Construction of solar collectors for warm water

Practical guide

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Safe energy for all

Women in Europe for a Common Future | WECF

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About WECF

WECF is an international network of over 100 women's and environmental organisations in 40 countries, implementing projects and advocating globally for a healthy environment for all. WECF's sustainable energy demonstration projects are implemented in the EECCA region (Eastern Europe, Caucasus and Central Asia).

About BMU / ICI

The International Climate Initiative of the Federal Republic of Germany ICI has been financing climate protection projects in developing and newly industrialising countries and in transition countries in Central and Eastern Europe since 2008. The International Climate Initiative receives funding from emissions trading and thus represents an innovative financing mechanism to support partner countries in the area of climate protection. With this new form of cooperation the Federal Environment Ministry supplements the existing development cooperation of the German government.

Solar water heaters

Our projects

The extensive EECCA region, including Eastern Europe, the Caucasus and Central Asia, has great potential for renewable energy, especially solar energy. WECF and its local partners work together with communities, universities and innovative businesses to demonstrate affordable energy solutions, using local knowledge and materials. In terms of solar energy, WECF and its partners have developed a low-cost, highly efficient solar collector model that is easy to build with locally available materials. It can be used all year round, even in harsh winter weather.

Solar collectors

Warm water is important for comfort and hygiene in daily life. Worldwide, water is traditionally heated in households with various fuels that are usually limited and often expensive. Especially in rural areas, extensive use of these fuels has severe impacts on the environment, such as local deforestation from fuel wood collection, as well as health impacts including respiratory problems in women and children from burning unsafe fuels like plastic waste.

This brochure shows how to use energy from the sun to heat water for your home.

The sun reaches everywhere on Earth, shining for all. Solar water heaters, also called solar collectors, use the energy from the sun to heat water. The solar collector can be used to heat water for showers, for use in the kitchen and, depending on the size, also for home heating. Fuels and resources previously used for heating water can be saved.
Even in countries with little solar radiation, this form of energy can be used. For example, in Germany many people have solar collectors despite the fact that solar radiation in this more northern country is weaker than in other parts of the world.
There are different types of solar water heaters, but all are based on the simple idea that a black surface absorbs the sun's heat and transfers it to the water. The easiest models can be constructed with simple materials and do not need any pumps or other electric devices. An effective solar collector even can be used in winter, due to the use of antifreeze.

Content

Theory: Solar water heaters

Components of a solar water heating system

Solar collector

The collector collects the energy from the sun and converts it to heat.
The flat-plate collector consists of:

1. a metal plate absorber of black colour, which intercepts and absorbs the solar energy, with metal tubes for fluid circulation welded to the metal plate
2. a frame (wood)
3. a transparent (glass) cover that allows solar energy to pass through but reduces heat loss from the black absorber plate
4. an insulated backing, reducing heat loss from the absorber.

The collector is connected to a hot water tank.

Hot water tank with heat exchanger

The heat exchanger transfers the heat produced in the collector to the warm water tank. It is a spiral (made from metaloplast or copper) which is put into the tank. A heat exchange fluid circulates through the heat exchanger spiral, heating the water in the tank. A mixture of water and propylene glycol (which is used in the food industry) or antifreeze can be used as a heat exchange fluid to protect against damage from freezing. For hygienic reasons, the water in the warm water tank should be well protected from the heat exchange fluid, which may be toxic. In the warm period of the year, the system can be run with normal water.
The hot fluid from the collector circulates through the spiral and heats the water in the tank.
as a heat exchange fluid to protect against freeze damage.

The length of the exchanger and the size of the tank are interrelated with the surface of the collector, as it is shown in the table.

Collector surface	Tank capacity	Heat exchanger length
2 m^2	100-200 l	6-7 m
3 m^2	150-300 l	9 m
4 m^2	200-400 l	12 m
etc	etc	etc

On page 16, you will find the instructions for building a 2 m^2 solar collector with a 200 l tank. The dimensions can be varied depending on your warm water needs.

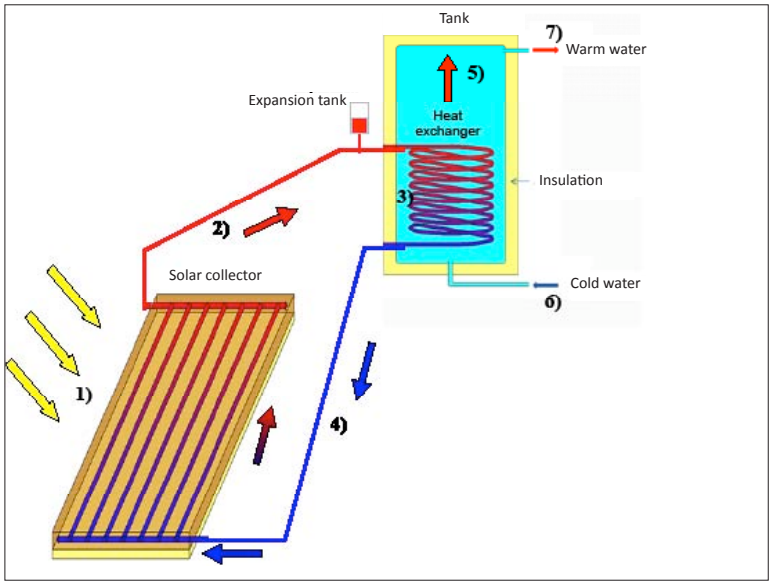
Theory: Solar water heaters

The principles of water circulation without pump

The solar collector system is a passive system requiring no electricity or pumps. The hot fluid circulates between the collector and the tank by convection, relying on the simple principle that warm liquid always rises.

The principle and operation of this solar system is as follows

1. The sun heats the fluid in the collector.
2. The heated fluid goes up through the collector and the pipes into the tank .
3. When the hot fluid enters the tank, its heat is transferred through the heat exchanger to the water in the tank.
4. As the fluid cools, it goes down the spiral and drains back into the collector from an outlet on the lower part of the tank.
5. The water heated in the tank goes up to the top of the tank.
6. The cold water from the fresh water supply is drained into the tank
7. Output of hot water is accessed at the upper part of the tank



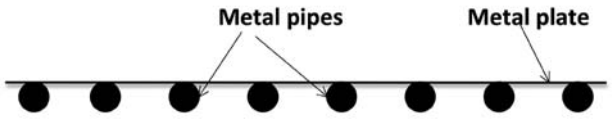
As long as the sun shines on the collector, fluid in the absorber pipes is heated and goes up to the heat exchanger in the tank, where it transfers the heat to the water in the tank, so there is a constant circulation. This process provides a tank full of hot water within just a few hours of sunshine on a sunny day.

