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Systems of solar energy harvesting, design and efficiency

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1.Basic concepts of light

2. Collector efficiency

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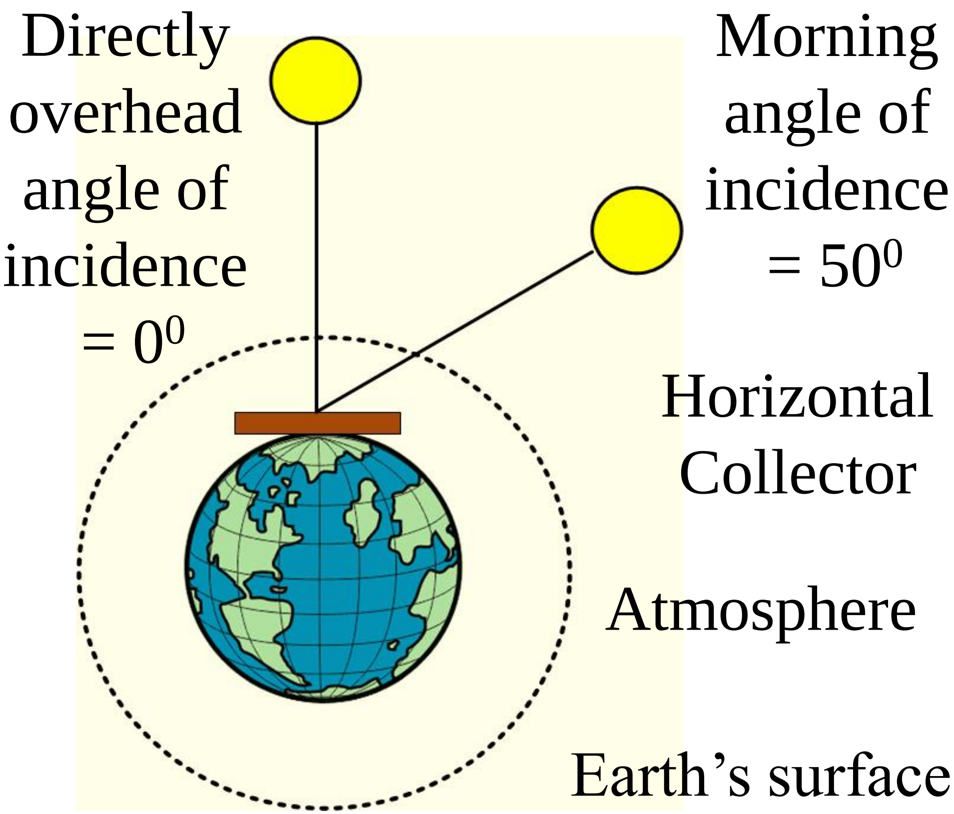
4. Solar collectors classification by operating temperatures and their application

5.KU proposal model of the solar collector.

1.Basic principles and knowledge

1.1 Irradiance and insolation



Angle of incident

Irradiance is the radiant flux (power) received by a surface per unit area. The SI unit of irradiance is the watt per square metre (**W/m^2**)

Insolation is the total amount of solar energy available over a period of time and is typically measured in kilowatt-hours per square meter per day (**$kWh/m^2/day$**).

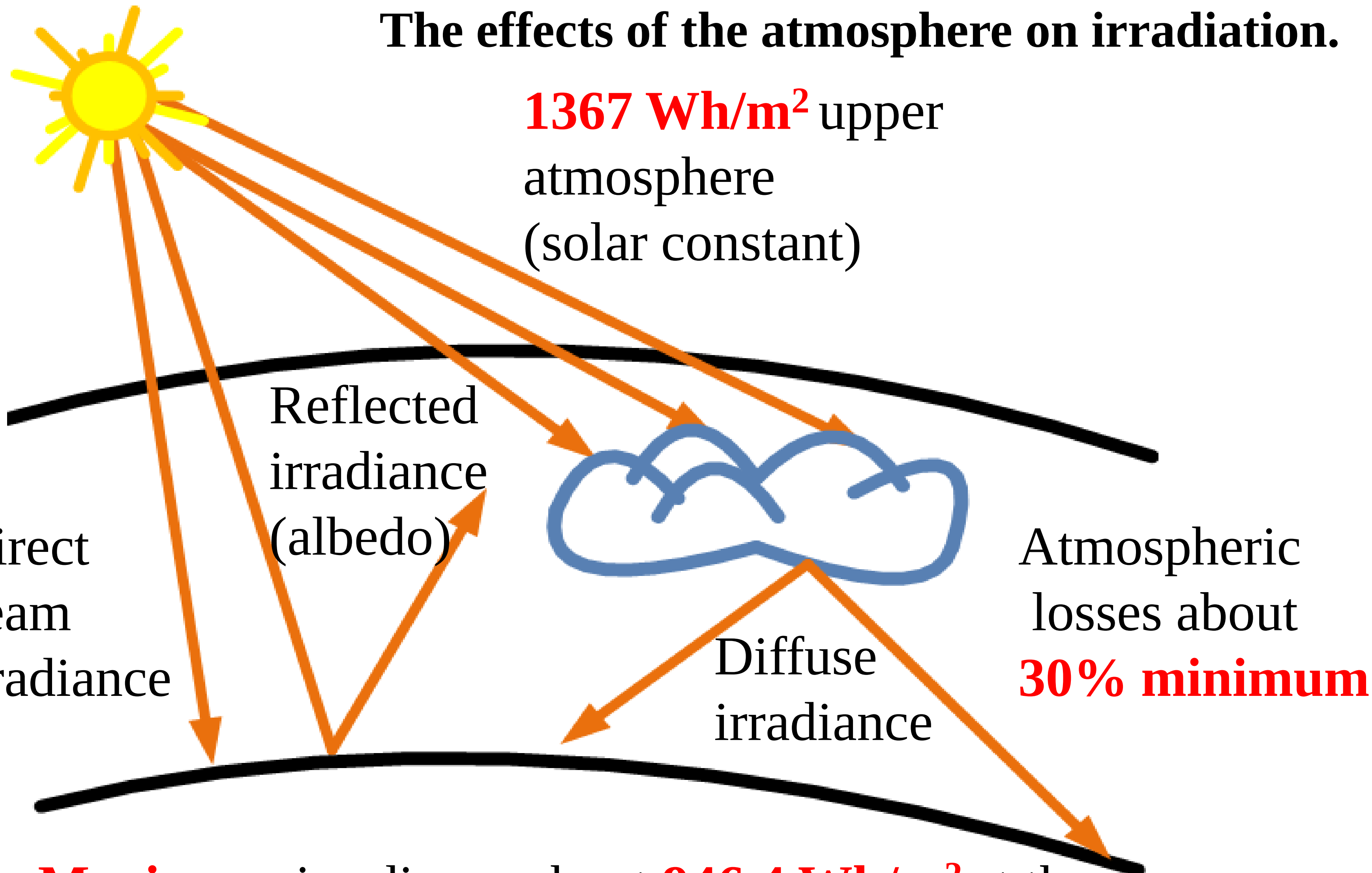
One sun hour is the equivalent of **1000 Wh/m^2**, or **317 BTU/ft^2**.

$$\mathbf{1}\ ft^2=\mathbf{0.092903}m^2$$

1.Basic principles and knowledge

1.1 Irradiance and insolation

The effects of the atmosphere on irradiation.



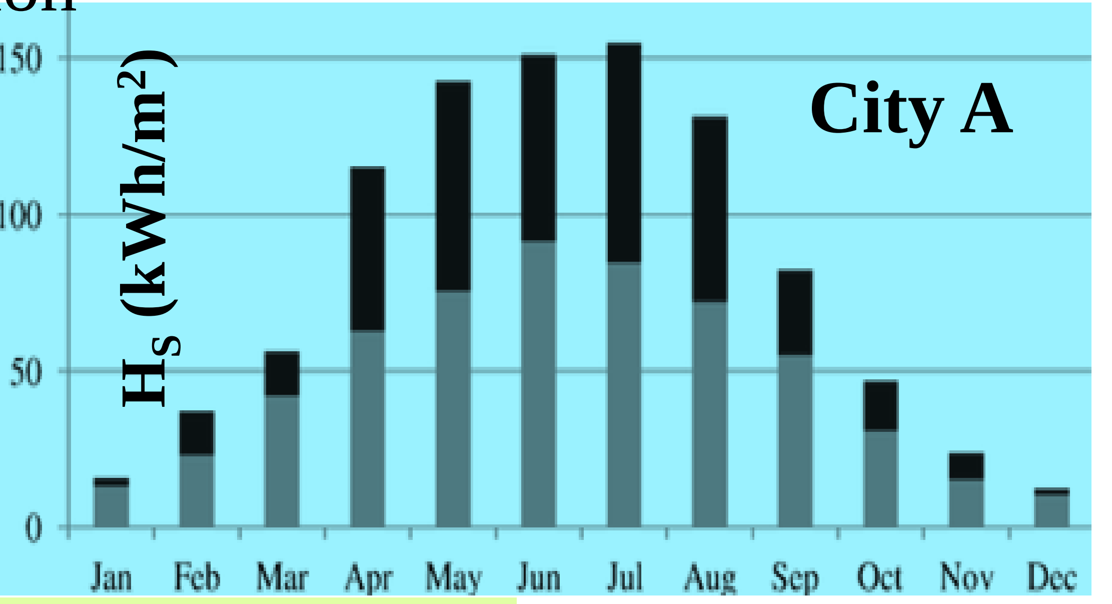
Maximum irradiance about **946.4 Wh/m²** at the surface of Earth

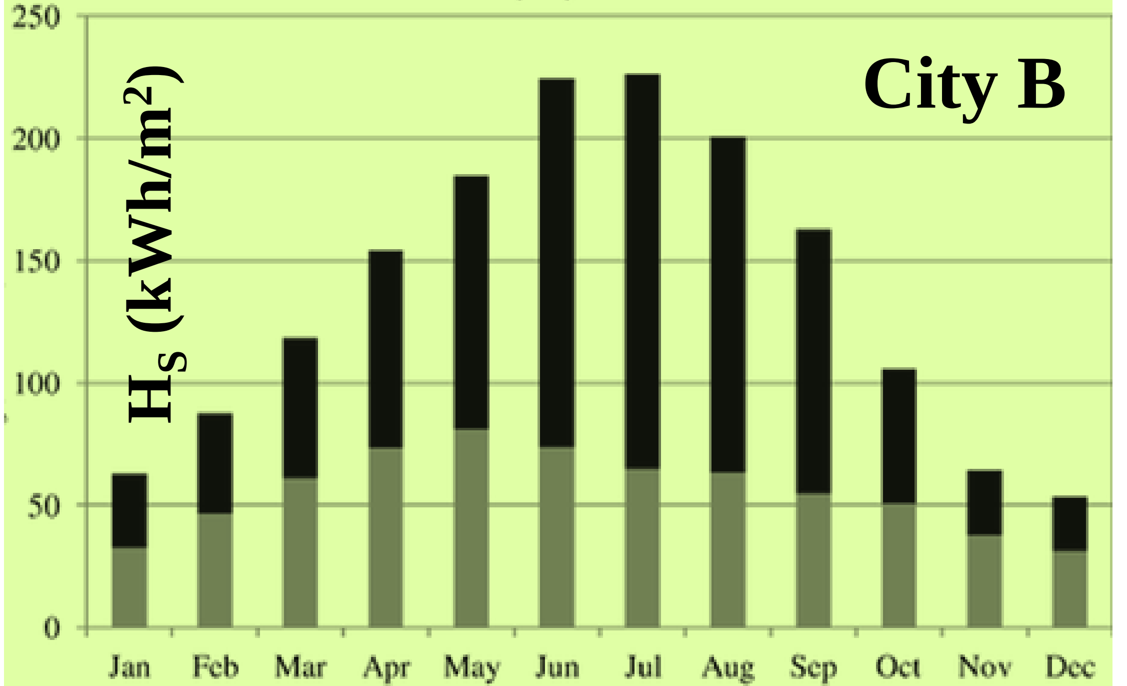
1.Basic principles and knowledge

1.1 Irradiance and insolation

Direct Solar Insolation

Diffuse Solar Insolation



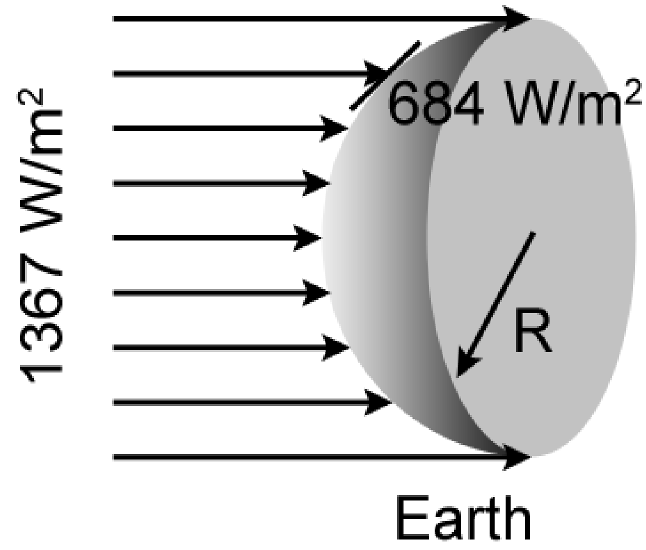


1.Basic principles and knowledge

1.2 Rough Estimates Of The Solar Energy Available At The Earth's Surface

The solar constant is the average extra-terrestrial (outside the atmosphere) insolation at the edge of the atmosphere:

$$I_{SC} = 1367\ W/m^2$$



A rough estimate of the irradiation incident per unit area (H) of the Earth's surface can be made if we assume that 30% of the Sun's energy is lost in the atmosphere and that the *one day is an average of 12 hours long at any location*.

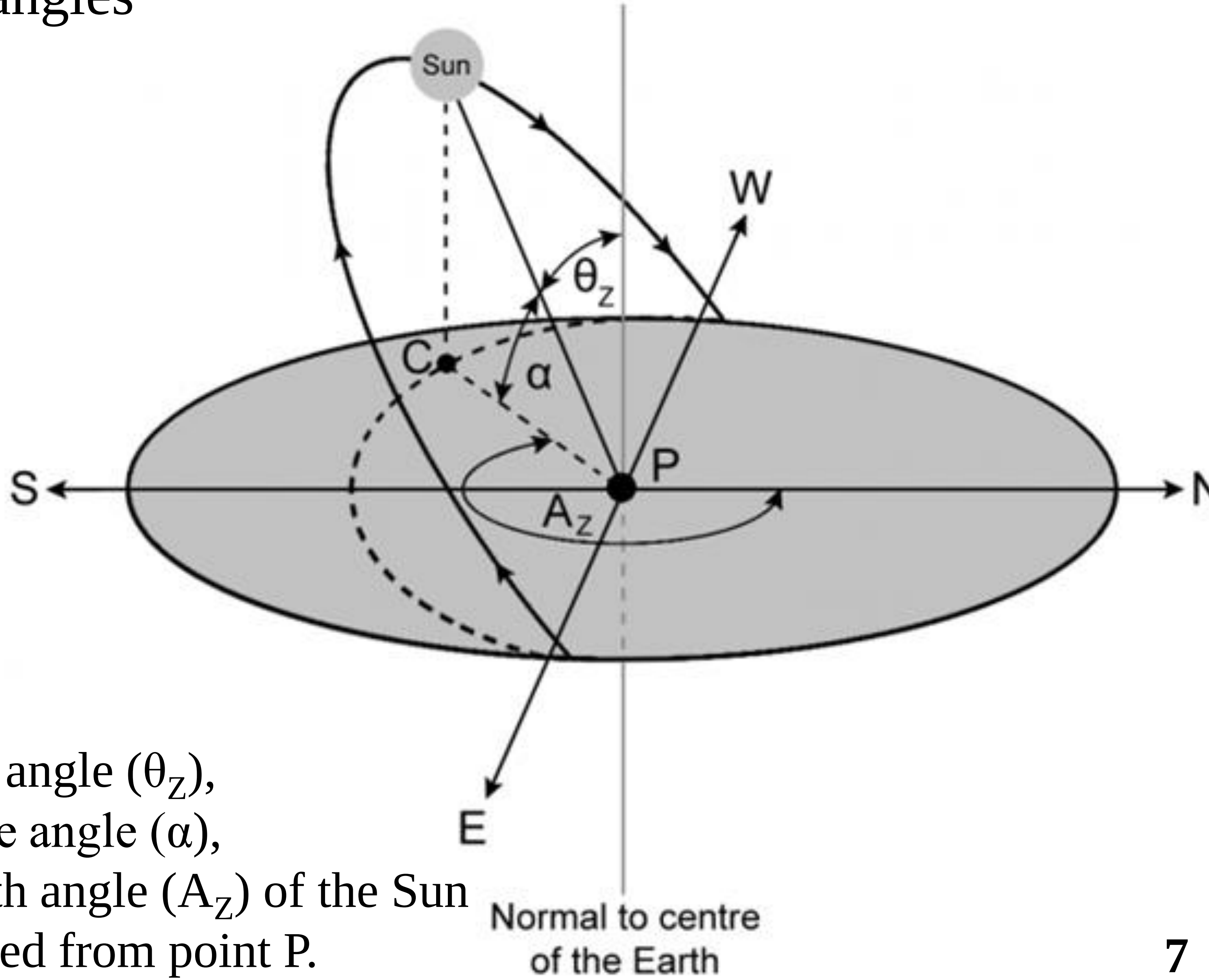
$$H = 0.7 \times 684 \times 12 = 5.75\ kWh/day$$

Or if we assume that the Sun is only at an appreciable strength for an *average 6 hours* in the day (as is likely in more northerly latitudes):

$$H = 0.7 \times 684 \times 6 = 2.88\ kWh/day$$

1.Basic principles and knowledge

1.2 Solar angles



The zenith angle (θ_Z),
the altitude angle (α),
the azimuth angle (A_Z) of the Sun
when viewed from point P.

