Department of Mechanical Engineering,
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Tribhuvan University

Sustainable Energy Technologies
(Session 4)

Solar Thermal Technologies

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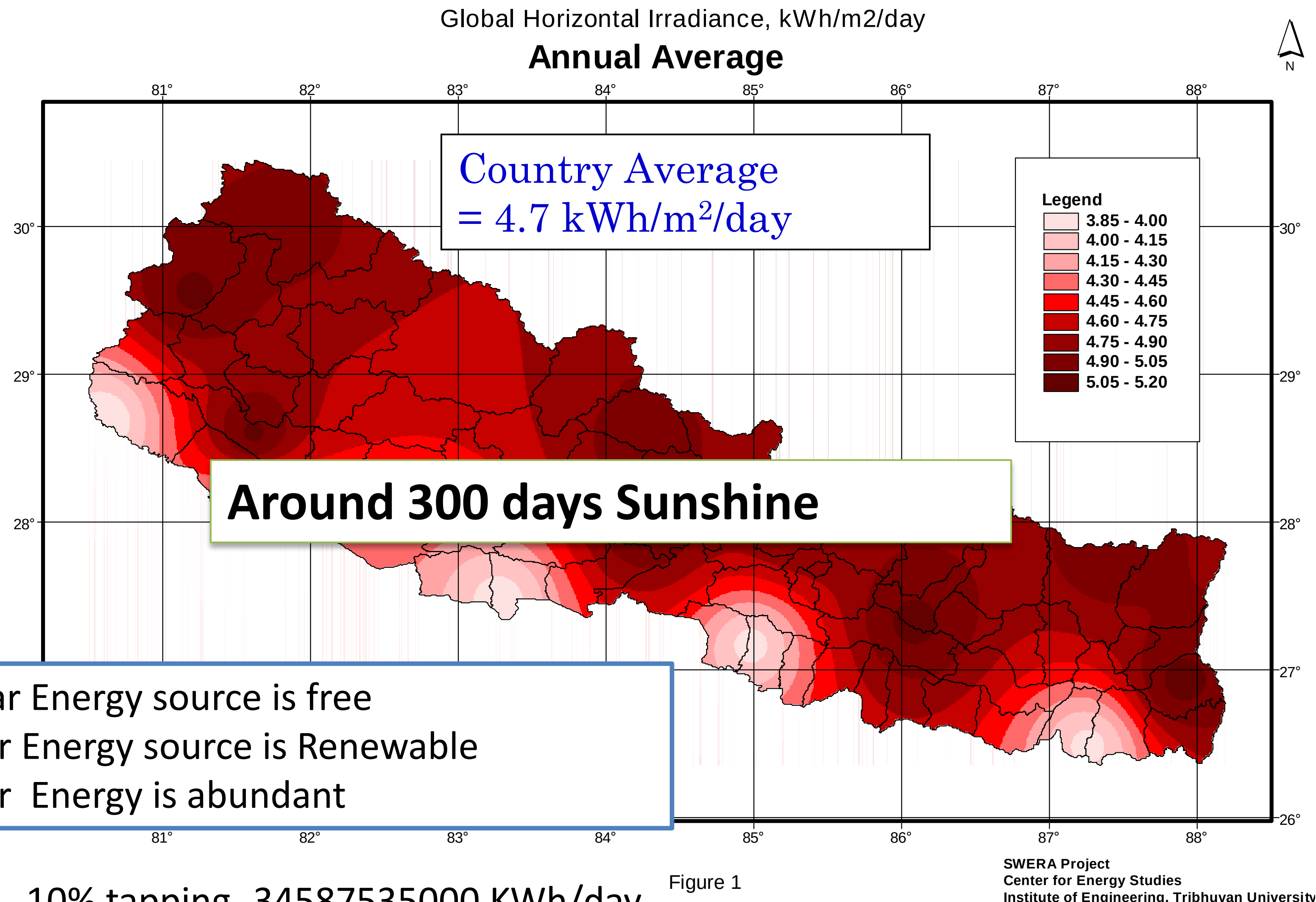
2016

Contents of Presentation

- Introduction
- Working Principles
- Types

Solar Energy Potential in Nepal



Country Average
= 4.7 kWh/m²/day

Around 300 days Sunshine

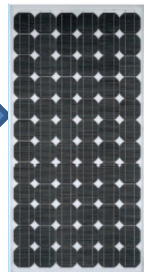
Solar Energy source is free
Solar Energy source is Renewable
Solar Energy is abundant

10% tapping- 34587535000 KWh/day

Solar Energy Technologies in Nepal

Solar Photovoltaic Technology

Solar Light Energy



- Solar Home System
- Solar Tuki
- Institutional solar PV system
- Solar Water pumping system
- Building integrated solar PV Systems
- Electrical vehicle charging station

