the forward facing half of the tank See Figure5.

Figure 5

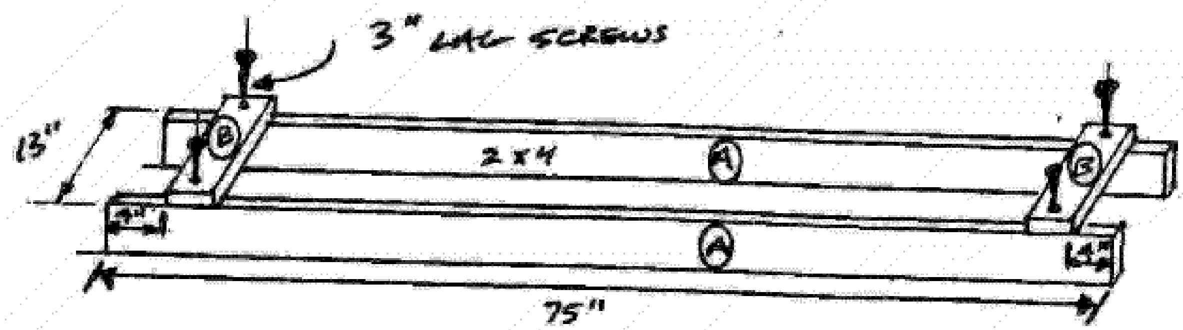


CONSTRUCTION PROCEDURES

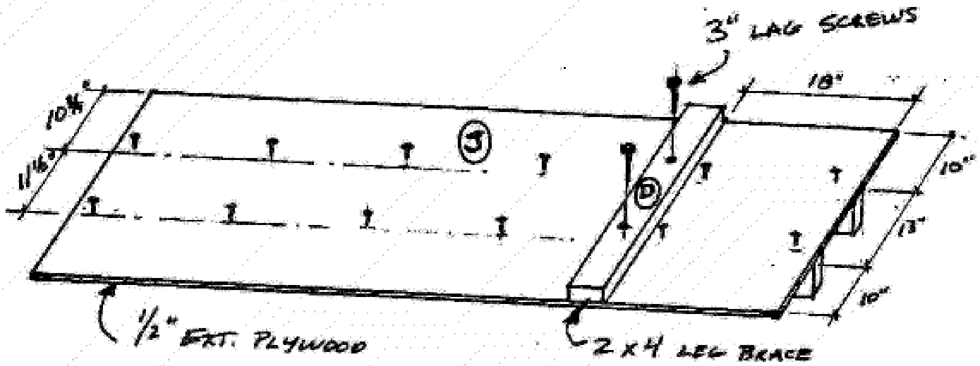
The collector construction sequence is set out in easy to follow graphical steps on the next five pages. Cross sectional drawings of the collector should also be referred to. Building two collectors should be a weekend project. One person could build the collector, but two make things a lot easier. Installing the system takes two people. Steps 2 though 5 can be done conveniently on a bench level, but after that it is easier to set the collector base on a lower working surface, such as saw horses or boxes, between 16” and 24” high.

1 CUT 2X4'S AND 2X2'S
SEE CUTTING DIAGRAM PAGE 18
CUT PLYWOOD (IF YOU DID NOT HAVE THE PLYWOOD CUT AT THE PLACE OF PURCHASE)
SEE CUTTING DIAGRAM PAGE 19

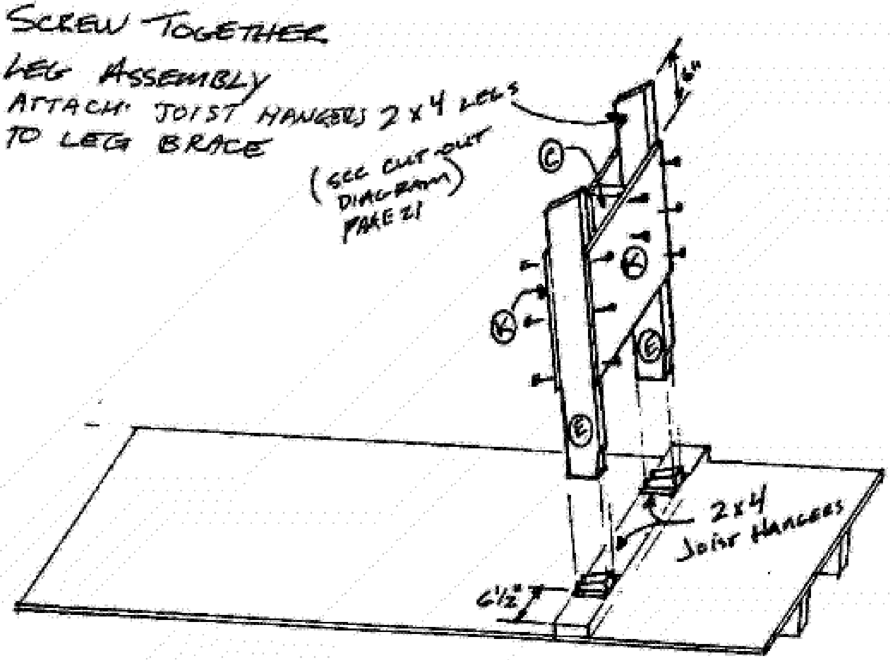
2 ASSEMBLE CRADLE AND COVER WITH ALUMINUM TAPE