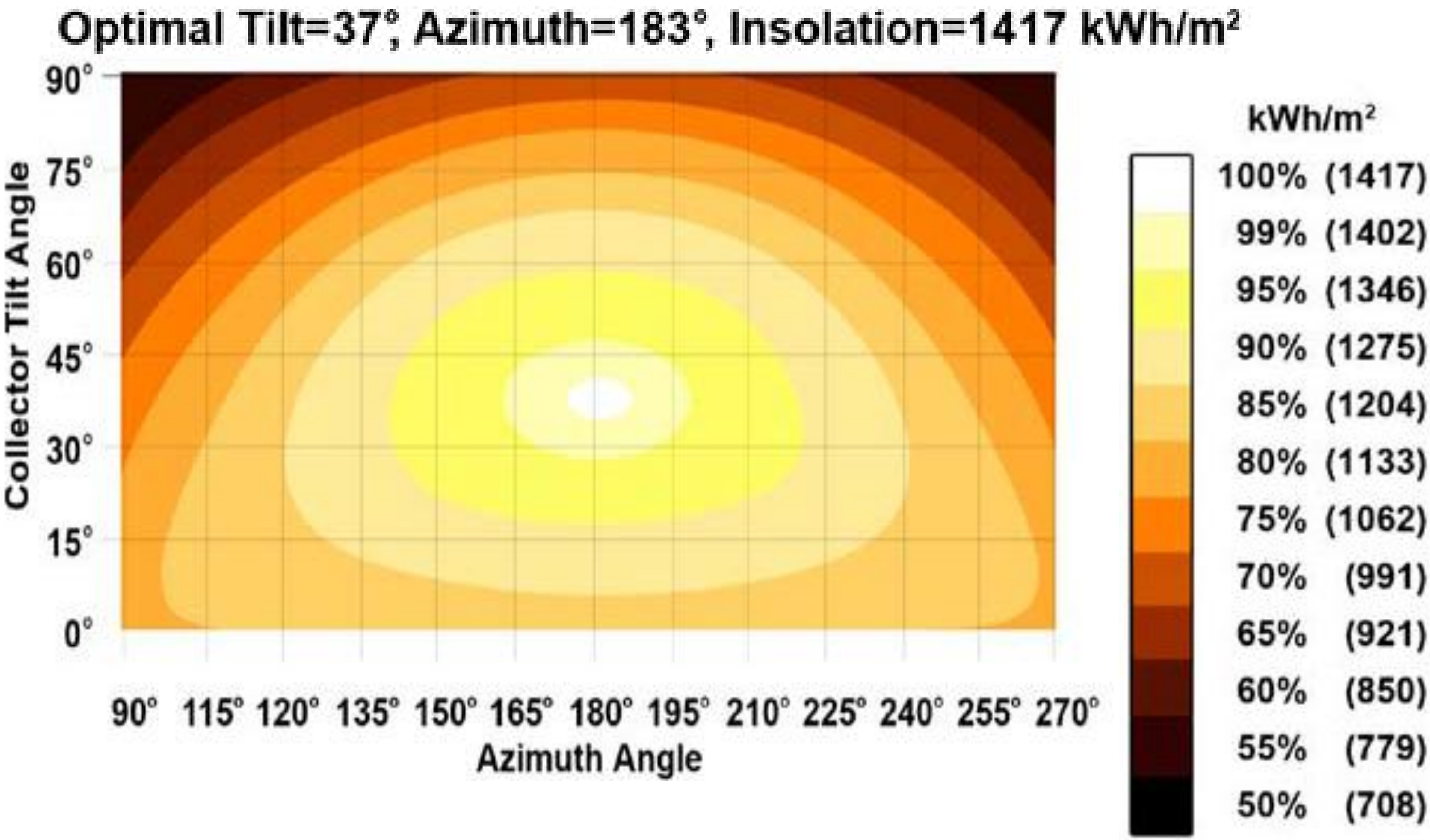
1.Basic principles and knowledge

1.2 Solar angels

Latitude	Solar altitude angle at solar noon		
	Winter Solstice	Spring/Fall Equinox	Summer Solstice
0 (the equator)	66.5°	90°	66.5°
10	56.5°	80°	76.5°
20	46.5°	70°	86.5°
23.5 (the Tropics)	43°	66.5°	90°
30	36.5°	60°	83.5°
40	26.5°	50°	73.5°
50	16.5°	40°	63.5°
60	6.5°	30°	53.5°
70		20°	43.5°
80		10°	33.5°
90 (the Poles)		0°	23.5°

1.Basic principles and knowledge

1.3 Collector orientation



1.Basic principles and knowledge

1.3 Collector orientation

While SOF charts will help quantify the effects of orientation on annual solar insolation, their application has some limits when applied to SWH:

- *The charts are based on data collected for flat surfaces.* For curved surfaces, such as evacuated tube collectors, the effects of azimuth may be less pronounced.
- *It is not always beneficial to orient collectors to maximize the annual solar insolation.* Due to the limitations of storing large quantities of hot water, SWH systems should be designed to maximize *usable* solar insolation.

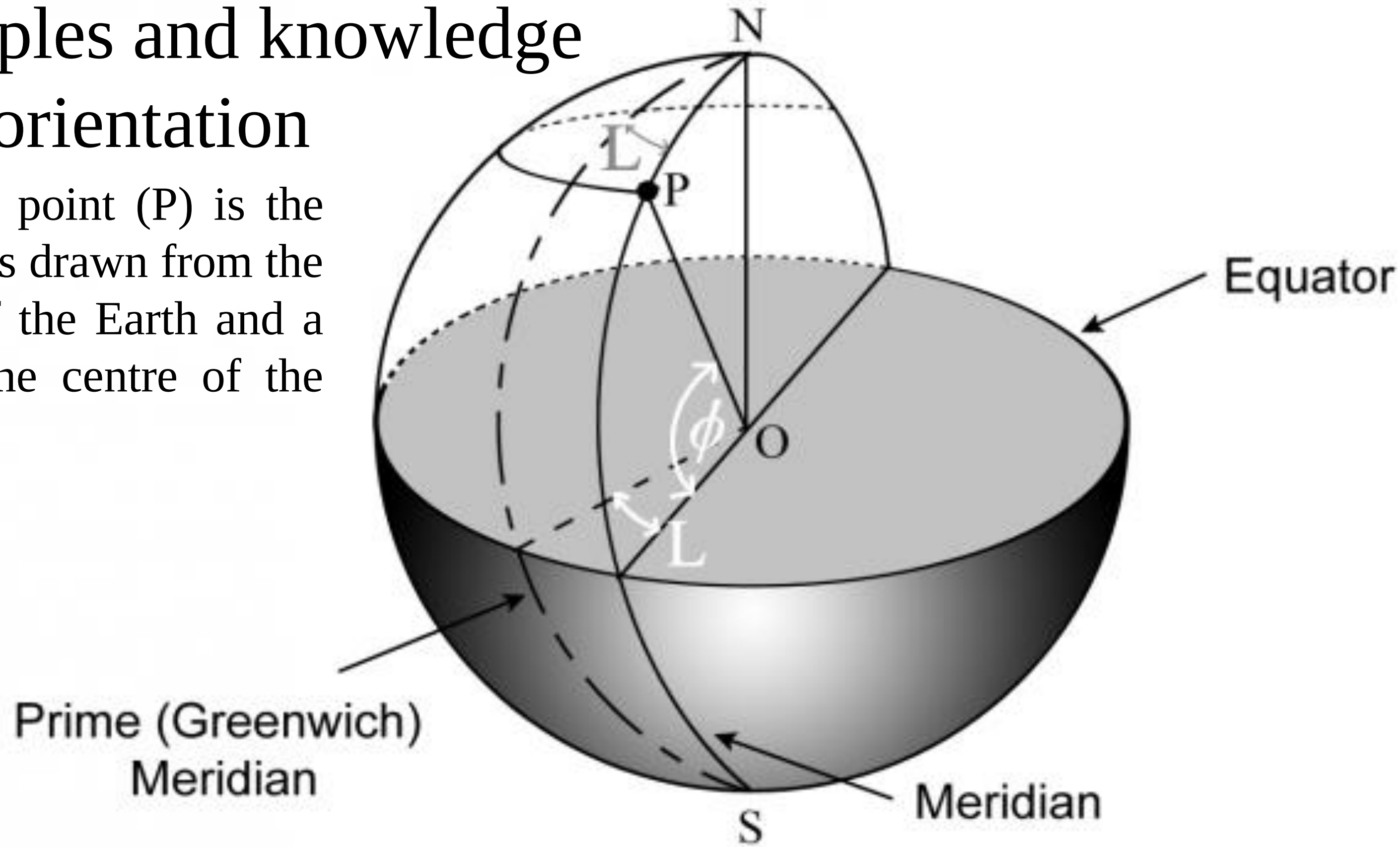
If a SWH system is designed to maximize *annual* solar insolation, it is likely to produce more heat than can be used or stored in the summer and less heat than is needed in the winter. The standard recommendations for collector tilt are as follows:

1.Basic principles and knowledge

1.3 Collector orientation

The latitude (φ) of a point (P) is the angle between a radius drawn from the point to the centre of the Earth and a radius drawn from the centre of the Earth to the equator

The longitude (L) of a point (P) is the angle between the Greenwich (or prime) meridian and the meridian that passes through the point.



The standard recommendations for collector tilt are as follows:

To maximize usable solar energy annually, such as

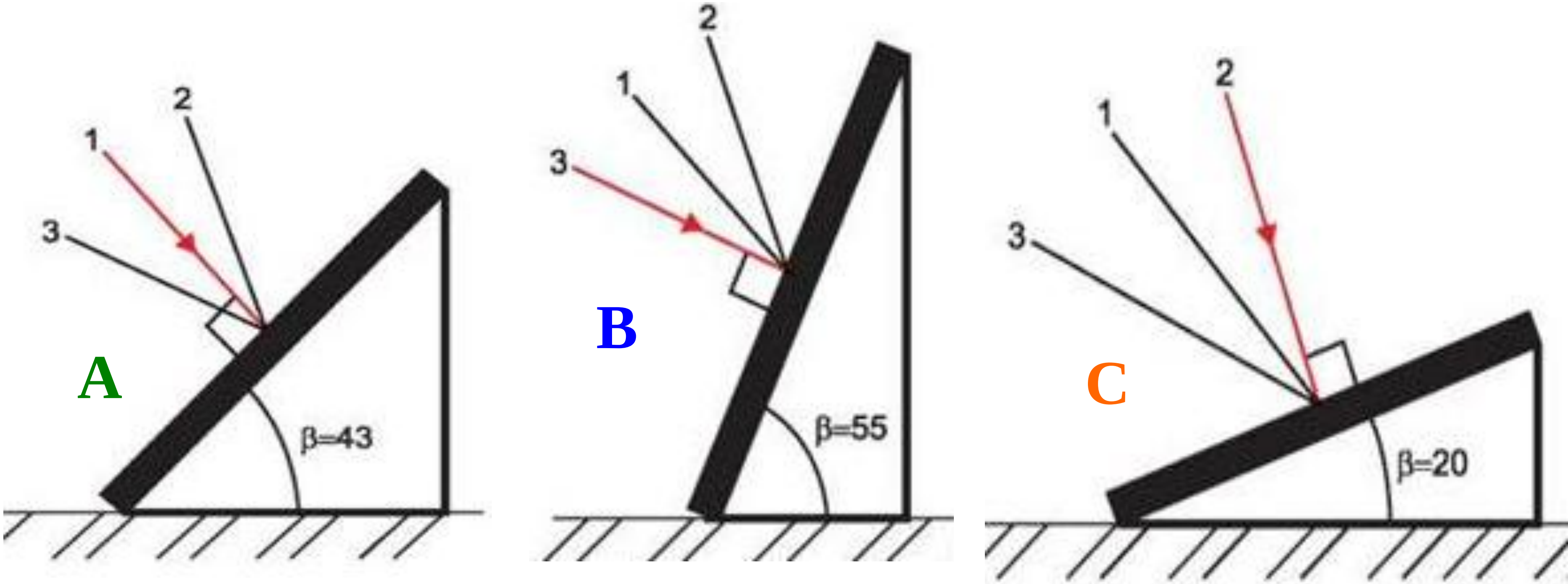
1. for domestic water heating systems, ***the collector tilt angle should be equal to the latitude of the site***.

2. pool heating, ***the collector tilt angle should be fifteen degrees less than the latitude of the site***.

3. for winter space heating, ***the collector tilt angle should be fifteen degrees more than the latitude of the site***.

1.Basic principles and knowledge

1.3 Collector orientation



Determination the optimum tilt of the collector for the **spring and autumn equinox (A)**, **at the winter period (B)**, **at the summer period (C)**

The arrows show the direction of solar radiation:

1- during equinox; **2 – in summer**; **3- in winter**

1.Basic principles and knowledge

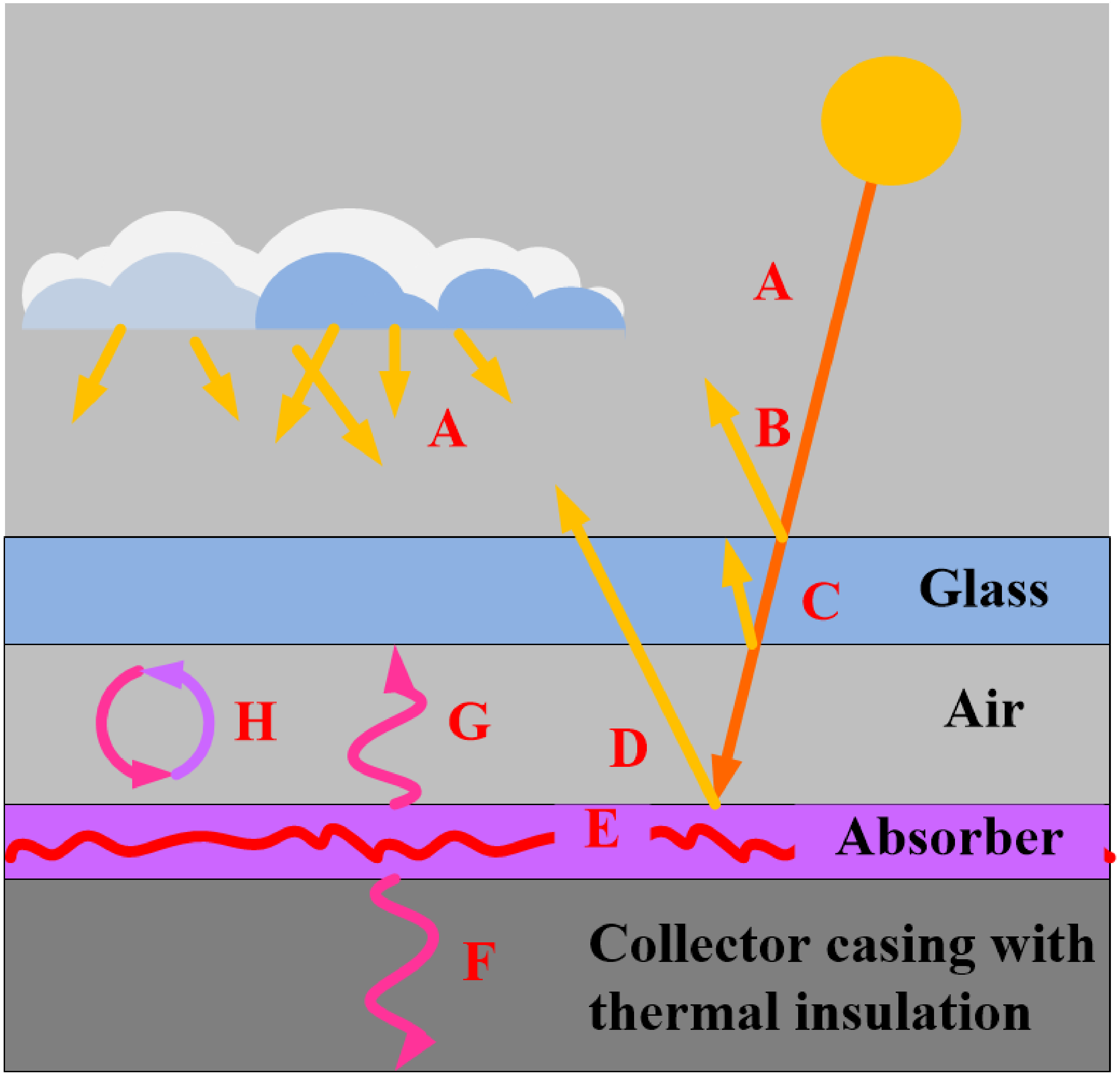
1.4 Effects of ambient air temperature

Ambient air temperature has a significant effect on the performance of SWH systems. The amount of heat loss from a solar collector is directly proportional to the temperature difference between the operating temperature of the collector and the temperature of the surrounding air.

- Summer has ideal conditions for collecting solar energy due to the high amount of solar irradiance, longer days, and warmer ambient temperatures.
- Clear winter days provide high solar irradiance, but the collectors are less efficient due to thermal losses from the collector to the colder outdoor air.

2. Collector efficiency

2.1Principle of energy flows in a solar collector



A- insolation on to collector

Optical losses

B- reflection of the glass pane;

C – absorption in the glass pane;

D- reflection of the absorber

Thermal losses

F- thermal conduction of the collector material;

G – absorber heat radiation;

H- convection

2. Collector efficiency

2.2Collector performance parameters

The collector performance is described by the equation **for the power output *q***:

$$\eta = A \cdot \left(\eta_0 \cdot G - a_1 dT - a_2 \cdot dT^2\right) (1)$$

With the operation conditions:

G – Solar irradiance on collector plane [W/m^2];

dT – Temperature difference between collector mean fluid temperature and ambient temperature [K];

And the collector performance parameters:

η_0 - optical efficiency;

a_1 - first order heat loss coefficient (a_1 at collector fluid temperature equals to ambient temperature), [W/(m^{2}K)];

a_2 - second order heat loss coefficient, [W/(m^{2}K^2)];

A – collector area, corresponding to the performance parameter, [m^2]

2. Collector efficiency

2.2Collector performance parameters

a_2 - second order heat loss coefficient, [W/(m^2K^2)];

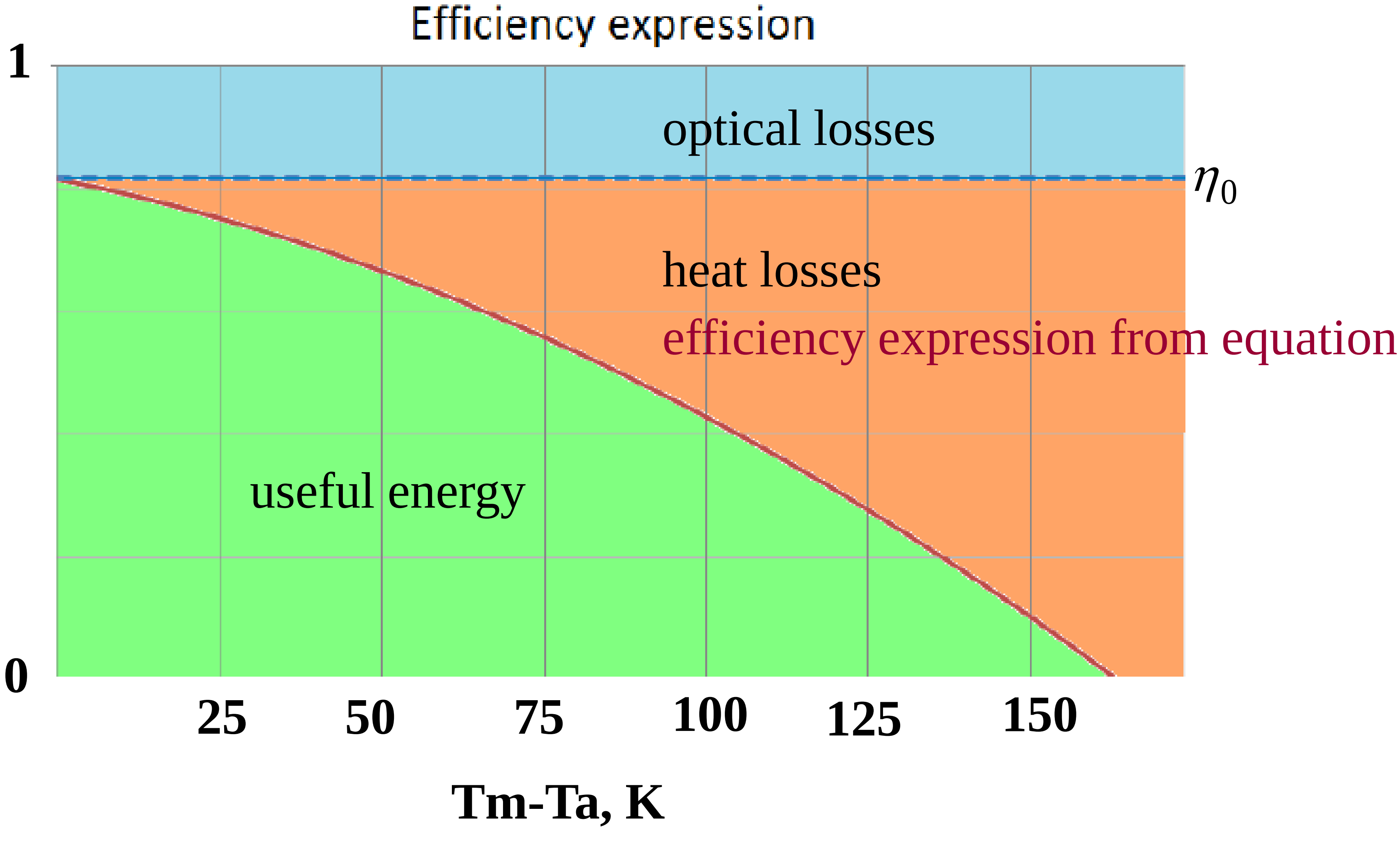
- The heat loss coefficient of a collector depends on the temperature. High values of a_2 indicates large temperature influence
- The higher the value of a_2 the more "hooked nosed" the power/efficiency curve)

A – collector area, corresponding to the performance parameter, [m^2]

