FUNDAMENTALS
OF SOLAR ENERGY

by Radiantec Company

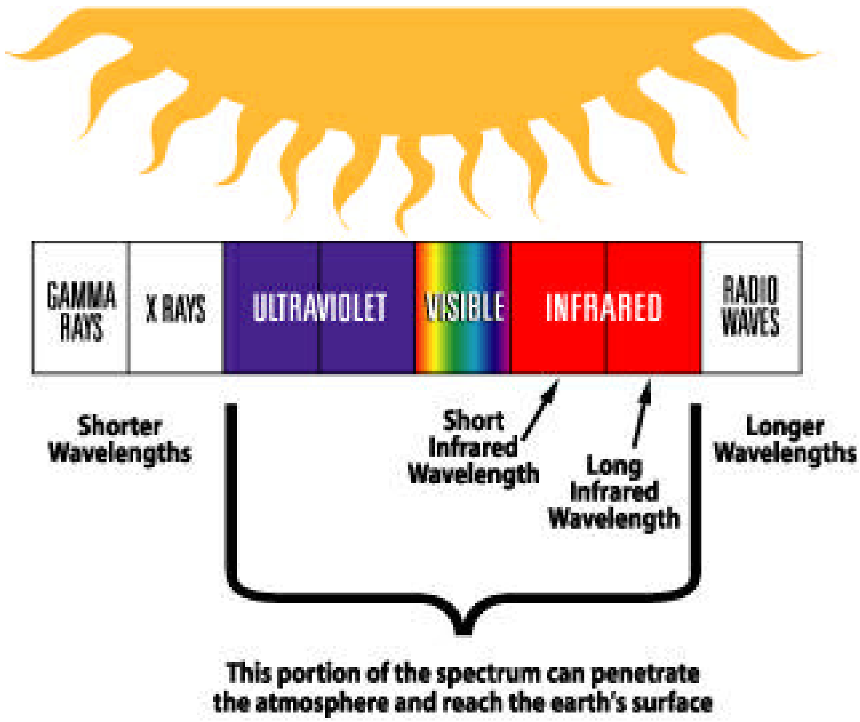
What is Solar Energy? What is the Sun?

The sun is a star, not much different from the billions of others in the universe. The main difference to us is that the sun is *our* star. Because we are much closer to the sun, its energy is more intense than that of the other stars and we can make use of its energy to meet our needs.

Our sun and the other stars are nuclear reactors that fuse hydrogen atoms together to form helium atoms. A great deal of energy is released in the process. The reaction is similar to what goes on in the explosion of a hydrogen bomb. The sun's power comes from the equivalent of many thousands of hydrogen bombs all going off at the same time.

We are fortunate that the sun is 93,000,000 miles away and that by the time the energy gets to us, it is gentler and more widely dispersed than it is at the surface.

Solar energy comes to us in the form of electromagnetic radiation.



When this solar energy comes into contact with matter, one of three things will happen to it:

1. **It may be reflected off of the matter, or**
2. **It may be transmitted through the matter, or**
3. **It may be absorbed by the matter and turned into heat.**

These three phenomena have much to do with the design and use of solar collectors.

SOLAR COLLECTORS – There are three main types of thermal solar collectors, low temperature, medium temperature, and high temperature. What you get out of a solar collector is the difference between what went into the collector and what the solar collector lost to its outside environment.

LOW TEMPERATURE SOLAR COLLECTORS

The low temperature solar collector has nothing to lose to the outside air environment because it operates at or below the outside air temperature. A solar swimming pool collector is a typical example. They are the simplest and most efficient collectors available, but they are limited to low temperatures. You just hang a black plastic mat out in the sun,and run pool water through it to take the heat away.

The black plastic receives and absorbs 95% of the available solar energy, with only a small amount reflecting away. You get to keep all of this energy harvest because the low operating temperature.