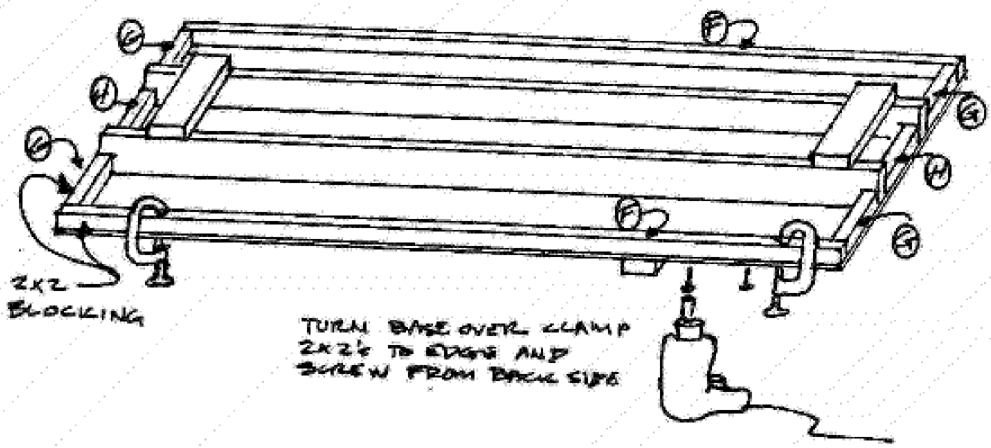
3 SCREW BACK AND LEG BRACE TO CRADLE



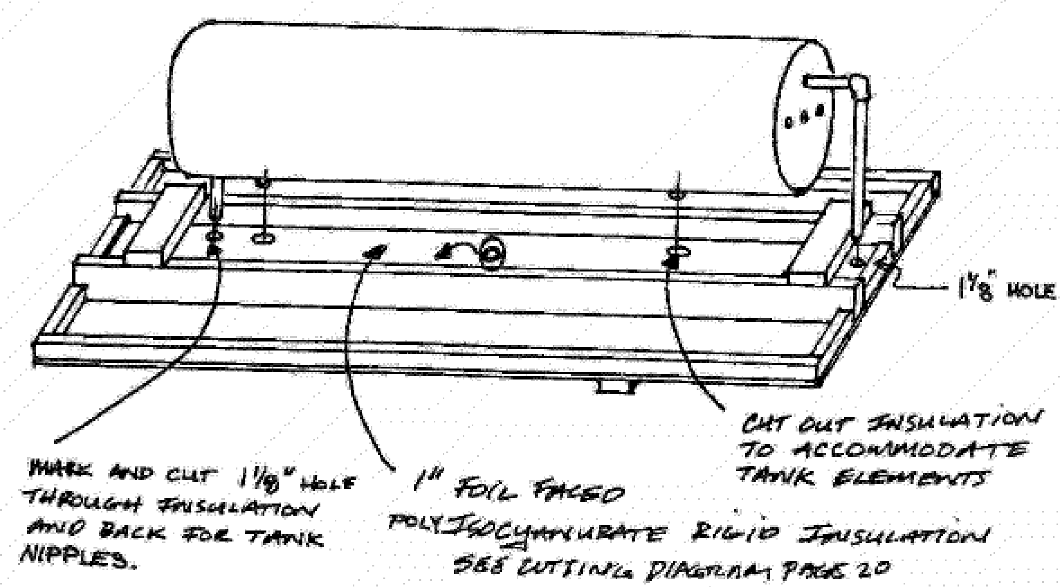
4 SCREW TOGETHER LEG ASSEMBLY
ATTACH JOIST HANGERS TO LEG BRACE



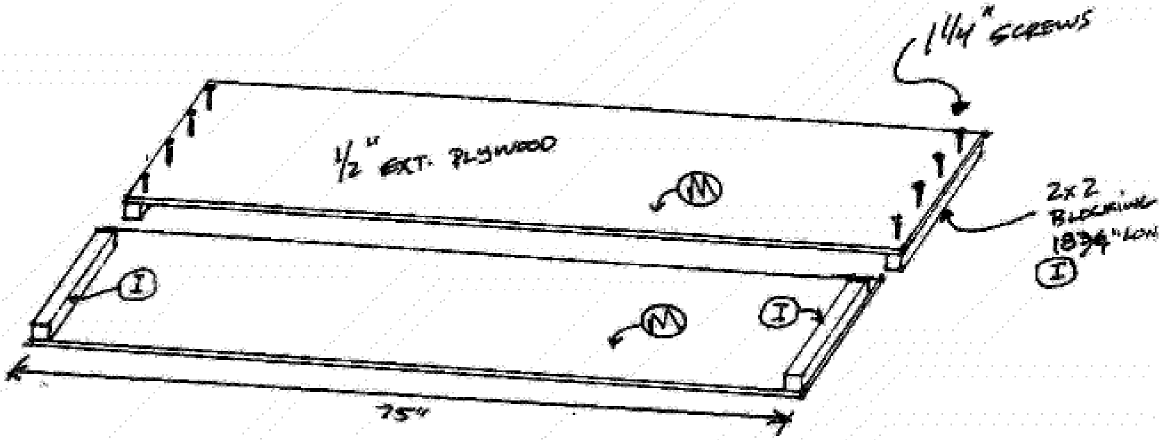
5 Screw Perimeter Blocking To Base



6 Install Cradle Insulation

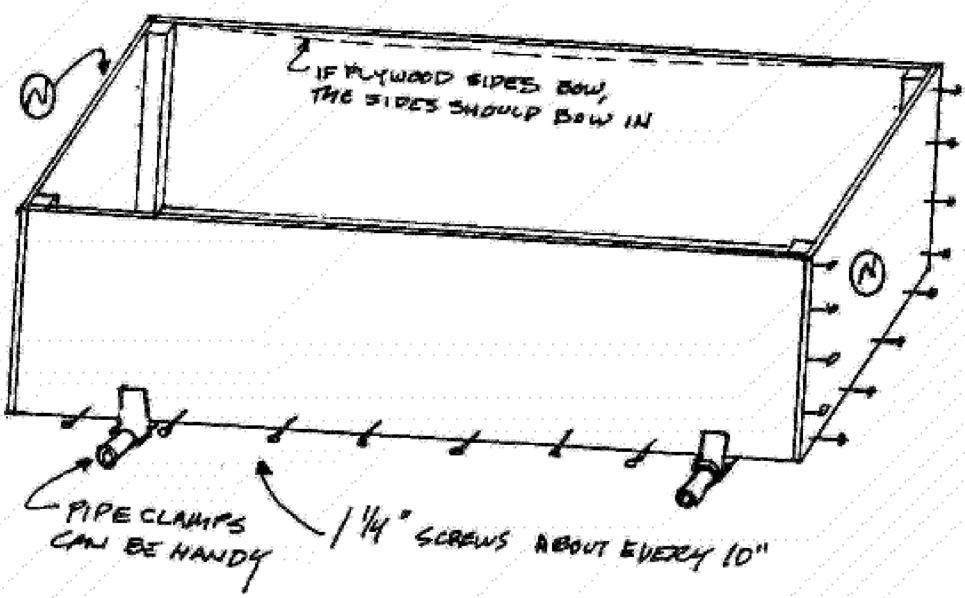


7 Assemble Sides



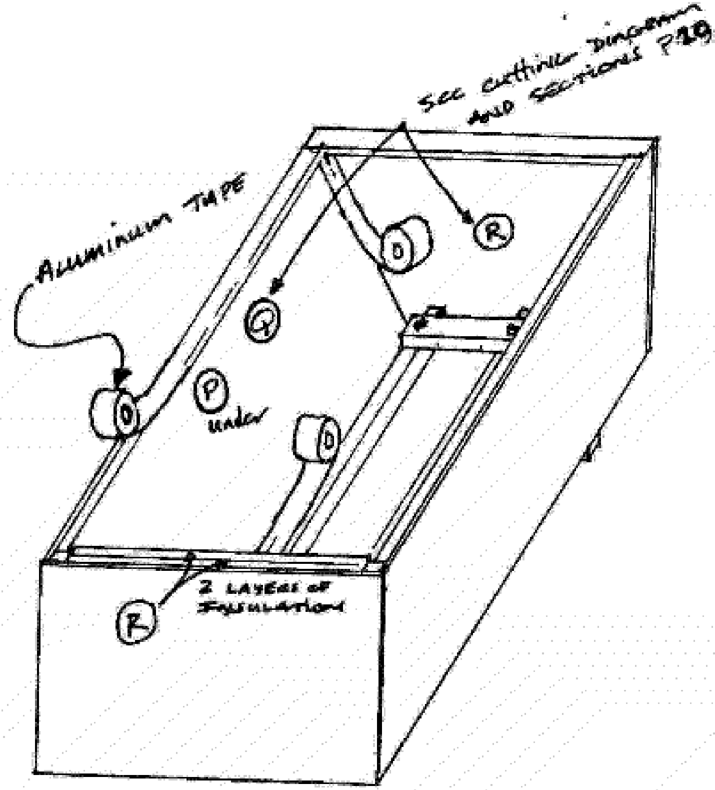
8 Screw Sides to Back

Screw End to Sides and Back



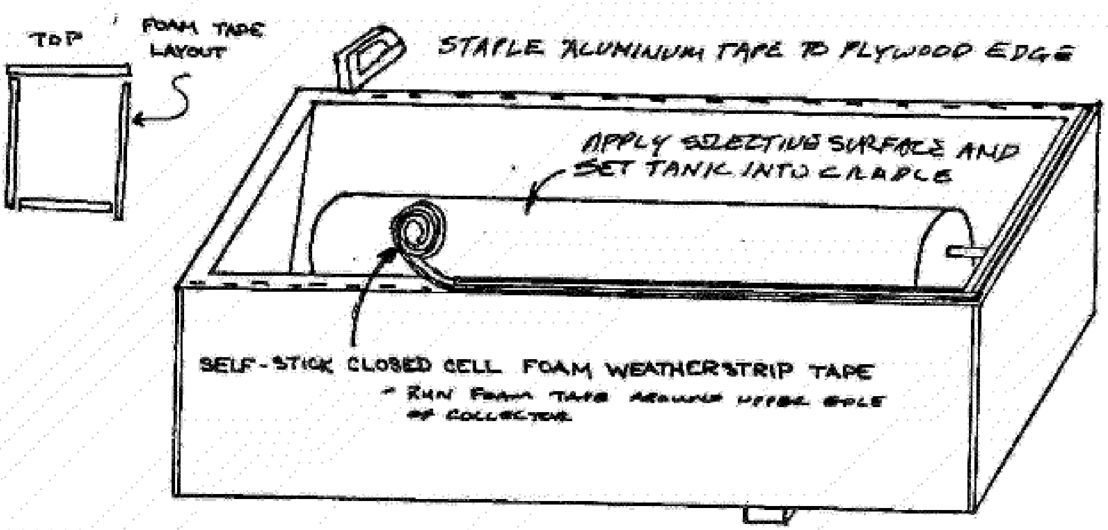
9 INSULATE SIDES AND END OF BOX

TAPE EDGES AND CORNERS

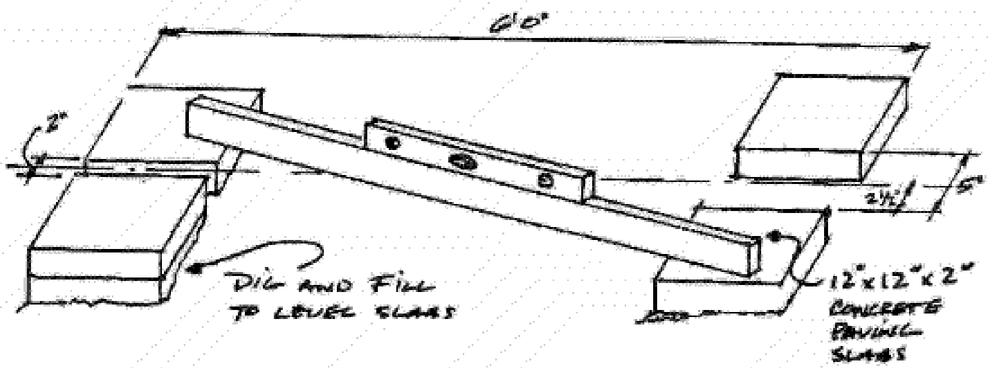


STAPLE EDGES

10 APPLY FOAM TAPE GLAZING GASKET

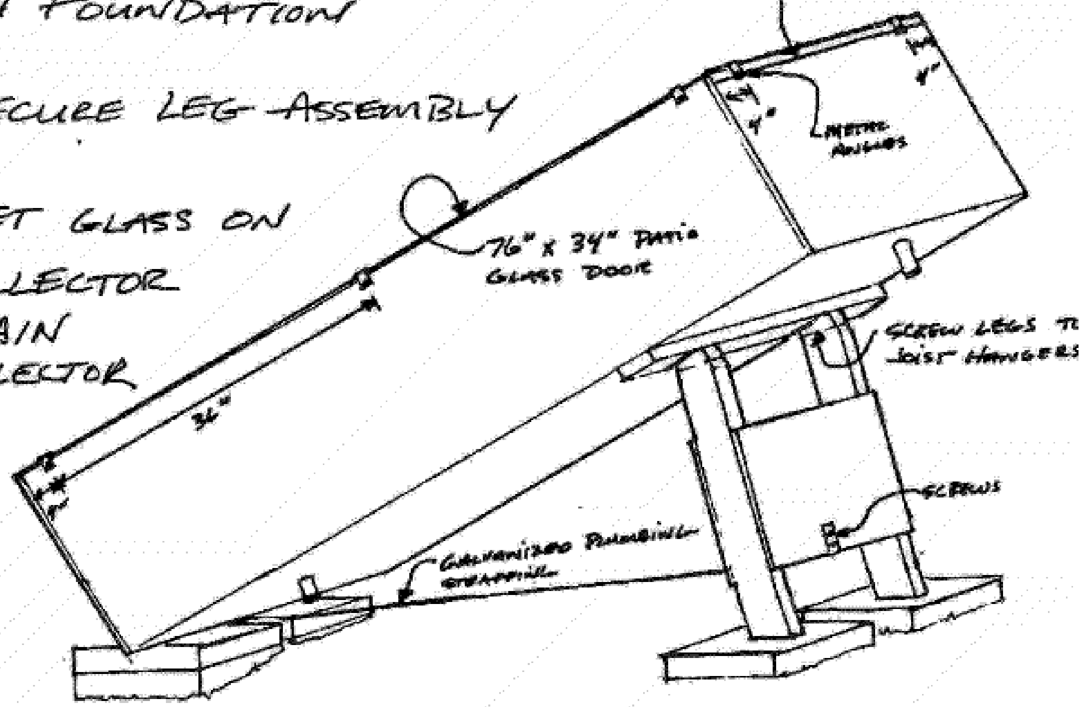


11 PREPARE FOUNDATION FOR COLLECTOR



12 * SET BATCH COLLECTOR ON FOUNDATION

* SECURE LEG ASSEMBLY
* SET GLASS ON COLLECTOR
* STAIN COLLECTOR



PLUMBING

With the major components in place, the collector and hot water heater, you can now begin plumbing them together.

Examine the Existing Water Heating System

Before starting, become familiar with your existing hot water heater. There will probably be at least three pipes connected to the water heater.

Look on the top of the heater for hot and cold labels where the pipes enter the heater. Find the hot water pipe, which connects the hot water heater to the various hot water faucets in your house. The pipe draws water from the top of the tank where the water is hottest.

Find the pressure relief pipe caning out of the tank. It is located either at the top of the tank or on the aide of the tank near the top. This pipe is usually very short. Screwed on the end of this is a pressure relief valve. This valve is the safety mechanism that prevents the tank from exploding if too much pressure builds up. There might be a pipe attached to the relief valve designed to carry off the steam or superheated water in the event of the pressure valve releasing.