Practice: Solar water heaters

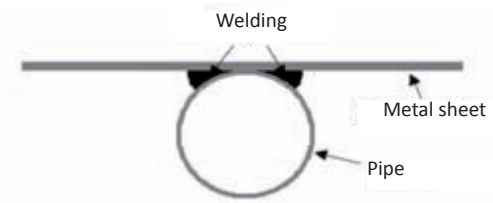
A closer look at the different parts of the solar water heating system

Metal flat-plate absorber

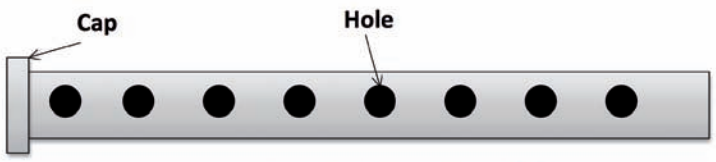
The absorber consists of a metal sheet welded to metal pipes. This gives the absorber a big surface for absorption of solar radiation, heating the water quickly. Usually an absorber for domestic needs is about 2 m^2 in size. The principle is to have a number of vertically aligned pipes, connected with two pipes of greater diameter placed horizontally, as shown at right. The water intake and outlet pipes must be placed parallel to each other, with the water intake (lower part of the absorber) and outlet (upper part of the absorber) on different sides of the panel (diagonal).



Cut view of the absorber plate



All connections between the various elements of the absorber are welded.
For better heat transfer from the metal plate to the pipes, the type of connection is important. The weld must be continuous along the whole pipe, as opposed to spot welding. And it is very important that the metal sheet and the pipes fit closely against each other. Other types of connections than welding (such as using a wire) are not useful, being considerably less efficient. The picture at right above shows a cross section with welding positions specified. To fix the vertical (long) pipes with the two horizontal pipes it is first necessary to drill holes in the two horizontal pipes matching the diameter of the vertical pipes. The distance between the holes should be identical. The picture below shows the pipe with location of the holes (for the exact dimensions see page 19).



Pipe with location of holes

Practice: Solar water heaters

To prevent water leakage, a metal cap must be welded at one end of each horizontal pipe. Good welding is needed to achieve a perfect seal. At the end of the welding, the absorber panel with its pipes is filled with water to test for leakage. Afterwards the metal sheet is painted black from above for better absorption of sunlight.
Important: welding and metal cutting work should only be performed when wearing a helmet shield and gloves.

Frame

The absorber is put into a wooden frame, covered with glass. The wood for the frame needs to be very dry, and the frame needs good insulation to keep the heat inside. The glass cover and the frame protect the collector and help retain the heat. As in a greenhouse, the sun's rays enter through the glass and heat the collector, and the glass prevents the heat from passing back out. Like the absorber, the frame is painted black, to better absorb sunligh. The glass also blocks air motion across the absorber. Without the glass cover, the collector would quickly lose heat due to wind, rain or snow, or cold outside temperatures.

Black paint

A special solar varnish is recommended for painting the absorbing parts of the collector because regular black paints can evaporate when hot, causing the cover glass to turn black. If there is no solar varnish available, you should where possible use a non-toxic (water-based) paint, e.g. pigment paint. The paint has to be completely dry before you put on the glass cover, in order to avoid any condensation from forming.
Important: Use of a respiratory mask and safety glasses is recommended when working with paints and varnishes.

Practice: Solar water heaters

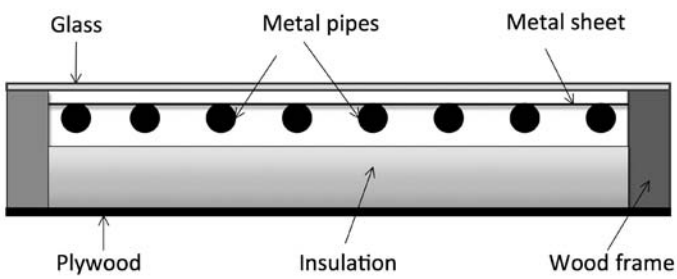
Heat insulation

Insulation is the main factor in preventing heat losses. Proper insulation of the tank and connecting pipes is important for the collector's efficiency. In a well insulated tank, the water will stay warm for several days, even when there is little or no sun.

- The insulation must be heat-resistant, otherwise it will melt if it gets too hot.
  Natural materials can be used for the insulation, such as sawdust or cellulose (they can be used at the maximum temperature of 100°C, i.e. for the tank and pipes), wool and also mineral wool and glass wool.
- The insulation should be at least 5cm thick.
- To assure reliable insulation for the tank, it can be wrapped for example in mineral wool and then inserted into a larger tank (see photo at right).
- Insulation must be installed so that that absolutely no water can penetrate the collector. If the insulation get wet it will lose its insulating capacity.

Important: Mineral wool and glass wool (fiberglass) are hazardous to human health. These materials require extra safety precautions: work only with gloves and a respiratory mask.

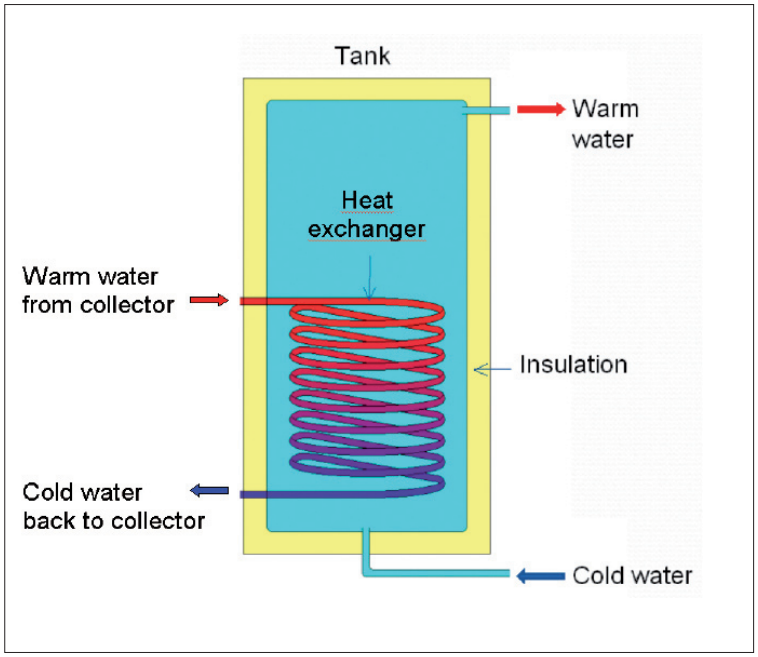
The scheme below shows a cross section of the assembled collector:



Practice: Solar water heaters

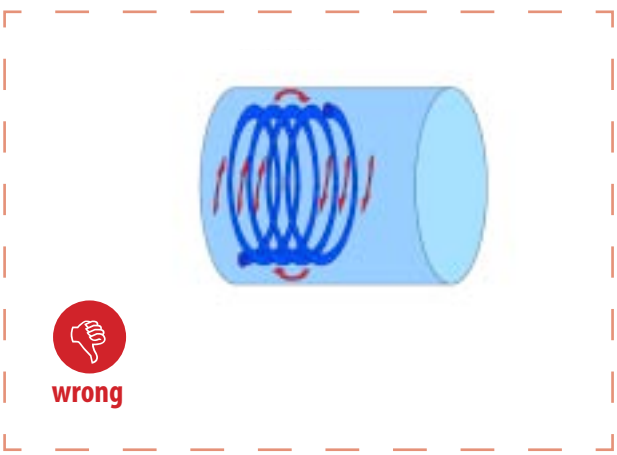
Hot water tank and heat exchanger

- The heat exchanger should be made from metaloplast tubes, which transfer heat very well. It can also be made from copper tubes, although copper is more difficult to work with.
- The heat exchanger must be located in the lower half of the tank. The cold water intake from the available water supply is at the bottom, and the heated water then rises in the tank.
- If the water from the tank is to be used for drinking / cooking, a special drinking water tank should be used.
- To preserve heat, the hot water tank has to be very well insulated.
- Fresh water supply: the tank must be hermetically sealed and resistant to the pressure up to 3 bar when directly connected to the central water supply. Another option is to have a big extra water tank to supply the hot water tank with water. The extra tank (see picture) must be on a higher place than the hot water tank to have water pressure. The cold water inlet from the water supply always has to be at the bottom of the tank. As the heated water rises, hot water always must be taken from the top.



Practice: Solar water heaters

The heat exchanger spiral has to be mounted vertically (as shown in the diagram at right, below) to allow circulation. If placed horizontally, circulation will not work. It is important that the fluid can circulate down freely.



Connecting pipes

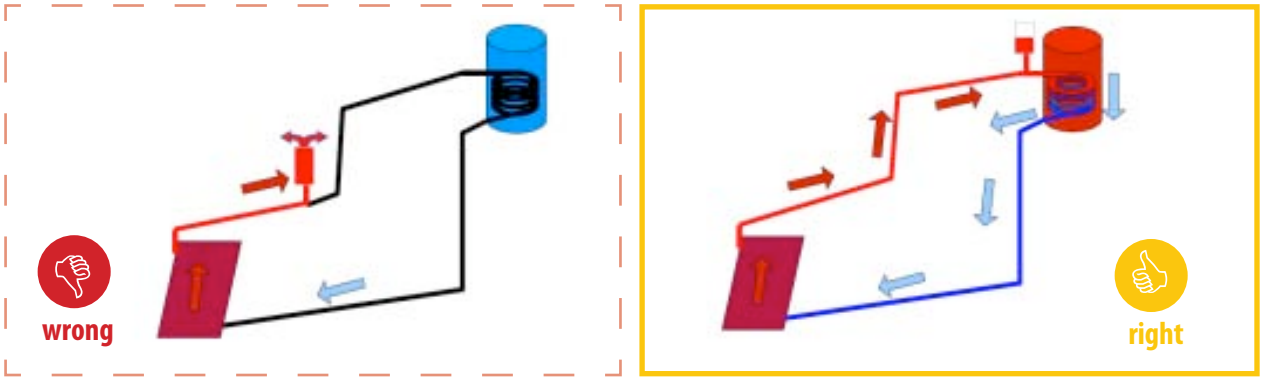
The collector is connected to the tank with the help of pipes (of metaloplast or copper) that go from the collector to the tank via the heat exchanger and back to the collector.
At this point it is very important that the heat does not get lost on the way: the distance from collector to tank should be as short as possible and the pipes should be very well insulated.

Practice: Solar water heaters

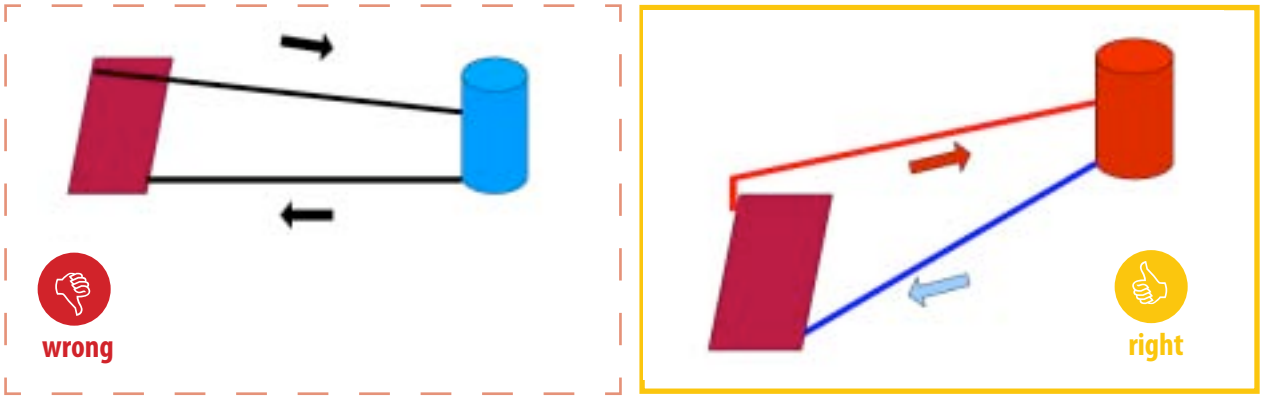
Expansion tank

The expansion tank is a very important element of the system. It is an open reservoir at the highest place in the fluid circulation loop. The expansion tank can be either a metal or a plastic receptacle. It allows the pressure in the collector to be controlled. Otherwise the heated water can expand and blow the pipes. And if there is air in the system, it also can escape here. The collector is refilled with fluid through the expansion tank, which must be covered to prevent evaporation.