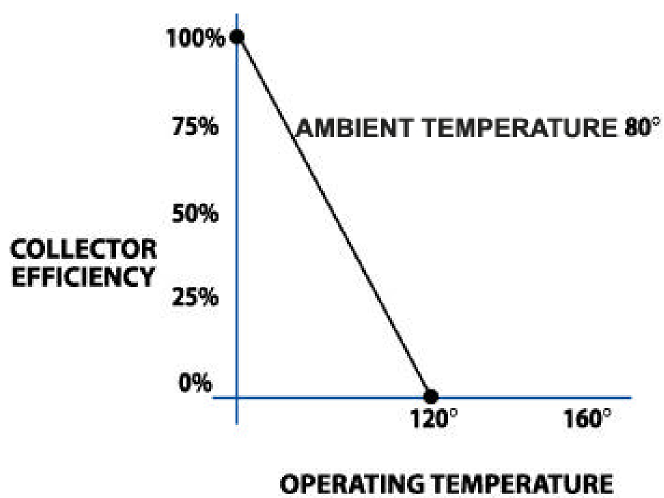
But if the operating temperature goes higher, the efficiency goes down rapidly.

Heat is transferred (and in this case lost) in three ways.

1. **by conduction** – When the molecules of one material come in contact with the molecules of another, heat is transferred from the warmer one to the colder one by kinetic energy of the molecules.
2. **by convection** – When a warm surface heats the air that is in contact with it, and the air flows away by gravity.
3. **by radiation** – All matter gives off long wave infrared radiation in proportion to its temperature. If the object gives off more radiation than it receives from the environment, it will lose heat.

Because the low temperature solar collector does not control any of these heat loss factors, performance falls off very rapidly as collector temperature rises above the ambient temperature.

Solar Collector Efficiency (Low temp collector) vs. Operating Temperature.



MEDIUM TEMPERATURE SOLAR COLLECTORS

But many of our heating requirements occur at temperatures well above the ambient air temperature. At these higher temperatures, simple collectors rapidly reach the point where they are losing as much heat as they are receiving, and the efficiency drops to zero.

What we need to do is construct a heat trap; something that will let the sun's energy in, but not let it out again.

With respect to the three heat loss parameters identified above, here are some of the things that we can do:

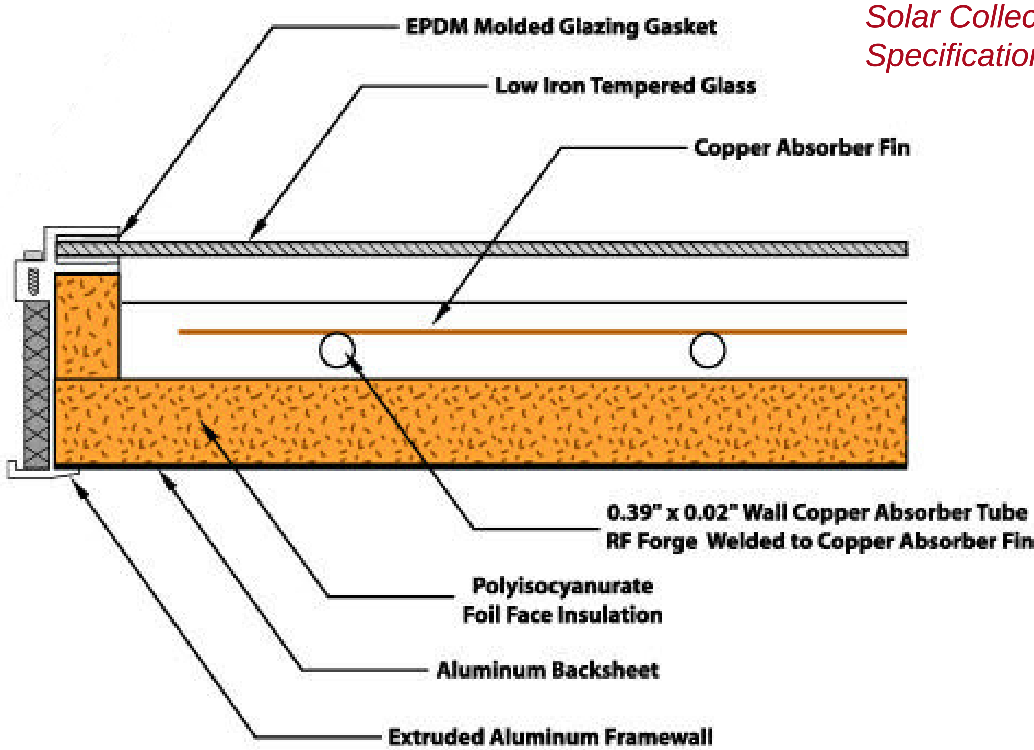
1. **Conduction** - We can put the absorber plate inside an insulated box. In that way, heat energy will be less able to escape by conduction.