Find the cold water supply pipe. Follow this cold water pipe away from the tank, there should be a gate valve before the pipe disappears into a wall or under the house. Closing this valve shuts off the incoming city water and relieves the entire hot water system of the city water pressure. This valve needs to be closed before any plumbing work starts. Note: Always turns off the electricity or gas to the hot water heater whenever working on it.)

It is the cold water supply pipe that will be tapped into when installing this batch collector. Some hot water heaters have only the hot and cold inlets, the relief valve being placed in the hot water line leading to the house. A solar hookup can be done equally well with either system.

Tapping into the cold water supply line

For ease of installation and freez e tolerance, all of the new plumbing should be done with 3/4inch polybutylene pipe. Before making final plumbing connections between the various components in the system, it is strongly recommended that all the pipes and fitting be assembled to ensure proper fit BEFORE they are connected up.

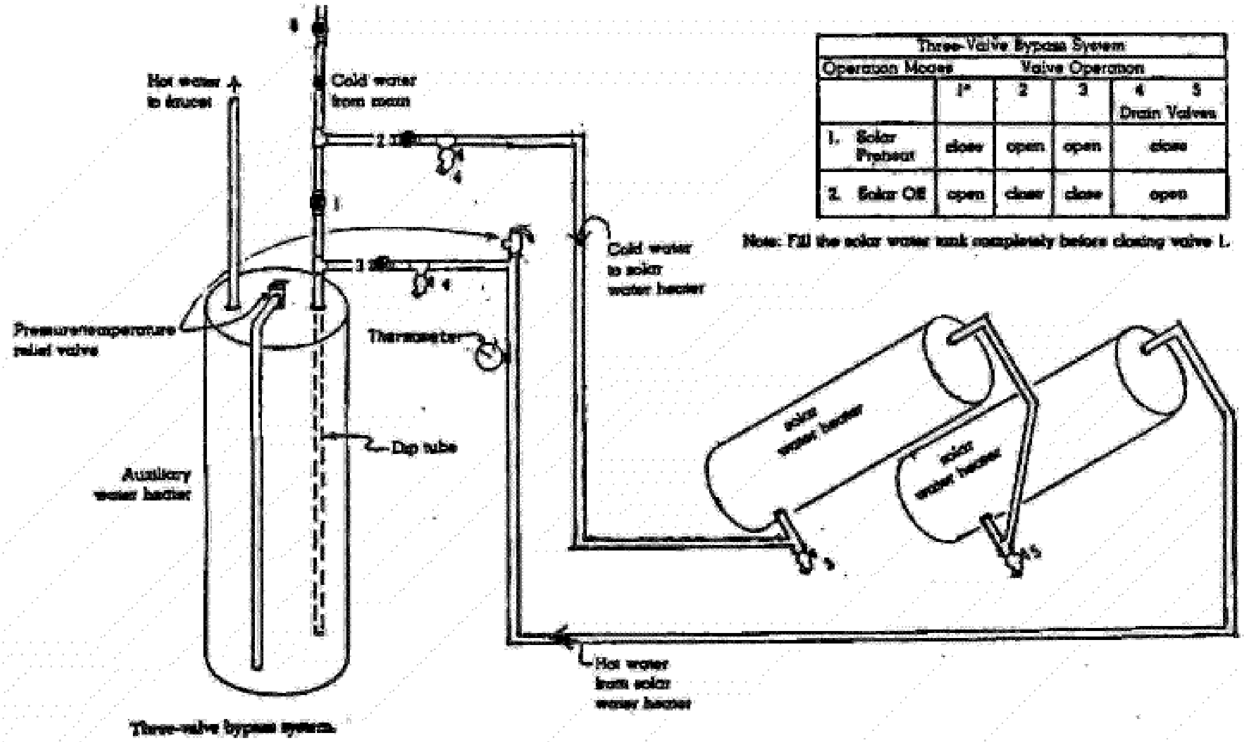
Plumbing to the Batch Collector

Cold city water will go directly to the collector. The cold water supply pipe going to the collector should start at valve # 2 and run to the inlet nipple at the lower end of the first collector. The return pipe run between the batch collector and the existing water heater starts from the nipple coming out of the high end of the last batch collector and ends at valve # 3. Valve # 3 will normally be open.

A pressure temperature relief valve should be placed near valve # 3 on the collector side of the valve. If more than one collector is used, they should be plumbed in series. The upper outlet of the first collector should be connected to the lover valet of the next collector see Figure 6).

There should be a drain valve #5) at the end of the inlet nipple on each collector. Their valves ate used to drain the collectors. Valves #4 should be opened when draining the tanks to let air into the system.

A thermometer for monitoring the performance of the system can be installed. It should be placed in the return line before it enters the hot water heater. Thermometers usually come with a ½" male screw fitting that allows easy connection at a t fitting in the plumbing.



Three-Valve Bypass System				
Operation Modes	Valve Operation			
	1*	2	3	4 5 Drain Valves
1. Solar Preheat	close	open	open	close
2. Solar Off	open	close	close	open

Figure 6
Plumbing Layout

INSULATION

The performance of a solar hot water system is adversely affected by poorly insulated pipes and storage tanks. This is particularly true when pipe runs
are long and water heaters sit in unheated areas.

Insulating Pipes

All plumbing between the solar collector and water heater must be insulated. It is especially important that all outdoor piping be insulated. To extend system performances into the cold December and January months, consider adding a layer of R11 fiberglass batt insulation to the pipe insulation listed below. Burying insulated pipe below the frost line can also reduce pipe freezing and improve the looks of the installation especially if the collectors are not adjacent to the house. A waterproof cover, such as flexible black plastic drainpipe, should be used to cover fiberglass insulation or buried pipes.

There are several types of pipe insulation available. The insulation will be made either to slide over the pipe or to clamp around it. In either case, the insulation is available for various pipe diameters. Pipe insulation exposed to the weather must be protected. The following table is a guide to several locally available pipe insulations:

Type	Brand Name	R Value/Inch	Wall Thickness	Weather Protection
Rigid Fiberglass	Microlok 650	3.0	1"	needs PVC or metal Jacket
Elastomer	Armaflex Rubstax	3.5	¾"	needs latex paint or PVC or metal Jacket
Polyethylene closed cell)	Zipcote Imcoaflex	4.1	¾"	needs latex paint or PVC or metal Jacket
Urethane	Solar 7 Insultec	7.0	1"	comes with PVC Jacket

Elastomers.

Elastomer insulation comes without slits and should be put on the pipes as the plumbing is done. Cut the insulation tube slightly longer than the pipe to be insulated. Slide onto the pipe and Ioin by butting, Use visegrips to hold back the insulation while soldering. Use the manufacturers recommended adhesive to seal the Ioints. Elastomer insulations will have to be double layered to get the recommended R4 insulation values. When layering the insulation is sure to stagger the points. Elastomer will deteriorate rapidly when exposed to weather or soil. They must be protected. If paint is used it should not be oil base end it should be reapplied every 35 years.

Insulating storage tanks

The water heater tanks should be insulated to at least R11. Check manufacturer literature to see if the tank is already insulated to this level. If not, it is necessary to add an insulating jacket. R11 fiberglass batts, wrapped around the tank and secured with duct tape, work well.

OPERATION AND MAINTENANCE

Batch collectors store a large quantity of solar heated water in the collector itself. Performance of the batch system is improved if hot water is used during or at the end of the day. Morning hot water usage is the worst situation; much of the solar heat is lost during the night.

The entire solar hot water system should be inspected at least once a year. If a thermometer has been installed to record solar collector output temperatures, periodic checks are suggested. If temperatures seem low, inspection of the system is advised.

Collectors

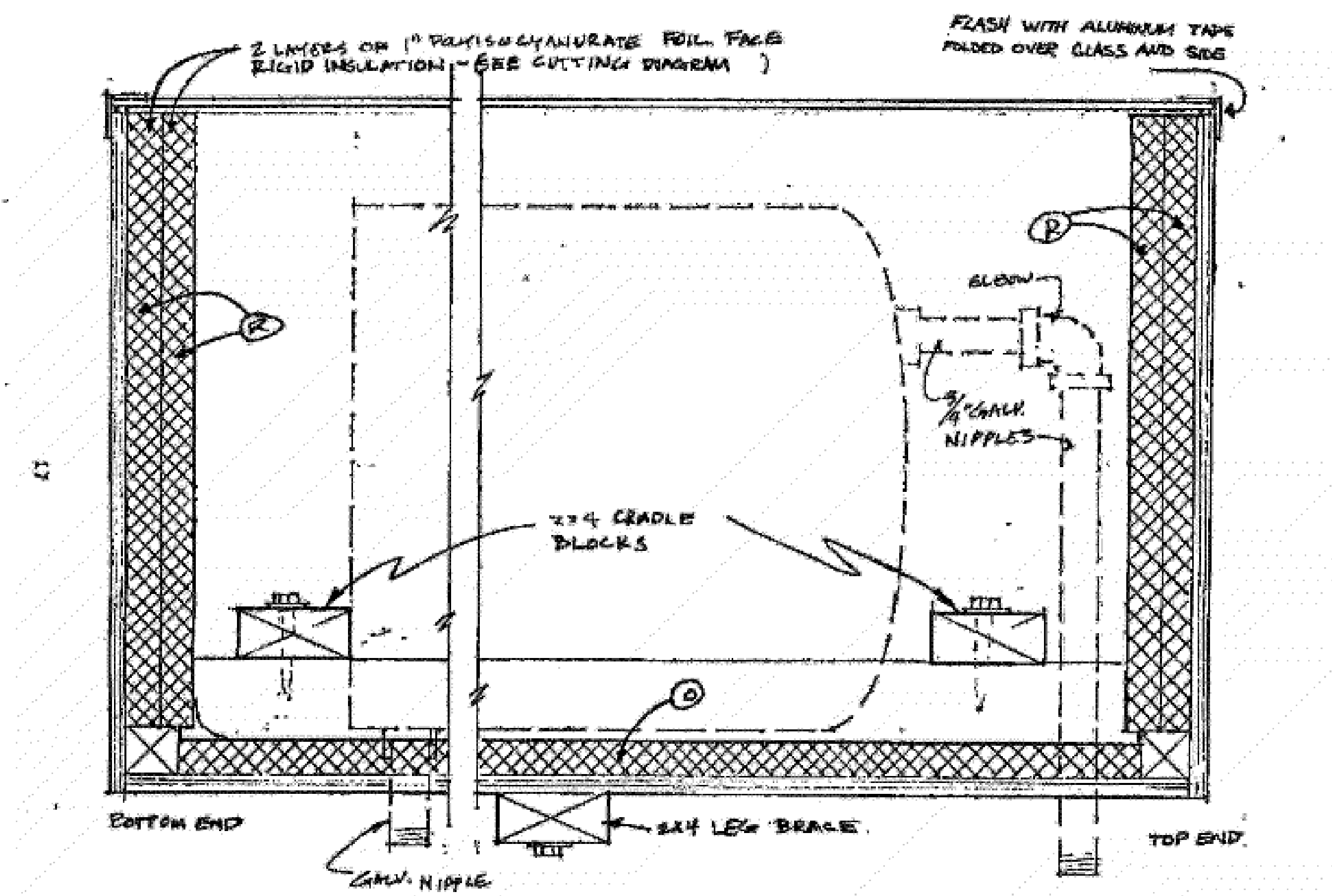
The glaring of the collector panels should be cleansed regularly. All exposed wood surfaces should be inspected and repainted or repaired as needed.