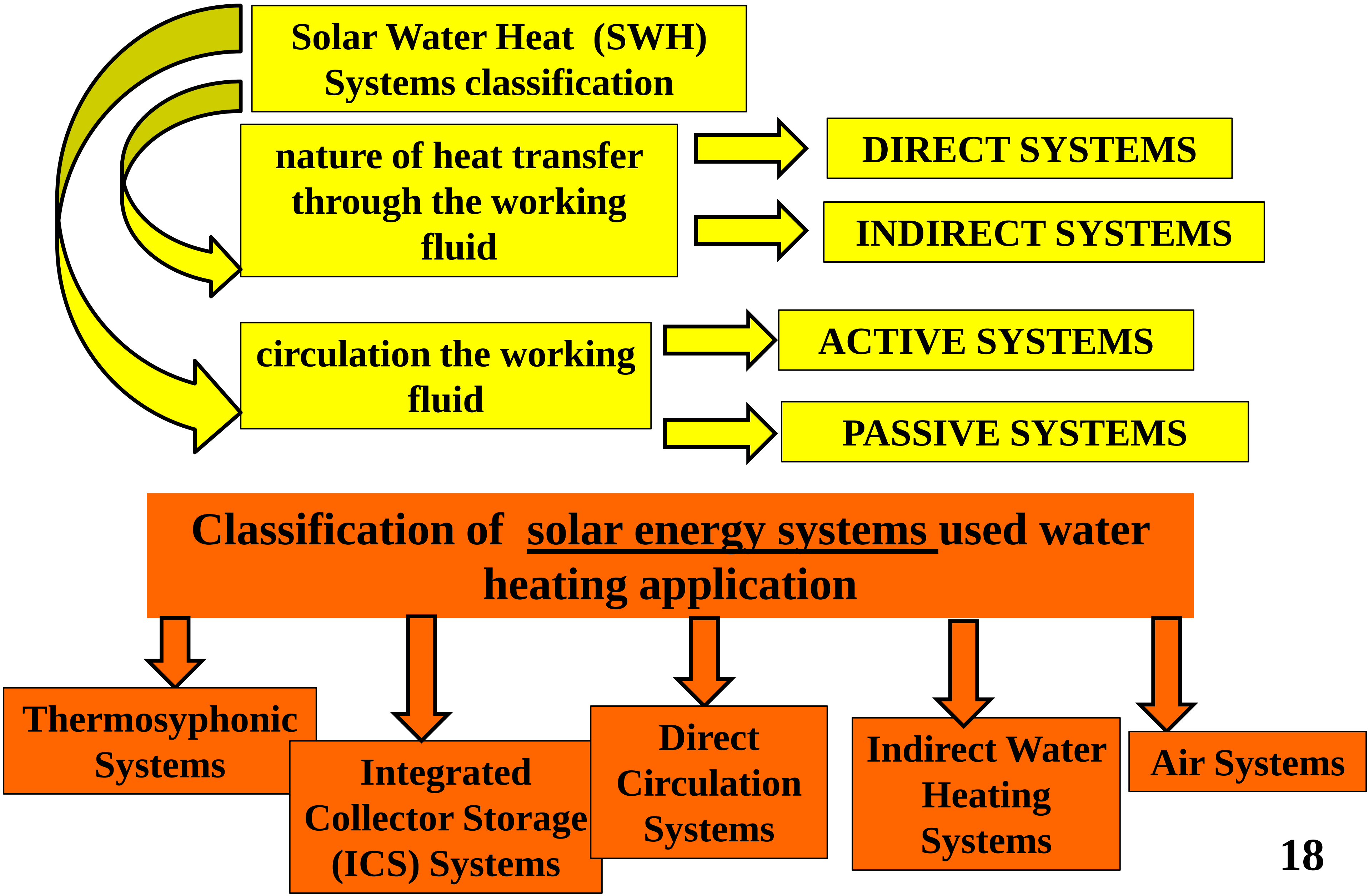
Two sets of performance parameters are determined according to European Standard EN12975-2 - one set corresponding to the absorber area and one set corresponding to the aperture area. It is important to use corresponding area / parameters. Normally the aperture area is used, which is: The area through which the solar radiation enters the solar collector

2. Collector efficiency

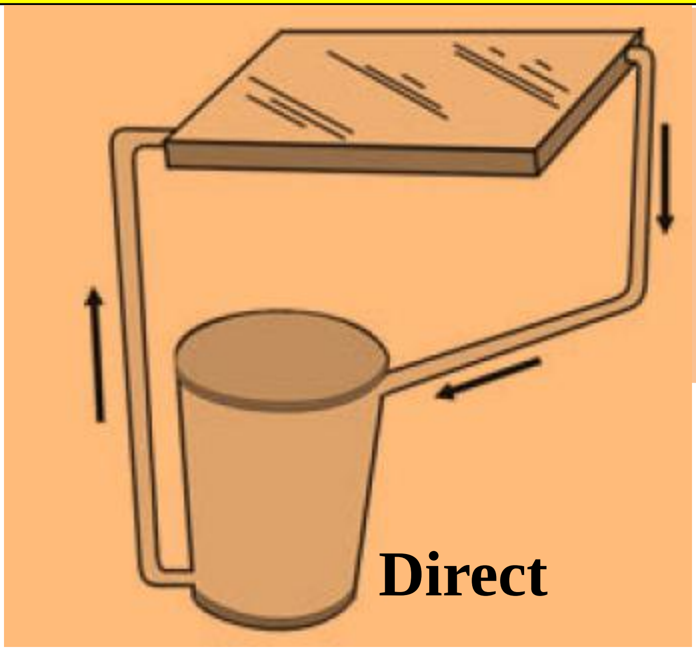
2.4Efficiency expression



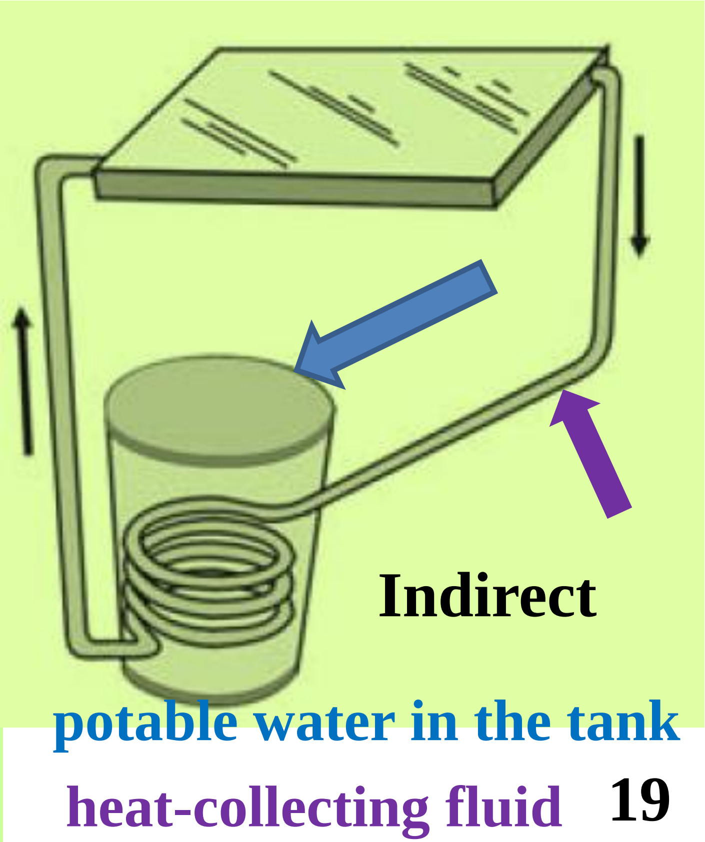
3.Solar radiation collectors systems, design and application.



Solar Water Heat (SWH) Systems classification

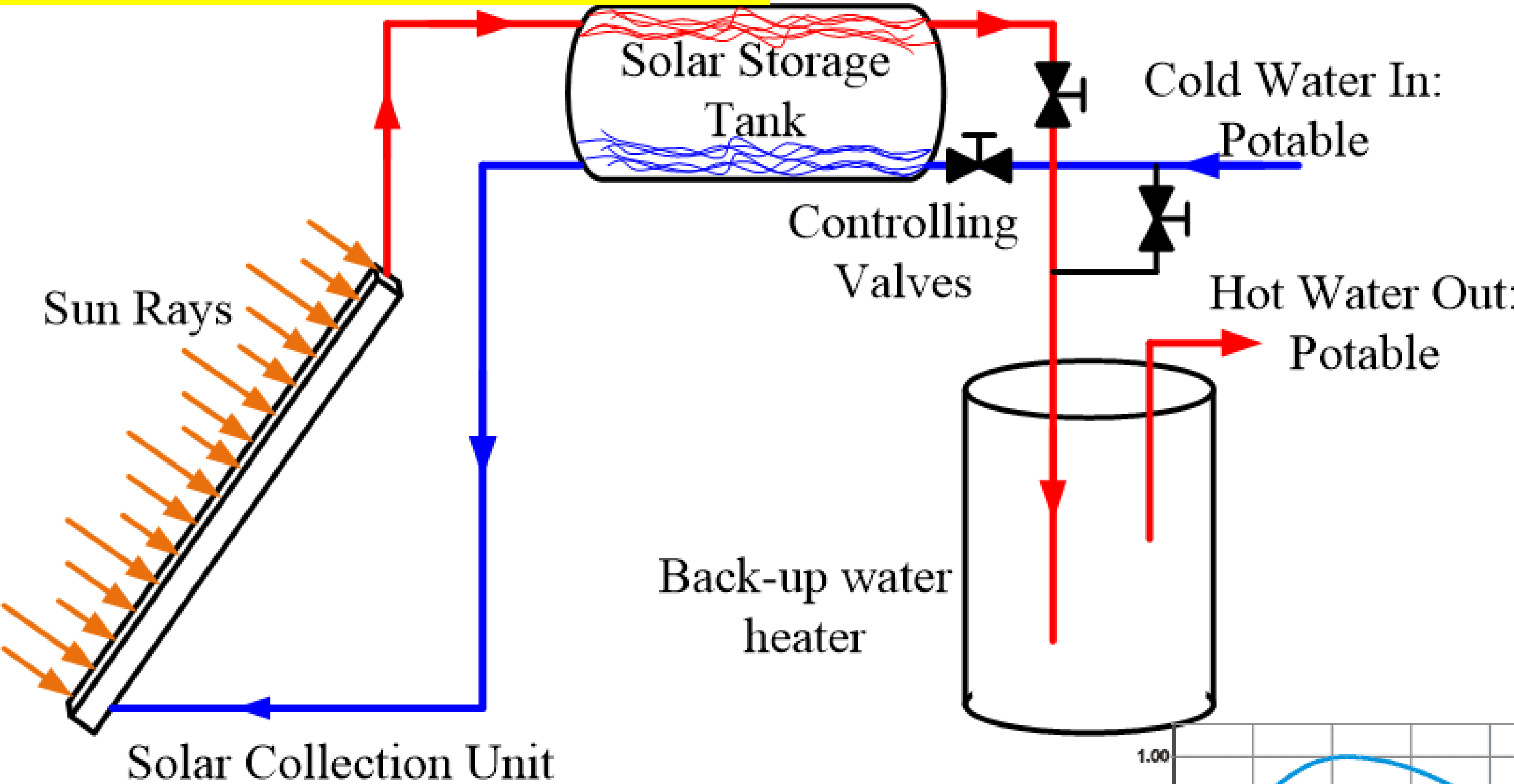


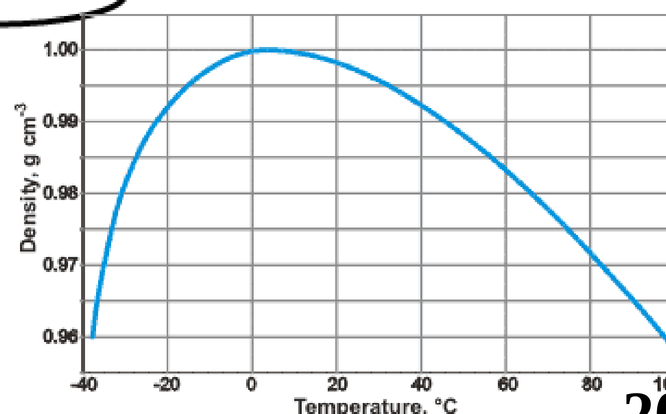
In a direct system, the potable water circulates from the storage tank to the collector and back to the storage tank. Thus, the heat collecting fluid is the same potable water that is in the water heater.



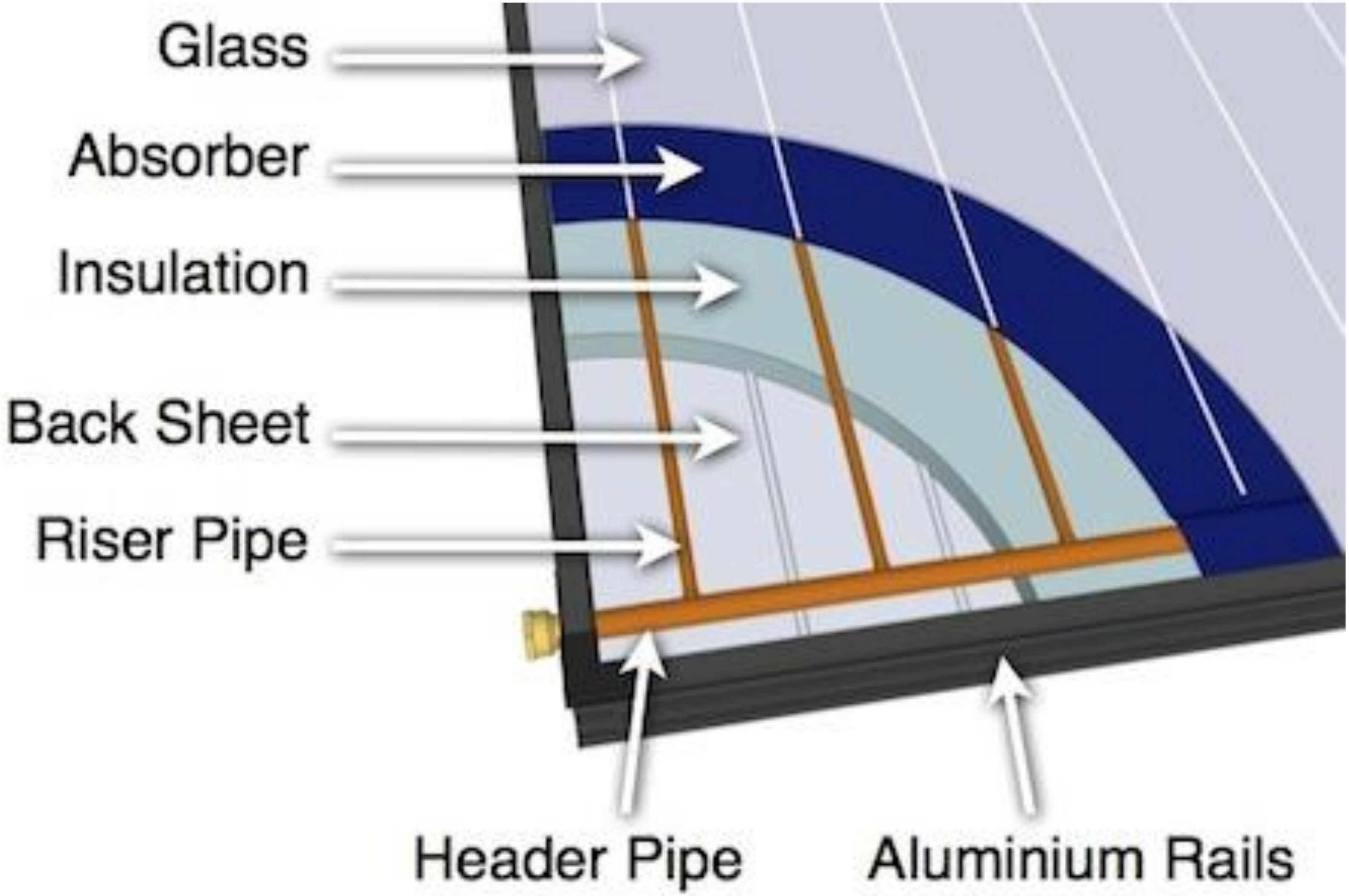
In an indirect system, the fluid that circulates through the collector may be water or it may be another heat transfer fluid. This heat-collecting fluid never comes in contact with the potable water in the storage tank. Instead, it transfers heat to the potable water through a heat exchanger

3.1Thermosyphon systems (passive)





3.1.1Thermosyphon systems (passive) with flat plate collector



3.1.1Thermosyphon systems (passive) with flat plate collector

The main element of a flat-plate collector is the **absorber plate**. It covers the full area of the collector and must perform three functions:

- absorb the maximum possible amount of solar irradiance,
- conduct this heat into the working fluid at a minimum temperature difference,
- and lose a minimum amount of heat back to the surroundings.

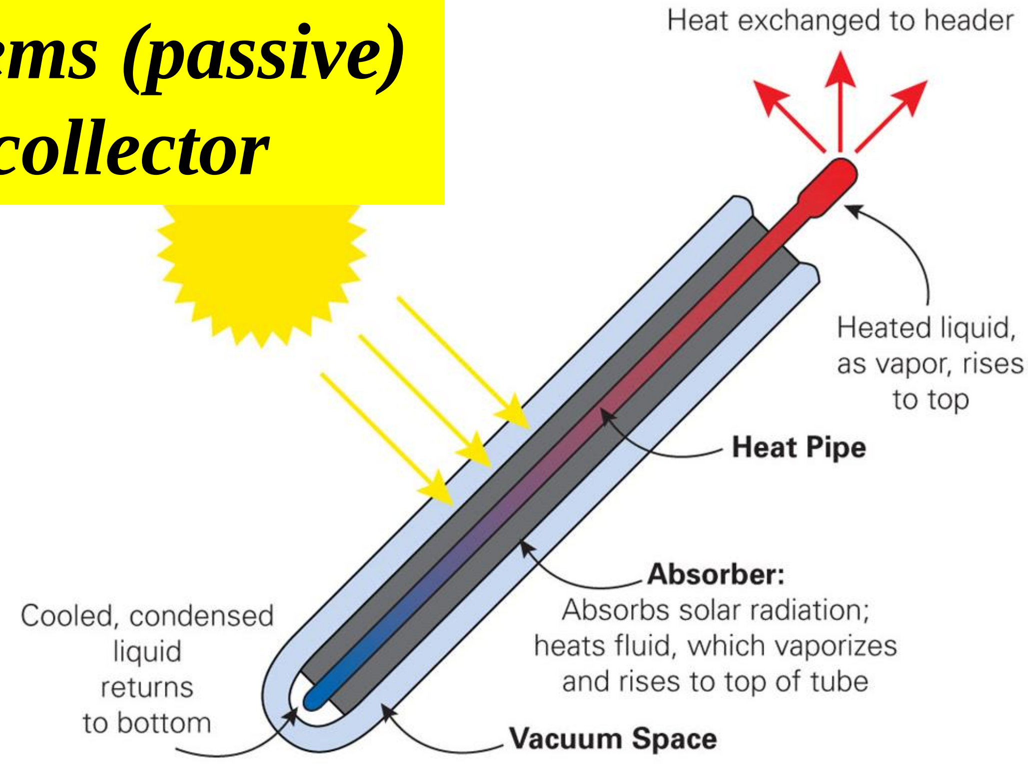
Absorption. Solar irradiance passing through the glazing is absorbed directly on the absorber plate without intermediate reflection. Surface coatings that have a high absorptance for short-wavelength (visible) light, are used on the absorber. Usually these coatings are flat, indicating that they will absorb radiation coming from all directions equally well. The sheet of metal absorbs most of the solar irradiance and acts as a transmitter to bring the absorbed heat into the fluid.