2. **Convection** - We can put a cover over the absorber plate. In that way, when the absorber plate heats the air above it by conduction, the heated air is not able to float away and escape. Of course, we will be looking for a cover that lets the sun's energy in.

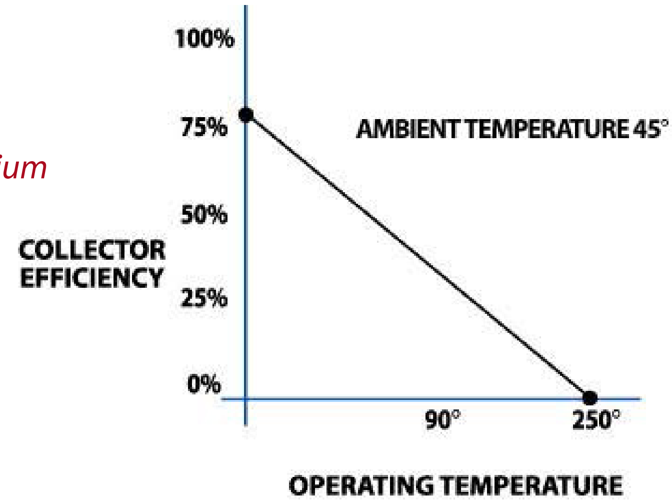
3. **Radiation** - We want our cover material to transmit short wave solar energy coming in, but block long wave infrared radiation going out.

Our cover material will be glass. There are only a few materials that will meet our requirements. Carbon dioxide will meet the optical requirements, but it wouldn't make a very good cover. Some plastic will work, but they are not stable enough at higher temperatures.

Solar Collector Specifications



Solar Collector Efficiency (Low-Medium temp collector) vs. Operating Temperature.



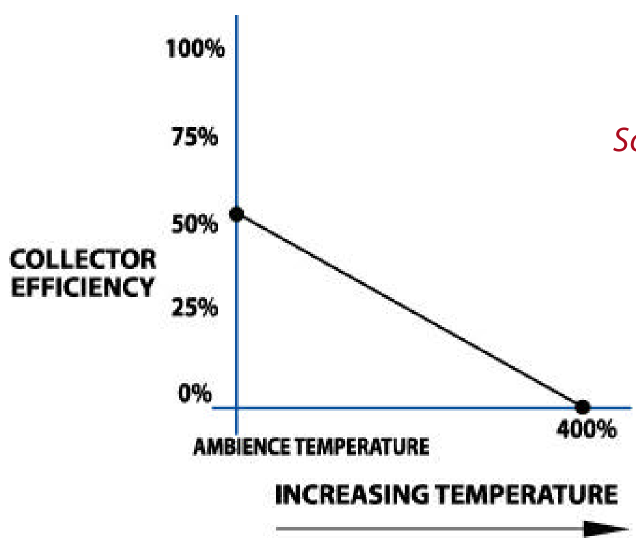
This is where we have arrived at after implementing the above. We have an insulated aluminum box with a black absorber plate in it and a glass cover sheet over it.

Now, we will get to keep much more of the solar energy that comes into the solar collector even though the collector is operating at higher temperature. <u>But there is a tradeoff.</u> We cannot find a perfect cover-sheet. The glass cover-sheet will reflect about 10% of the incoming solar energy and absorb another 14% for a loss of about 24%.

If we want to work with higher temperatures, the solar collectors will cost more money, and we will lose some of the available solar energy right from the start.