Plumbing

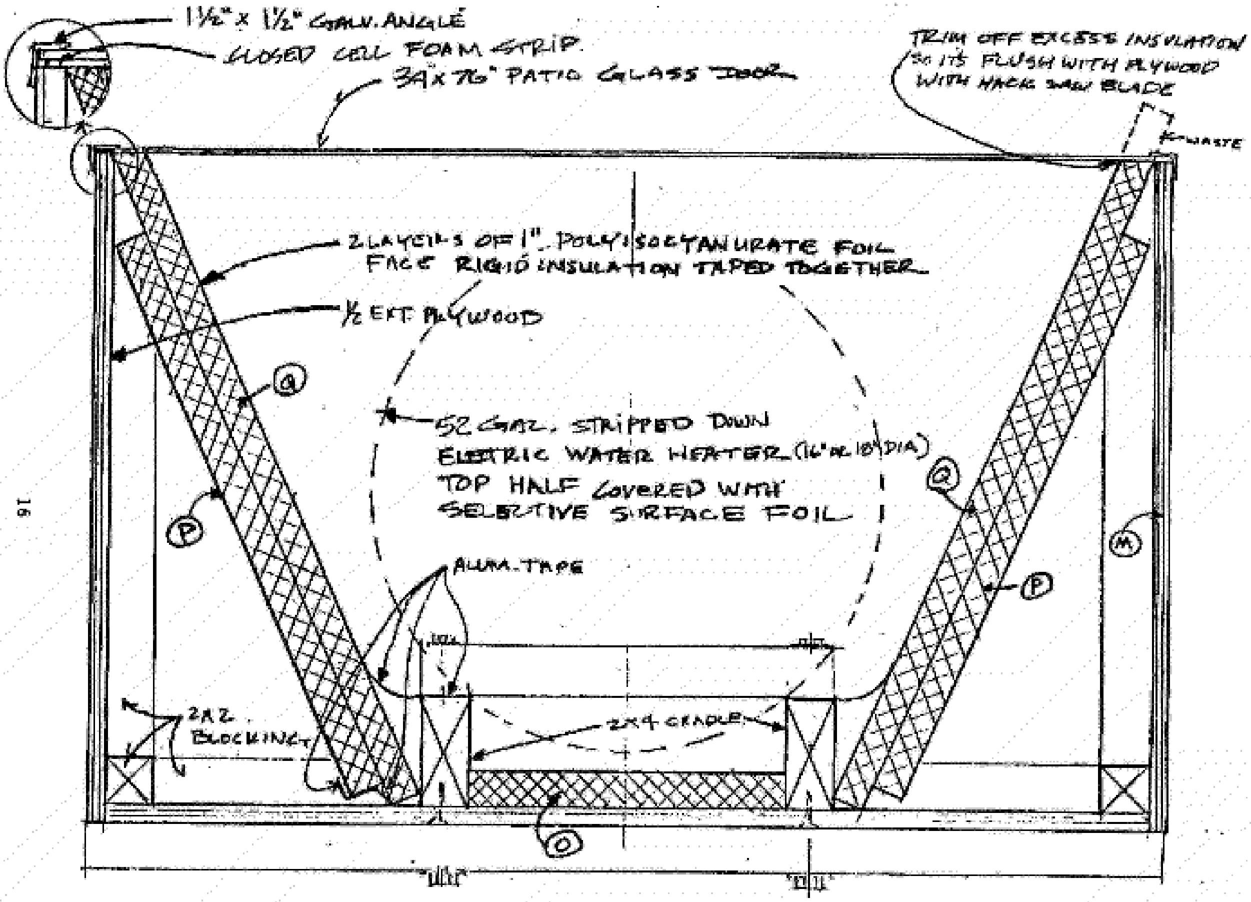
Check for leaks around valves and fittings. Check pipe insulation to make sure it is tight and has not deteriorated.

Tanks

Drain and flush tanks once a year. Check tank insulation for tight fit.



SECTION 3" = 1'0"

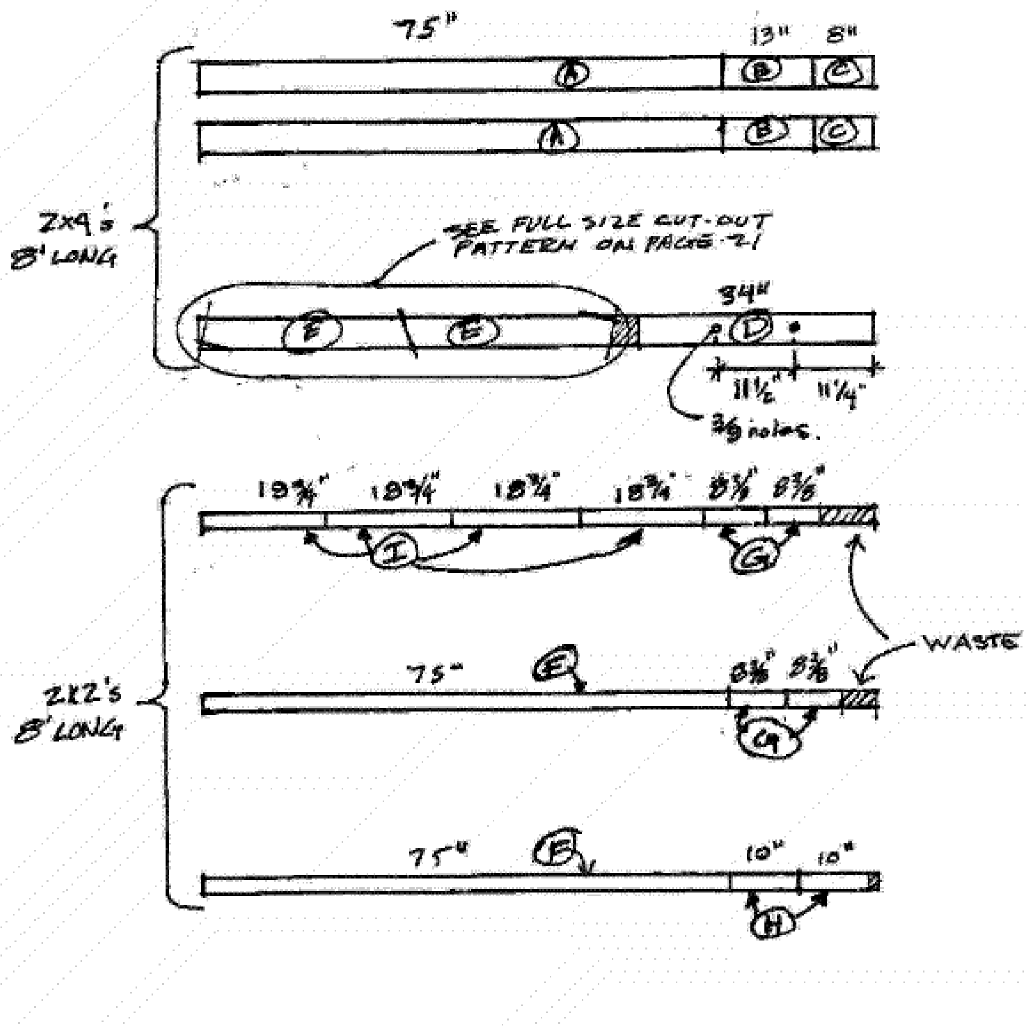


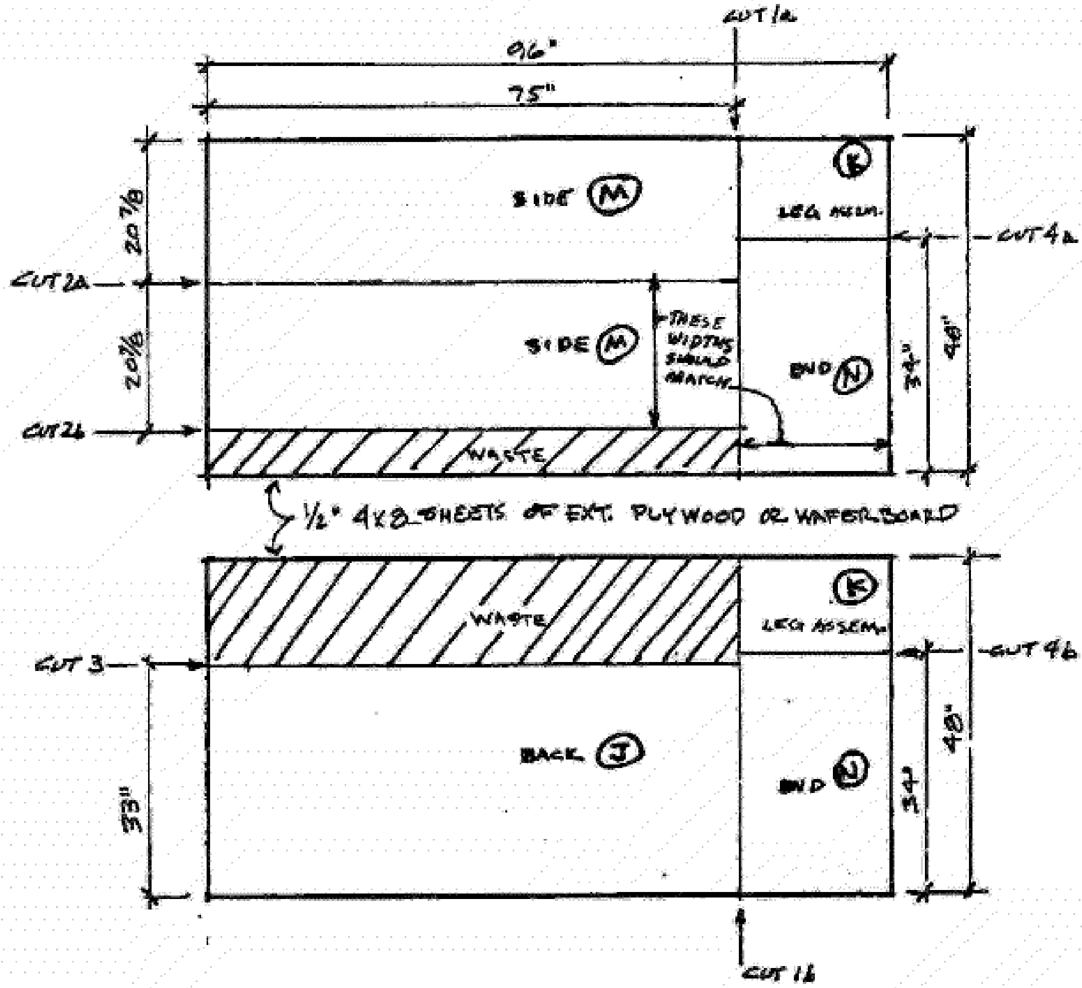
1½" x 1½" GALV. ANGLE
CLOSED CELL FOAM STRIP
39"x 76" PATIO GLASS DOOR
TRIM OFF EXCESS INSULATION SO ITS FLUSH WITH PLYWOOD WITH HACK SAW BLADE
WASTE
2 LAYERS OF 1" POLYISOCYANURATE FOIL FACE RIGID INSULATION TAPED TOGETHER
½ EXT. PLYWOOD
Q
P
52 GAL. STRIPPED DOWN ELETRIC WATER HEATER (16" or 18" DIA) TOP HALF COVERED WITH SELECTIVE SURFACE FOIL
Q
M
P
ALUM. TAPE
2X2 BLOCKING
2X4 CRADLE
O

