DO IT YOURSELF
Solar Water Heating System
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Solar water heating is a renewable energy technology. Solar water heating collectors capture and retain heat from the sun and transfer this heat to a fluid. Solar thermal heat is trapped using the “greenhouse effect”, in this case it is the ability of a reflective surface (a transparent glass sheet) to capture the heat in the solar collector. Heat and infrared radiation (IR, invisible radiant energy that is emitted particularly by heated objects) are produced when sun rays hit a collector’s absorber. The heat is then trapped inside the collector. The “working” fluid for the heat transfer is usually pure water because water has high heat capacity. Water in contact with the absorber collects the trapped heat to transfer it to the storage.
All solar systems consist of three main elements: a **collector**, a **hot water storage tank** and a **distribution system**. The collector is often a combination of glass or plastic glazing and an absorptive material to capture the sun’s energy. The collector’s surface must be facing the sun. The collected heat must then be distributed for use or stored in the tank for when it is needed. Distribution systems can be **passive**, where they depend on the natural circulation of heated air and water, or they can be **active**, relying on a mechanical method to transfer heat, such as an electric pump or fan.

In this guide only a **direct passive** system is described and it is based on the following criteria:

• **“Do It Yourself”** principle, hereafter referred to as DIY. The solar system components described in this guide can be made using tools and materials available locally. However it should be noted that for some tools technical skills and background knowledge are required.

• **Direct system** with no separate circulation systems, so there is no danger of frost damages.

• No need for an electric pump as the **thermo-siphon effect** is used.

• Ability to meet the domestic water heating requirements in households with a **low hot water demand**, but can also be produced in bigger scale.

• Use of locally available materials for fabrication in the region.

• Durability over a long life-time.

• Minimization of Health and Safety risks.

The development of systems meeting these objectives will generate the potential for reduced use of electric showers heads and other inefficient methods. It will also help in regions with no available options for domestic water heating.
The Thermo-siphon Effect

Thermo-siphon is a physical effect and refers to a method of passive heat exchange based on natural circulation of fluids. The fluid circulates without the necessity of a mechanical pump. Thermo-siphoning is used for circulation of liquids and gases in heating and cooling applications, including solar water heating systems.

Basically, hot water has a tendency to move slowly up, and cold water has the tendency to move down. Heated water from the collector is moving up through its pipes and the transfer pipes connected to the hot water storage. From there, cold water moves down the pipes into the solar collector where it is being heated again. There is no need for an electric pump. Circulation from the solar collector to the hot water tank through thermo-siphon requires the tank to be situated above the collectors. It is important that the storage has to be placed above the solar collector (see picture on page 3). This is marked as “Height difference”. The driving force for fluid circulation in the system is the density difference between the colder and warmer water caused by heating. A gradient is necessary to achieve the flow. In some cases and reports, positioning a transfer pipe with an upwards gradient will make thermo-siphon effect possible even if the collector and cylinder are at the same height. Positioning the tank above the collectors complicates installation on a pitched roof (installation beside the building is a better option); on a flat roof it only requires a sufficiently high base for the tank to be mounted on.

As mentioned before, the system features a separate solar collector (in this guide two solar collectors where made) and hot water storage tank. During sunshine there is continuous circulation through the input and output pipes to the solar collector to heat the tank. The hot water input of the tank is higher up so that hot water flows into the top of the tank (although at a lower level than the output pipe which leads to showers to prevent air bubbles in the pipes if the water level drops). The return pipe or cold water output to the collectors is placed below it, in the cold part of the tank.
Main Parts

The collectors
Solar collectors take the heat from the sun and pass it to a fluid.

Hot water storage tank
An insulated water storage tank mounted above the solar collectors.

The distribution
Pipes and valves are necessary to connect the solar collectors with the hot water storage tank, including the supply of hot water to the household.
The Solar Collector in Layers

The flat plate solar collector described in this guide consists of four main parts, a dark flat-plate absorber (absorber plate), a transparent cover that reduces heat losses (glass cover, solar glass), a heat-transport fluid (in this case water) to remove heat from the absorber, and a heat insulating backing (thermal insulation - for example rock wool).

There are two different types of copper tubing (the pipes containing the solar fluid which transports the heat energy) described in this guide - the “meander” or “serpentine” shaped tubing and the “harp” shaped tubing depending on the materials and tools available.
1. A drill and drill bits
Get an adjustable drill machine with a drill bit set for wood, plastic and metal.

2. Forstner drill bits
Used for making holes in wood, plastic or metal. Can be used to drill holes in the storage tanks, holes for input and output pipes etc. Called also hinge cutter bits. Spade bits can be used too.

3. Screwdriver set
Screwdriver set with a variety of types of screwdrivers (slow, cross, torx etc.). Faster and easier to use with an electric drill.

4. Right angle clamps
This useful but optional tool helps to make easy 90° angles without the need for holding it all together with hands.
5. A saw
A simple hand saw for metal and wood will do. But an easier way is a precise circular electric saw for cutting metal and wood in a desired angle.