HIGH TEMPERATURE SOLAR COLLECTORS

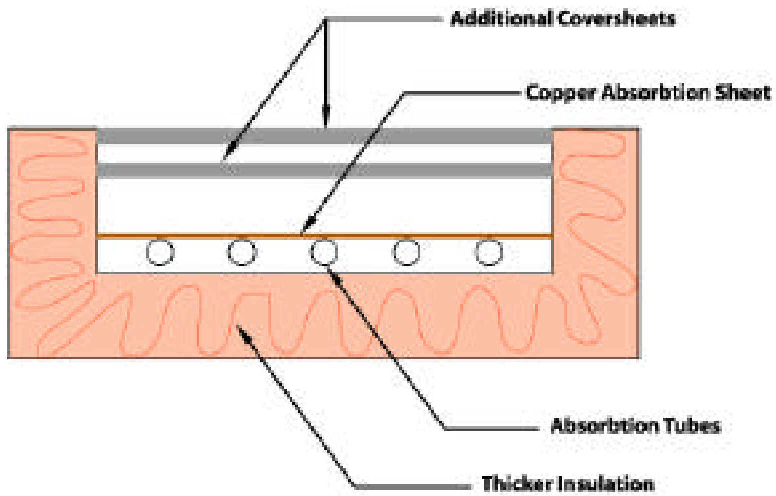
Now, lets look at the high temperature collectors. We can indeed conserve more of the energy that comes into the collector in a couple of ways. We can add thicker insulation, or we can add additional cover sheets, or we can evacuate the air from the solar collector. All of these measures will result in a collector that can operate at a higher temperature, <u>but there will be increased tradeoffs.</u> The measures that conserve even more energy will prevent even more solar energy from striking the absorber plate.



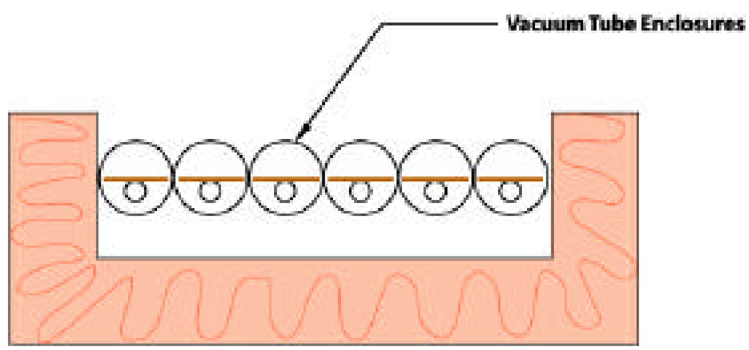
Solar Collector Efficiency (High temp collector)

More cover plates will reflect or block even more solar energy from getting in. Thicker insulation and evacuated tube collectors both result in less solar aperture, (Less black area in the sun.) so again, less solar energy will arrive at the collector in the first place.

Solar Collector with Double Glazing



Evacuated Tube Solar Collector



CONCLUSIONS

1. Low operating temperatures are good. High operating temperatures are bad.

2. High temperatures are not the same as high efficiency. There are more BTU's in a bathtub full of warm water than there are in a pot of very hot water. (BTU stands for British Thermal Unit and is a measure of heat. It is the amount of heat needed to raise one pound of water 1° F in temperature.) When you are making heat, BTU's are the name of the game, not temperature.

3. If you want to take a bath, don't make high temperature steam and then cool it to 105° F. Find something that will make 105° F water from the beginning.

4. Simplicity has many advantages in solar design. Low-medium solar collectors are efficient and reliable. They do not have the material degradation problems that high temperatures cause, and they are safer. Abide by the KISS Principle. (Keep it simple, stupid.)

STORING SOLAR ENERGY

If solar energy is going to be very useful to us, we will have to figure a way to store it. After all, the sun doesn't shine every day, and it never shines at night.

As we investigate good ways to store our solar energy, we will need to understand certain properties of matter.

1. **Thermal mass (or heat storage capacity)** - This is the ability of matter to store heat.

2. **Conductivity** - This is the ability of matter to transfer heat from one material to another by being in contact with it.

3. **Insulation ability** - This is the ability of matter to resist the flow of energy from one material to another

When we want to store heat, we will select materials with high heat storage capacity.
The following chart shows the heat capacity of several common materials.