SECTION 3" = 1'0"

MATERIAL CUTTING DIAGRAMS

USE THE DIAGRAMS ON THE FOLLOWING PAGES AS REFERENCE WHEN CUTTING AND ASSEMBLING WOOD AND INSULATION MATERIALS.

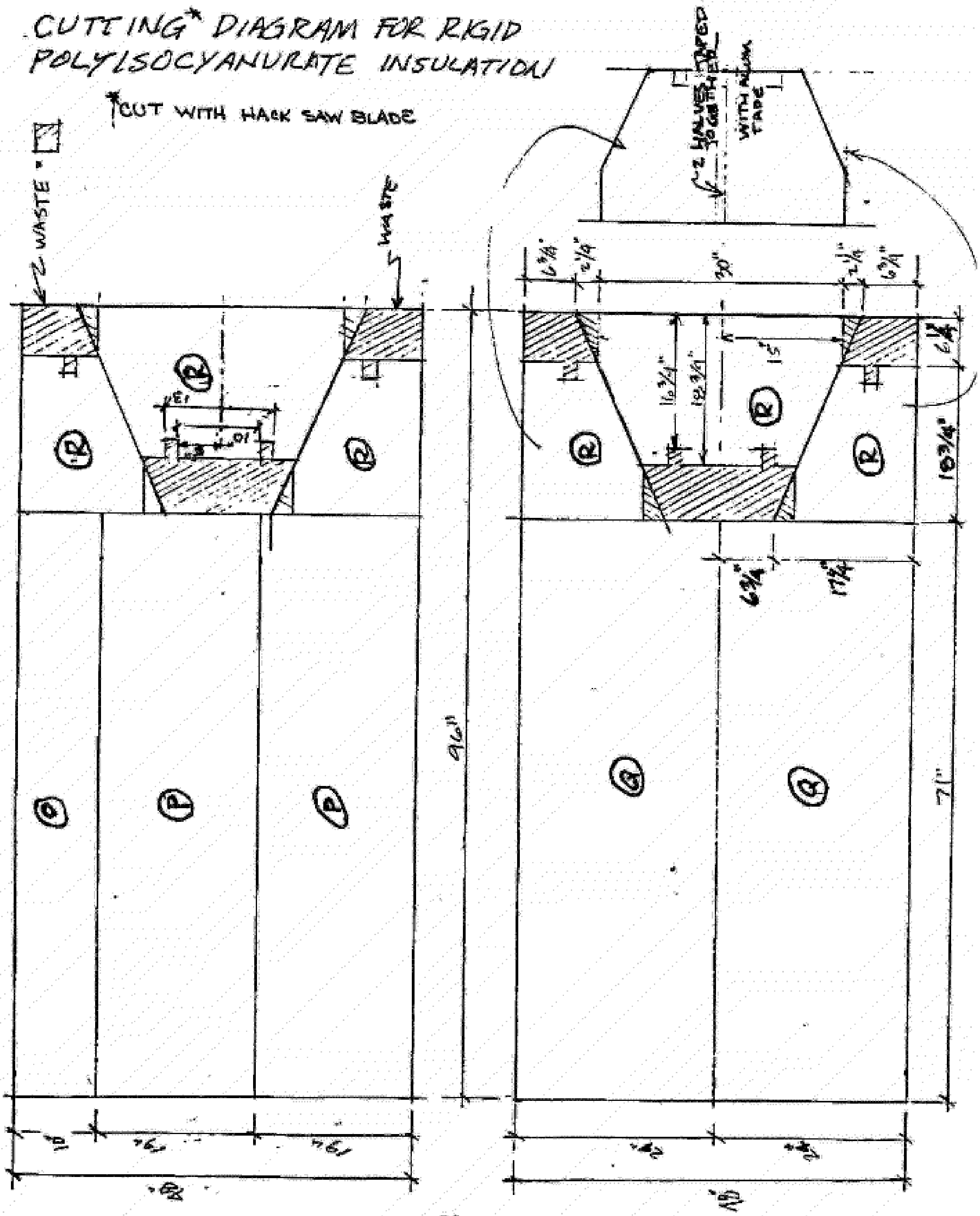




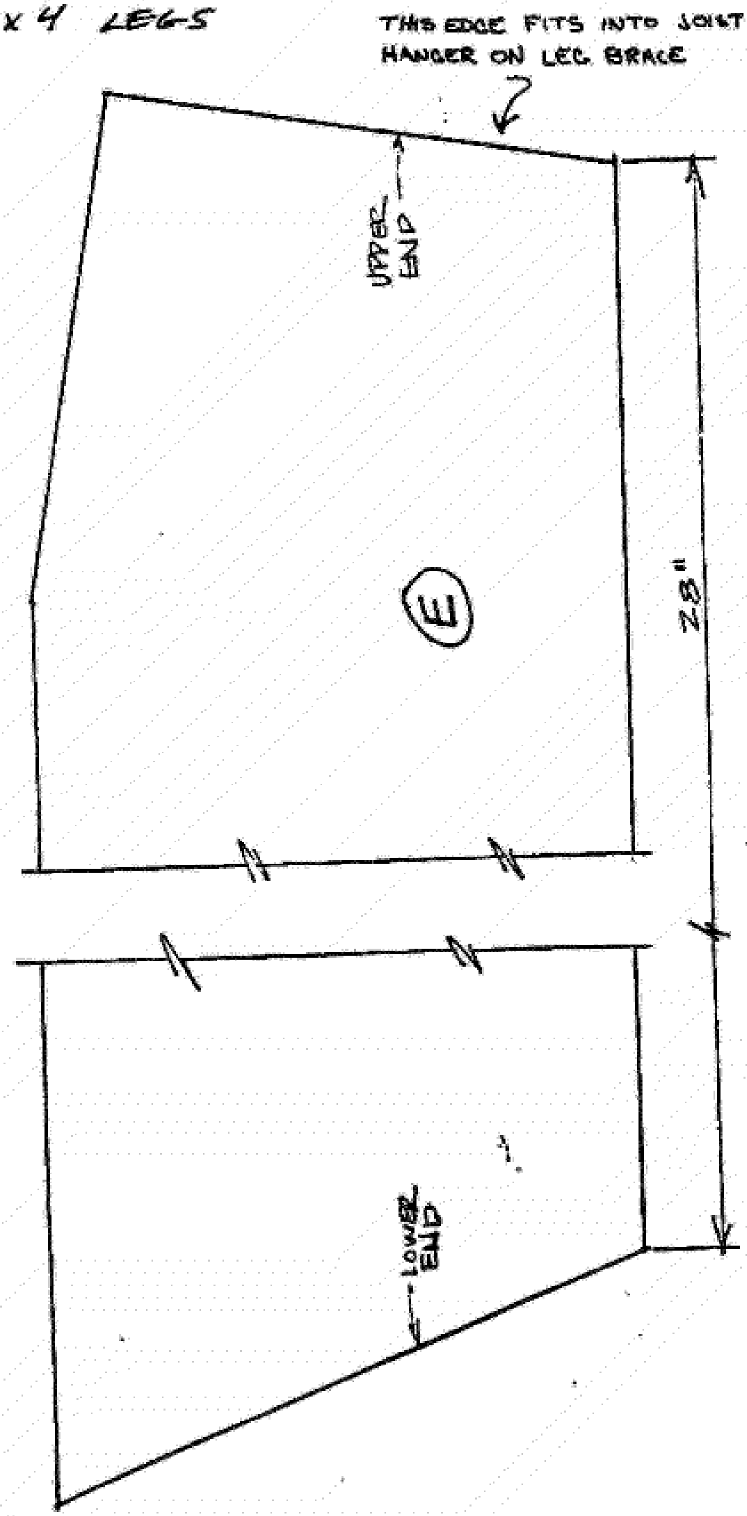
CUTTING PLYWOOD SHEETS — LUMBER YARDS WILL OFTEN CUT SHEET MATERIAL FOR LITTLE OR NO COST — A CONVENIENCE WORTH CONSIDERING.