6. Metal sheet scissors
Scissors specially made for cutting sheet metal like copper or aluminium.

7. Copper tubing cutter
Used for cutting copper tubes. When using a tubing cutter, hold the copper tubing and clamp the cutter around the pipe where you want it cut. Then spin the cutter around the pipe, tightening the knob slightly on each turn to increase the cutting wheel pressure on the pipe. After making the cut you may find some burrs in the pipe's cut edge. Remove these with a small file or de-burring tool for this purpose.
8. Paint brushes
Used for applying paint on the copper pipes, absorber plate and inner walls of the collector. Plan ahead because maybe more layers have to be applied and dried before the whole absorber is covered.

9. A burner and soldering equipment
Used to solder copper tubes together. The equipment includes a burner (propane/butane gas cartridge applicable) and soldering equipment including solder (lead-free) and soldering paste flux. It is possible to solder copper to copper tubes, or also copper to brass joints and adapters used while connecting different pipes and elements.

10. Silicone gun
Used to seal off the solar collector. It is applied between the wood, the metal profile, the solar glass etc.
11. PP-R pipe welding equipment

PP-R (Polypropylene Random Copolymer) pipes & fittings are most reliable in plumbing and water supply plants. Due to their chemical features and fusion welding, they are easy to use and approved by the Health Organisation. To weld them heat is used and applied to the joints and pipes making them melt. Only 3 seconds of heating are enough and the two pieces of PP-R can be welded together.

12. Copper pipe bending tool

The tool is used if the copper tubing in the solar collector is made with a single copper pipe. The copper pipe is bent in a meander shape. The pipe used in this guide is 12mm in diameter. It is good to have a tool with adjustable pipe diameter so pipes from 10 mm up to 24 mm can be bent. While bending no force should be used because it can damage the pipe.
13. PP-R pipe scissors
While working with PP-R pipes, special scissors (cutters) are used to cut the pipes.

14. Standard tools from the tool box
What a standard working space needs including hammers, both metal and plastic, meters, measuring equipment, different types of clamps, a scalpel, a wrench etc.

15. Safety equipment
Safety equipment is used always and in all phases, especially while cutting metal with a circular saw, working with drills or a burner, and similar.
Materials

1. Treated wooden planks
Wooden planks are used to make the collectors frame. Other materials like plastic or metal can also be used. But, wood is cheap and is easier to process. In this guide standard wooden planks from pine (dimensions 510x100x18 mm and 1500x100x18 mm) are used to make frames of 1500x500 mm. The frames are made according to the dimensions of the transparent cover glass (solar glass) that will be used.

2. The cover glass (transparent cover)
The cover is usually the material that determines the collectors dimensions. The cover used in this guide is an acrylic (known as plexiglas, lucite or cyrolon), it is transparent or translucent, easy to install, has good weatherability and resists high contraction and expansion. But it should be used only in low temperature applications only. The ideal cover material for solar collectors should have high temperature capability, transmit light very well, have long life when exposed to UV and high temperatures, be impact resistant, light weight and easy to work with, opaque to long IR to reduce heat loss and should be cheap. Glass is a good cover material for solar collectors. High transmission (low iron) tempered glass is used on the majority of commercial solar collectors, but it is heavy, breakable and expensive. Another good and cheap choice are also polycarbonate sheets used for greenhouse and sunspace glazing (can be singlewall or multiwall). For use in collectors, it must have a coating or additives to resist UV.
3. Aluminium sheet
Aluminium is an useful and easy to work with material. It is used as the absorber and the solar collector frame and its protection from the elements. It can be bought in rolls. In this guide an aluminium sheet 0,5 mm thick, 1 m wide and 6 meters long was used to cover the backside, the sides and make the absorber plates in two solar collectors with the dimensions 1,5m x 0,5m.

4. Aluminium L profile
Used to seal the solar collector and to hold the solar transparent cover (solar glass) together with the wooden and aluminium frame. Can be bought in different dimensions and cut as needed. In this guide three pieces of 20x20x6000mm were used.

5. Aluminium foil
Ordinary aluminium foil used in the kitchen for food preservation is used to cover the thermal insulation in the solar collector to prevent condensation on the side of the insulation and it’s degradation. It is placed between the insulation and the absorber.
6. Copper tubes
In this guide 18 meters copper tubes (diameter 12mm) in a role were used. The copper tubes were bent into a “meander” (“serpentine”) shape for two solar collectors of 1.5m x 0.5m. If the solar collector tubing is made into a “harp” shape, the tubes should be straight.

7. Insulating material (rock wool)
The inner solar collector walls should be isolated with an insulating material. Rock wool is temperature resistant and easy to work with. In this guide 5m² were used to isolate the backsides of the solar collectors and a 60 liter barrel as hot water storage.