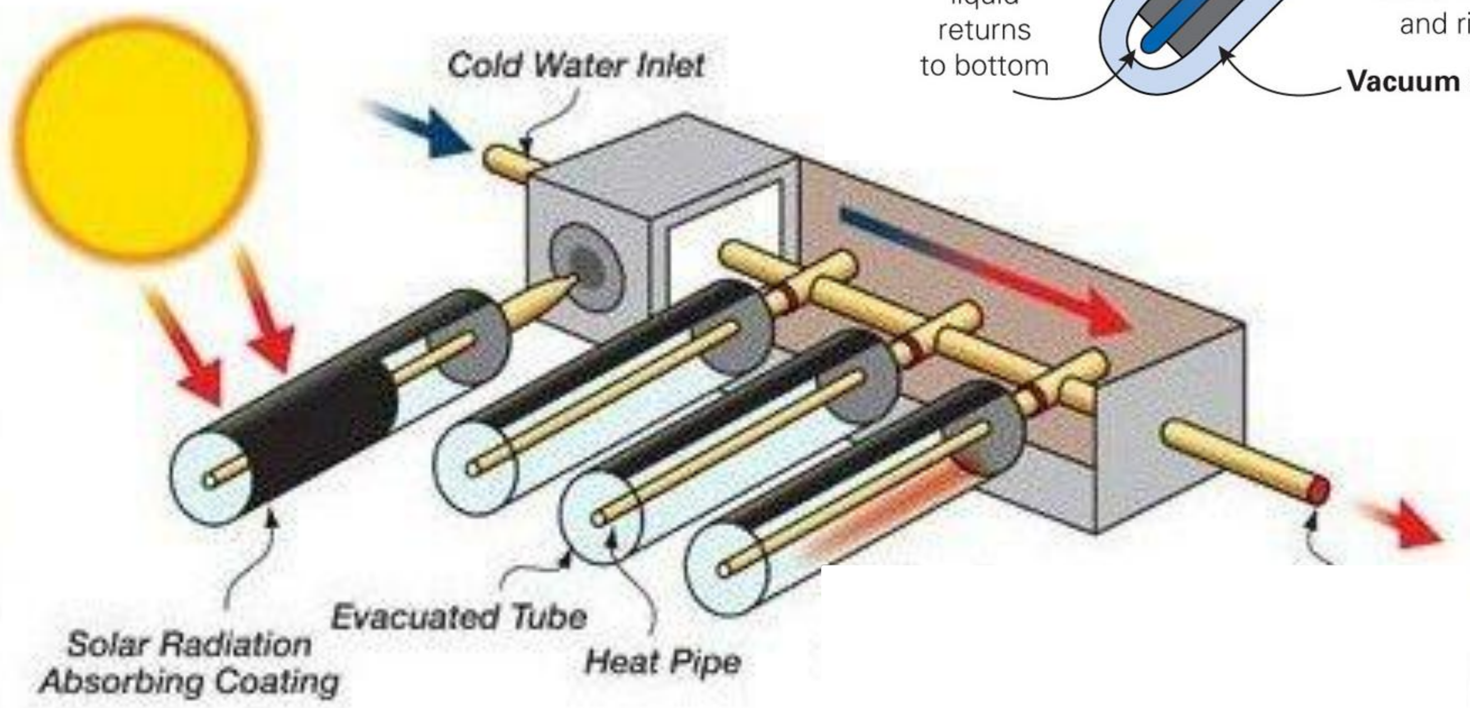
3.1.1Thermosyphon systems (passive) with flat plate collector

Here a table about matters that absorber plate may be made from:

Material	Absorptance (α)	Emittance (ε)	Break down temparature (°C)
Black silicon paint	0.86-0.94	0.83-0.89	350
Black silicon paint	0.9	0.5	300
Black copper over copper	0.85-0.9	0.08-0.12	450
Black chorome over nickel	0.92-0.94	0.07-0.12	450

3.1.2Thermosyphon systems (passive) with evacuated tube collector





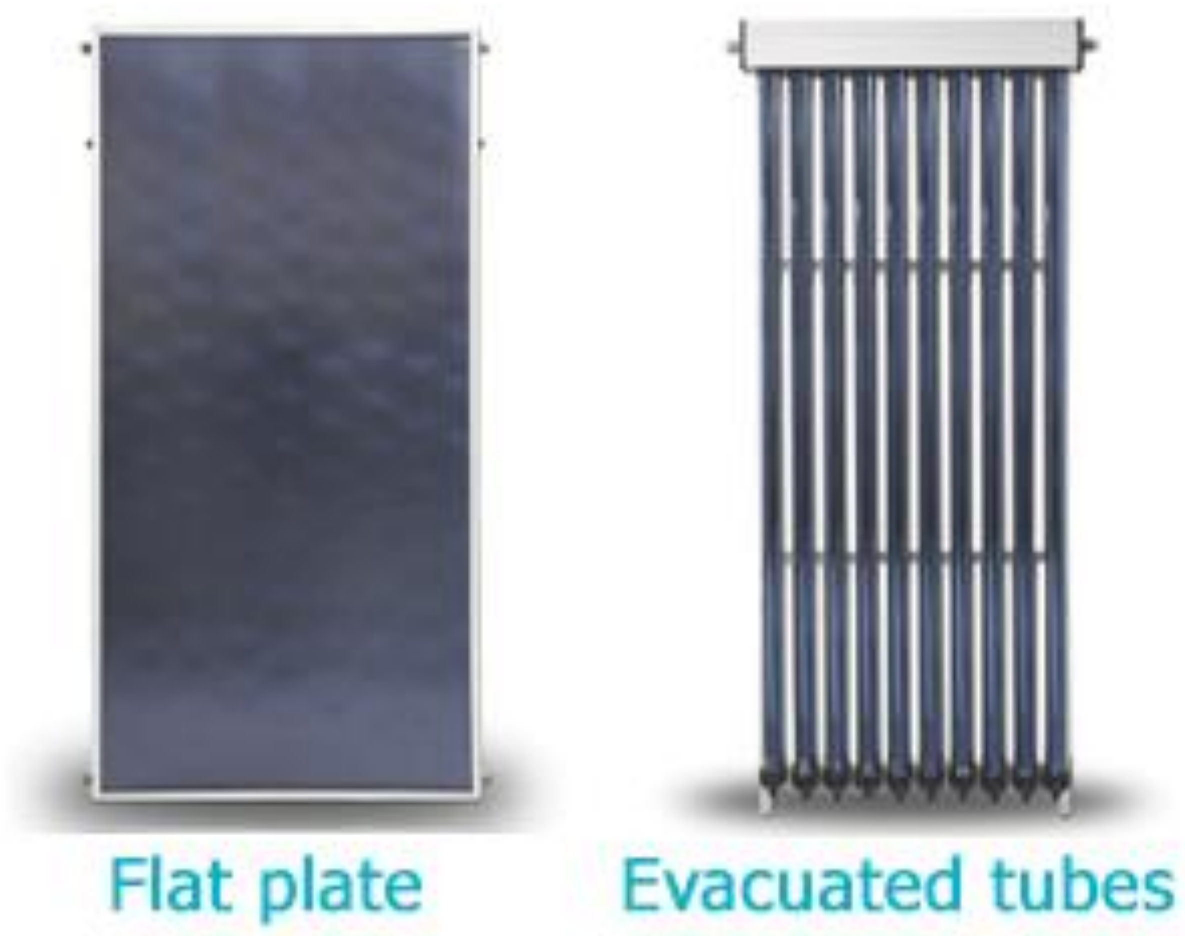
3.1.2Thermosyphon systems (passive) with evacuated tube collector

Evacuated-Tube Collectors

Evacuated-tube collectors depend on vacuum technology as vacuum is an excellent thermal insulator. Even a relatively small space filled with a vacuum provides much better insulation than the foam, fiberglass, and glass cover of a flat-plate collector. With superior heat retention, evacuated tubes are often preferred in colder climates and cloudy regions where flat-plate collectors have lower performance.

The most popular evacuated-tube design incorporates a heat exchanger in each tube. In these designs, the heat exchanger consists of a single tube—a "heat pipe"—bonded to the absorber plate. The solar radiation heats the tube absorber, which heats the heat pipe, boiling and vaporizing the fluid (typically alcohol or purified water with special additives) inside it. At the top of the tube, a heat exchanger transfers the heat from the vapor to a manifold, through which collector-loop fluid circulates. The heat-pipe design allows each evacuated tube to be a separate collector and makes the entire system modular. Since there is a "dry" connection between the absorber and the header, installation is much easier than with direct-flow collectors. Individual tubes can also be exchanged without draining the entire system of its fluid. Finally, should one tube break, there is little impact on the complete system.

3.1Thermosyphon systems (passive)



41-47%

50-56%

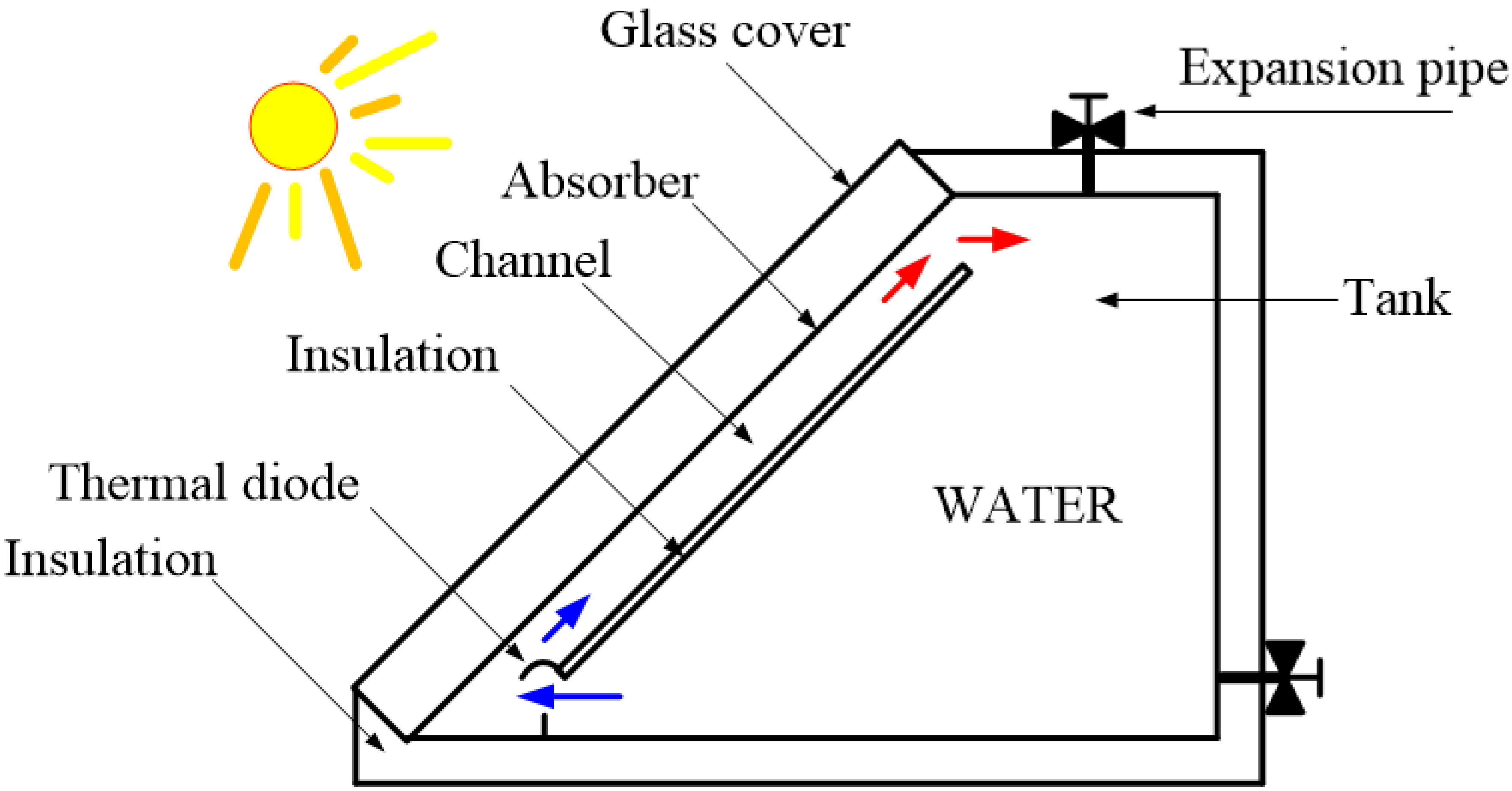
Experimental results have shown that the mean daily efficiency of SWH using a housing heat exchanger can reach **up to 50%.** This reported value may be lower than that of thermosyphon flat-plate SWH without heat exchanger, but higher than that of an all-glass evacuated tubular SWHs.

3.1Thermosyphon systems (passive)

Evacuated tube systems are more efficient than flat plate systems, particularly in the cooler months and on cloudy days. This efficiency comes from the vacuum insulation, which minimises heat loss, and the curved surface of the tubes that allows the sun’s rays to strike perpendicular to the water pipes for a greater part of the day. Evacuated tube systems weigh much less than flat plate systems but cost significantly more. Individual tubes can be replaced in the event of damage, making long term maintenance potentially less costly. In warmer climates the additional cost of evacuated tubes is usually not warranted over flat plate solar collectors.

3.2 Integrated collector storage systems (passive)

An easy-to-manufacture integrated SWH system



3.2 Integrated collector storage systems (passive)

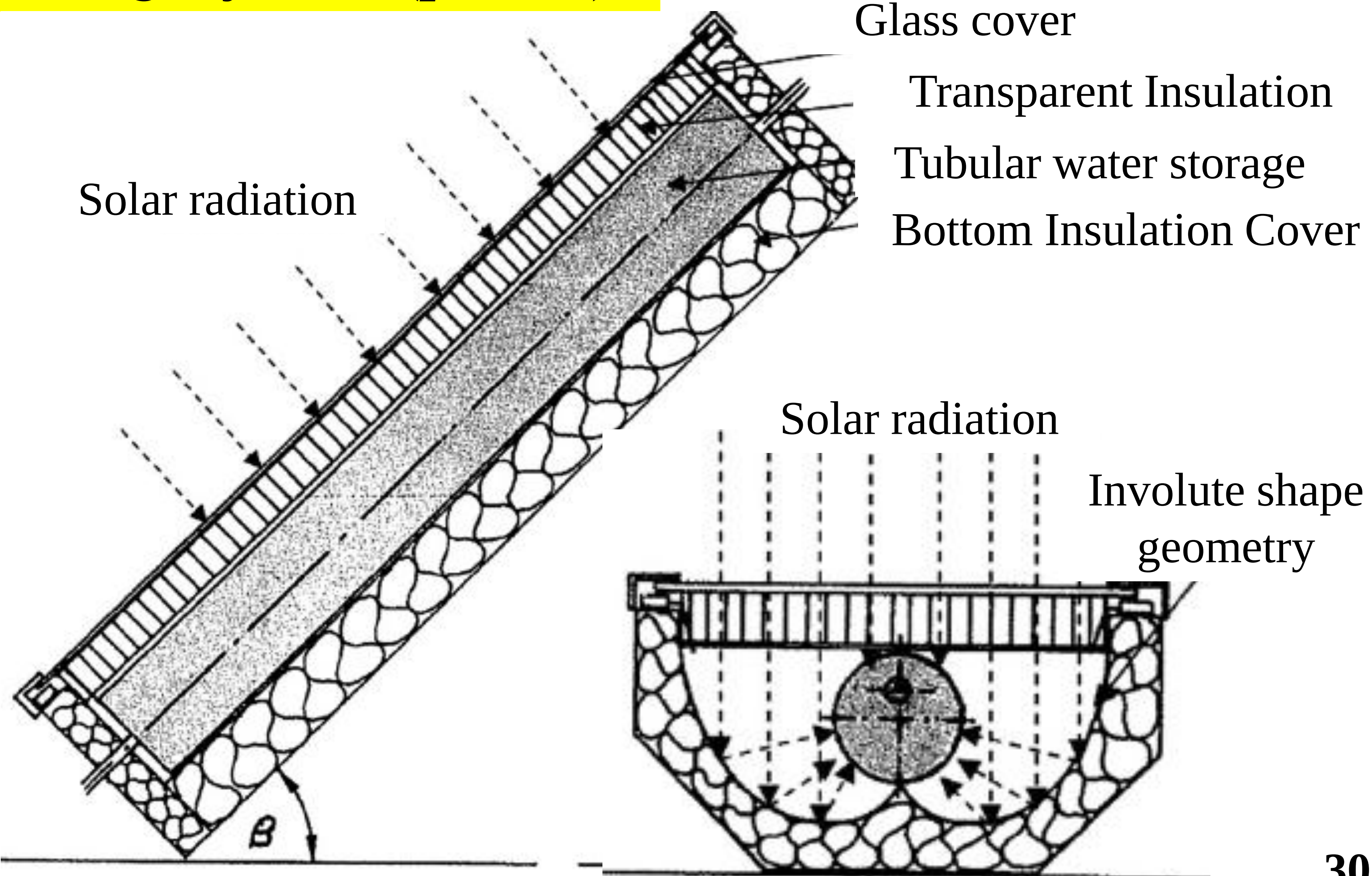
An easy-to-manufacture integrated SWH system

Unlike the conventional SWH system in which a collector acts as an absorber of sunlight, the ICS system utilizes both the collector as well as the storage tank as an absorber to collect solar radiation. In most cases, the entire exterior part of the reservoir acts as an absorber. However, these systems have sufficiently heavy heat losses, especially during non-sunshine hours. Several approaches, such as selective absorber surface coatings, insulating materials, and a single or double glazing glass covers have been used to reduce the heat losses. A few other techniques were also attempted to culminate the heat loses: movable protection cover, insulated baffle plate, and utilizing phase change material(PCM) inside the storage tank. Researchers have also attempted to use transparent insulating materials for the appropriate exposed parts. Further, to reduce the heat losses, the storage tank was operated on thermal stratification modes, by drawing the hot water from the top of the storage tank and cold water inlet to the bottom of the tank.

Several design parameters, such as storage tank design and its' orientation, methods of glazing, insulation, reflectors, use of PCM in the storage tank, use of baffle plates, and this influence on optical efficiency and thermal performance have also been detailed in a lot of studies. Various studies have suggested that tubular storage system is better than rectangular storage system, since it is more pressure resistant, and be able to connect water mains directly. An easy-to-manufacture integrated SWH system in which a thermal diode was used to avoid the reverse flow of hot water during the night time. The results proved that the thermal diode significantly reduces the heat losses.