Heat Storage Capacity of Common Materials

MATERIAL	Heat Storage Capacity BTU/Cubic ft./°F
Water	62.5
Cast Iron	54.0
Concrete	31.7
Glass	27.7
Oak	26.8
Brick	24.8
Earth	20.0
Gypsum	20.3
Pine	18.1
Air	0.018

When we want to move heat from one place to another, we will select a material with high conductivity. The metals, such as copper, aluminum, etc. have high conductivity.

When we want to prevent the movement of heat from one place to another, we will select a material with low conductivity.

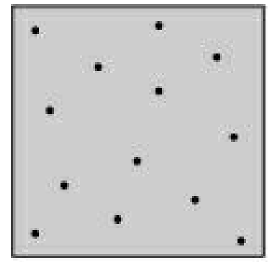
If a material is a gas, the molecules are spaced far apart. There are fewer molecules in a given volume of materials. Because heat is the kinetic motion of molecules, and because there are fewer molecules, a gas will store less heat than a solid. We would also expect a gas to conduct heat less effectively than a solid because there are fewer molecules to move the heat to the other material.

Gas - Low heat capacity - low conductivity - high insulation value

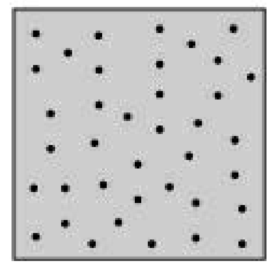
Solid - High heat capacity - high conductivity - lower insulation value.

SPECIAL CASES - Lets look at some special cases.

Gas Molecules



Solid Molecules



Water - Note the very high heat capacity of water. This is because of the particular shape of the molecules. It has a "polar" shape such that the molecule has a positive charge at one end (the hydrogen end) and a negative charge at the other end (the oxygen end). They tend to stick together better like little magnets.

Without getting into too much atomic physics, this means that it takes a lot more energy to make the molecules move, and therefore, it takes more energy to warm it up and it will give off more energy as is cools to the original temperature. This means that:

1. Water is a good material to use for storing heat or cooling.
2. Water is a good material to transport heat. (Because you don't have to move that much of it.
3. Water is an expensive material to heat, and hot water is expensive to waste.

Metals - Metals are very good conductors of heat because the molecules form a particular kind of crystal structure that conducts heat better.

SHELTER - A knowledge of these fundaments of nature leads to sheltering concepts that our ancestor knew well and that some are learning more about today. Our ancestors had to make maximum use of what nature provides for free because there were no fossil fuels to misuse. We do not have to give up our lifestyle in order to live more sensibly. We only have to look at what we can do with what is around us and what nature provides for free.

Living with materials that store heat.

All of our ancestors chose shelters made of materials that store heat.

Our Paleolithic ancestors lived in caves.

This modern time cave dwelling in Petra, Jordan is called a "Troglodyte" and has been lived in for at least 10,000 years

A more contemporary Greek home on Santorini uses masonry construction and makes good use of the sun.

Our 17th century ancestors built log cabins to protect their families from the extremes. And many people still use this intelligent building method today.

Some of our earlier ancestors used stone construction to naturally buffer natures extremes in temperature.

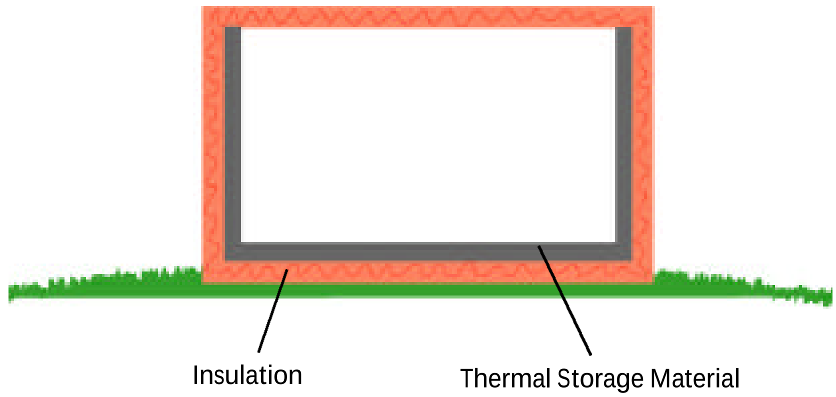
The Pueblo and Auasazi Indians faced their buildings directly south and used material that would store heat and cool temperatures.