8. Barrels for hot water storage
In this guide a high-density polyethylene (HDPE) barrel was used as a hot water storage tank and isolated with rock wool. Metal barrels can also be used but rust is a constant problem. A good choice is food grade plastic as HDPE (recycle symbol 2) and polypropylene (recycle symbol 5) as both are temperature resistant for hot water applications.
9. Matt Glass Paint  
(Temperature resistant)  
The paint used in constructing the system has to stick on metal. Black silicone-based heat resistant paint is a better choice.

10. Silicone  
Use simple sanitary silicone for application around the solar collector and thermostable for inside the solar collector. Thermostable silicone can be used also to fill the space between the copper tubes and the aluminium or copper plate (the absorber). As silicone has a better heat transmittance than air thermostable silicone helps to transfer the heat accumulated inside the solar collector to the water flowing inside the copper tubes.

11. Screws for metal and wood  
In this guide two types of screws were used, around 100 pieces of 20 x 2.9 mm screws for attaching the aluminium L profile and the aluminium sheet on the wooden frame, and 32 pieces of 40 x 3.5 mm screws for wood to attach the walls of the wooden frame together.
12. Check valve
A check valve, clack valve, non-return valve or **one-way valve** is a valve that normally allows fluid to flow through it in only one direction. In this guide the check valve is installed into the hot water output pipe so the hot water can not return into the solar collector. This prevents overnight heat loss from the tank due to ‘reverse thermo-siphon’, when colder solar fluid flows from the collectors to the tank which is at a higher temperature.

13. Different types of adapters, valves and rubber seals
The connecting of the pipes with the PP-R pipe system and the storage tanks is variable and depends on the diameters of the pipes and the method used. In this guide copper pipes make the input, the inner tubing and output of the solar collector. After the copper pipes (12 mm) brass adapters are welded onto the copper pipes which allow the PP-R adapters to be connected. The connection to the storage tanks and the storage tanks input and outputs are made of PP-R pipes and adapters where valves are installed so the fluid can be drained from the collector and the storage tanks.
14. Thread seal tape
Also known as PTFE tape or plumber's tape, the tape is a must have material while connecting different adapters and valves. The tape is sold cut to specific widths and wound on a spool, making it easy to wind around pipe threads. It is sometimes incorrectly called also “Teflon tape”.

15. PP-R pipes
In this guide PP-R pipes 20 and 25 mm in diameter were used. The pipes connecting the solar collectors and the storage tank should have a bigger diameter than the copper tubing to enhance the thermosiphon effect.

16. Tape and plastic wrap
A good tape (like duct or duck tape) is used for wrapping the insulating material around the hot water storage tanks. The insulating material and the tank should be wrapped together into a wind and moisture blocking material like a plastic wrap which is cheap and easy to use because it sticks to itself.
Warnings And Dangers

⚠️ Danger of scalding
Any solar water heating system presents a danger of scalding. Water over 70 °C can burn skin and cause injury.

⚠️ Legionella infection
Legionella bacteria is commonly found in water. The bacteria multiply where temperatures are between 20-45°C and nutrients are available. Water stored at 30-50° is considered high risk for the growth of this bacteria, which, transmitted by an aerosol such as a shower, can result in Legionnaires disease. Legionnaires has similar symptoms to pneumonia, and can be fatal for old or frail people. The bacteria are dormant below 20°C and do not survive above 60°C. The danger of legionella bacteria developing is present in the hot water storage tanks when water is not used and stays. Pasteurising should occur daily, for a minimum period of one hour at 60 °C to ensure elimination of legionella bacteria. As the solar system in this guide has no other heat source other than the sun in the colder months the solar energy will be insufficient to heat the water in the storage tanks to that temperature.
With no additional heating provision for the tank, this Legionella prevention measure is impossible for this solar system. However various alternative methods of Legionnaires prevention in hot water tanks and water systems are available. Chlorination on a regular basis or hyper- chlorination are the most common. Use of Chlorine Dioxide, mono-chloramines and Ionization are also possible. Also, the solution is to use the daily ratio of hot water and clean and disinfect the tanks periodically.

⚠️ Use food grade plastic
The above mentioned materials are food grade and approved from the Health Organisation. If PP-R pipes and HDPE barrels are not used, the replacement materials should be food grade and shouldn’t release toxic chemicals. A good choice is food grade plastic as HDPE (recycle symbol ♦️ 2) and polypropelene.
(recycle symbol ☢️ 5) as both are temperature resistant for hot water applications.

⚠️ Danger of injuries
The above mentioned tools are easy to use. However, the person working on the system should get familiar with all of the tools. The main rules in working with power tools are:

• Use the right tool for the job.
• Examine each tool for damage before use and do not use damaged tools.
• Operate tools according to the manufacturer’s instructions.
• Use properly the proper personal protective equipment.