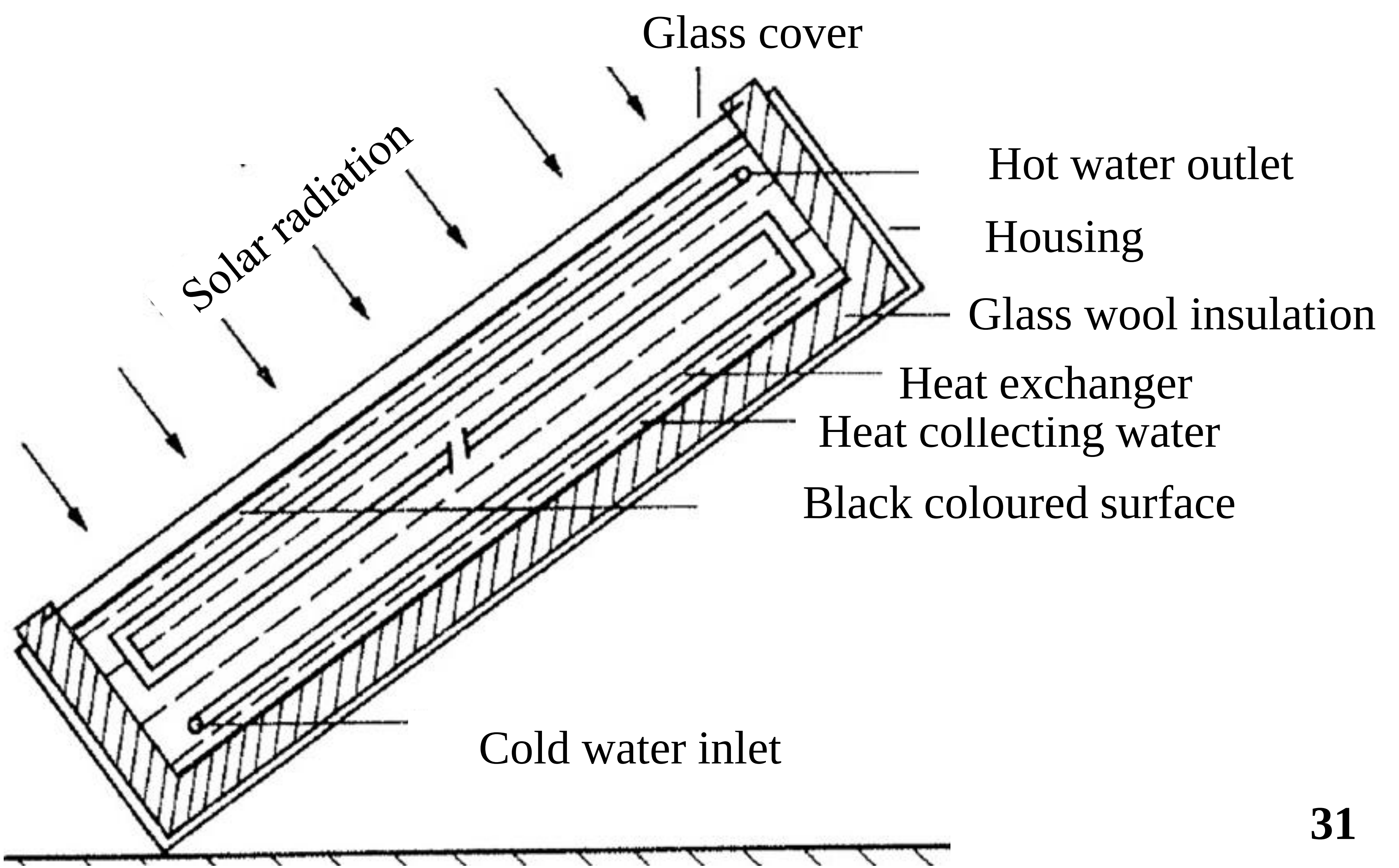
3.2 Integrated collector storage systems (passive)

ICS system for cold region



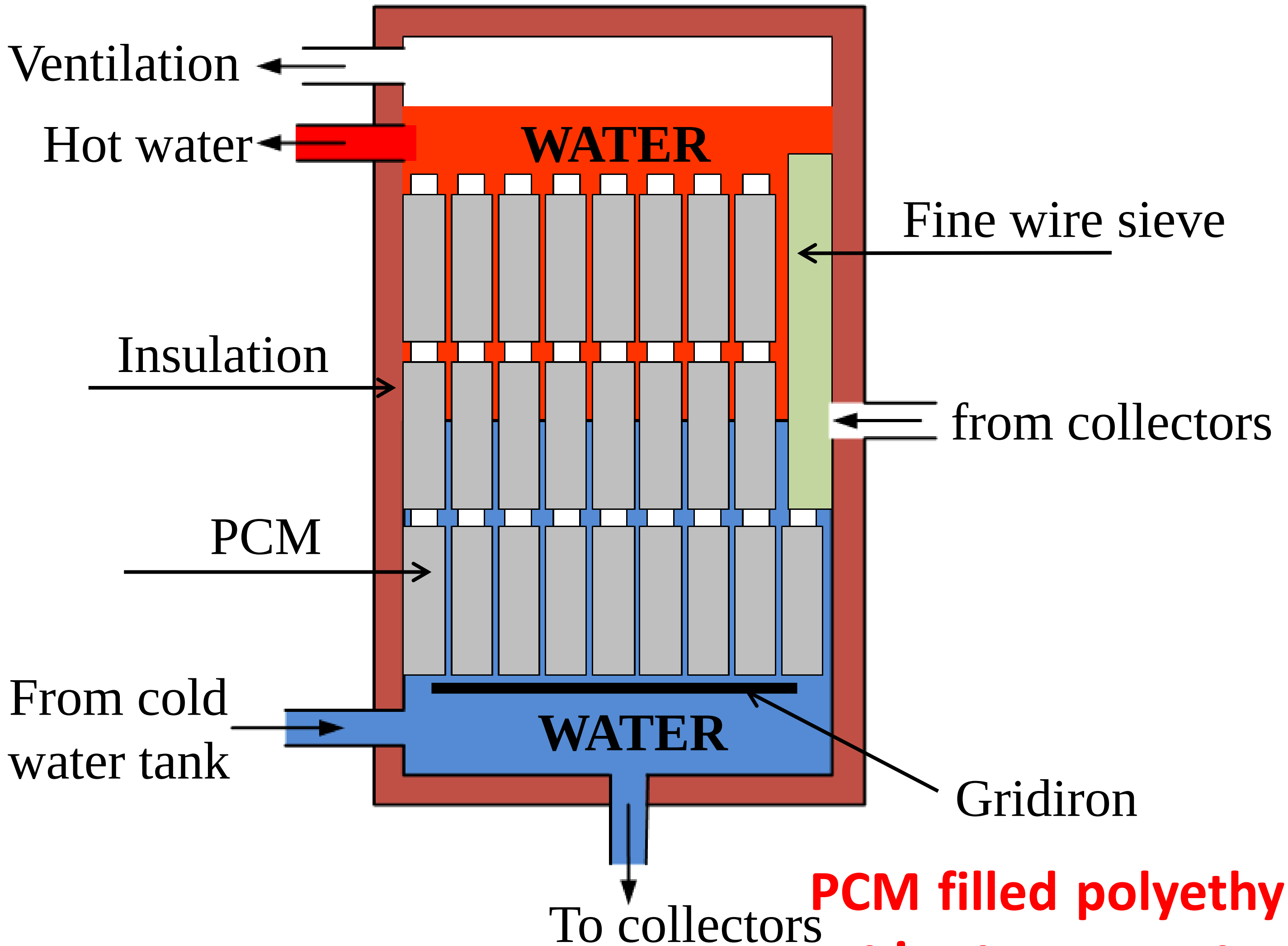
3.2 Integrated collector storage systems (passive)

Built-in-storage solar water heater incorporated with heat exchanger plate designed



3.2 Integrated collector storage systems (passive)

Cross-sectional view of heat storage tank combined with PCM



Phase change materials (PCM) are substances that absorb and release thermal energy during the process of melting and freezing.

PCM filled polyethylene bottles were set in storage system in three rows

3.2 Integrated collector storage systems (passive)

Cross-sectional view of heat storage tank combined with PCM

During the effect of sunlight, water gets heated and eventually heat is transferred to the PCM (phase change material) stored in the form of capsules at the bottom of the tank. During the period of no sunshine, and the time of withdrawal of hot water from the storage tank, the PCM releases energy by changing its state from liquid to solid that keeps the water warm. Paraffin wax (MP54 1C) is widely used as thermal energy storage medium.

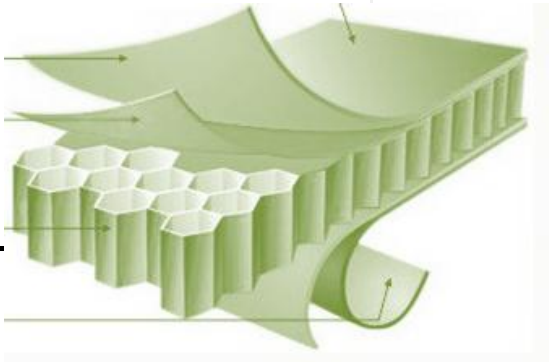
Several other phase change materials, such as ammonium alum, fatty acid, palmitic acid, and stearic acid with melting temperature varying 50 1C to701C have been used for ICS water heating system. PCM-filled polyethylene bottles were set in storage system in three rows. The cross-sectional view of the system is show here. Results were compared with the conventional SWH system and found that the hot water production and the accumulated heat in the SWH system were roughly 2.6–3.5 times higher in case of with the PCM-charged system.

When a PCM freezes, it releases a large amount of energy in the form of latent heat at a relatively constant temperature. Conversely, when such material melts, it absorbs a large amount of heat from the environment. PCMs recharge as ambient temperatures fluctuate, making them ideal for a variety of everyday applications that require temperature control.

3.2 Integrated collector storage systems (passive)

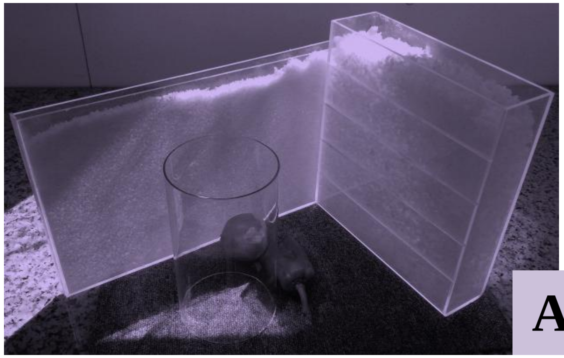
Typical characteristic values for some transparent insulation material

Insulation material	Thickness, (cm)	Transparency, (%)	Heat loss coefficient, $(W/m^2/K)$
PMMA foam	1.6	58	3.6
Honeycomb structure	10	60	0.8
Aerogel pellets	1.6	53	1.25
Aerogel pellets evacuated	1.6	53	0.8



Honeycomb structure

poly(methyl methacrylate)-PMMA



Aerogel pellets

3.2 Integrated collector storage systems (passive)

Typical characteristic values for some transparent insulation material

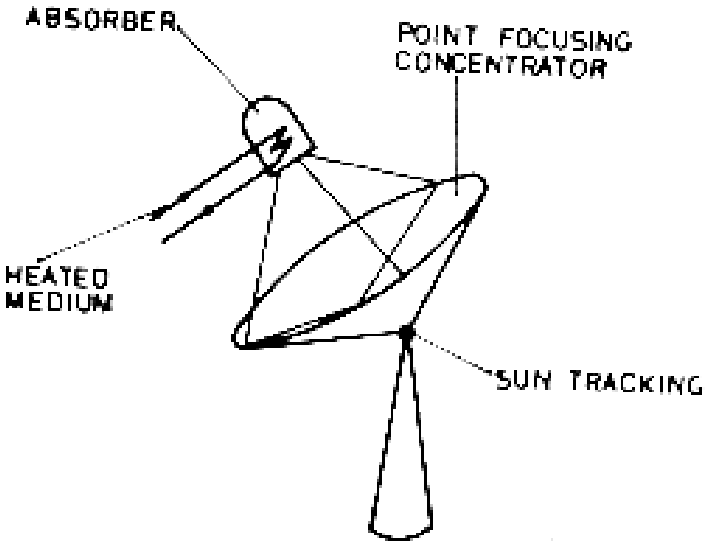
Numerous studies have been conducted to increase the thermal performance of an ICS device by incorporating transparent insulation material to the appropriate sections of the solar collector and storage tank .

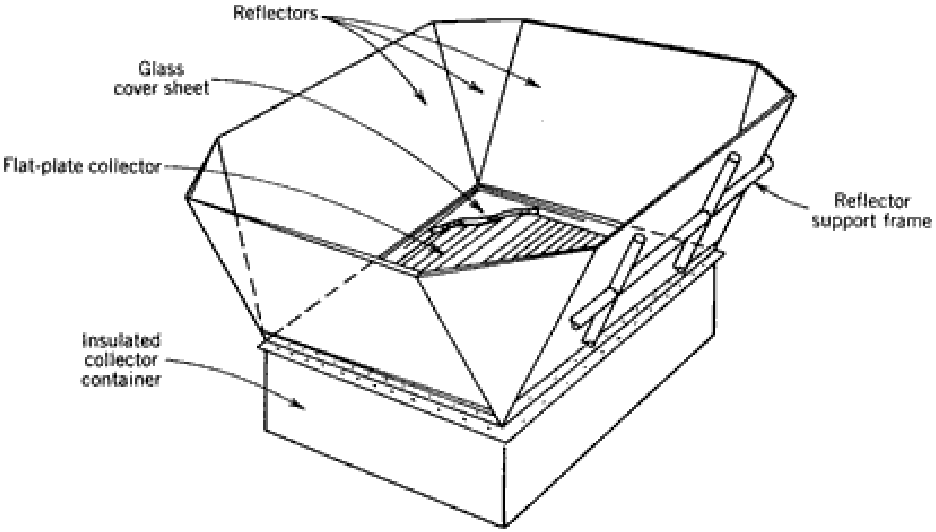
Here you can see different types of transparent insulating materials that could be used over the absorber/collector plate (Table2).

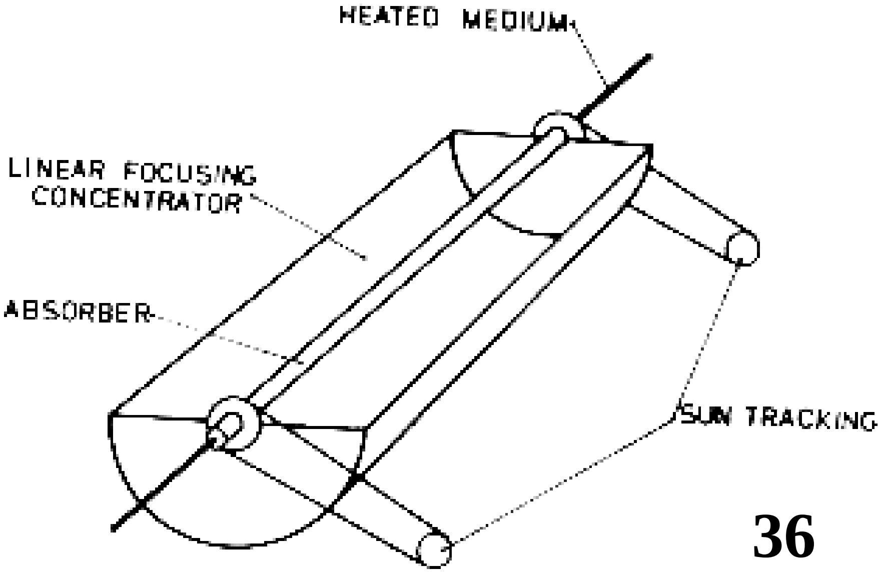
With the use of transparent materials like glass and polycarbonate a translucent wall, window or roof can be constructed. Simply fill the hollow volume of the wall with aerogel pellets or large granules of aerogels for windows to construct a translucent insulating panel. With aerogels your can enjoy dual energy savings both on illumination and heating.

3.2 Integrated collector storage systems (passive)

Collectors' shape







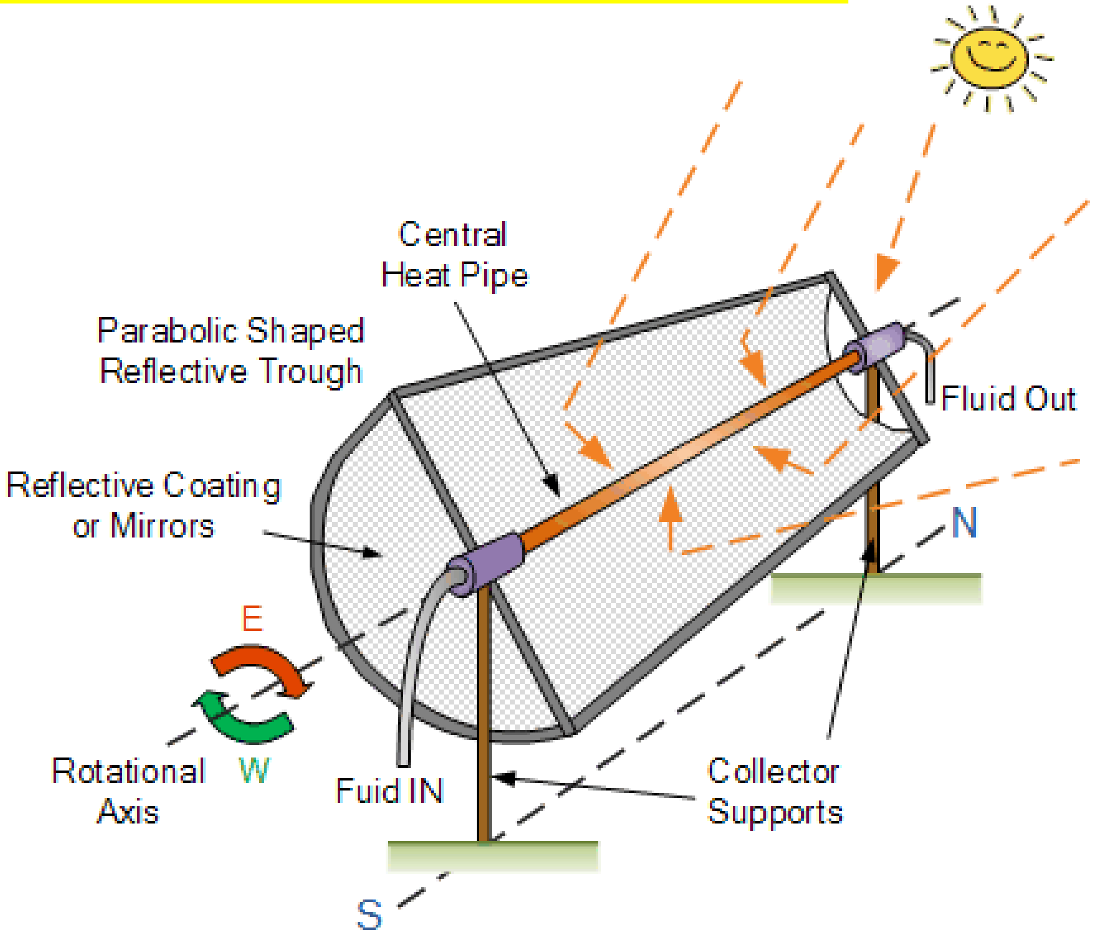
3.2 Integrated collector storage systems (passive)

Collectors' shape

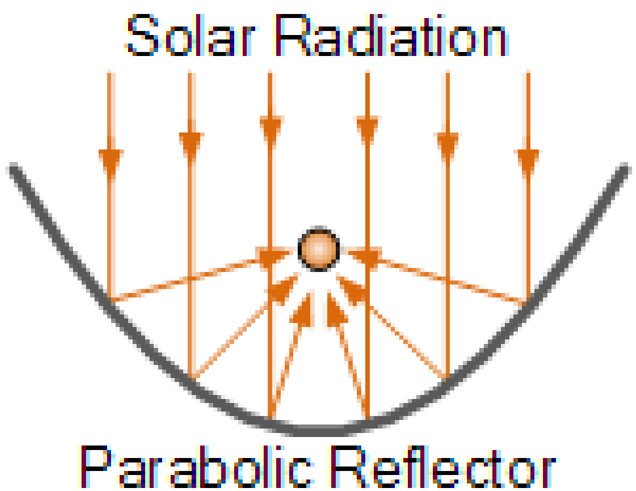
in order to generate higher temperatures with good efficiency a solar collector in the form of a parabolic trough reflector maybe required. The parabolic trough reflector is a solar thermal energy collector designed to capture the sun's direct solar radiation over a large surface area and focus, or more generally "concentrate it" onto a small focal point area increasing the solar energy received by more than a factor of two which means more overall heat per square meter of trough. The shape of concentrating solar collectors must be specifically designed so that all the incoming sunlight reflects off the surface of the collector and arrives at the same focal point no matter what part of the collector the sunlight hits first. Concentrating solar collectors for residential applications are usually a "U-shaped" parabolic trough (hence their name) that concentrates the sun's energy on an absorber heat tube called a receiver that is positioned along the focal point axis of the reflective trough.

3.2 Integrated collector storage systems (passive)

Collectors' shape



parabolic collector



3.2 Integrated collector storage systems (passive)

Collectors' shape

Parabolic Trough Reflectors or PTR, are made by simply bending a sheet of reflective or highly polished material into a parabolic shape called a parabola. Since solar light waves essentially travel parallel to each other, this type of solar collector can be pointed directly into the sun and still achieve a total focal output from all parts of the trough shaped reflector as shown.

The parabolic trough reflector when used as a solar thermal energy collector is constructed as a long parabolic reflecting mirror which is usually painted a reflective silver, or made from polished aluminium, or uses mirrors which extends linearly into the trough shape. A metal black heat tube inside a sealed glass tube which can also be evacuated is used to reduce heat losses. The heat tube contains a heat-transfer fluid which is pumped around a loop within the tube absorbing the heat as it pass through.