There are plenty of ways to use what we have learned about the natural properties of materials to fashion modern contemporary buildings that are sensible and sustainable.

We will use materials that insulate around the outside perimeter of the building. Materials that have air cells within them, such as fiberglass batting, or foam boards such as Styrofoam or polyurethane are useful.

Then we should incorporate materials that will store heat within the building. Materials with high thermal mass such as concrete, steel, earth, sheetrock, water, will be good, as well as any other materials that are heavy. Often we can incorporate thermal mass into the building simply by placing the insulation in a place where it will facilitate thermal mass. For instance, if you have concrete foundation walls, insulate on the outside of the walls and not on the inside so that the thermal mass of the concrete is incorporated into the building.

Building with Thermal Storage Mass



Now, we have a building that is a considerable improvement over standard construction all by itself. This building can just "coast" through periods when the outside ambient temperatures are out of the comfort zone. If it is warm during the day, and cold at night, the occupants of this building do not have to buy any energy at all.

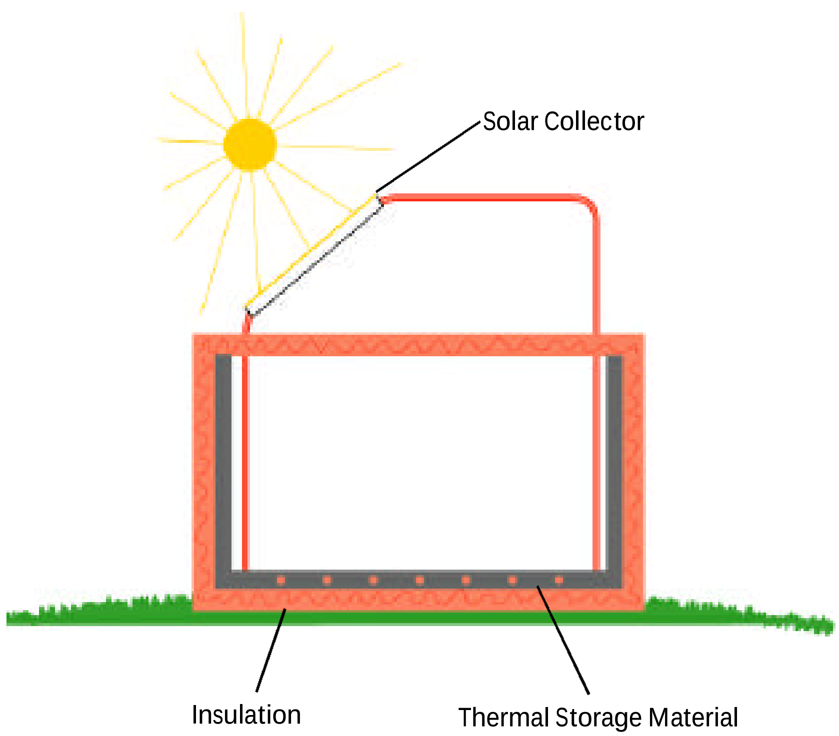
Those who live in buildings that do not have thermal mass may have to use air conditioning in the daytime and the heating system at night in order to remain comfortable within a 24-hour period. That is a sad situation.

The occupants of a house with thermal mass will need almost no energy during the "swing seasons" of spring and fall when temperatures are comfortable at some point during the day. They just open windows, as they would normally incline to do when the weather is comfortable outside.

When it is consistently cold outside and simple comfort management is not enough to maintain comfortably warm temperatures, the thermal mass will perform double purpose. It can also serve as the storage vehicle for solar collectors.

Then we can use medium temperature solar collectors and underfloor radiant heating tubes to inject solar heat into the building when it is available. The thermal mass of the building will help to tide the building over in periods when the sun is no longer available.