Rules for installation

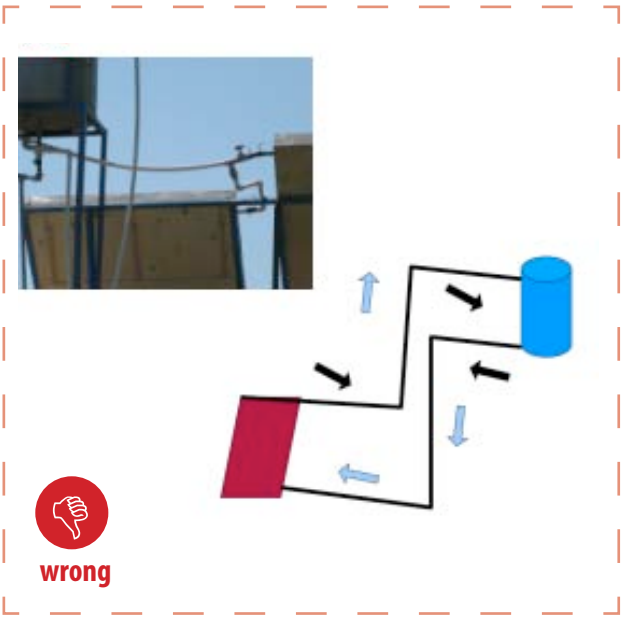


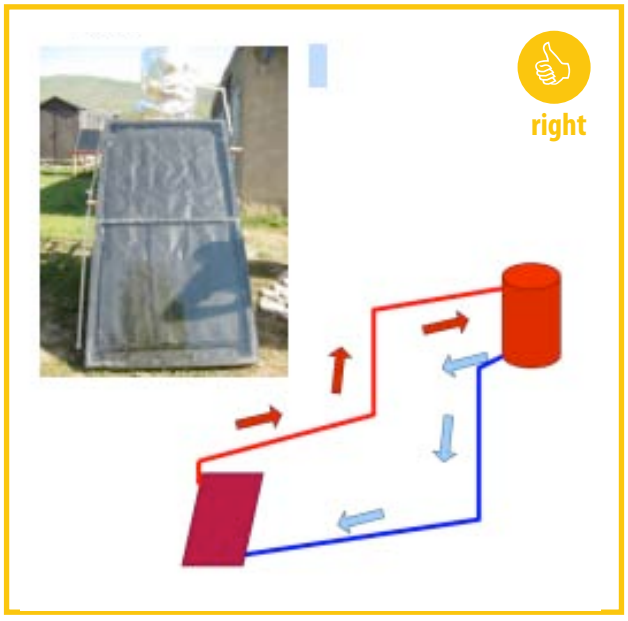
The tank has to be higher than the collector (min. 0,5 m higher) for proper circulation to occur.
The water has to go up from the collector to the tank, to enable circulation without a pump.



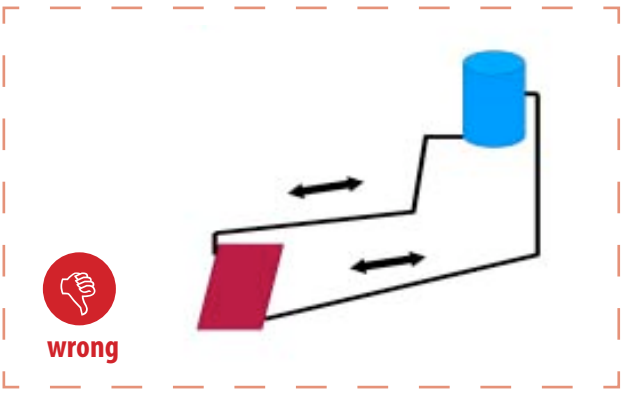
Practice: Solar water heaters

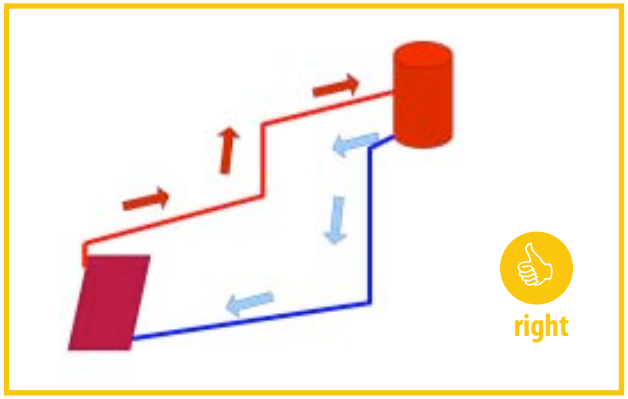
The heated fluid must rise to enter at the highest point of the heat exchanger inlet. There it conducts heat to the water in the tank, and leaves when cool from the bottom of the tank, returning to the lowest point of the collector (inlet). This circulation is only possible if there are no cross-flows. In other words, the pipe must not sag at all.





The heated fluid inlet has to be at the upper side of the tank., and the cold water outlet at the bottom. If it is the other way round, the circulation principle will not work!