Solar Thermal Technology

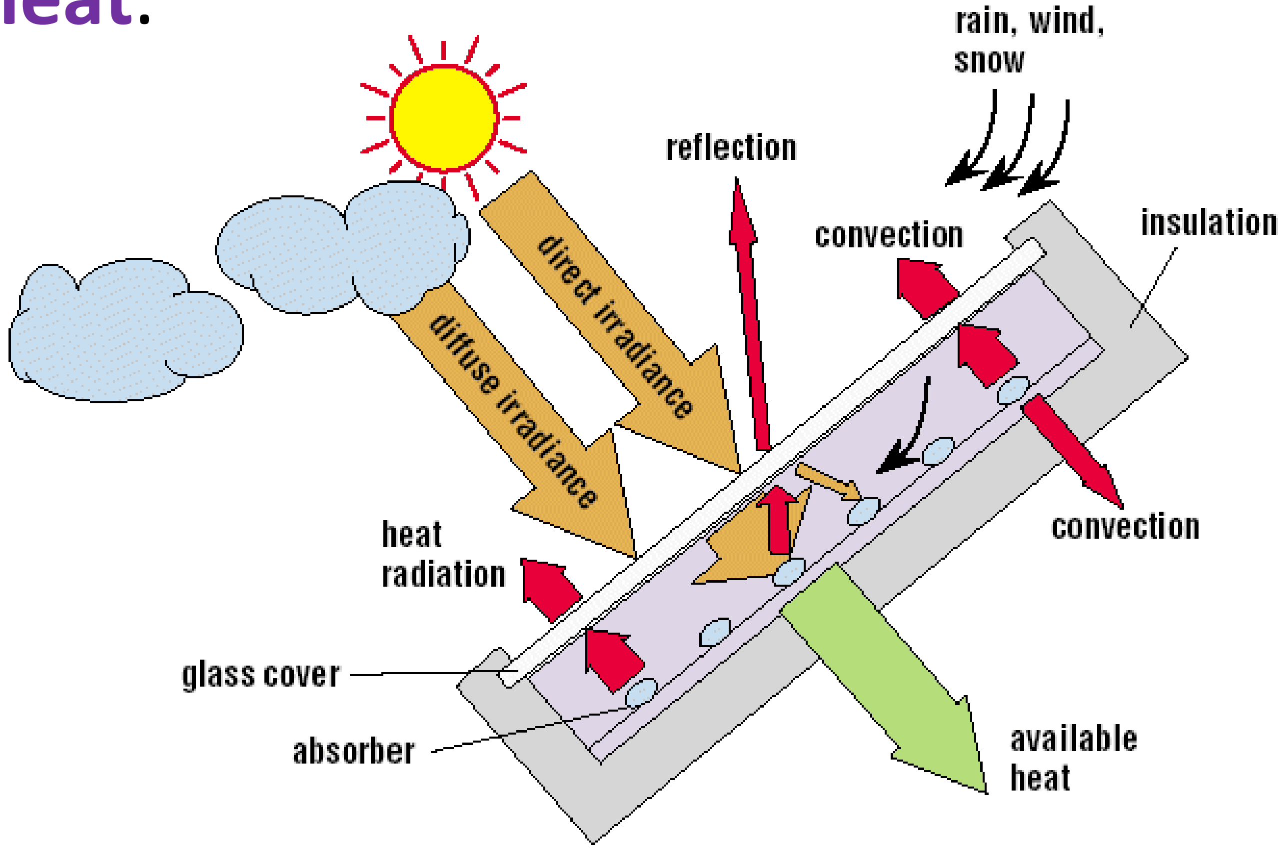
Solar Heat Energy

- Solar Dryer
- Solar Cooker
- Solar Water Heater
- Solar room heating system
- Solar Refrigeration

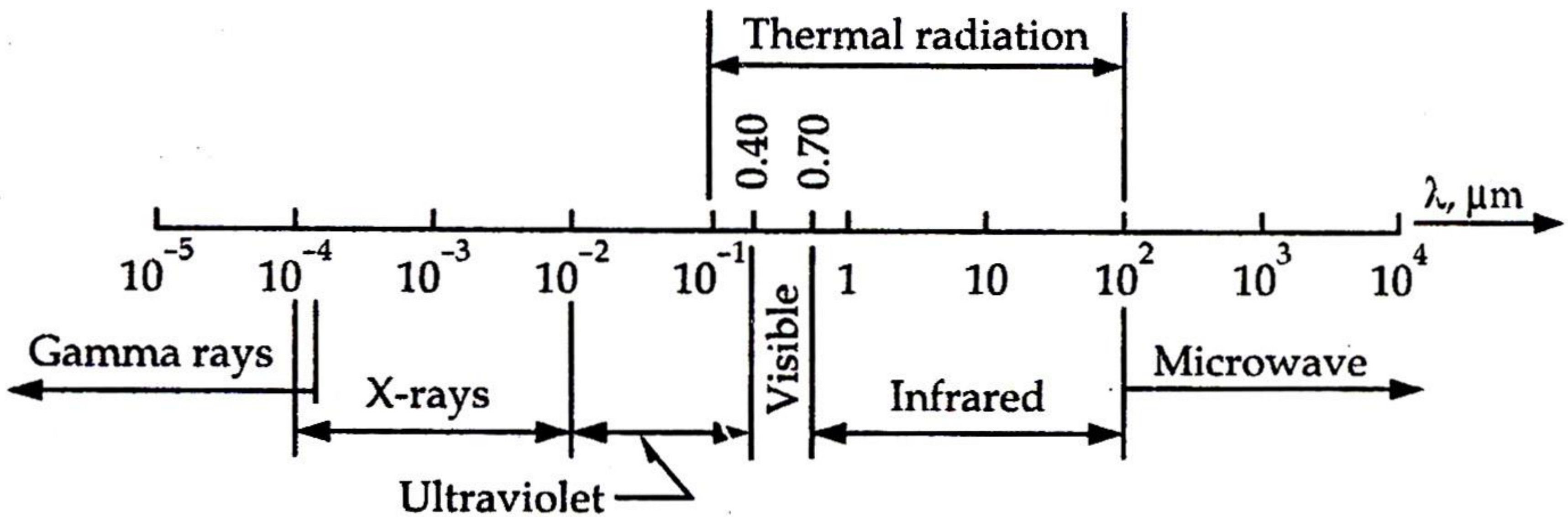
Basic Knowledge of Thermodynamics and Heat Transfer