CUTTING* DIAGRAM FOR RIGID POLYISOCYANURATE INSULATION

*CUT WITH HACK SAW BLADE



FULL SIZE CUT-OUT PATTERN FOR 2x4 LEGS



MATERIAL LIST FOR ONE BATCH COLLECTOR

- 3, 2 x 2's 8' long.
- 2, 2 x 4's, 8' long
- 2 sheets, 1/2" Exterior plywood or 7/16" wafer board 4'x 8' (Recommend cutting it according to cutting diagram at place of purchase)
- 2 sheets, 1" Foil Laced rigid polyisocyanurate insulation ("Thermax") 4'x 8'
- 4 (min), 12"x 12"x 2" Concrete paving slabs (slopped sites require more)
- 1, 34"x 76" Tempered patio door glass (Used or seconds are OK and cheaper)
- l roll, Aluminum duct board tape (widths between 2" and 4" OK)
- 20', 3/8"x3/16" Self stick closed cell foam weatherstrip tape (17' rolls)
- 10, 1 1/2"x 1 1/2" Galvanized corner angles.
- 2, Joist hangers for 2 x 4's 6, 3" x 3/8" Lag screws with washers
- 1 box (100), 1 1/4" #8 or #10 Zinc plated hex heed sheet metal screws
- 1 box 1/4" staples
- 1 roll, Plumbers Tape (perforated galvanized metal strapping)
- 1 gallon, Water repellent wood stain (enough for two collectors)
- 1 tube, Paintable caulk
- 1 can, Flat black high temperature stove paint
- 1 New or used water heater (52 gallon preferred 16" or 18" diameter)
- Selective surface (enough to cover front half of tank, about 2'x 5')
- Plumbing fittings, 3, 3/4" galv. pipe nipples 5", 6"and 14; 3
- 3/4" galv. male plugs (nipples and plugs may vary depending on tank)
- 3/4" galv. elbow;
- 3/4" hose bib; roll of teflon plumbing tape

TOOLS LIST

- Hack saw
- Utility knife
- Screw drivers
- Tin snips
- Tape measure
- Caulking gun
- Hammer
- Shovel
- Paint brush

- 3" 'C' clamps
- Scissors
- Surform
- Magnetic compass
- Hand staple gun
- Pliers
- Sandpaper
- Saw (circular preferred)
- Variable speed elec. drill
- Drill bits 3/16", 3/8", and 1 1/8"
- Screw bit for electric drill
- Pipe clamp over 40" (not mandatory)
- Level (24" or over)
- Extension cord
- Garden Hose (for tank testing)

Selective Black Foil Products

Product	Availability	Width	Cost per Sq. Ft.	Absorptance (100% = Ideal)	Emittance (0%=Ideal)
Sunsponge	Berry Solar Products 2850 Woodbridge Ave. Edison, NJ 08837 (201) 549-0700	24"	$2.20, 25 sqft min.	0.95	0.10
Maxorb	Novamet 681 Lawlins Rd. Wyckoff, NJ 07481 (201) 891-7976	6"	$2.00	0.97	0.10
Solar-L-Foil	Solar Components Corp Box 237 Manchester,	24"	10 ft roll=$2.50/sqft 25 ft roll=$2.40/sqft	0.95	0.11

Batch Plan #3

This solar batch water heater consists of a 30 gallon glass lined steel tank covered by a 1 ½" thick solar collector cover panel. This is designed to preheat water going to your conventional water heater or in southern climates could supply all your hot water. This system provides an excellent dollar per BTU ratio. The only precaution taken is that in northern climates, the unit should be drained for winter months to prevent freezing damage.

Parts List

1-1/2" thick x 34" x 44" Glazing Panel

Solar Components 30 Gallon Steel Tank

1" x 3" Aluminum Angle Trim

6" Wide Aluminum Flashband

1-3/16" Flat Head Screws

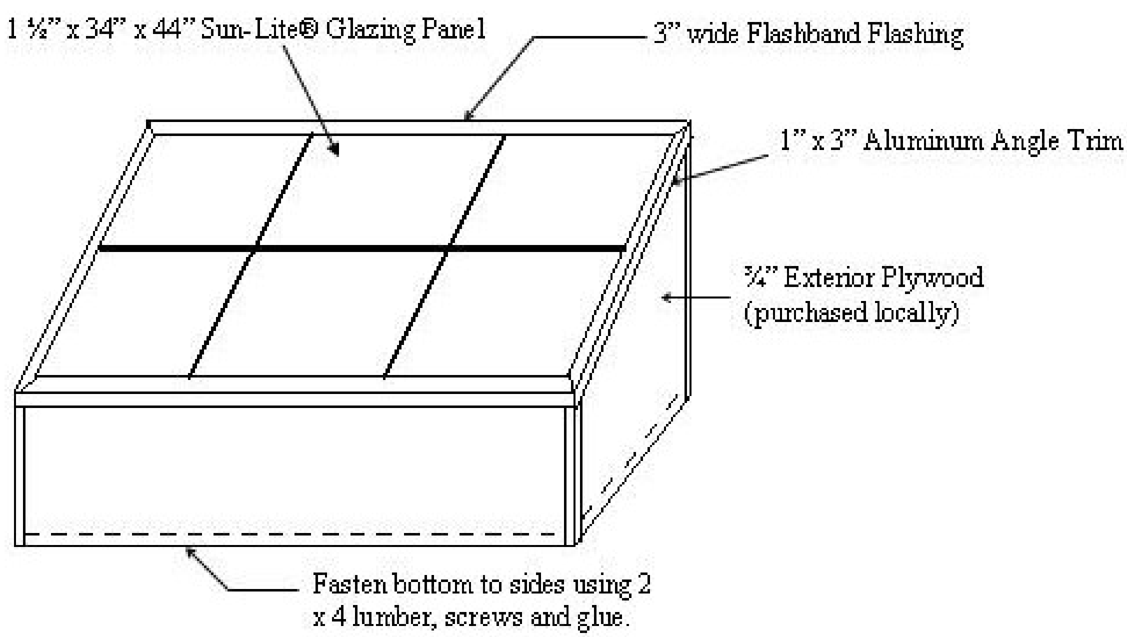
1 Can Black Spray Paint (UV-Heat type)

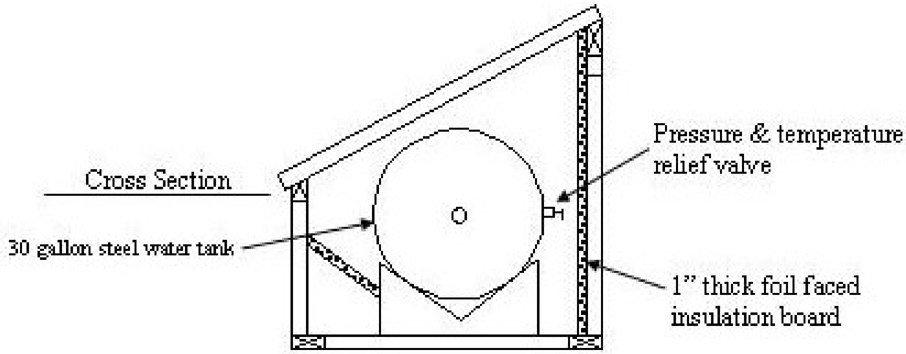
Pressure & Temperature Relief Valve (purchased locally)

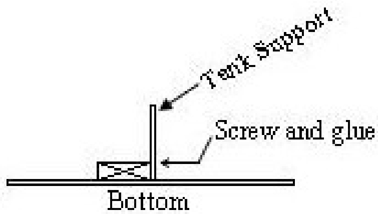
3/4" x 4" x 8' Exterior Plywood (purchased locally)

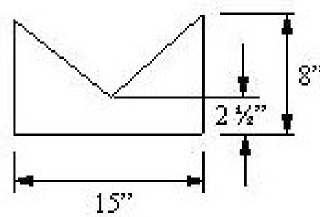
1" Thick x 4' x 8' Foil Faced Insulation Board (purchased locally)

2" x 4" x 8' Lumber (purchased locally)









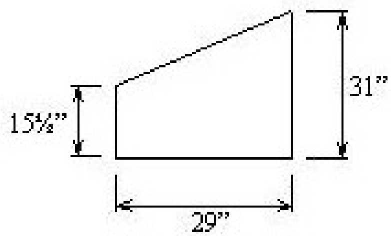
Tank Support
¾" Plywood (3-required)

Cut from ¾" Plywood

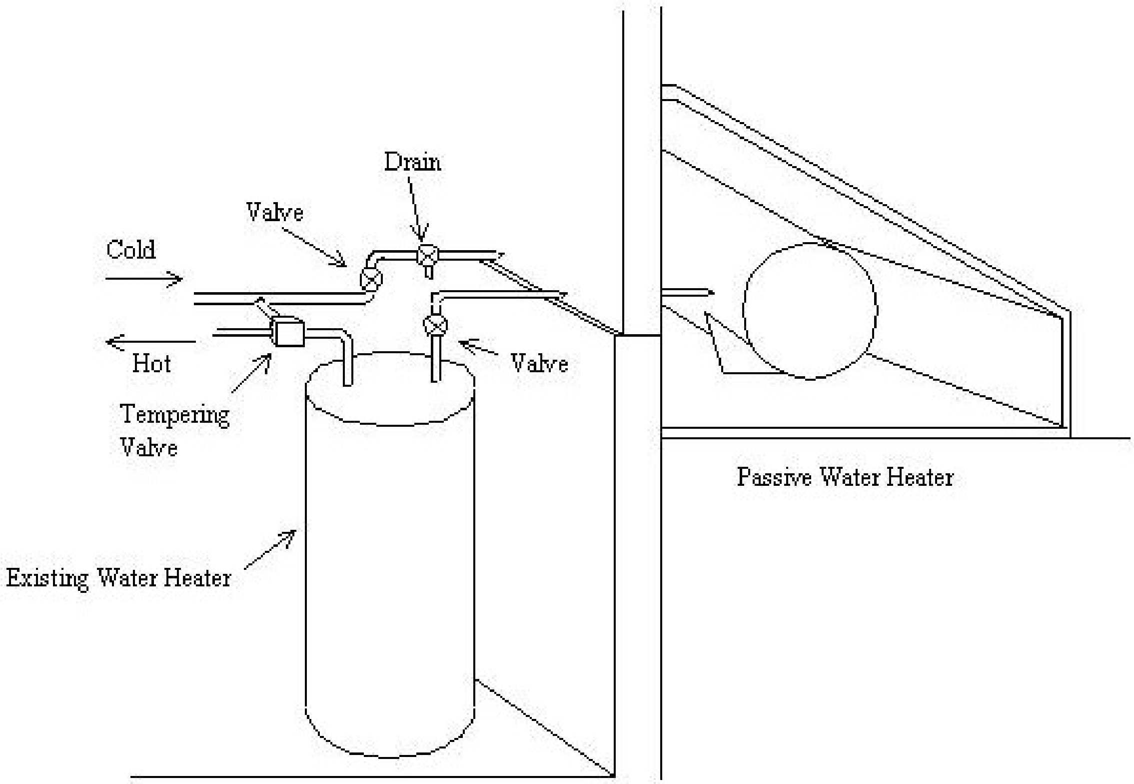
1 pc. 15½" x 44" – Front

1 pc. 31" x 44" – Back

1 pc. 29" x 44" - Bottom



Sides (2-required)



Typical Installation

Thermospin Solar Water Heater Plans

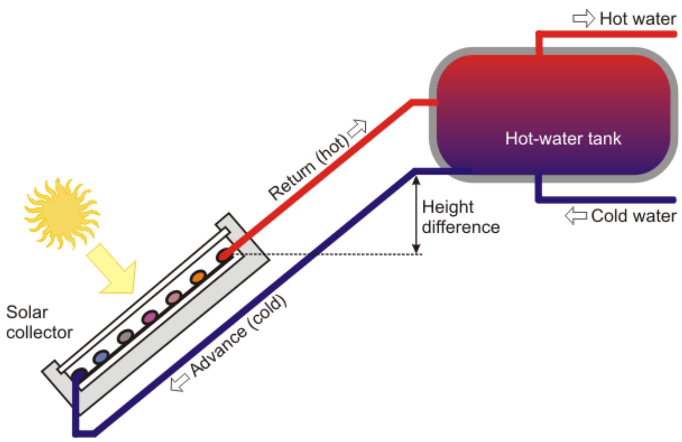
Why solar water heating?
Amount of energy used today to heat domestic water is enormous.
Compared to burning of fossil fuels, direct energy from the Sun produces heat that is almost free, environmentally clean and socially more acceptable.
Possible energy savings for hot water in sunnier places are 80 percent or more and in cloudiest climates are from 50-60 percents.