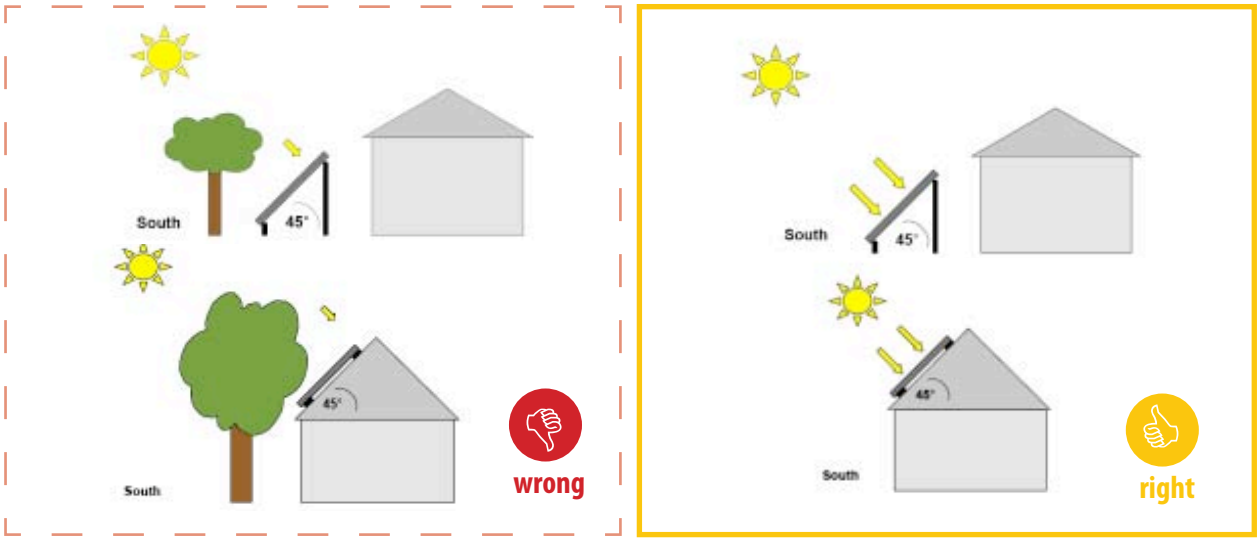




Practice: Solar water heaters

Positioning and mounting

The optimal collector position is facing south, between the southeast and the southwest. It is very important that the collector is not placed in the shadow of a building or trees. The collector can be mounted on a roof (if the roof is strong enough) or on the ground. (The disadvantage of putting the collector on the roof is that the tank has to be higher than the collector.) The most suitable place for the tank is inside of the house under the roof where it is better protected against low ambient temperatures. In any case, the tank needs to be insulated in the same way as if it were placed outside.



A general recommendation for determining the inclination angle for the collector to the horizontal surface is the following: the inclination angle of the solar collector to the horizon needs to correspond to the latitude of the area where it is placed. However, we recommend for the annual use to increase the angle by approximately 15°. In this way the solar collector will be working to the optimal extent in winter too. For summer conditions only, it is recommended that the inclination angle be 15 ° less. An optimal inclination angle needs to be defined for practical use if this angle will not be changed during the year.

Example: appropriate angles between the collector and the ground (for the south of Ukraine and the Caucasus) are:

- for year round use: 60°
- for use only in spring, summer and autumn: 45°
- for use only in summer: 30°

Practice: Solar water heaters

Maintenance

To make sure your collector works well, you should regularly do the following:

- check and refill the fluid for circulation (check fluid level in the expansion tank)
- clean the glass cover so the sun's rays can pass through easily
- check the insulation of all parts to prevent heat losses (e.g. can water enter the insulation?)
- check the pipes and connections that there are no leaks
- always make sure the warm water tank is filled with water

How to build a solar collector ?

Building materials for the solar collector

The example below represents a collector with external dimensions 2000 mm x 1000 mm

Material		Size	Quantity	Note
Collector frame				
1a	**Wooden bars – for the vertical parts**	100 mm x 50 mm x 2000 mm	2 pcs. Total 4 m	even (without knots)
1b	**Wooden bars – for the horizontal parts**	100 mm x 50 mm x 900 mm	2 pcs. Total 1.8 m	even (without knots)
2	**Wooden lath**	50 mm x 50 mm x 900 mm	3 pcs. Total 2.7 m	to reinforce the plywood and provide support to the absorber and glass (if it consists of two parts)
3	**Waterproof plywood**	4 mm thick 2000 x 1000 mm	2 m^2	or a galvanized metal sheet 0.4 mm or a polycarbonate sheet
4	**Heat insulating material (e.g. basalt wool sheet 50 mm thick)**	2 m x 1 m	2 m^2	
5	**Wood screws**	80 mm	20 pcs.	
6	**Heat resistant matt black paint or solar varnish**		1 kg	or matt black selective coating
7	**Window glass**	4 mm 2m x 1 m	2 m^2	can also be made of 2 parts 1m x 1m
8	**Silicone adhesive**		1 tube	
9	**Nails (or staple gun)**	35 mm	300 g	
10	**Rubber gasket, U-shaped**		6 m	optional
11	**Aluminium angle steel**	35 x 20mm	6 m	optional
Solar absorber				
1	**Metal sheet (steel)**	**1820mmx870mm** 1.0 mm thick	1.6 m^2	Thickness can vary 1-1.5-2 mm but the thicker the sheet, the more it weighs and the longer it takes to get it heated
2	**Metal solid-drawn pipe**	14 mm **length 1826 mm**	8 pipes 1826mm x 8 = 14.6 linear m	or 14-16 mm (1/2") or steel shaped pipe (rectangular cross-section)
3	**Metal solid-drawn pipe**	21 mm length 1050 mm	2 pipes 1050mm x 2 = 2.1 linear m	or 22 mm (3/4") or steel shaped pipe (rectangular cross-section)
4	**Welding electrodes**	2 mm	2.5 kg	It is recommended to use semi-automatic welding or soldering

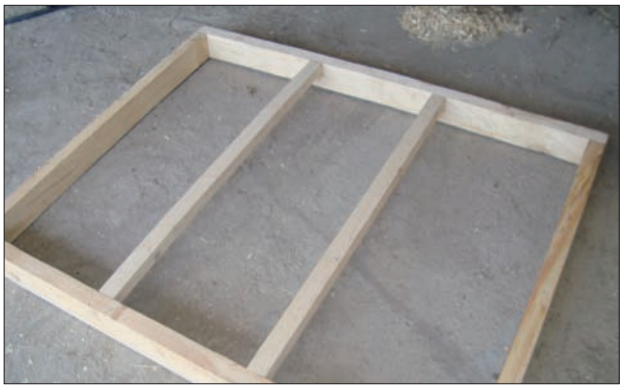
	Material	Size	Quantity	Note
Hot water tank with heat exchanger				
1	**Prefabricated hot water tank (from metal)**	200 liters	1	or self-made; do not use plastic tank (not heat resistant)
2	**Heat exchanger: a metal-plastic pipe (e.g. for heating the floor) or soft copper pipe**	20-25 mm	7 m	A copper pipe transfers heat better
3	**Pipe adapters**	¾"x ¾"	4 pcs	For the entrance and exit of the heat exchanger spiral and inlet and outlet collector pipes
4	**Insulating material for the tank and the pipes (e.g. basalt wool, for external insulation – foil-coated basalt wool)**			Quantity depends on the assembly conditions
5	**Metal-plastic connecting water pipes**	20-25 mm	10 m	Approximate estimation, depends on the assembly conditions
6	**Drain tap (for emtying the system)**		1 piece	
7	**Thermometer or thermo manometer**		1 piece	Optional
Expansion tank				
1	**Plastic or metal tank**	Capacity 2-3 liters	1 piece	
2	**Adapter**	½" x ¾"	1 piece	
3	**Freeze-resistant liquid for circulation**		about 10 liters	Antifreeze
Materials for water supply system (depends on the assembly conditions)				
1	**Plastic water pipe**	¾"		Length depends on the assembly conditions
2	**Adapters, fittings, pipe couplings**			Quantity depends on the assembly conditions
3	**Pressure control valve**		1 piece	
4	**Taps for cold and hot water**		2 pcs	
5	**Insulation for pipes**			Quantity depends on the assembly conditions