Driver of Solar Thermal Systems
Processes at a flat-plate collector

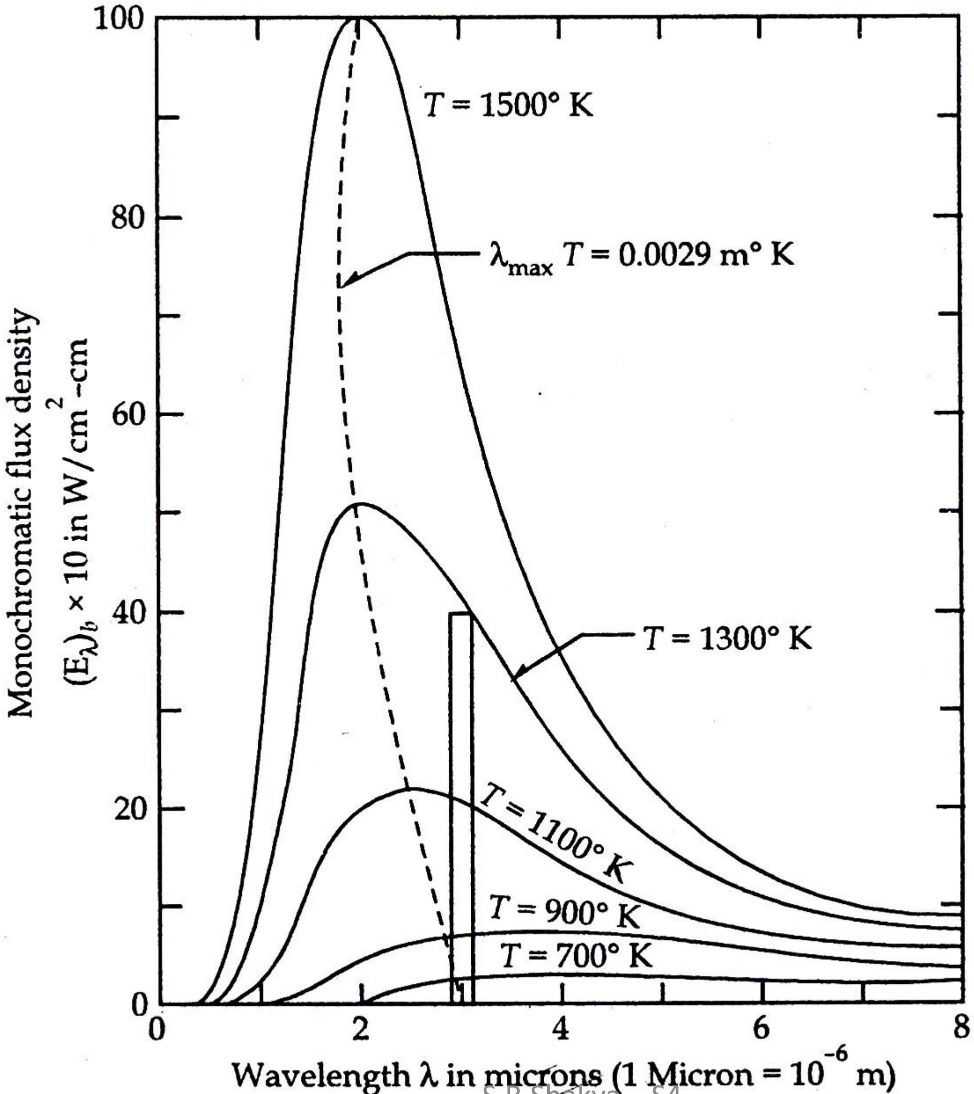
The **heart of a solar thermal system** is the **solar collector**. It **absorbs solar radiation**, **converts** it **into heat**.



Driver of Solar Thermal Systems
Solar Radiation Electromagnetic Spectrum

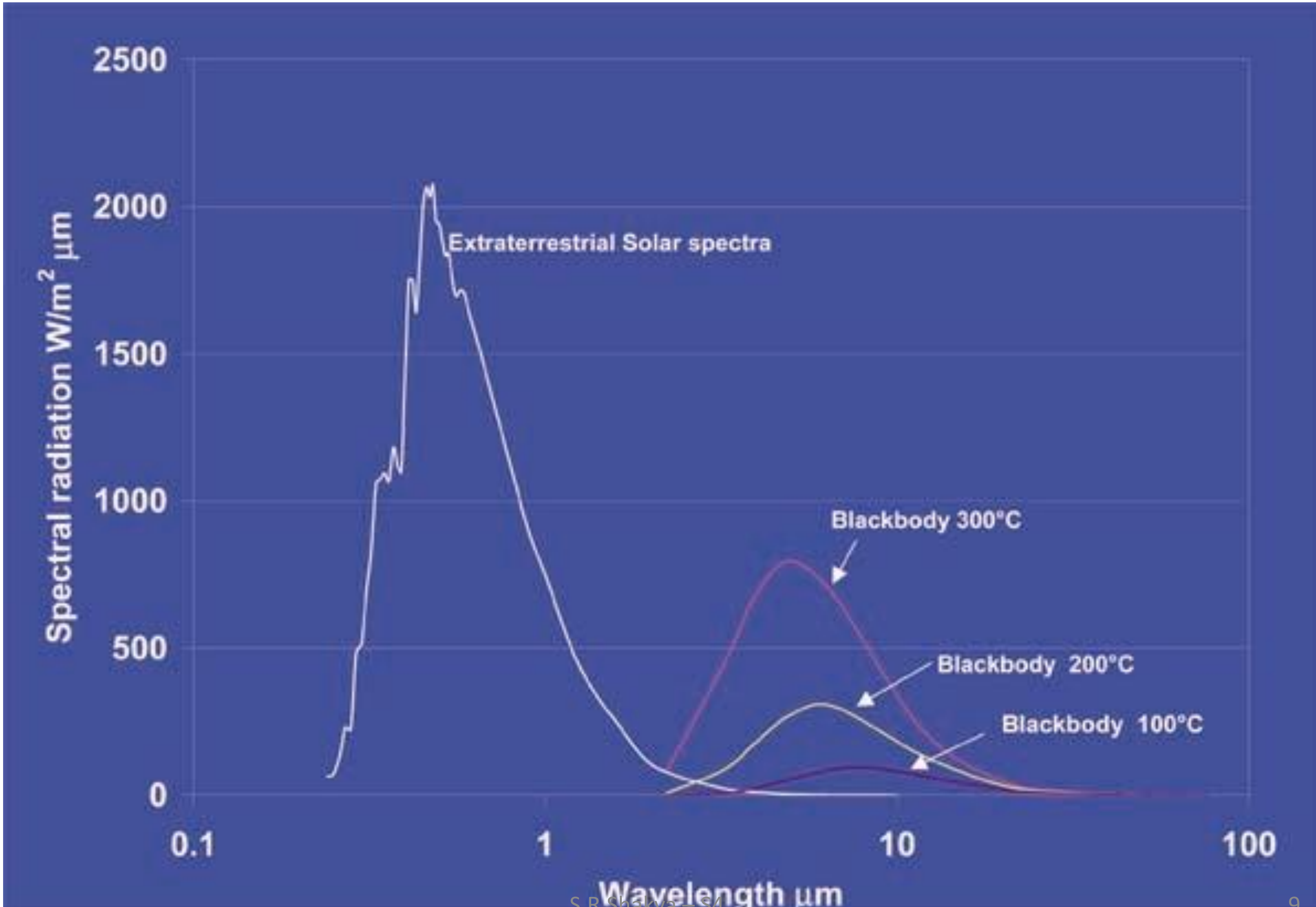


Radiation Heat Transfer Contd.