Building with Thermal Storage Mass & Solar Collectors

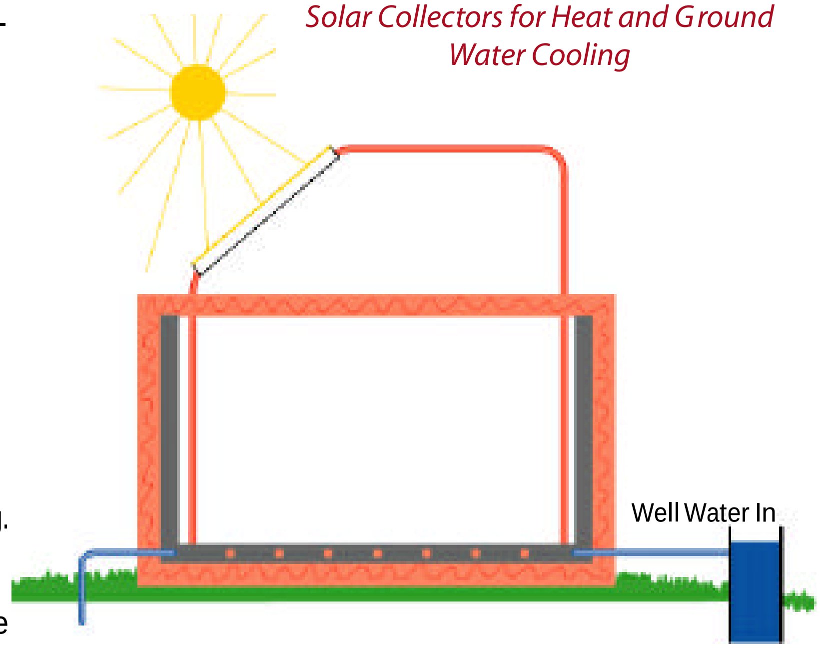


If we need supplemental cooling for the building, it might make sense to look to water to help us. Remember water has the highest thermal mass of any common material.

Water flows through our lives every day; in fact a lot of water flows through our lives every day. A typical house may use 400 gallons per day or more.

We can let this cold water "pass through our lives like waiters in a restaurant",* or we can make use of it as an absolutely free, natural and environmentally benign source of cooling.

Building with Thermal Storage Mass & Solar Collectors for Heat and Ground Water Cooling



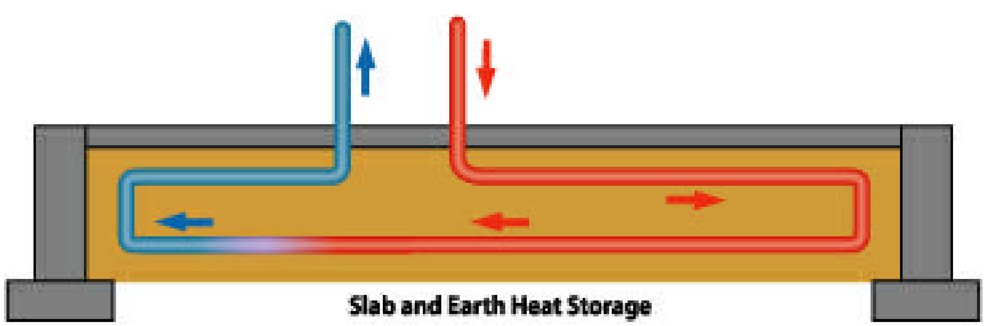
We make use of it by passing it through the floor so that the water can take heat out of the house. The relatively cooler floor will lower the temperature of the entire building in a similar way that a warm floor warms the whole building. In the manner of radiant heat transfer, the floor receives more heat than it gives off, thus it is warmed by radiant exchange while the rest of the building is cooled.

Ordinarily, cooling of the floor does not carry a liability of condensation and moisture problems. But, in very humid conditions, an air conditioner can be run at a low leveling order to lower humidity levels.

S. King., Stand by Me.

LONG TERM PASSIVE HEAT STORAGE

The following detail can be used to store a large amount of heat.