Tools

1 Welding apparatus + electrodes
2 Pvc pipe welding machine (possible to use collet couplings)
3 Angle grinder
5 Electric drill
4 Pipe and metal cutter
6 Paint brushes 2 pcs
7 Hammer
8 Pliers
9 Pipe vice
10 Bores of different sizes (4-12 mm)
11 Roller bit 36-40 mm (to drill holes in the frame of the collector)
12 Angle Ruler
13 Leveling instrument with an angle ruler
14 Handsaw
15 Caulking gun
16 Hand plane
17 Staple gun
18 Sandpaper
19 Big scissors
20 Tape measure
21 Center punch
22 Hand pipe cutter

Collector building instruction

Step 1. Cut the wooden bars to the necessary length and assemble the frame (See Appendix).



Step 2. Fasten the ends of the bars together (this can be also done with the help of metal angle brackets).

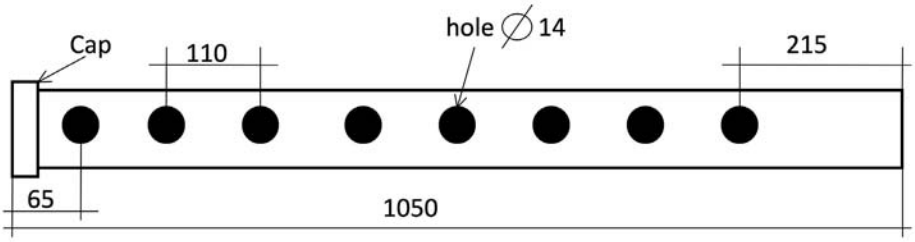
Step 3. Attach 4 mm plywood (or a galvanized sheet, or a polycarbonate sheet – it is lighter and does not become deformed) to the bottom of the frame.

Step 4. Insulate it with compacted heat insulation material.

Step 5. Drill 8 holes in both metal ¾" pipes, each hole with a diameter of 14 mm and 11 cm apart from the next (see diagram below)

Collector building instruction

This shows the pipe, with the location of the holes and their sizes.



Step 6. Weld eight ½" pipes to the two ¾" pipes after having cut the ends of the ½" pipes so they adjoin the holes of the bigger diameter pipes as tightly as possible (see the picture) and plug each of the two ¾" pipes with a metal cap at one end. Fill the pipes of this "grid" with water to make sure there is no leakage.

Step 7. Weld the metal sheet and the pipes together. The ¾" pipes should stick out of the edges of the sheet for 7-10 cm – one above and another below (see the diagram with dimensions in Appendix).

Collector building instruction

Step 8. Turn the absorber pipe side down and paint the metal sheet and pipe extensions with matt black paint or solar varnish.

Step 9. Drill the entry and exit holes in the wooden frame.

Step 10. Place the absorber with the pipe side down into the frame.

Step 11. Paint the frame with the matt black paint and let it dry completely. Attach a wooden bar across the frame in the middle for the glass installation and glue any sealer to the bar.

Collector building instruction

Step 12. Border the glass with a U-shaped rubber gasket. Insert the 4 mm thick glass in the frame and fix it around the frame perimeter with silicone. Carefully press and fasten a piece of aluminium angle steel 35 x 20 mm to attach the glass to the frame. The easiest way is to attach the glass with the help of silicone adhesive only, but that does make it more difficult to remove the glass when something is broken.

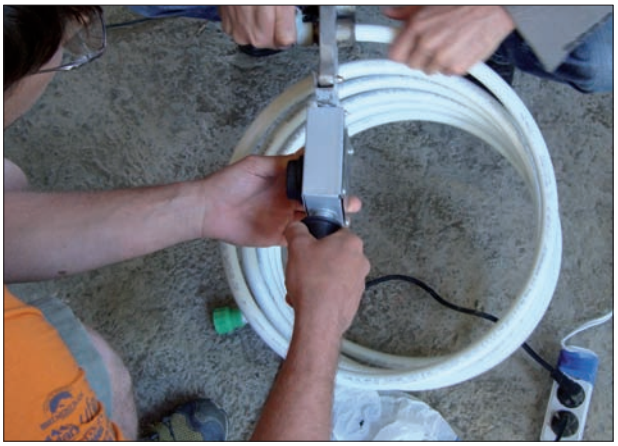
A finished collector

How to build a heat exchanger tank?

How to make a tank with a heat exchanger

A storage tank can be ‚home-made' from a stainless steel plate or can be purchased. Plastic tanks are not recommended because they have short life span and become deformed when heated. The optimum tank capacity is 70-100 litres per 1 m^2 of the absorber's surface.
In this particular case for a 2 m^2 collector we have used a ready-made tank with capacity of 200 litres.

Step 1. Make a heat exchanger. The spiral diameter should be only slightly less than the tank diameter, and the diameter of the metal-plastic pipe of the heat exchanger should match the diameter of the horizontal pipes of the absorber. When forming a spiral make sure that the pipe has no bends and that liquid can circulate free.



Step 2. Attach the pipe adapters to the pipe at both ends.

Heat exchanger tank building instruction

Step 3. Drill two holes in the tank to connect the adapters of the heat exchanger with the pipes leading to and from the collector, one hole (the inlet for heated water from the collector) above another (the outlet for cooled water from the heat exchanger to the collector). The spiral should take up no more than 2/3 of the height and be located towards the bottom of the tank. Drill two more holes in the tank for water: one hole in the upper part of the tank and another one in the lower part of the tank.

Step 4. Place the heat exchanger into the tank. It is very important that the exchanger spiral does not have adverse slope, i.e. the liquid can go down free from the top to the bottom. Then attach the adapters.