Radiation vs wavelength wrt. temperature

Solar Spectra



Thermodynamics and Heat Transfer

Heat transfer is the **transfer of energy because of temperature difference**. Heat **always flows from high temperature** to **low temperature**.

The heat transfer processes **involve the transfer of energy**, and **obey the first** as well as the **second law of thermodynamics**.

It may appear that the principles of heat transfer are derived from the basic laws of thermodynamics. But **there are certain differences between heat transfer and thermodynamics**.

Thermodynamics and Heat Transfer

The **science of thermodynamics deals** with the **amount of heat transfer** as a **system undergoes a process** from **one equilibrium state** to **another**, and **makes no reference to how** long the process will take.

But in engineering, we are **often interested in the rate of heat transfer** and **spatial variation of temperature**, which is the topic of the **science of heat transfer**.

First Law of Thermodynamics

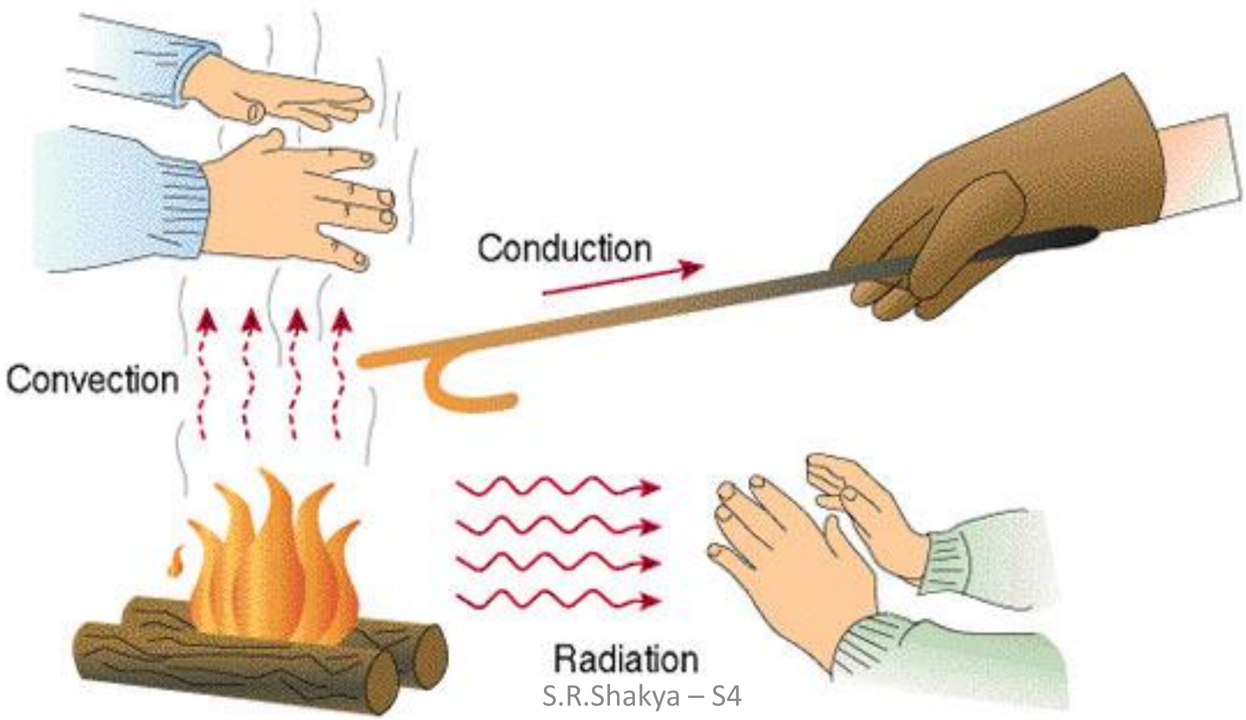
First Law of Thermodynamics is **based upon the conservation of energy**.

The ***net change*** *(increase or decrease)* ***in the total energy of the system*** *during a process is* ***equal to*** *the* ***difference between the total energy entering and the total energy leaving*** *the system during that process.*

$$\begin{pmatrix}\text{Total energy}\\ \text{entering the}\\ \text{system}\end{pmatrix} - \begin{pmatrix}\text{Total energy}\\ \text{leaving the}\\ \text{system}\end{pmatrix} = \begin{pmatrix}\text{Change in the}\\ \text{total energy of}\\ \text{the system}\end{pmatrix}$$

Heat Transfer Mechanisms

According to the **physical mechanism** and the governing law associated with them, **heat transfer is classified** into **three modes**: **conduction, convection and radiation**.