Why Do-it-yourself?
First reason is price.
Although there are many different types of solar water heating systems on the market and they are paid-off in few-year period, they are still big investment for most of the people.
Second, making of one is not too complicated, even for less experienced DIYers (from own experience), but there are few important points to remember:

- Solar water heating relies on one simple principle:
  dark colors absorbs heat
- The bigger the surface exposed to sun, more heat you get
- Heat is energy that is inclining to entropy, in other words, if not stored heat gain will be rapidly lost

How does it work?

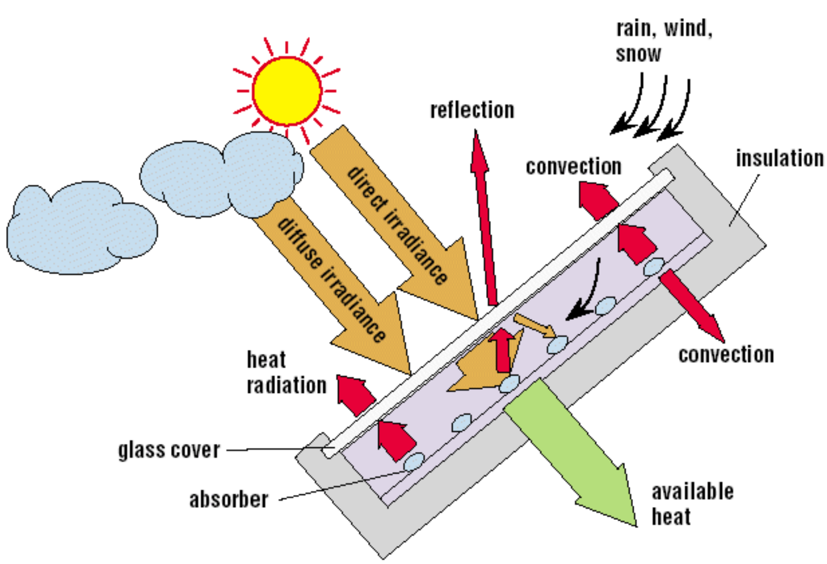
Thermosyphon system shown here is one of the most popular water heater worldwide.



Picture 1.

They are easily recognizable by the fact that the water reservoir (tank) must be located directly above the collector.
Thermosyphon systems work on the principle of heat rising. In so-called open-loop system (for non-freezing climates only), the potable water enters the bottom of the collector and rises to the tank as it warms. If tank is well insulated there will be less heat loss when there is no sun.

Heart of the system, solar collector shown below, works on the simple principle of heat absorption. It consist of network of pipes through which water is heated. On a typical summer day (sunny and warm) the fluid in the collector reaches 60-80°C. On a clear winter day (sunny and cold) it can reach 50-65°C. When is cloudy and warm it can reach 20-30°C, and on a cloud and cold day 10-15°C. As long as temperature in the collector is greater than that of your incoming cold water (10°C) your solar hot water is saving you energy.



Picture 2.

Collector

It consist of 4 main pieces put in the wood box, attached from back up:

I) Aluminum plate (back)
II) Wooden frame + insulation (mineral wool)
III) Copper pipe matrix with attached aluminum plates so called “clip-fins”
IV) Glazing cover - Polycarbonate plate (front)
See picture 4.

Materials and tools needed

	Dimenzions	Pieces
Wood pieces	2000x100x20 mm	2
Wood pieces	1000x100x20 mm	3
Wood pieces	2000x30x7 mm	3
Wood pieces	2000x10x10 mm	2
Aluminium plate	2000x1000x0,5 mm	2
Twin wall polycarbonate plate	2000x1000x4 mm	1
Aluminium foil	2000x1000 mm	1
Copper pipes, ∅ 22	2000 mm	1
∅ 15	1900 mm	5
Copper fittings	T 22/15/22 mm	8
Copper fittings	„knee“ 22 mm	2
Copper reduction	22/15 mm	2
screws for wood	80x6 mm	20
	20x4 mm	100
Mineral wool, insulation	2000x1000x50 mm	1
Black mat colour for metal + primer	750ml	1
Wood protection paint	750ml	1
Plastic holder for pipe ∅22		2
Silicone mastic	1 tube	1
Wood glue	750g	1
Soldering alloy	1 roll	1
Cleaning paste for soldering	1 tube	1

Using all these things we will obtain a 2 square meter solar collector ready to be installed.

Tools

	pieces
Screwdrivers, + & -	2
Hand woodsaw (or small electric one)	1
Portable electric drill	1
Drill for metal = 4 mm	1
Drills for wood = 3.5, 7, 22 mm	1 pcs each
Sand paper	10 sheets
Soldering lamp	1
Scissors for metal	1
Hammer	1
Rubber hammer	1
Bending tool for alu sheet, see below!	1
Paint brush	2

Copper pipe cutter or saw for metal	1
Cutter	1
Riveting tool	1
Working gloves	1
Tape measure	1

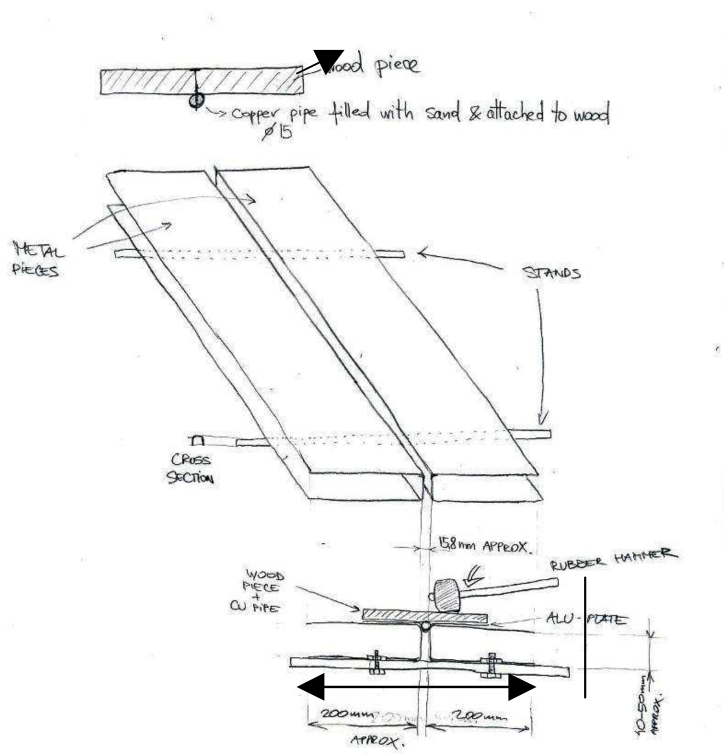
Bending tool

It is used to bend the alu-plates so they can fit on the pipes and transfer heat with bigger surface.
Needed materials are:

Steel rectangular profile 50x50, 2mm thick = 2 pcs. of 650mm long
Steel rectangular profile 30x30, 2mm = 2 pcs. of 120mm long, for stands.
Metric screws 50x6mm = 4 pcs.
Hard wood (oak) 600x120x25mm = 1pcs.

Tool can be assembled in few minutes if all these materials are provided.
Once You have this tool you can use it for future DIY collectors or lend it Your neighbor!

Hard wood



50 mm

Picture 3.

Step by step

Most important pre-phase is to calculate and to measure parts.
If the outer measures of the collector are 2x1 meter, inside box measures will be decreased by thickness of the wood pieces.(Maybe you cannot find exactly 2cm thick wood)

Depending on collector box inside measures, calculate copper matrix and alu clip-fins (later painted black mat to absorb heat). Make copper matrix that way distances between vertical pipes (15mm) are equal. That way you will have 5 alu clip fins in horizontal line and 3 in vertical line, total of 15.

So, if the inside measures are 196x96cm (2cm thick timber), copper matrix with attached clip-fins should be just big enough to fit into collector box.