⚠️ Danger of damages caused by freezing
The system is safe if the water temperature stays above freezing level. If the outside temperature falls below freezing in the night the water in the solar collectors has to be drained so it can’t damage the copper pipes. While freezing the water expands and this can damage the pipes and the joints (especially the welded areas).
After filling the system the system has to be tested and monitored for a few days so the best position and operating mode is achieved, and all eventual leaks are fixed.
Step By Step
The Preparation

For the purposes of one household a solar system consisting of 2 to 4 m\(^2\) collector surface and a hot water tank size between 200 and 300 liters is sufficient in normal conditions.

For a simple calculation of the number of collectors and the collector surface that is needed in the household the following calculation can be applied:

\[
\text{In Winter: collector surface area} = \text{number of persons} \times (m^2) \\
\text{In Summer: collector surface area} = \frac{\text{number of persons}}{2} (m^2)
\]

For example, for a household in Croatia (Zagreb) with 4 members at least two collectors (each of 2 m\(^2\)) are needed, and in summer only one collector. This calculation is based on the average consumption of hot water, and the average solar collector efficiency. Accurate assessment is based on individual needs for hot water, geographical location, the average annual insolation and system efficiency.

In this guide a system of 1.5 m\(^2\) (two collectors, 1.5 x 0.5 m each) is made for a low hot water demand. The system is made so it can be easily moved and for a small household. The hot water storage is 60 liters. As an additional option another cold water tank of 60 liters can be attached to the hot water storage as a filling system (described later as optional on Page 41-42) so the additional tank fills the hot water tank with cold water when the hot water falls below a certain level.

A good rule of sizing the collector surface is to allow 2 m\(^2\) of collector area for each of the first two family members, and around 1-1.5 m\(^2\) for each additional person. This can be customized for bigger or smaller household demands. The bigger the hot water storage tanks the better as they will keep hot water more efficiently if insulated properly.
Usually the starting point of the whole process when building a solar system is the solar transparent cover (the solar glass). The material is sometimes expensive and the solar frame and the dimensions of the collector can be easily adjusted to fit the solar transparent cover. Especially if the solar transparent cover is glass or tempered glass, the size of the glass determines the size of the solar collector.

It is important that the wooden frame is at least 0.5 cm bigger on all four sides than the solar transparent cover because the cover changes in size when subjected to a temperature change. But the frame should fit properly, so the aluminium L profile can fit over the cover and hold the cover and the frame in place.
The wooden frame is made according to the dimensions of the solar transparent cover. The wooden frame should be at least 0.5 cm bigger on each side than the solar cover so it can move and stretch with temperature variations. Also, the aluminium L profile should easily cover the wooden frame and the solar glass cover holding it in place. The wooden planks used to build the frame should be at least 10 cm wide, so there is enough space (depth) for 5 cm of thermal insulation, the solar absorber and copper pipes. The planks used in this guide are pine planks of 510x100x18 mm and 1500x100x18 mm. The shorter planks have been attached over the longer planks so they have a length of 510 mm. By using right angle clamps and an electric drill two frames have been built using 40 x 3.5 mm wood screws.
Backside of the Frame and the Aluminium L Profile

The backside of the frame and all the walls of the frame (except the front side covered with the solar glass cover) should be covered with a metal sheet. The aluminium sheet is durable, doesn’t rust and is easy to cut and work with. If there is no aluminium sheet plastic or wood can be used. UV resistant plastic should be used if using plastic. UV and water resistant paint should be used on the wooden planks if choosing only wood for the frame construction. Already used aluminium sheet was cleaned and reused for the solar system in this guide. The used aluminium sheet was found on metal garbage dump and it was part of old big billboards. With the metal sheet scissors the aluminium sheet is

Tools needed:
- Metal sheet scissors
- Saw for metal
- Drill and drill bits for metal
- Screwdriver set
- Silicone gun
- Clamps to hold the frame while working on it
easily cut in the right dimension. Before the sheet was attached to the backside the aluminium L profile was cut in the right dimension to fit the backside of the wooden frame. In this guide an electric circular saw has been used because it is easy to cut the L profile in the exact angle. Before the L profile can be screwed onto the wooden frame, holes in the L profile have to be drilled. There is no need to drill holes in the aluminium sheet (0.5 mm thick) as it is very thin and the screws will easily get through it. Before the aluminium sheet is placed onto the backside of the wooden frame, silicone has to be applied to make the collectors backside air and watertight (picture above). Help yourself with clamps to ensure everything stays in place as shown on the picture to the right. When finished with this step, the inside and the frontside of the solar collector are next to work on.
The inside of the frame should be covered with thermal insulation. The important part is the backside, on the backside aluminium sheet, under the solar absorber and the copper pipes, as this is the biggest area (surface) where heat trapped in the collector can be lost. If it is possible, the inner frame walls of the collector can be insulated also. In this guide rock wool (5 cm thick) was cut with a scalpel into the right dimensions and placed onto the aluminium sheet. After this step it is important to cover the rock wool with aluminium kitchen foil. The foil prevents moisture (condensation) building up in the rock wool that causes less efficient insulation and it’s degradation. No glue or tape is needed to apply the aluminium kitchen foil.
The Absorber and the Copper Pipes

There are few principles when considering making a solar absorber and piping:

- The pipes should have a diameter big enough to allow the thermo-siphon effect to happen. 12 mm copper pipes where used for the system in this guide. Self-made solar collectors made with 10 mm pipes also work with the thermo-siphon effect. Copper pipes have a good heat transmittance and are easy to work with. Aluminium pipes or galvanized steel are also an option but they are more difficult to work with.