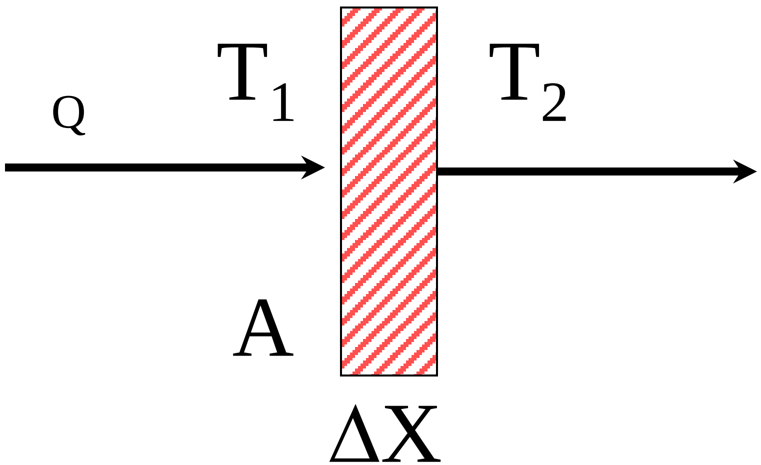
Conduction

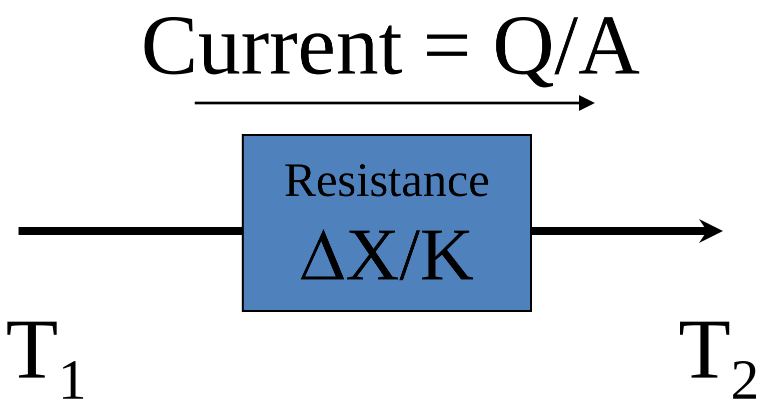
Heat conduction is **due to the property of matter** which **allows the passage for heat energy** even its parts are **not in motion relative to one another**.

Magnitude of conduction heat transfer is given by **Fourier Equation**

$$\dot{Q} = -kA\frac{dT}{dx}$$

Conduction Heat Transfer





$$Q/A = T_1 - T_2 / (\Delta X/K)$$

- $Q = KA\ \Delta T/\ \Delta X$
- Q = heat energy; K = thermal conductivity
- T_1= source temperature; T_2 = sink temperature
- X = thickness; A = heat transfer area of the plate.

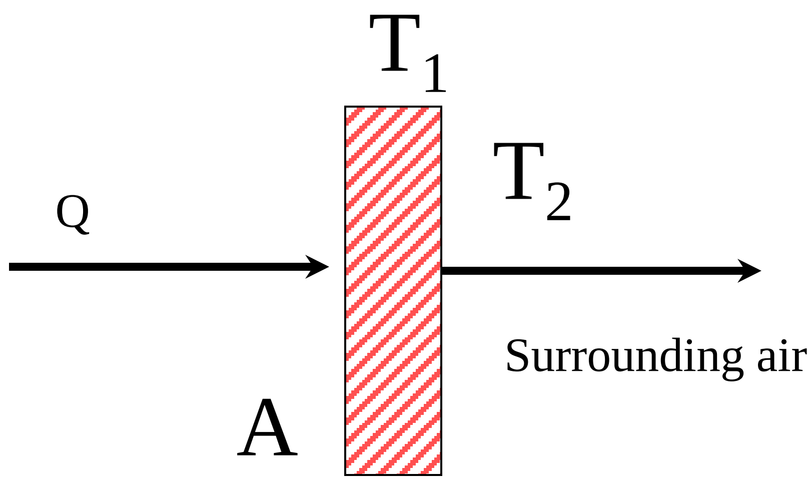
Convection

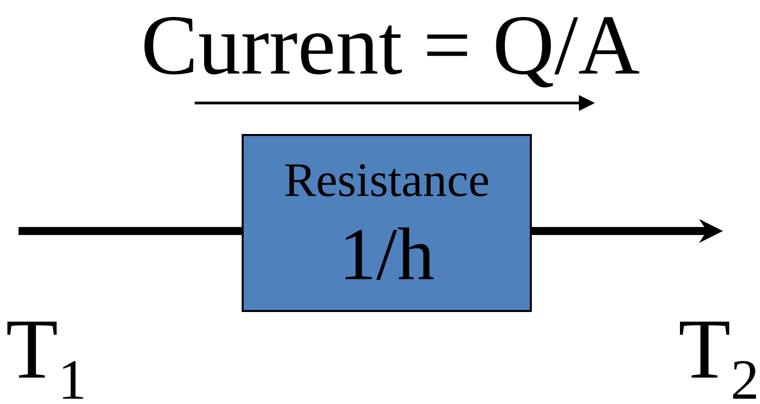
Convection heat transfer occurs **in fluid medium** and heat is **transferred by the actual movement of the molecules**.

Magnitude of convection heat transfer is given by **Newton's law of cooling**

$$\dot{Q} = hA(T_s - T_\infty)$$

Convection Heat Transfer





$$Q/A = T_1 - T_2 / (1/h)$$

- $Q = hA\,\Delta T$
- Q = heat energy; h = convective heat tr. coefficient
- T_1 = plate temperature; T_2 = air temperature
- A = Area of the plate (heat transfer area)

Convection

Convection heat transfer is classified into **two types**: **free convection** and **forced convection**.

Convection heat transfer process in which **flow of fluid is caused by density gradient** is called **free convection** or **natural convection**.

Convection heat transfer process in which **flow of fluid is caused by some external devices** such as pump, fan, blower, etc.