3.2 Integrated collector storage systems (passive)

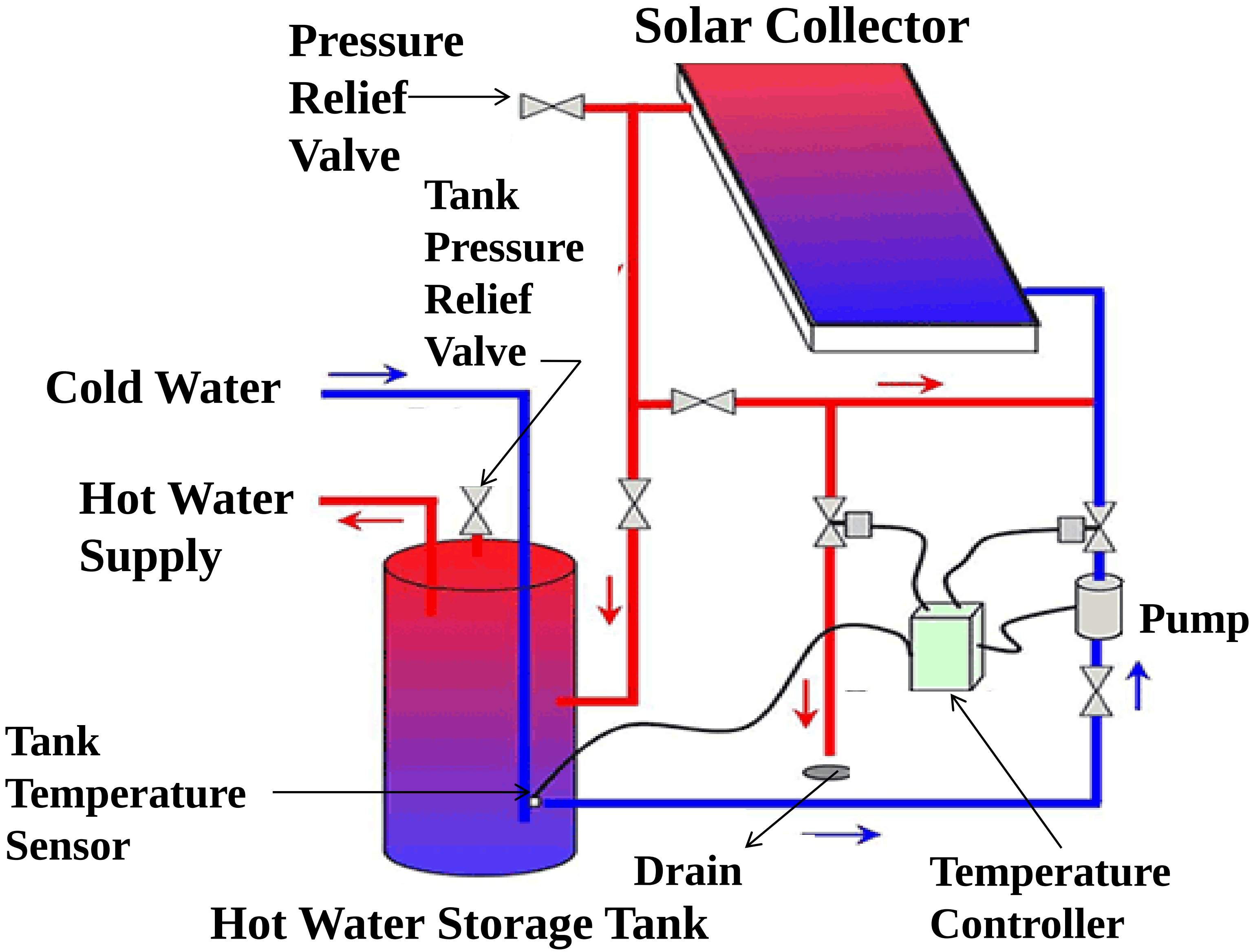
Collectors' shape

most concentrating collectors require some form of mechanical equipment that constantly orients the collectors towards the sun keeping the heat pipe absorber at the correct focal point. This is achieved by using a Tracking Solar Concentrator that aligns the trough with the sun throughout the day, maximising the solar heat gain. The collector generally has a single rotation axis along the length of the trough which can be orientated in an east-to-west direction, tracking the sun from north to south, or orientated in a north-to-south direction and tracking the sun from east to west.

Parabolic troughs are generally aligned on a north-to-south axis, and are rotated to track the sun as it moves across the sky each day from morning to night.

The advantages of this type of tracking mode is that very little collector adjustment is required during the day resulting in the solar trough always facing the sun at noon time, but the collector performance early in the morning or late in the afternoon is greatly reduced due to the large incidence angles of the trough.

3.3. Direct circulation systems (active)

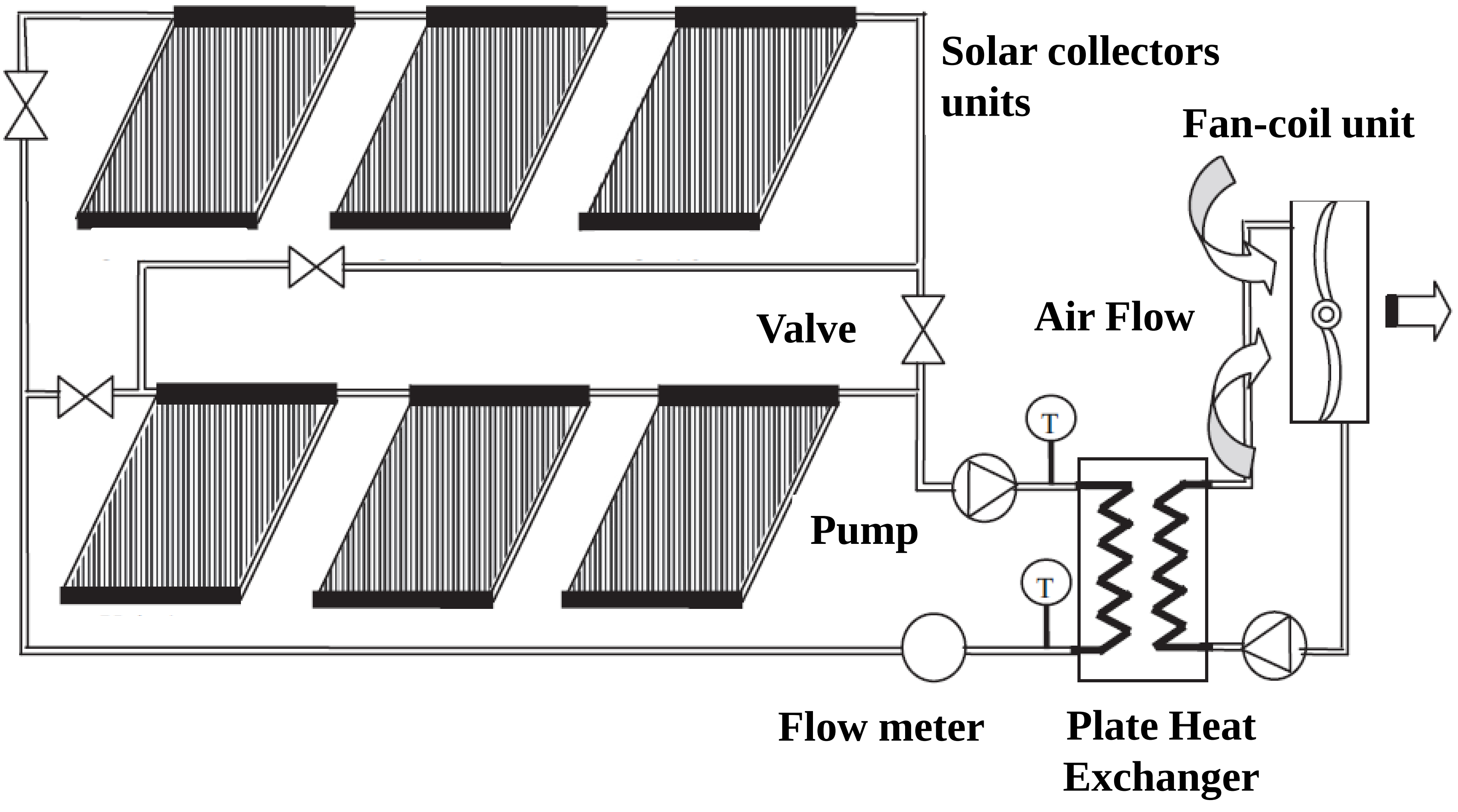


3.3. Direct circulation systems (active)

Unlike thermo syphon systems, direct circulation systems require a pump to circulate water from storage tank to the collector to get heated. The hot water flows back to the storage system and is ready for the users. The pump is usually controlled by a differential thermostat that regulates water at the top header by a sufficient margin to the bottom of the tank. A check valve prevents the reverse circulation to avoid night time thermal losses from the collector. The collectors can be positioned either above or below the storage tank as pump is used to activate circulation. Direct circulation system is generally used only under situations when freezing is not a concern. Sometimes, water from the cold storage tank or city water supply can be used directly into the system. Care should be taken when quality of water is hard or acidic, in a direct circulation system since it may cause clogging or corrosion of the collector tubes. Direct circulation systems more commonly employ a single storage tank which is with an auxiliary heater.

3.3. Direct circulation systems (active)

DCS with all-glass vacuum tube collector



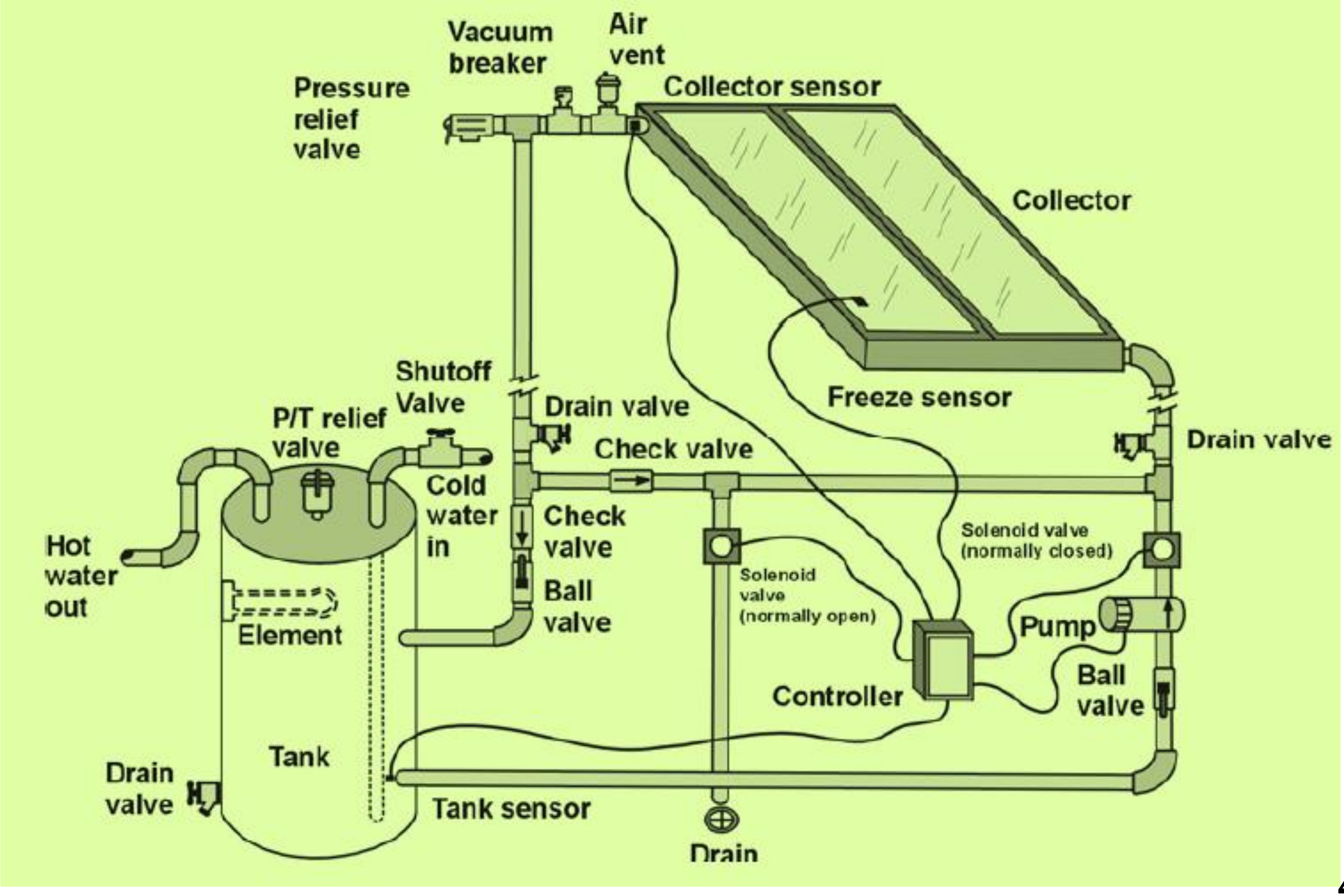
3.3. Direct circulation systems (active)

DCS with all-glass vacuum tube collector

Here you can see designed and installed a direct circulation SWH system at the Social Security Administration's Midatlantic Center in Philadelphia. Evacuated-tube heat-pipe solar collector of 36m2 net absorber area was employed to energize the storage tank. The simplicity in design and low erection cost made the system attractive to be implemented in commercial buildings.Unlike conventional systems, in this system the incoming water was preheated in the recirculation loop.

3.3. Direct circulation systems (active)

Drain-down systems



3.3. Direct circulation systems (active)

Drain-down systems

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

In a drain down system , sensors and a controller activate one or more automatic valves that isolate the collector loop from the tank.

A DDS: The automatic valve should be installed to allow collector loop drainage when power to the electrically operated valve is interrupted. The collectors and piping for these systems must be installed so that no gravity traps or low spots occur so that the collector loop fluid will drain totally by gravity.

3.3. Direct circulation systems (active)

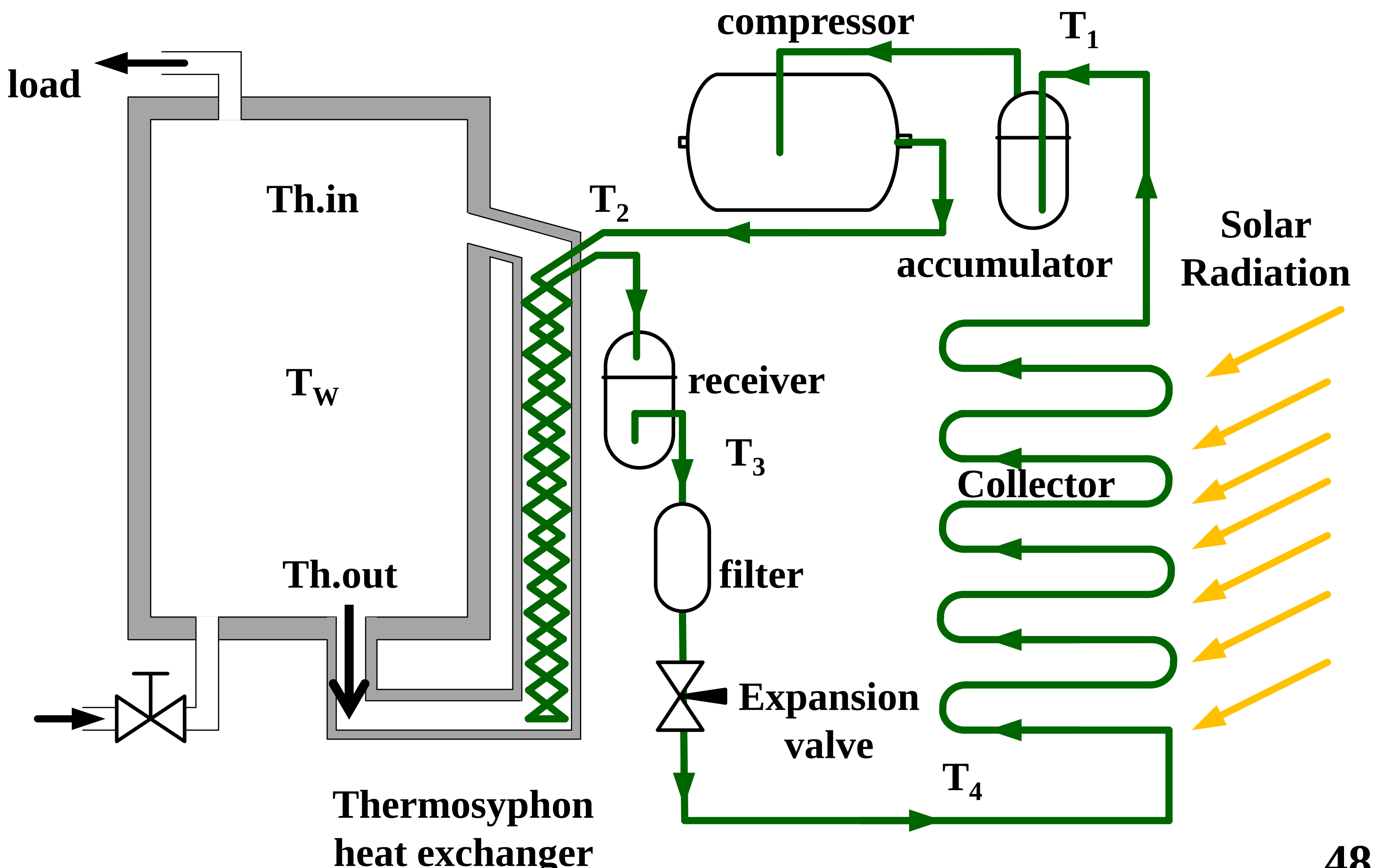
Drain-down systems

Manual Drain-down (MDD)

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

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

3.4. Indirect circulation systems (active)



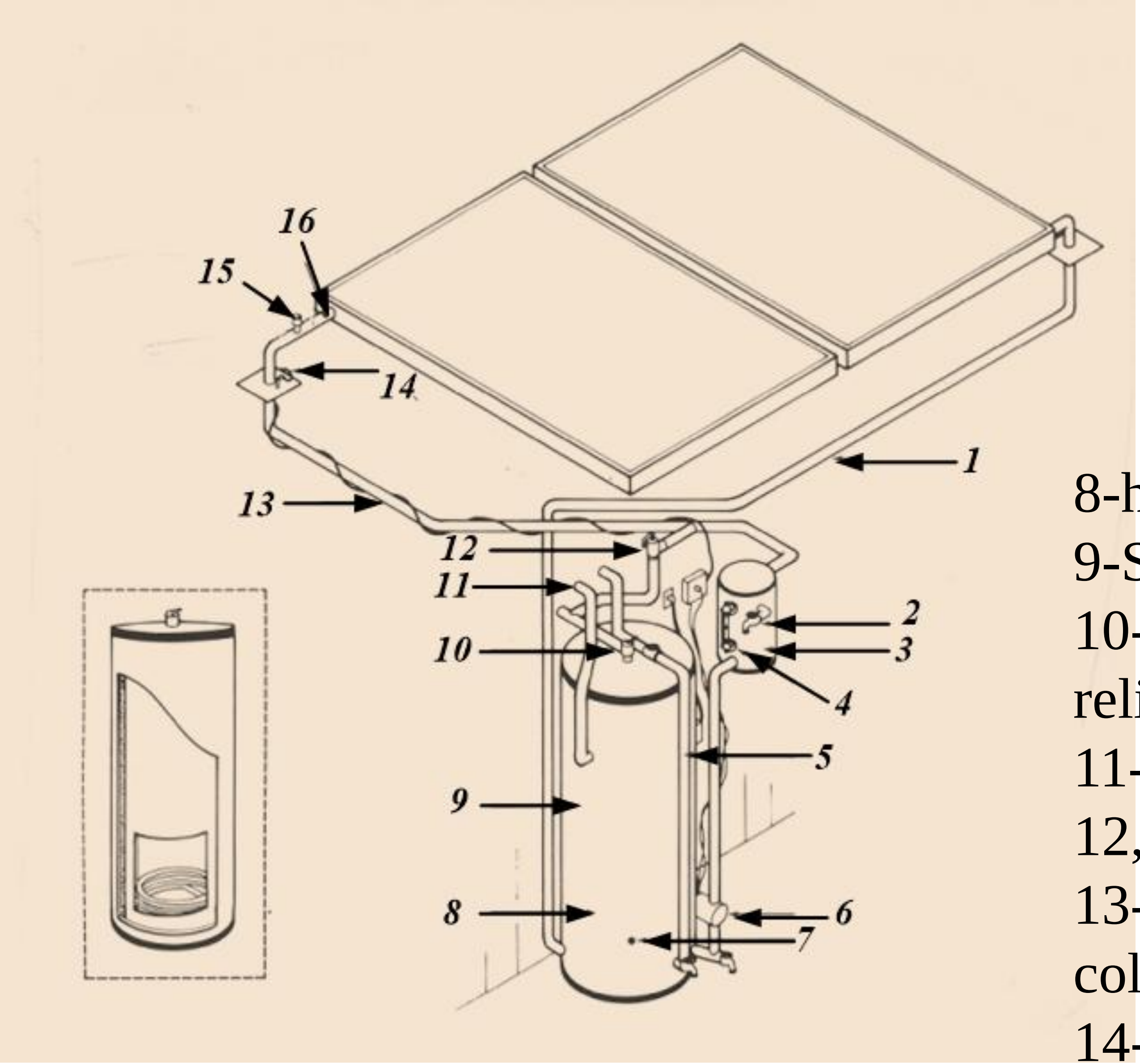
3.4. Indirect circulation systems (active)

Indirect systems of SWH utilize two circulation loops to effect heating: (a)the closed-collector loop and (b)the open storage tank loop. Usually, the heat transfer fluid is circulated within the closed-collector loop, to gain the heat and is then passed through a heat exchanger where heat is transported to the potable water that flows in an open loop to the storage tank.