- Efficiency but also the price of the solar collector increase while increasing the length of pipes in the collector. In this guide 18 meters of copper pipes where used on a surface of 1.5 m\(^2\) (two collectors, 1.5 m x 0.5 m each).

- The solar absorber (in this guide aluminium sheet painted black) should be attached to the copper tubes with the minimum amount of air in between the absorber and the pipes allowing the heat to transfer easily to the copper pipes and the water flowing inside them. Copper sheet can be used also as an absorber but it is more expensive.

- The copper tubing can be made into a “meander” shape also known as “serpentine” shape or a “harp” shape (see picture below).

- If the piping is made into a “meander” (“serpentine”) shape the cooper pipes can be bought in a role and cut as needed. If the piping is made into a “harp” shape the copper pipes should be bought in straight pieces, cut into
the right dimensions and then welded together using copper T adapters. The “harp” shape requires more starting materials like copper T pieces and if the welding is not done correctly there is a constant threat of leakage. The “meander” (“serpentine”) shape requires more skill in bending and the copper pipe bending tool.

In this guide both types are presented.
“Meander” or “Serpentine” shaped Copper Tubing

Before the copper pipes can be worked with they should be straightened out. This can be done by unrolling the pipes on a big flat surface (for example on the street) using the hands and feet. The length of the pipes can then be easily measured and cut into the right pieces. In this guide two collectors were made and 9 meters of copper pipes have been used in each. The tool for bending the copper pipes can be made for a single diameter or as on the picture on the left, for a range of diameters from 10 mm to 24 mm. The right attachments of the tools have to be put together to use it. The length of each pipe curve should be correctly calculated without mistakes because the “meander” shape is usually made from one single piece of pipe.

Tools needed:
- Copper tubing cutter
- Copper pipe bending tool
- Plastic (rubber) hammer
- Drill and drill bits
- Forstner drill set
- Clamps from the tool box for cutting and working with the copper wire
- Paint brushes
- Copper welding equipment
- A burner
- Measuring equipment (meter)
IMPORTANT: Practice on one short piece of copper pipe before starting with the “meander”. Calculate how many “cm” the curves need to have, what is the diameter of the curve and therefore what is the length between each curve and the straight part, how many curves fit in the solar collector, and where to start bending to get the right length on each curve (the pipe stretches a bit while bending).

The picture below shows how two pieces of wood carefully shaped were and used to carefully bend the pipe to the last position where the “meander” has parallel pipes. Usually, the tools for bending copper tubes stop at an angle that is lower than a 180° curve. If the maximum length of pipes wants to be achieved the pipes after each curve in the “meander” should be parallel. However, if the maximum efficiency wants to be achieved, the diameter of the pipe on every curve should not be damaged (that can happen easily if not being careful). This increases the tube length in the solar collector. But a slight angle on the other side (pipes are not parallel) helps with the thermo-siphon flow as all the pipes slightly point up. A compromise should be achieved in between this two positions (parallel or not parallel pipes).

Use rubber or plastic hammers if the equipment gets stuck. Plastic hammers will not damage the soft copper and the tool. Use the hammer carefully. The “meander” shape from this guide has 17 curves and the distance between two parallel pipes is 8 cm. Every curve is 2 cm away from the inner wall of the solar collector. Both ends of the pipe (the input and the output) are on the same side of the collector making it easier to attach with the second collector which has of
the collector. That way it is easier to connect two solar collectors placed one beside the other.

**IMPORTANT:** Before placing the pipes in the collector, drill holes (picture on the right) above the level of the aluminium sheet on the top and bottom side of the collector (shorter walls of the frame) to achieve a low air flow through the collector, and therefore preventing condensation on the solar glass cover which decreases the efficiency of the collector. Do not drill into the rock wool! Three holes, each 4-5 mm in diameter, have been drilled on the top and the bottom of the collector from this guide. To prevent the rain from entering the holes a shield (little roof) made from the remaining aluminium sheet scraps has been made.

After the “meander” shape is finished, two holes in each collector should be drilled for the input and output pipes (picture on the left). A forstner drill can be used to drill the holes. The next step is the absorber plate made from the aluminium sheet. Ideally, the aluminium sheet should fit around each cooper pipe, surrounding half of its surface (as later described for making the “harp” shaped solar tubing). In this guide the aluminium sheet was placed below the copper pipes and attached with copper wire, not surrounding the pipes. This method is less efficient but the “meander” shape is difficult to work with as it bends and
deforms while being handled. The absorber plate is attached around the pipes in “harp” shaped piping as it is easier to work with straight pipes.