Radiation Surface Properties

For any given surface, the **radiation received** must be **reflected, absorbed or transmitted** through the material i.e.,

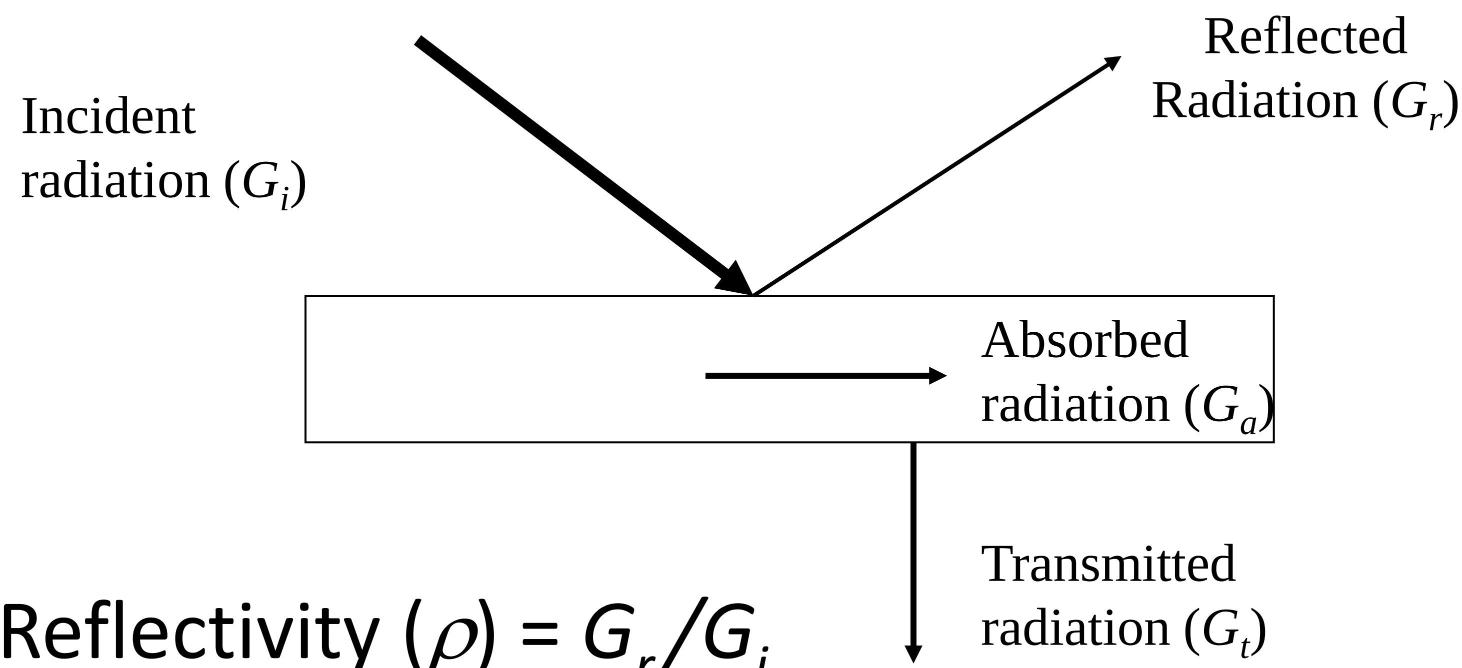
$$E_{incident} = E_{absorbed} + E_{reflected} + E_{transmitted}$$

$$\frac{E_{absorbed}}{E_{incident}} + \frac{E_{reflected}}{E_{incident}} + \frac{E_{transmitted}}{E_{incident}} = 1$$

$$\alpha + \rho + \tau = 1$$

Sum of coefficients for **reflection, absorption or transmission** through the material **will be 1** (Conservation of energy)

Radiation Heat Transfer



- Reflectivity (ρ) = G_r/G_i
- Absorptivity (α) = G_a/G_i
- Transmissivity (τ) = G_t/G_i

$$\rho + \alpha + \tau = 1$$

Two Main Categories:

Solar Thermal

Water heating and cooking

Solar Photovoltaic (PV)

Electricity production

Solar Thermal Energy

Cooking

Water Heating

Use of solar thermal Energy - Technologies

Low temperature (LT < 150°C)

- Swimming pool heating
- **Domestic hot water**
- **Space heating**
- Solar drying
- Distillation - drinking water preparation

Medium temperature (<400°C)

- Solar cooling and air conditioning
- Prosess heat (paper- , food- industry)
- Power station (DCS concept)

High temperature (<1000°C)

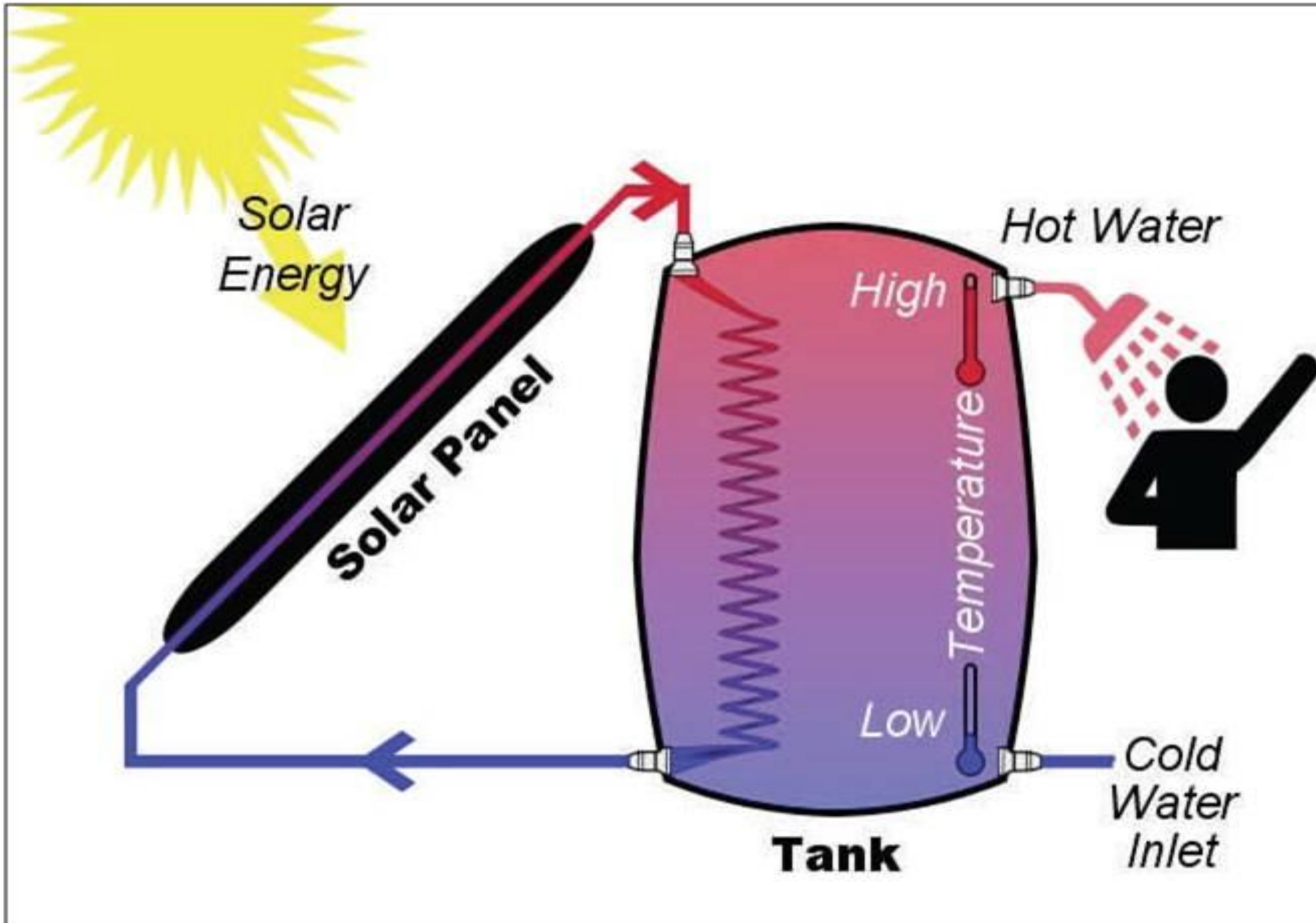
- Prosess heat (metal-, cement-, glas-industry)
- Power station (tower concept)