Step 5. Mount the expansion tank at the top of the system.

Heat exchanger tank building instruction

Step 6. Connect the heat exchanger to the collector (above: fluid entry, below: fluid exit) and the tank to the water supply system. The inlet for the cold water from the water supply system (or an additional reservoir) is located in the lower part of the tank, the outlet for the heated water for consumption is in the upper part of the tank. Install a tap at the bottom of the system to be able to discharge liquid (antifreeze or water) from the system (see scheme).

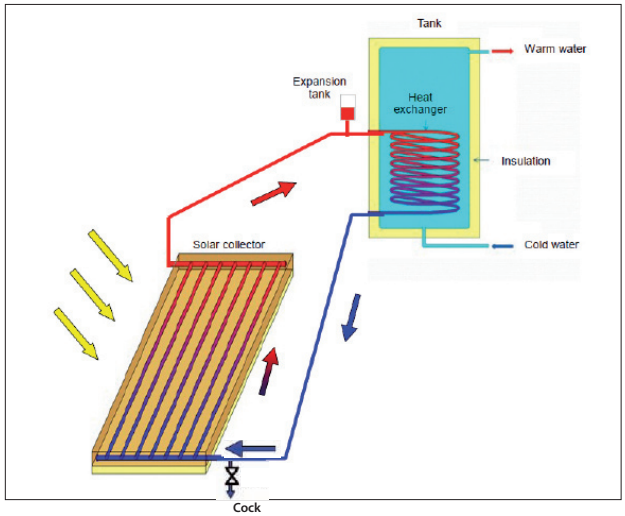
Step 7. Close the tank and insulate the pipes and the tank.

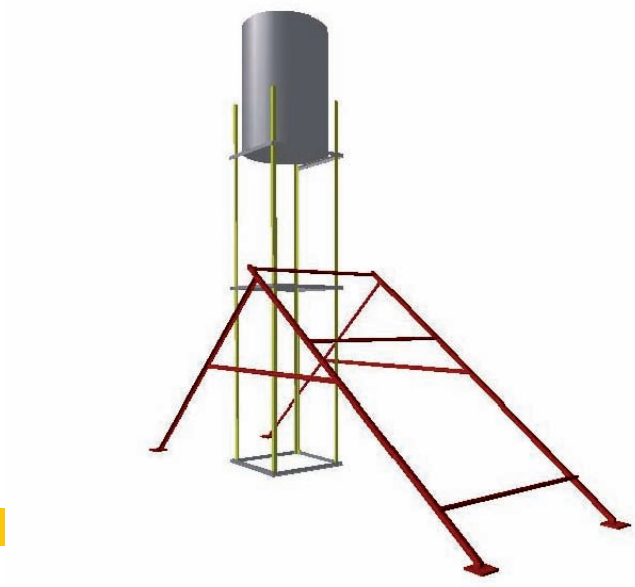
Step 8. Fill the tank with water.

Step 9. Fill the collector with antifreeze liquid. IMPORTANT: until it is filled the collector should be protected from the sunlight to prevent overheating!

Supporting structure for the collector and tank

The type of supporting structure for the collector and tank depends on where and how they are mounted. They can be welded for e.g. from angle plates 35x35x3 mm. the distance between the top of the collector and the bottom of the storage tank should be at least 50 cm.

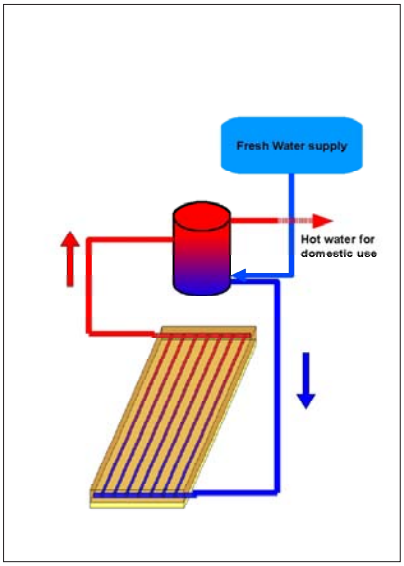




Other solar water heater models

Summer model without heat exchanger

If there is no danger of freezing or the collector is not be used during winter time, the system can be built without a heat exchanger. In this case, the warm water inlet from the collector has to be at the top of the tank, and the cold water outlet to the collector at the bottom of the tank. The external cold water supply inlet is at the lower part as well. Warm water for domestic use is taken from the upper part of the tank. If there is danger of freezing, the solar collector must be emptied to avoid breaking the pipes.



Solar collector from radiators

If available from somewhere, very simple and cheap solar collectors can be constructed using old radiators (see the picture). The radiators have to be painted with black colour, and put into a wooden frame with insulation and glass cover. Because they are not so efficient, these collectors are more suitable for single-loop systems without a heat exchanger. Radiators from a car can be also used. If you use old radiators in single-loop systems, they should be thoroughly washed inside.

Other solar water heater models

Solar collector from plastic tubes

In principle, plastic tubing can also be used instead of a metal flat plate. The tubes can be painted black with heat resistant paint. The big disadvantage is that most plastic tubes are not heat resistant. Tubes have to be tested before use on a hot place in the sun under a glass cover. If you find some which are heat resistant, they may turn out to be cheaper than metal. In this case, the plastic tubes have to be mounted in such a way that the water can also go constantly up inside the collector to ensure proper circulation (see picture at right). Metal-plastic tubes can also be used, but we do not recommend them as they are very hard to bend.

Solar collector from copper

A similar solar collector as described above can be made from copper, if you are able to work with a soldering apparatus for copper pipes. Copper is without any doubt the most appropriate and effective material for solar collectors. It is usually used in high performance solar collectors, as it has the best heat conducting properties.
For low-cost solar collectors, copper is probably not the first choice, because it is more expensive than iron and special soldering equipment is required.

System with pump

All the systems shown here can also be built with a pump, in which case it is not necessary to put the tank above the collector. However there is then the disadvantage that they will not work during electricity outages. And if there is no sun, the pump has to be switched off, otherwise it will pump cold fluid from the collector into the warm water tank, which will cool all the water in the tank.