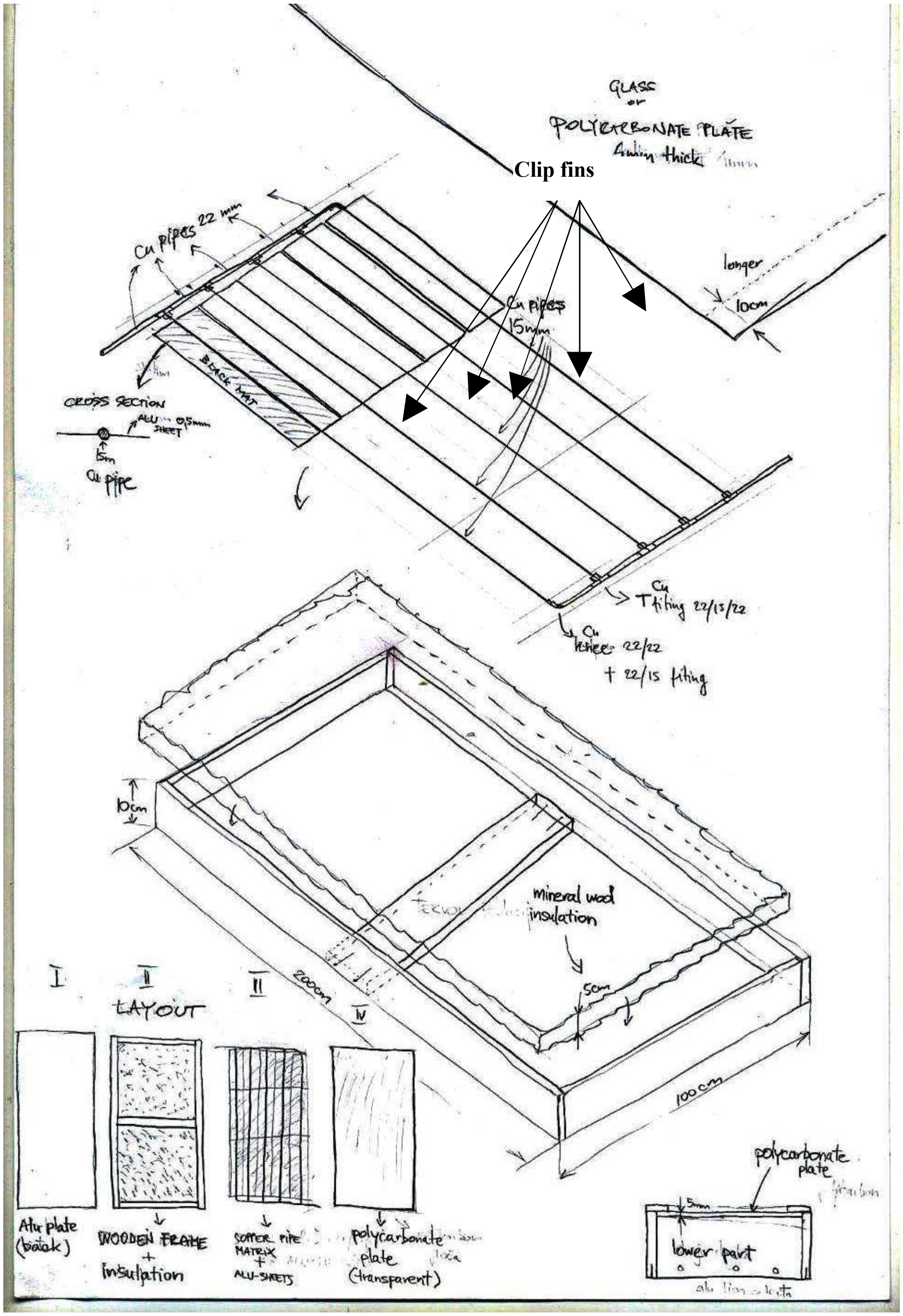
Measure how much pipe is entering the fitting (calculation is shorter for this amount), and dimensions of the fittings, and leave 2 cm on the top and bottom for the plastic pipe holder (measure it too).
First do the sketch with all measures and than start to cut the pipes.

When measuring the dimensions of the clip fins (3 per each pipe), calculate the bent part (half circle around pipe 15, see step 4).

So, clip fin width should be increased by difference between half circle (O/2) and diameter of the pipe 15mm. By formula $O=2r\prod$, it comes out:
$O = 2 \times 0,75 \times 3,14 = 4,71cm$
$O/2 = 2,35cm$
$\Delta = 2,35 - 1,5 =$ **0,85 cm**

Lengths of the clip fins will be according to the distance of the vertical pipes when it is fixed and soldered in the matrix.(from T fitting to T fitting)
For vertical pipes use 15mm, and for horizontal 22mm (standard).
Fittings used are Copper T-part 22/15/22 and two diagonally situated are knee-fittings + reduction 22/15.

Polycarbonate will be 96 cm wide(inside measure) and should be 10 cm over the bottom edge of the box. That way water does not collect and rot the box.



Picture 4. Solar collector assembly

Step 1
Constructing collector box

Wood that you use should be flat, good quality and already prepared.
Cut 2 planks 200 cm long, and 3 planks 100 cm long.
Attach them in a way shorter ones will be between longer ones, and put 3rd in the middle, parallel with back of the box. Use larger screws for wood and wood glue.
After that you can put 1st coat of wood protection paint on the box.
important: bottom plank should be 4-5mm lower, so polycarbonate can fit.
See picture 4.

Step 2
Constructing copper matrix.

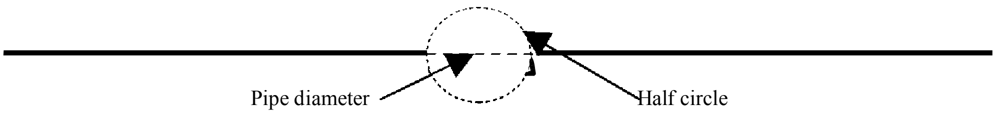
Cut the pipes, according to your measures. Use copper cutter.
You have to cut 5 pieces of 15mm, and 10 pieces of 22mm.
Pipes going in and out the matrix (22mm) should be long enough to reach 10cm out of the collector box, in order to leave space for fittings.
After that it should look like on the **picture 4.**
Than you have to solder the joints.
It is maybe the most difficult part for DIYers. Try to do it with somebody who is experienced, (plumbers usually know it!). Once you try, it goes relatively well.
After the soldering, check if the matrix is waterproof, pour the water in one side of it and check carefully every joint.

Soldered joints will look like on the picture 5.

Picture 5.

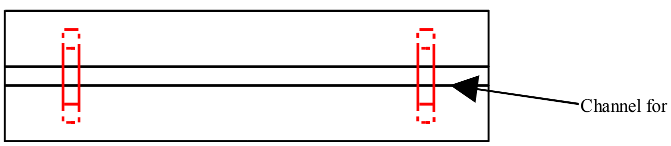
Step 3
Making alu clip-fins

You can find aluminum sheet in 2x1m dimensions,0,5mm thin, and it should be just enough for the clip fins. After calculating dimensions of the clip fins, mark it on the sheet, and cut it with scissors. You need 15 clip fins.
Than put fin on the middle of the the bending tool (mark the center line along the fin), and press it with copper pipe attached to piece of wood. See **picture 3.** Good rubber hammer will make lot of noise :) , and bend the alu fin fast.
After the bending profile should look something like this.

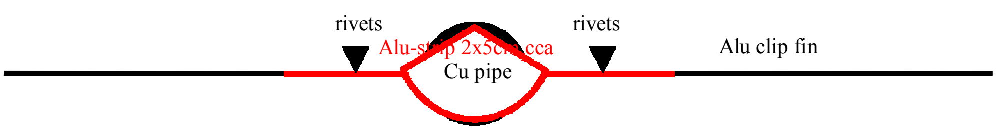


Step 4
Attaching clip fins

As said before, you will have 3 fins per vertical pipe, total of 15, so fins should be placed that way on the matrix. They will probably be too loose on the pipes and one of the way to fix them is to cut small pieces of alu sheet 2x5 cm approx. (you will have some leftover) and rivet each fin with 2 pieces. First drill 4 holes on each fin(4mm drill), in the middle of red dashed marked areas (on each side of the pipe channel). That will be places for small alu strips. See below.



Than drill a hole for the rivet on the one side of the small piece. After riveting the one side, drill the hole through other side and rivet it. Use riveting hand tool and rivets small enough to hold firmly. Good and firmly attached fins on the pipe will allow proper heat conduction.
There is profile view below.



After constructing whole matrix you can paint top side with metal primer and leave it to dry (3-4 hours) and than paint it (1 or 2 coats) with black mat color for metal, resistant to heat.

Picture 6. Completed copper matrix with attached clip fins.

Step 5.
Attaching back side

While the paint is drying, you can put back side of the collector box. Attach aluminum sheet (2x1m, 0,5mm) to the wood frame using smaller screws. If the plate is bit bigger, you can bend it around edges with hammer.

Picture 7.

Step 6.
Insulation

When you have the back of the box you can put insulation in.

Insulation used is mineral wool, but if you can find more environmentally friendly/recycled materials such as coconut-fiber or cellulose based insulation use it.
Dimensions will be like inside of the box, so cut mineral wool if needed.
You can find pieces of 100x50cm, 5cm thick.

Than put thin aluminum foil on the insulation and fix it with staples.

Step 7.
Assembling matrix to collector box

At this stage you should have box with insulation and copper matrix with clip fins painted black. They have to be attached together.
Put matrix on the box and mark place where you will cut wood and drill hole.
If your calculations were right, matrix with fins will fit in the box and you will have 2cm spacing on top and bottom for the plastic holders.

On the one side drill 22mm hole for the entering pipe and on the diagonally opposite drill same hole and than cut cone piece of wood to lay the exiting pipe (it can be vice versa). After fixing the matrix with plastic pipe holders, put wood cone piece back and glue it with wood glue and sawdust mixture.
You can also seal other side with glue+sawdust.

Matrix should be placed between insulation and polycarbonate and ideally should not touch any.

Wood cone piece first cut than put back and glued

Picture 8.

Step 8.
Putting polycarbonate sheet

In order to put polycarbonate sheet, support beadings should be fixed to inner side of the box. Attach it with small screws that way from the top edge of wood box to the beading there is 4mm (thickness of the PC sheet).

For the support beadings use wood pieces, 200x1x1 cm and cut it according to inner measures.

Top edge of wood box

Support beadings

Picture 9.

You can put PC sheet now, and remember to leave approx. 10 cm overhang on the bottom, for rain not to enter the box.
Than put top beading (200x3x0,7 cm) along the longer sides and on the shorter side put only the top one. Attach it with smaller screws, and put silicon mastic between PC sheet and top beading. That way you will close the collector.
Make sure that you paint top beadings with wood protection paint at least once before attaching, and after it paint all wood once again.

Picture 10. Fixing top beading with small screws.

Finnaly, your collector is ready to install!

There is drawing how you should connect it to water reservoir and thermosyphone system.

Most of the pipes used here are plastic water hoses, except one that goes up from collector to reservoir.(very hot water in sunny conditions). Fittings are regular plumber messing fittings.
"Holender" fittings used are simple to assemble and disassemble.
Reservoir is HDPE for potable water, 150-200 liters.
The water inside the reservoir is not under pressure so plastic one is good choice.

Valve with float bowl is one usually used in older toilet water tanks. It is self-regulated,so when the level of water in the reservoir during shower is falling, float bowl will fall to and open the valve to feed new water.
Be sure that water pressure on the valve is not too high.

Of course remember to face your small solar water heater to Sun side (South on the North hemisphere), and enjoy warm shower.

Materials needed for this system are:
1) messing fittings (x 3):
   consisting of:
   - inside thread piece (15mm to 1/2 inch)
   - outside thread piece (1/2 inch to water hose)
   - rubber plate
   - metal plate
2) "holender" fittings for 22mm pipe (x 2)
3) mixing valve for plastic hoses
4) one way valve for water
5) metal holders for hoses
6) "toilet" valve with float bowl
7) Y-part, plastic
8) shower tap
9) copper pipe 15mm
10) knee fittings; 15mm and 22mm
11) metal hose holders (10 pieces)
12) HDPE (High Density PolyEtilen) reservoir 150-200 litres
13) plastic water hose

Conclusion

I realize you have been given a ton of information. I suggest working with a batch water heater as your first try as these are easy to build. I know many people who have reduced their electric bill a great deal after subsidizing the water heater with a batch solar water heater.

Good luck with your project. Have fun with it.