**IMPORTANT:** Adjust the “meander” shape the aluminium sheet is in close contact with the pipes. The left space between can be filled with thermostable silicone (which has better heat transmittance than air). The aluminium sheet was attached with copper wire (single, full profile wire) to the pipes as seen on the pictures on the left and above.

The whole absorber and inner side walls of the collector are then painted with black thermostable paint. Use more layers if needed so the whole surface is covered and black. Plan ahead because the paint needs to dry before a new layer can be applied. As seen on the picture on the next page the copper pipe can be cut off with the copper tubing cutter so an equal length of copper pipe is sticking out of the collector. The needed output adapters can be
welded (in this guide brash adapters onto copper pipe) to the end of the pipes so the collectors can be attached and detached easily with the rest of the solar system.

**IMPORTANT:** When building more solar collectors for a thermosiphon system, the length and the diameter of the pipes should be equal in each collector. The solar collectors are then attached parallel to each other (all the inputs on the lower side of the collectors are attached together into one single input, and the outputs on the upper side of the collectors are attached together into one single output).

Improvements can be made by modelling the aluminium sheet around the copper pipes. It should be done with care because the copper pipes are easily damaged. By doing so the contact of the copper pipes and the aluminium sheet is better and the collectors are much more efficient.
“Harp” shaped Copper Tubing

The “harp” shaped solar copper tubing is the most used copper tubing when building solar collectors. The length of each copper tube is equal, and they are all parallel and connected with a single input and output pipe. The input and the output pipe (on the picture on the left shown as a horizontal line) should be with a bigger diameter than the parallel ones. For example, if the vertical pipes have a diameter of 15 mm the horizontal pipes should be 22 mm so the thermo-siphon flow can be achieved. Also, more collectors can be connected in a series as shown on the picture above.

The starting point for building the “harp” shaped solar tubing is the required equipment. As shown on the right, a copper T adapter is needed as additional material to connect all the parallel copper pipes. The pipes should be carefully cut and the length should be exactly calculated so a rectangle “harp” shaped copper tubing is achieved. The

Tools needed:
• Copper tubing cutter  
• Plastic (rubber) hammer  
• Self-made tool for making absorber wings - three planks, one harder pipe in the same dimensions as the copper pipes used  
• Drill and drill bits  
• Forstner drill set  
• Clamps from the tool box for cutting and working with the copper wire  
• Paint brushes  
• Copper welding equipment  
• A burner  
• Measuring equipment (meter)
pipes are welded together using the soft copper welding equipment. The weld area should be clean and free of oil, grease, dirt, paint and oxides before welding. Brush the weld area with a bronze wire brush and then degreas with a suitable cleaning agent. The oxide film formed on the pipes during welding should also be removed with a wire brush after each weld run. On both welded parts the welding paste should be applied as instructed by the producer, and then connected. The material should be preheated with a burner. It is desirable to limit the heat to as localized an area as possible to avoid unnecessary heating of the material. It is also important to ensure the preheat temperature is maintained until welding of the joint is completed. After the desired heat is achieved the welding wire is applied at the connection point. While melting it is “sucked” into the joint and the welding is completed after a drop of liquid welding wire appears on the downside of the joint. The result is a “harp” shaped copper structure as shown on the picture on the right.

The absorber plate on this picture is only placed under the copper tubing and then attached with copper wire. However, “harp” shaped copper tubing allow the application of “absorber wings”, flat plate copper or aluminium absorber plates bent around the copper tubing which increases its efficiency. One of such absorber wing is shown on the picture on the left. The “wings” are made from aluminium or copper and the slide (the hole in
which the tube is placed surrounding 50 % of the tube surface) is made by hammering a firmer pipe (for example steel pipe) of the same diameter placed between to wooden planks with a slit as shown on the picture above. Before attaching each straight pipe to the “absorber wing” holes are drilled into the “wings” so they can be attached to the pipe as seen on the picture on page 35. Thermostable silicone can be applied between the “wings” and the copper pipes so maximum heat transmittance is achieved. As the last step, thermostable black paint is applied in layers on the pipes and the absorber covering all the surface.

**IMPORTANT**: The “harp” copper tubing should have an input on one side of the collector and an output on the other side of the collector. The input and output should not be on the same side of the “harp” tubing.
The Solar Transparent Cover

Place the solar transparent cover onto the collector frame. Before doing so, clean the saw dust and unwanted material inside the collector. Ensure the drilled holes for low air circulation and ventilation on the top and bottom of the collector are free. Peel off the scratch protection film if present on the solar cover material from both sides. Drill holes in the aluminium L profile before application of silicone. In this guide around 100 screws of 20 x 2.5 mm were used for the aluminium L profile on all sides of the collector.

Apply silicone (see picture below) on the wooden frame, the glass cover and the aluminium L profile before attaching and screwing it all together.

After the glass cover is placed and screwed onto the frame use silicone to fill all remaining holes where air could leak or moisture could penetrate the collector.