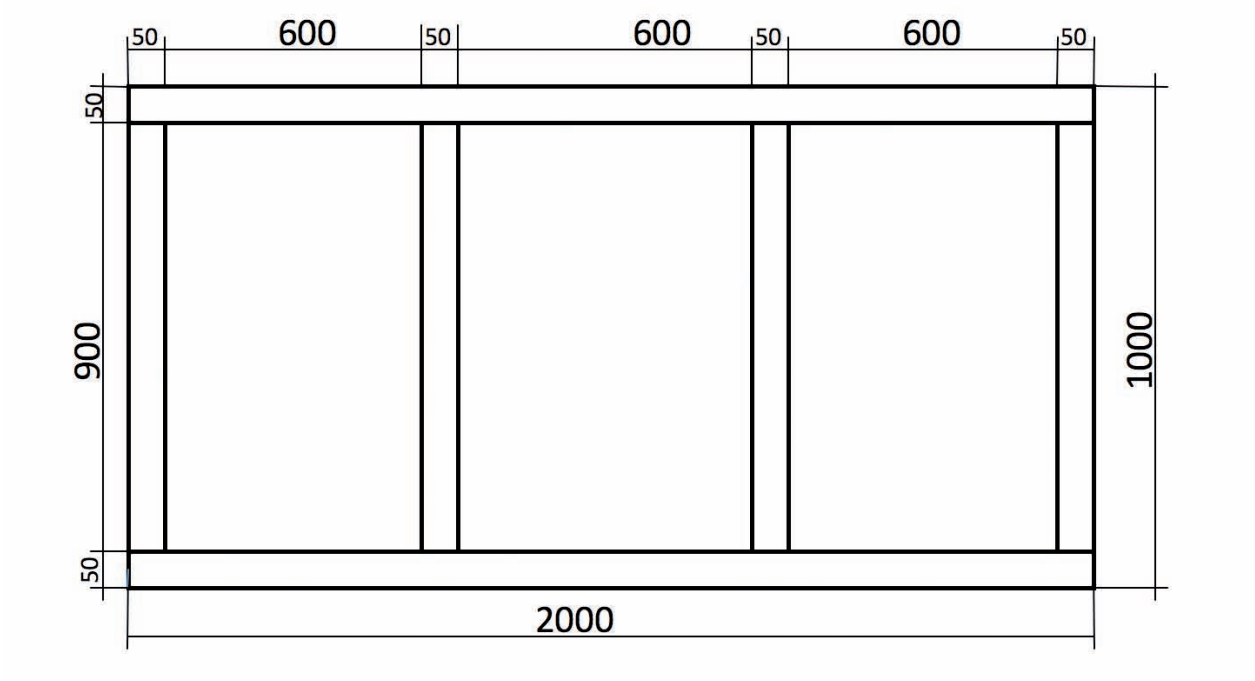
Solar water heaters

Review

Solar energy is available all over the world, for free. The use of solar energy has no negative impact on the environment and saves rare resources such as gas, coal, wood and other fuels. With decreasing availability of resources, increasing environmental damages and unpredictability of the climate, this is becoming ever more important. Besides, aside from the initial investment for material and construction of a solar collector, the use of solar energy does not require extra costs or major additional work, thus increasing the disposable income and comfort of its users.
The goal of this manual is to spread the knowledge about solar collectors and encourage interested people to build for themselves a solar collector they can easily install at their homes, achieving maximum benefit with minimum investment.
Especially in countries with high solar radiation and a big potential for solar energy on the one hand, and on the other with scarce resources and insufficient energy infrastructure, for instance in rural areas, it will be the government's task to encourage and support citizens' use of sustainable energy sources like solar energy by actively promoting sustainable energy solutions (as it is already happening in countries like Germany).

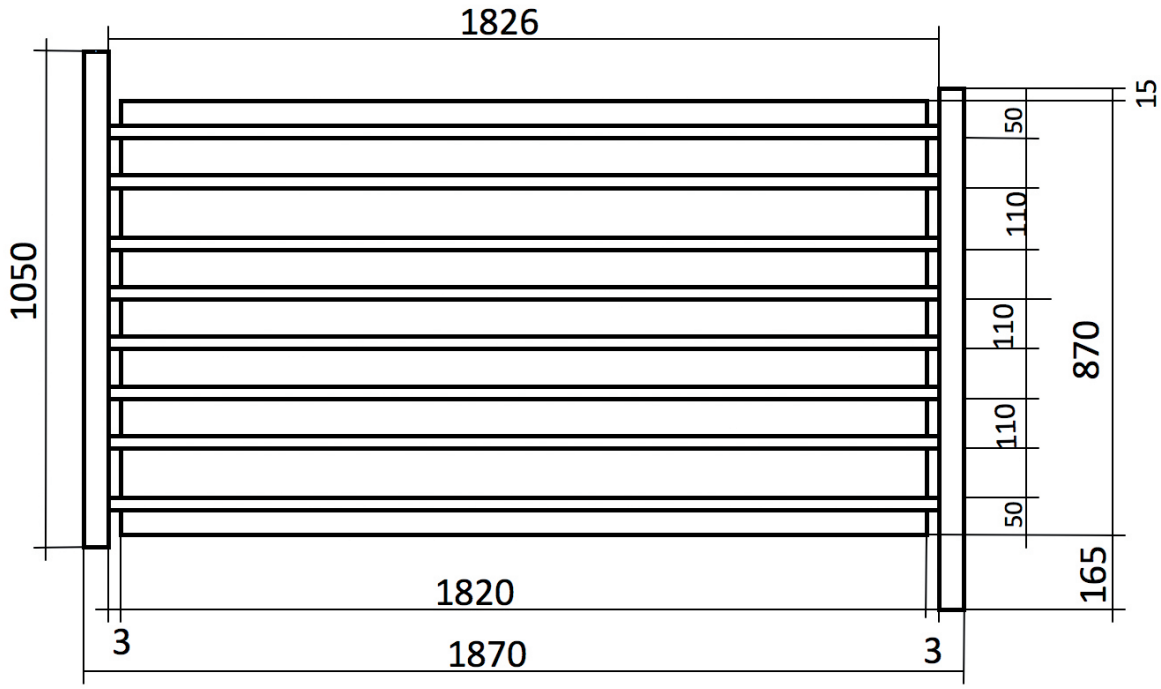
Annex

Scheme of the solar collector frame with dimensions



Annex

Scheme of the absorber with dimensions



This guide introduces an inexpensive, very efficient model solar collector which has been developed by WECF and its partners. This collector can be used all year round and does not require electricity.

In this brochure you will find instructions on how to build and install this solar collector for your home from materials available at the local market.

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