There are several different types of working fluids used in the closed loop, such as water, refrigerants, and antifreeze mixtures. The heat exchanger can either be an internal system (placed inside the water storage tank or outside of the storage tank) or as an external system. An expansion tank integrated with a pressure relief valve is used in the closed circulation loop system. In the pressurized system, the tank is provided (an additional expansion tank) to have a control on temperature and pressure of the working fluid. However, for the unpressurized system, the tank is provided to release the pressure when required to vent.

3.4. Indirect circulation systems (active)

Drain-back systems



1-cold fluid to collector;
2-Fill connection;
3-Sight glass;
4-Drainback reservoir;
5- cold water supply;
6- pump;
7,16 -Sensor;
8-heat exchanger;
9-Stoarage tank;
10-Preasure-temperature relief valve;
11-Hot water to house;
12,15- pleasure relief valve;
13- Hot fluid from collector;
14-Sensor wire;

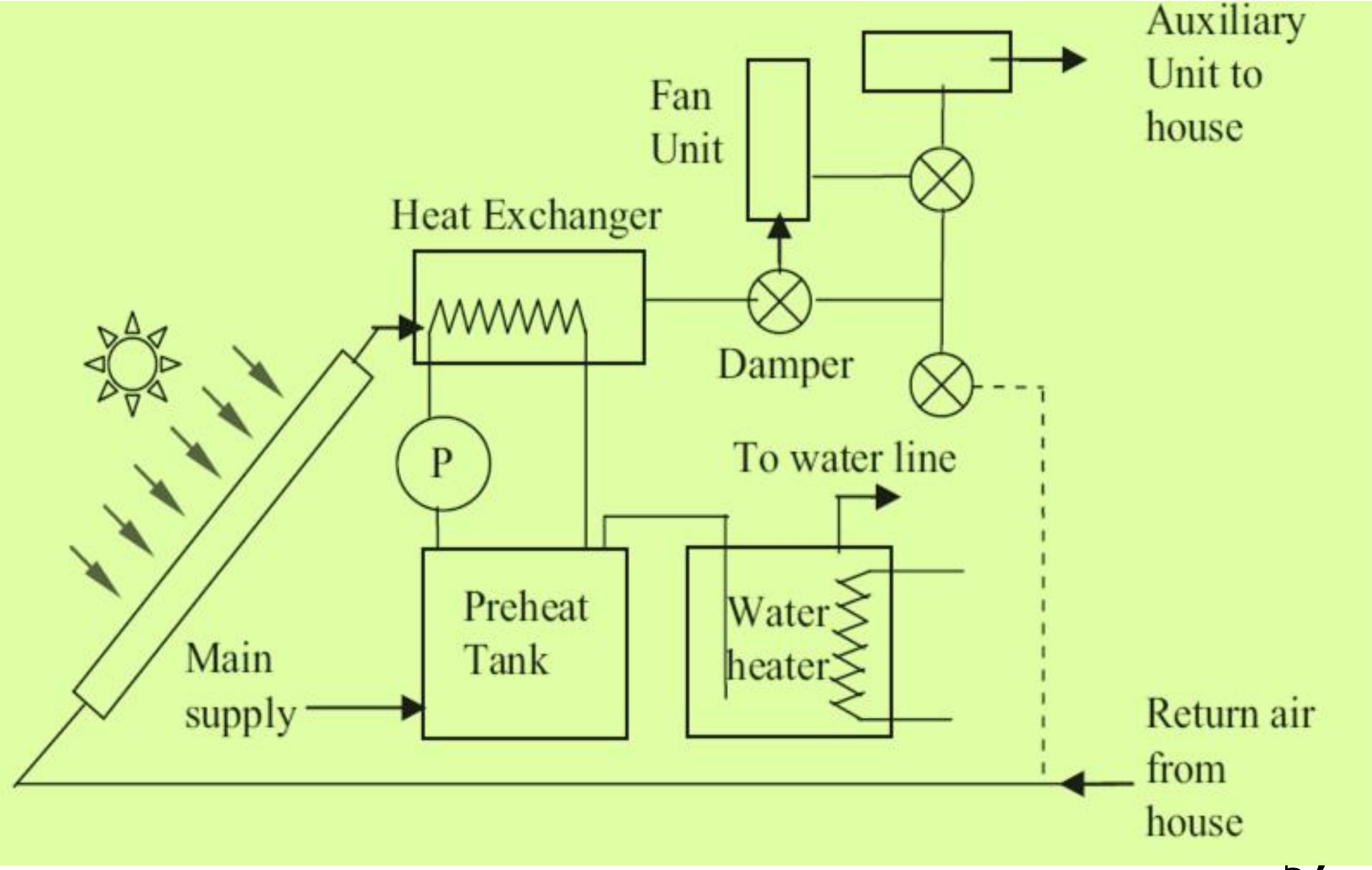
3.4. Indirect circulation systems (active)

Drain-back systems

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

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

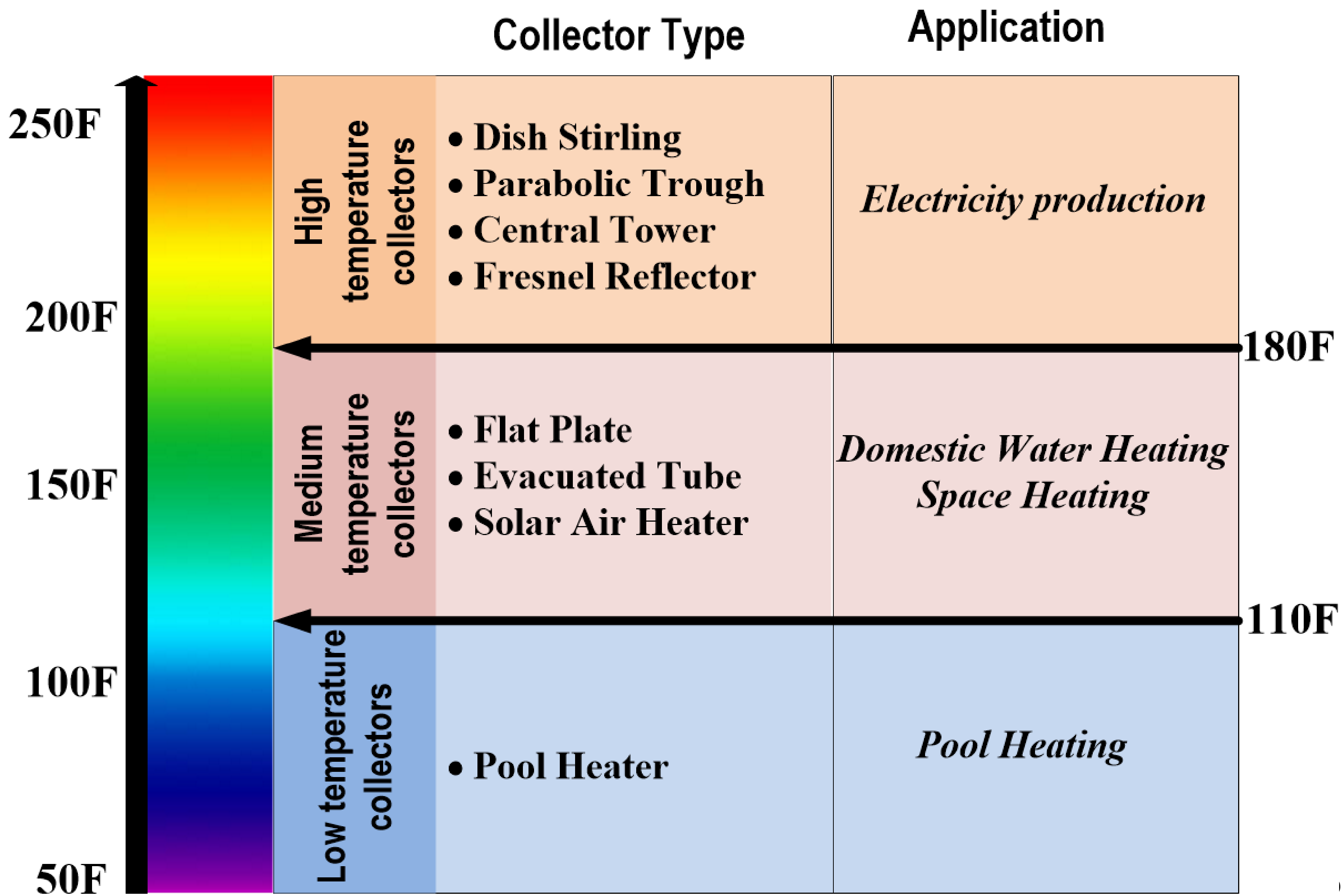
3.5. Air systems (active)



3.5. Air systems (active)

Unlike water or other refrigerants, air has also been used as working fluid, for its unique advantages. Compared to the conventional SWH system, air can be used as a working fluid even during freezing weather conditions, is non-corrosive, and requires only low maintenance requirements. However, the system is generally large and requires considerably large space for air handling unit. A typical arrangement of a solar air heating system incorporated with a pebble bed storage unit is illustrated in Fig. 19. Fans and dampers are incorporated to aid the system operation. The heat gained by the air in the collector duct is released through a heat exchanger to aid domestic hot water supply of up to 80 1C. A major drawback of the air systems is that air has low heating capacity and its performance deteriorates further when the ambient temperature is very low.

4. Solar collectors classification by operating temperatures and their application



4. Solar collectors classification by operating temperatures and their application

The classifications for solar heating collectors are based on the approximate operating temperatures that can be produced under normal levels of solar radiation. Low temperature collectors are used for applications where operating temperatures are below 110°F (45°C), such as for heating swimming pools. Medium temperature collectors are used in applications ranging from 110°F (45°C) to 180°F (80°C), including domestic water heating (DWH), space heating, indoor pool heating, car washes, and other commercial applications with sufficient heat demand. High temperature collectors concentrate the sun’s heat and are used for industrial process heating and other applications that require temperatures above 180°F (80°C), including the production of steam for utility-scale electricity production. Due to the fundamentals of physics and economic considerations, particular styles of collectors best correspond with specific applications. For example, high temperature collectors can be used for DWH, but the return on investment and overall system effectiveness will usually be far greater if medium temperature collectors are used instead.

5.KU proposal model of the solar collector.

5.1 Heat systems design

Figure1

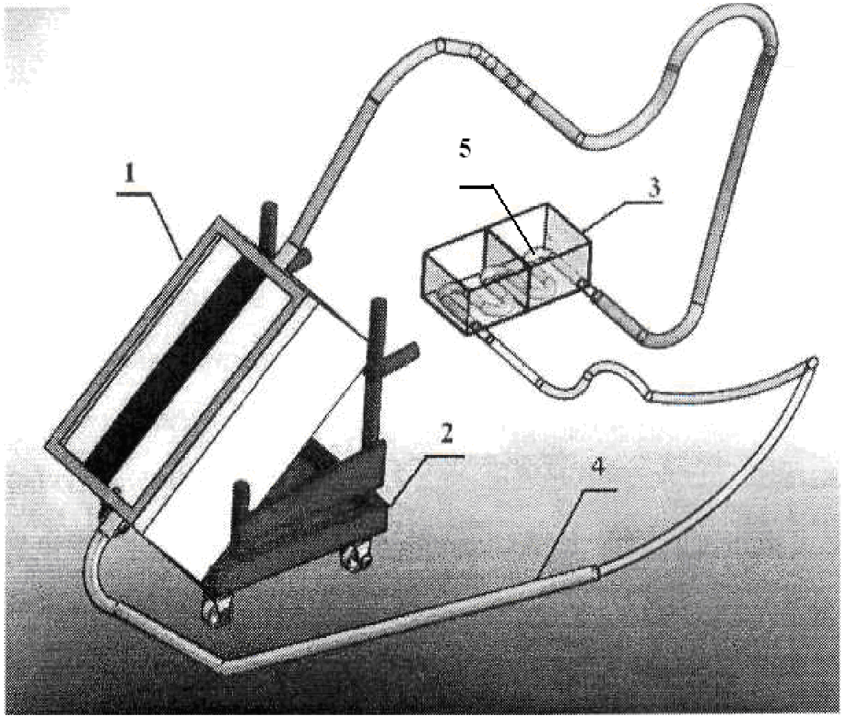


Figure2

Heating system scheme: 1 – solar collector; 2 – collector rotation trolley; 3 – heated container/tank filled with artificially contaminated soil; 4 – hoses with additional insulation; 5 – heating element (coil).

5.KU proposal model of the solar collector.

5.1 Heat system design

A heating system constructed in Klaipeda University and consisting of solar collector, hoses and containers for heated soil was used for the experiment and heating of soil contaminated with oil products. This system was made from recycled materials, i.e. waste metal and construction materials. The elements of the system were insulated additionally in order to reduce the heat loss and to increase the efficiency of the system. Solar collector is the most important device of the system. It absorbs the heat of the sun rays and transfers it to the water circulating inside (heat transfer medium). Experimental solar water heating system works on the principle of natural circulation due to the difference of density of cold and hot heat transfer media (water). In order to achieve a natural circulation of heat transfer medium, the heated containers filled with contaminated soil have to be installed above the solar collector (Fig. 2). The gap between the solar collector and the heated tanks has to be at least 0.5 m.

5.KU proposal model of the solar collector.

5.1 Heat systems design

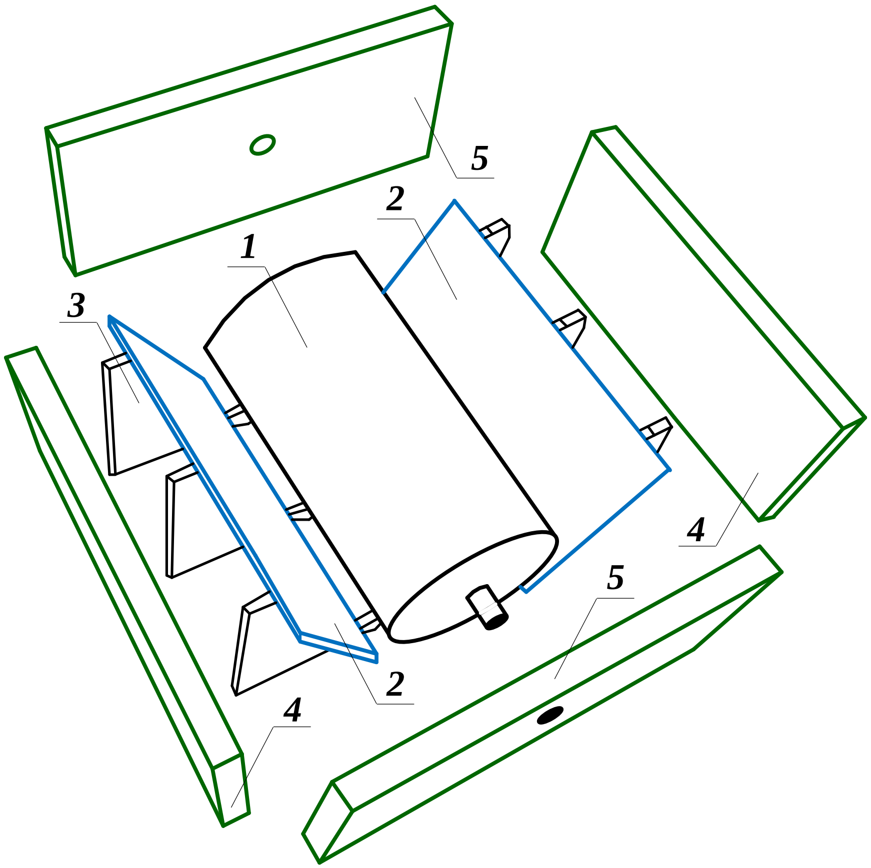


Fig. 1: Elements of solar collector: 1 – Water tank (absorber); 2 – Reflector; 3 – Housing of reflector; 4 – Side heat insulation plates; 5 – Back heat insulation plates

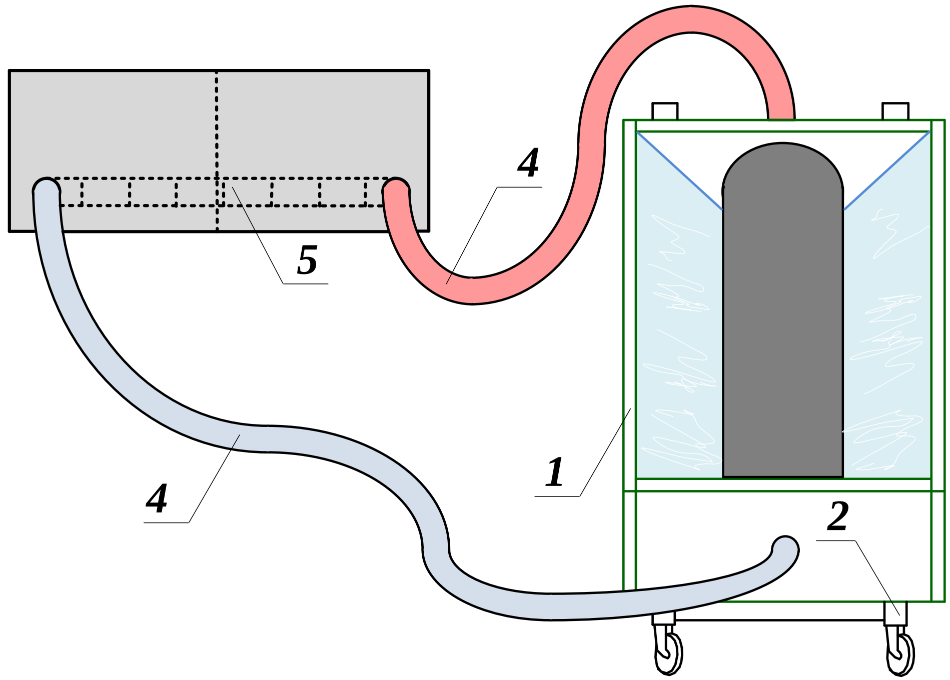


Fig. 2: Heating system scheme: 1 – solar collector; 2 – collector rotation trolley; 3 – heated container/tank filled with artificially contaminated soil; 4 – hoses with additional insulation; 5 – heating element (coil).

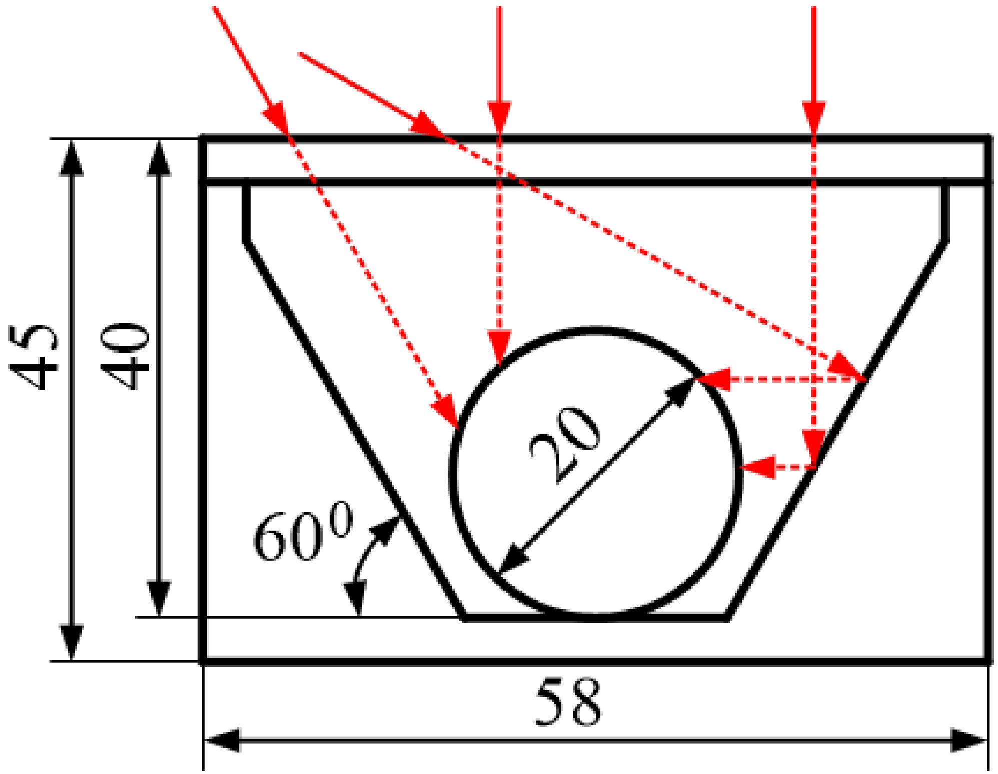
5.KU proposal model of the solar collector.