Seal the left holes for the input and output pipes so everything is airtight. Make a small roof (water protection) for the holes on the top and bottom of the collector which prevent condensation building up in the collector.

Tools needed:
- Drill and drill bits for metal
- Screwdriver set
- Clamps for holding the pieces together
- Saw for metal
The Hot Water Storage

In this guide two 60 liters HDPE barrels were used, one for the **hot water storage** and the second one for the hot water storage filling system. The second barrel is not necessary and will be described as optional after this step. The important thing is to follow the instructions given on page 3 so the dimensions and the positions of the input and output holes are exact. That way the thermo-siphon system will work efficiently. The holes in the barrels are drilled with the forstner drills to fit the size of the adapters which will be screwed into the holes. The adapters used in this guide are PP-R adapters with a **male brash end** so they could be fastened from the inner side of the barrels with PP-R adapters with a **female brash end** (see picture below). It is important to use rubber seals to prevent from water leakage. The adapters can be also elbow fittings or fittings with a right angle end. In most occasions the

### Tools needed:
- Drill and drill bits
- Forstner drill set
- PP-R pipe welding equipment
- PP-R pipe scissors
- Wrenches
- Measuring equipment (meter)
materials and technology are not the same in different countries and the adapters, piping and other equipment needed for connecting the collector and the barrels will have to be a factor of individual adjustment. The most important thing is that the hot water storage has **one input** for hot water coming from the collectors (upper part of the hot water tank) and **one output** (bottom of the barrel as seen on picture on the left) for cold water returning to the collectors. In this guide the two holes described have a diameter of 3/4˝ (bigger size to allow the thermo-siphon effect to happen). The third hole is drilled for the **hot water consumption output** where a valve (water mixing valve to prevent scalding) or faucet can be attached.

The hot water tank is then covered in insulating material (in this guide rock wool 10 cm thick was used). Handle the rock wool carefully as it brakes when being wrapped and wear gloves. The wool is held in place with adhesive tape and wrapped in plastic wrap as it is the wind and moisture protection.
Before starting the wrapping it is advisable to weld the input and output pipes so all together can be wrapped and isolated (see picture on the left, barrel is turned upside down). Holes have to be cut in the insulation to attach the piping and this will just damage the insulation.

Start applying the rock wool on one side (picture on the right). The tape makes it easier to hold everything in place. Turn many rounds with the plastic wrap until everything is solid and firm. The shape and the visual effect are not important.

**IMPORTANT**: No leaks and no heat losses should occur due to lack of isolating material. Never use too much force while wrapping because if you squeeze the rock wool too much the volume will be reduced hence the efficiency of the insulation will be decreased.
Optional: The Hot Water Storage Filling System

In this guide a second barrel was used to build a filling system, placed above the solar hot water storage. The second barrel is just sitting above the hot water tank and water flows only by gravity into the hot water tank. The hot water storage tank needs to have a forth hole drilled on the top of the tank as seen on the picture on the below. Into that hole and inside the barrel a toilet flush valve system is attached. When the hot water level falls under a certain amount, it opens the water flow from the upper filling tank and fills up the hot water storage with cold water where it is heated again. The filling system is installed because the hot water storage is not attached to another water source, and 60 liters are used very quickly, so there is no need for opening and filling up the tank and opening it up too often hence losing heat.

As seen on the picture below the toilet flush valve has been attached using PP-R elbow adapters. A piece of PP-R pipe has been attached onto the toilet flush valve to make the cold water input from the filling tank into the hot water tank longer. Cold water flows into the bottom of the hot water tank where it is mixed with the warmer water and moves also by gravitation into the solar collectors.
The two tanks are connected according to the scheme shown on the picture below.

The dimensions on the picture are given for the system built in this guide. If a bigger or smaller system is made the measures are calculated and interpolated according to the scheme below. So if a system with double the size is built, the dimensions should be interpolated with the dimension given on the picture.

The scheme also shows two outputs ("I" and "III") and one input ("II") of the hot water tank. The output "I" is the cold water output, where the cold water from the tank flows to the solar collectors into the lower cold water input of the collector. The input "II" is the hot water coming from the solar collector and therefore heating the water in the hot storage tank. The output "III" is the hot water output for end-use where a mixing valve and a faucet can be attached.
The Connection and Setup

Before the system can be installed the installation place and the orientation of the solar collectors have to be determined. In general there’s one main rule: if the system is installed in the Northern Hemisphere, the collectors should face true south. Also, the tilt angle (the angle between the horizontal ground and the solar collector) as shown on the picture to the left can be changed every month depending on the position of the sun. The tilt angle degrees are given for each month for the location Dushanbe, Tajikistan for solar collectors facing true south.