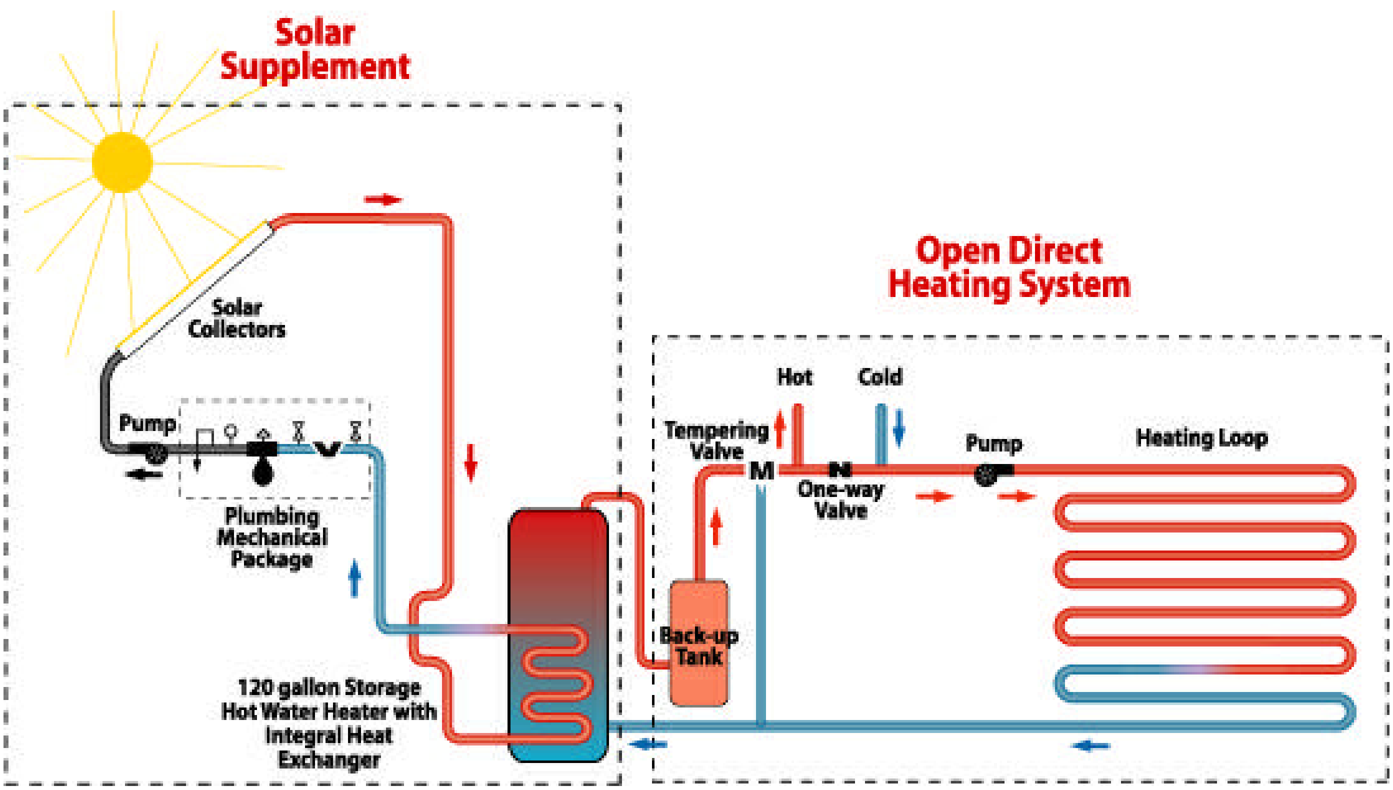


In many cases, this detail has little extra cost associated with it. If about 1 foot of topsoil must be removed before construction,and if the elevation of the building should be 1 foot above grade to drain rainwater away, there will be a need to bring in 2 feet of fill anyway.

Extensive research has shown that this approach will enable high solar heating percentages in difficult climates such as Northern Vermont. A US Department of Energy report is available from Radiantec, and a scientific paper (in technical language) is available on our website.
Go to radiantsolar.com/libraryindex.html

USING WATER STORAGE

If we note that water has the highest heat storage capacity of any common material, and then, if we also note that a domestic hot water heater is usually provided in most buildings, we can readily see the advantages of combining heat storage in water, domestic hot water, and solar heating.



This is one detail that can be used in buildings that do not have the opportunity to store large amounts of heat within the building materials.

1. The domestic hot water heater provides heat for the building space.
2. A solar heating system makes and stores domestic hot water for space heating as well as domestic hot water.
3. Free cooling is provided by the use of water for domestic purposes.

Go to radiantsolar.com/optionII.html