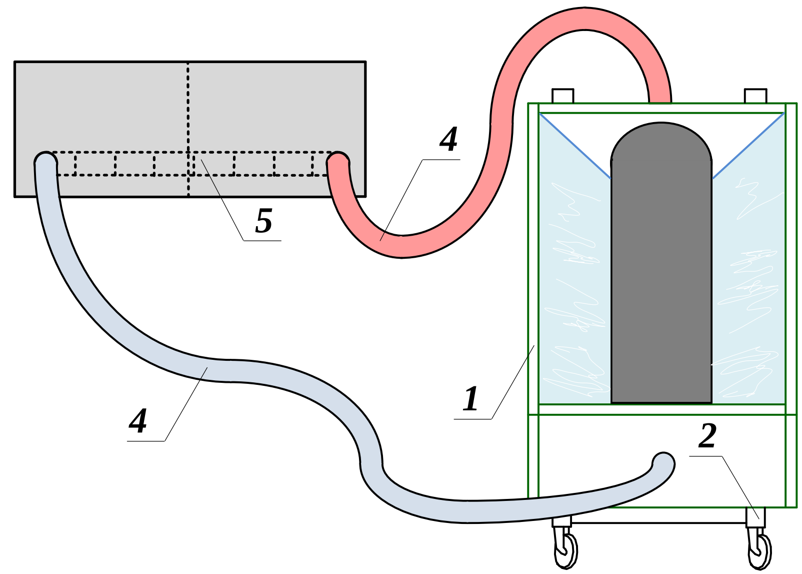
5.1 Heat systems design

A reflector was installed additionally inside the experimental solar collector, which is unusual to other solar collectors (Fig. 1), as well as water collection/accumulation tank (absorber). The reflector diverts the sun rays to the water tank (absorber). As the water tank is installed inside the solar collector, the heated water could maintain heat longer. Such solar collectors are more suitable to be used in such climatic conditions that are characteristic of Lithuania (Smyth et. al. 2004). The reflector of the collector (Fig. 1) was made from a mirror. 22 litre capacity water heating tank was installed in the place of concentration of rays. In order the sun rays could be better absorbed, the tank was painted with black bituminous paint characterized by high degree of absorption (0,92 - 0,97). The cavity of the collector is covered with 4 mm thick double glass with a gap of air. Glass was selected, as it is one of the best transparent covers. It conducts 85 - 90 % of solar radiation depending on the amount of iron in the glass. Glass, differently from organic glass or plastic films, is heat and weather resistant. The housing of the collector (Fig. 1) was welded from the steel plates. The bottom and side walls of the collector were lined with a layer of heat insulation – glass mineral wool – in order to avoid heat losses in the absorber. The width of the finished collector - 58 cm, height - 45 cm, length 80 cm. The active area of the collector is F = 0,5 m2.

5.KU proposal model of the solar collector.

5.1 Heat systems design





The principle of operation of the solar collector is based on easy conduct of short-wave ultraviolet (wave length - 0,3-3 μm) radiation by the transparent cover of the collector that retains the thermal infrared (wave length > 3 μm) radiation. Using a rotating trolley, the solar collector is oriented to the sun and is positioned at 55° angle in respect of the horizon. The more perpendicular is the angle of radiation in respect of the collector, the sooner the water inside the absorber is heated.

5.2 Heat systems performance

$$q = A \cdot \left(\eta_0 \cdot G - a_1 dT - a_2 \cdot dT^2\right) (1)$$

With the operation conditions:

G – Solar irradiance on collector plane [W/m^2];

dT – Temperature difference between collector mean fluid temperature and ambient temperature [K];

And the collector performance parameters:

η_0 - optical efficiency;

a_1 - first order heat loss coefficient (a_1 at collector fluid temperature equals to ambient temperature), [$W/(m^2K)$];

a_2 - second order heat loss coefficient, [$W/(m^2K^2)$];

A – collector area, corresponding to the performance parameter, [m^2]

5.2 Heat systems performance

$$\eta = \frac{Q_{out}}{Q_{in}} \quad (2)$$

$$Q_{out} = V \cdot \rho \cdot C \cdot \Delta t^{0} \quad (3)$$

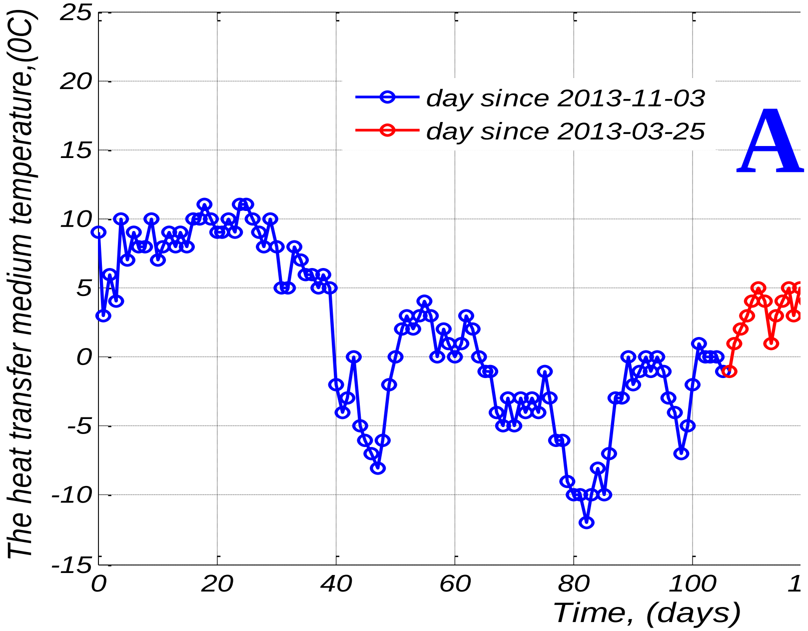
V – water' volume [m^3];
ρ – water' density [kg/m^3];
C- water' specific heat [kJ/(kg C^0);
Δt- water' temperature difference at the period of observation, [C^0];

$$Q_{in} = \frac{H_a}{365} \cdot t \quad (4)$$

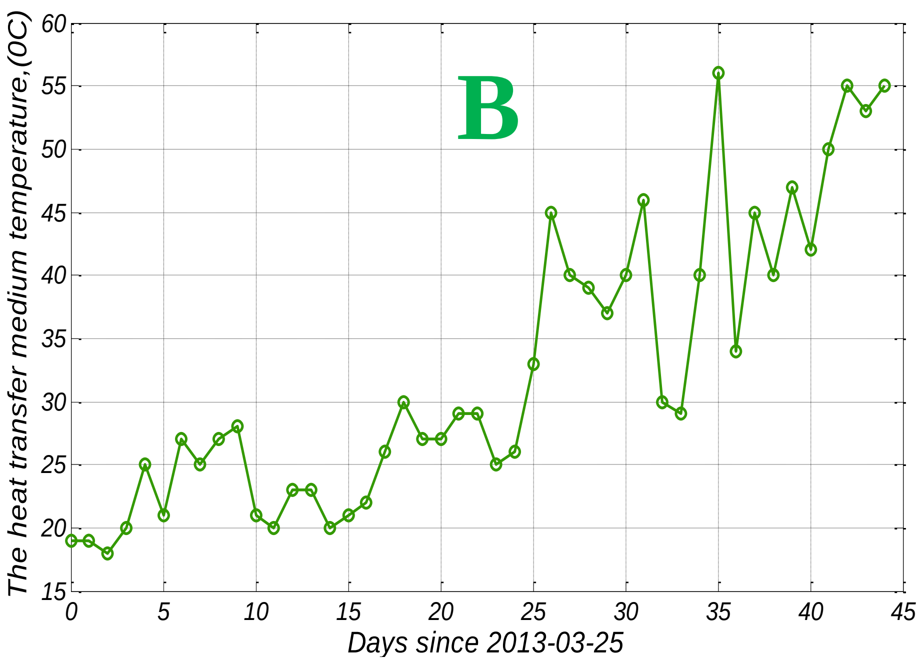
H_a – average amount of annual solar insolation in Lithuania [kWh/m^2];
365 – the number of days in the year ;
t - time in days, required to heat water from t_1 to t_2 C^0;

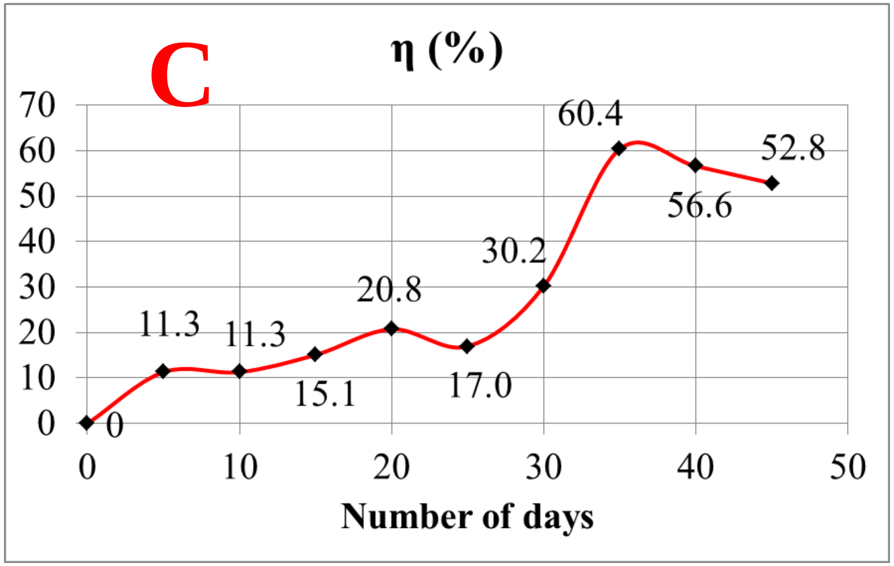
5.KU proposal model of the solar collector.

5.2 Heat systems performance



The change of the temperature of the heat transfer medium during the experiment: A-at cold season, B-at spring time; C- system' performance at spring time



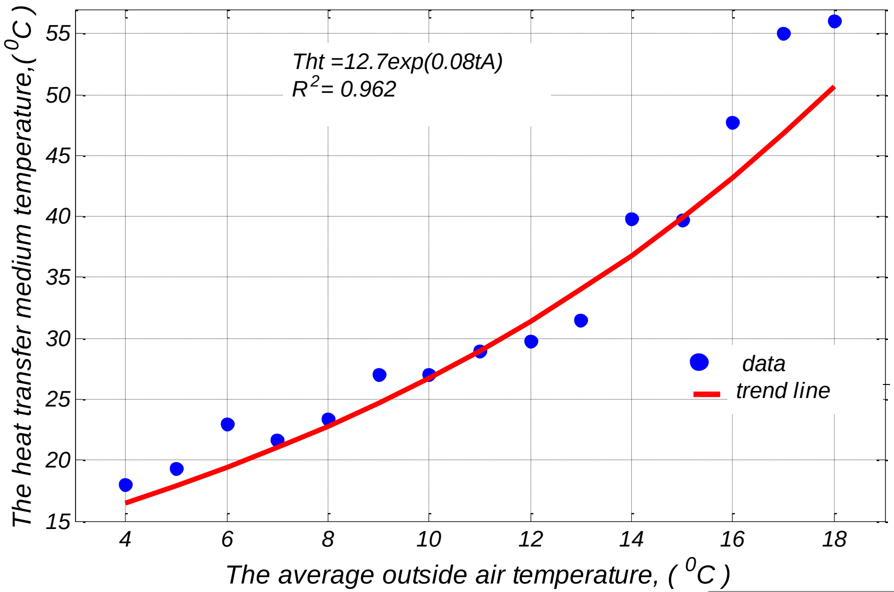


5.2 Heat systems performance

The graph show that at cold season the water temperature decrease up to minus 13 in the collector. That is unacceptable and this situation have to be improved so that even under negative ambient temperatures during the long period, the water temperature remains equal zero.

The next two graph represented at this slide depict with the performance of system at spring time when temperatures of outer air were positive. During 45 days of experiment, the working fluid temperature with slightly variation increased form 0 up to 55degrees Celsius. And as a result, the efficiency of system increased up to 60% at this period.

5.KU proposal model of the solar collector.

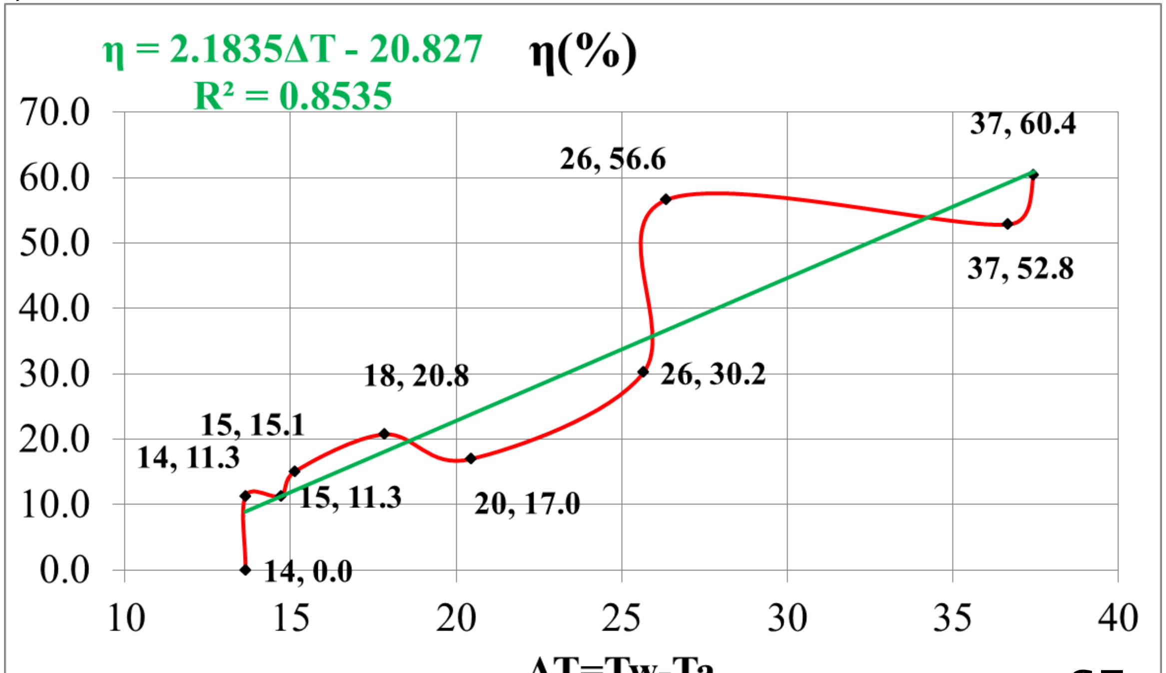


5.2 Heat systems performance

Fig. 3: Impact of the average outside air temperature on the temperature of the heat transfer medium

$$t_{wf}=12.7e^{0.08Ta}$$

<u>in spring season</u>

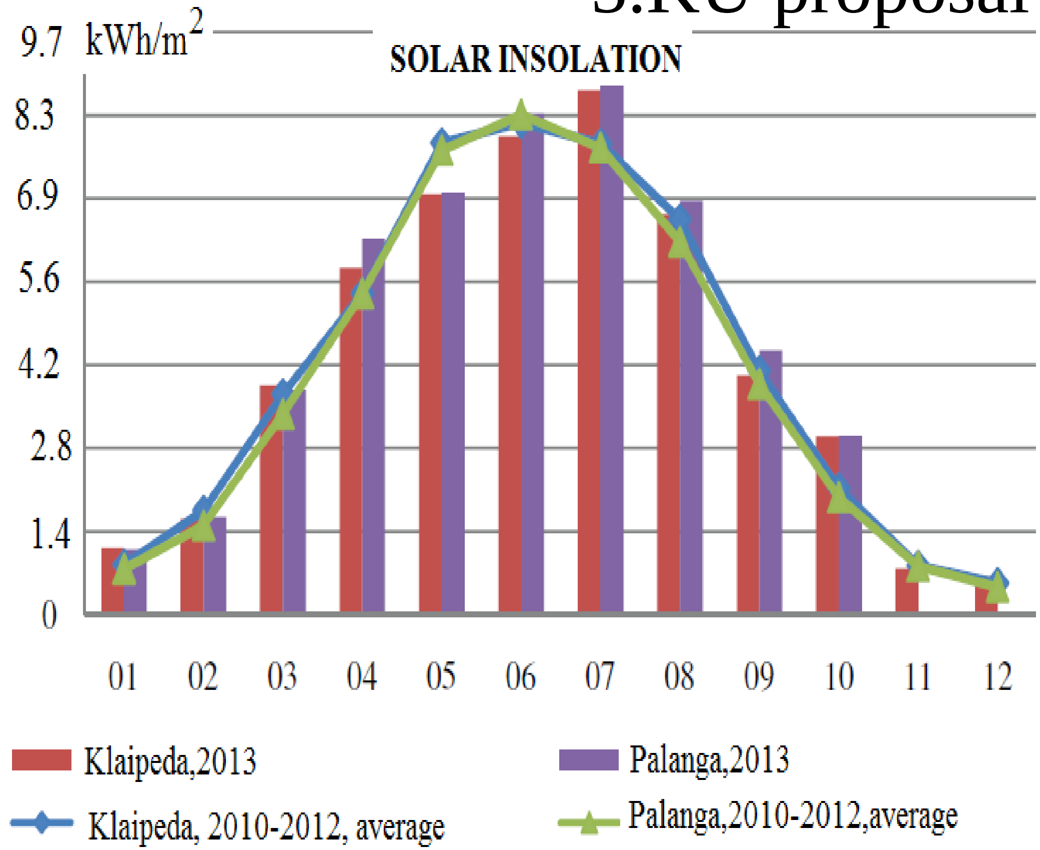


5.2 Heat systems performance

the water temperature increases exponentially with increasing air temperature at spring time. For the achievement of better efficiency of system it is more important to know the efficiency dependence on difference between ambient and heat transfer media temperature. The temperature difference is very important for the efficiency estimation. As you can see, the biggest possible value of efficiency *at around 60%) is connected with the difference of temperatures difference at 37 degree Celsius.

For the efficiency improvement of proposal solar water heating system, the temperature difference should be equal or more than 40 degree Celsius. In Lithuania the average annual insolation is equal 1000 kWh/m2. This figure can be significantly more or less and relates with clear weather condition.

5.KU proposal model of the solar collector.



5.3How to improve efficiency?

For the efficiency improvement of proposal solar water heating system, the temperature difference should be equal or more than 40 degree Celsius. In Lithuania the average annual insolation is equal 1000 kWh/m2. This figure can be significantly more or less and relates with clear weather condition. In reality, the weather is mostly cloudy and wet in KLAIPEDA. These conditions weaken solar insolation up to: **$H=0.6*684Wh/m^2*6=2.5kWh/*m^2day$.**

It is mean that the solar insolation is diffused. To collect the diffused insolation and modify the proposal solar water heating system model the Fresnel Lens will be used.

At the moment the design of new model with Fresnel Lens is in progress. Therefore, I can not present you any results about this matter. But I hope that in the nearest future it will be possible.