SOLAR WATER HEATER

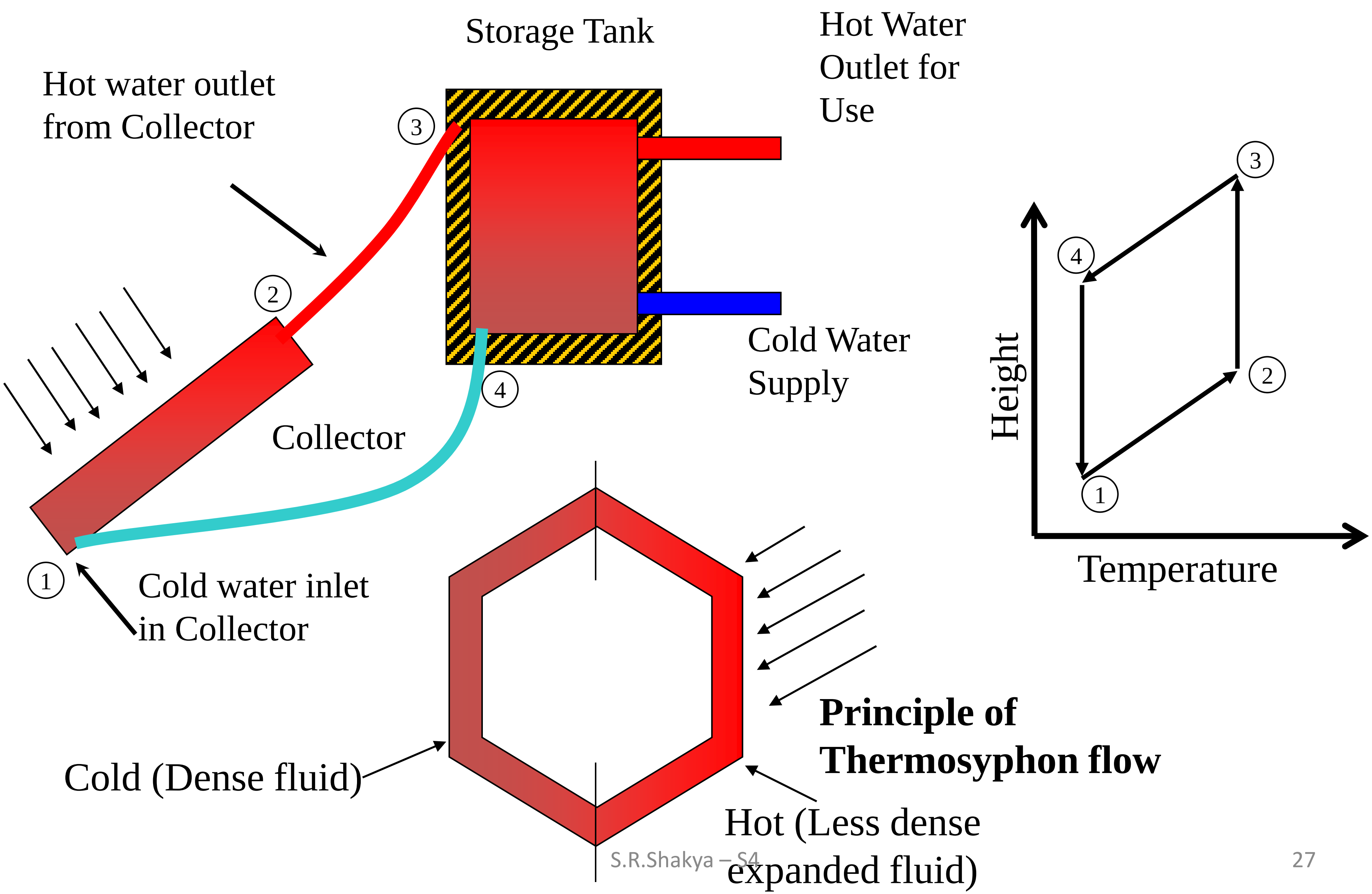
Simple integral type SWH

Source: http://www.associatedcontent.com/article/283635/66_beer_bottles_land_son_in_hot_water.html?cat=16