<table>
<thead>
<tr>
<th>Tilt angle (degrees, °)</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>54</td>
<td>46</td>
<td>38</td>
<td>30</td>
<td>22</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>30</td>
<td>38</td>
<td>46</td>
<td>54</td>
<td>62</td>
</tr>
</tbody>
</table>

To achieve this, a simple adjustable stand for the collectors should be built. For the system described in this guide a wooden stand was built as show on the picture below. If the tilt angle wont be changed during the months an ideal angle should be chosen. This option is not recommended as the system will

Tools needed:
- PP-R pipe welding equipment
- PP-R pipe scissors
- Wrenches
- Measuring equipment (meter)
- Drills and drill bits
- Screwdrivers
function less efficient. The stand should be strong enough to support the solar collectors already filled with water.

As seen on the picture the left the solar collectors have been placed so the input and output pipes face one to each other. So it is easy to connect the collectors parallel to each other. Brass adapters have been welded onto the copper pipes (input and output of “meander” tubbing) sticking out of the solar collectors. The brass adapters make it easy for the attachment of PP-R adapters and the use of PP-R pipes to connect the collectors with the hot water storage tanks (see picture to the right).

For the tanks two stands have been constructed. There is no need for a stand if there is already a higher position available at the location. Concrete blocks can be used also to make a stand for the tanks.

Two wooden stands have been constructed to support the tanks. Each has a height bigger then the height of the top of the solar collectors when put in position for use.
If the hot water tank filling system wants to be installed two stands have to be constructed as shown on the picture to the right. The lower stand is for the hot water storage tank.

The finalisation of the system is the connection of all pipes according to the scheme on page 3. The final step is the filling of the system. Check for leaks and fix them if they are present. A thermometer can be installed on the hot water output pipe which leads to the hot water storage tank so the water temperature can be measured and monitored.

**IMPORTANT:** The system is safe if the water temperature stays above freezing level. If the outside temperature falls below freezing in the night the water in the solar collectors has to be drained so it can’t damage the copper pipes. While freezing the water expands and this can damage the pipes and the joints (especially the welded areas).

After filling the system the system has to be tested and monitored for a few days so the best position and operating mode is achieved.
Some details of the system are given in the pictures on the right and below. The picture on the right shows a finished system with a hot water storage tank and a filling system. The toilet flush valve has been installed in the second barrel which is a filling system. The system is filled with the second barrel as cold water flows into the warm water storage by gravity. In the end the collectors ventilation holes are covered with the left scrapes of the aluminium to prevent rain and dirt of entering the solar collector and damaging it.
# Check List - Tools And Materials

<table>
<thead>
<tr>
<th>Tools</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Drill and drill bits ✓ ✗</td>
<td>1 Treated wooden planks ✓ ✗</td>
</tr>
<tr>
<td>2 Forstner drill bits ✓ ✗</td>
<td>2 Cover glass (transparent cover) ✓ ✗</td>
</tr>
<tr>
<td>3 Screwdriver set ✓ ✗</td>
<td>3 Aluminium sheet ✓ ✗</td>
</tr>
<tr>
<td>4 Right angle clamps ✓ ✗</td>
<td>4 Aluminium L profile ✓ ✗</td>
</tr>
<tr>
<td>5 Saw ✓ ✗</td>
<td>5 Aluminium foil ✓ ✗</td>
</tr>
<tr>
<td>6 Metal sheet scissors ✓ ✗</td>
<td>6 Copper tubes ✓ ✗</td>
</tr>
<tr>
<td>7 Copper tubing cutter ✓ ✗</td>
<td>7 Insulating material (rock wool) ✓ ✗</td>
</tr>
<tr>
<td>8 Paint brush ✓ ✗</td>
<td>8 Barrels for hot water storage ✓ ✗</td>
</tr>
<tr>
<td>9 Burner and soldering equipment ✓ ✗</td>
<td>9 Matt glass paint (temperature resistant) ✓ ✗</td>
</tr>
<tr>
<td>10 Silicone gun ✓ ✗</td>
<td>10 Silicone ✓ ✗</td>
</tr>
<tr>
<td>11 PP-R pipe welding equipment ✓ ✗</td>
<td>11 Screws for metal and wood ✓ ✗</td>
</tr>
<tr>
<td>12 Copper pipe bending tool ✓ ✗</td>
<td>12 Check valve ✓ ✗</td>
</tr>
<tr>
<td>13 PP-R pipe scissors ✓ ✗</td>
<td>13 Adapters, valves and rubber seals ✓ ✗</td>
</tr>
<tr>
<td>Tool box (hammer, meter, clamps, scalpel, wrench etc.) ✓ ✗</td>
<td>14 Thread seal tape ✓ ✗</td>
</tr>
<tr>
<td>15 Safety equipment ✓ ✗</td>
<td>15 PP-R pipes ✓ ✗</td>
</tr>
<tr>
<td>16 ✓ ✗</td>
<td>16 Tape and plastic wrap ✓ ✗</td>
</tr>
<tr>
<td>17 ✓ ✗</td>
<td>17 ✓ ✗</td>
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<tr>
<td>18 ✓ ✗</td>
<td>18 ✓ ✗</td>
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<td>20 ✓ ✗</td>
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<td>21 ✓ ✗</td>
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