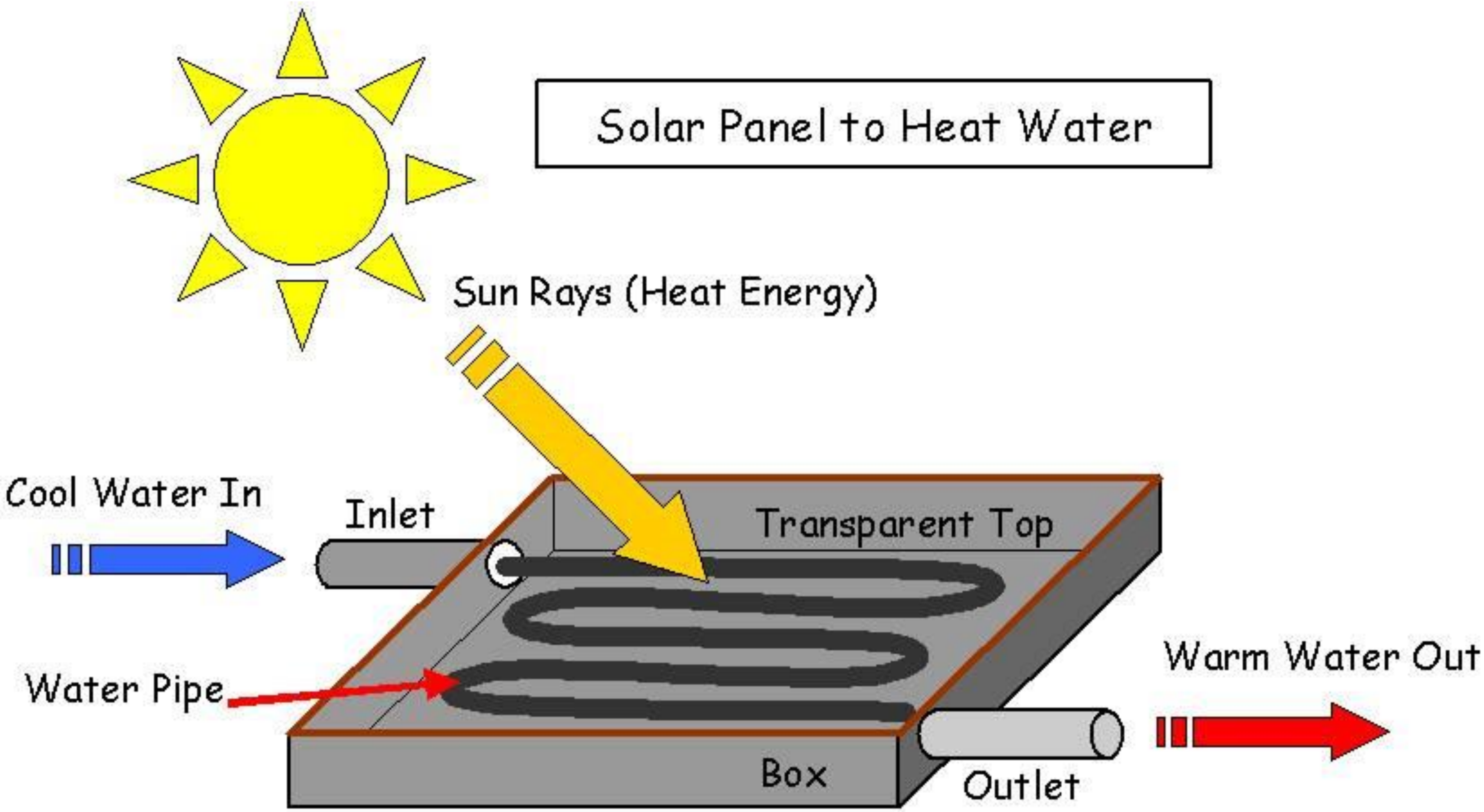
Solar Water Heating



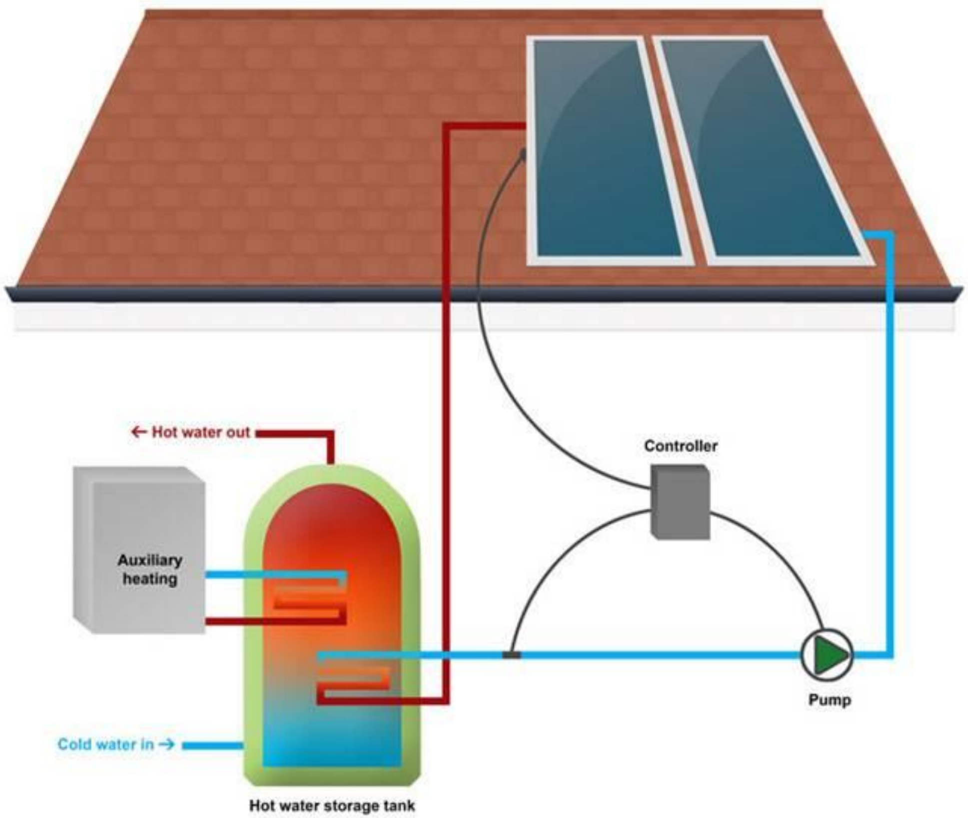
Working Principle of Solar Water Heater



How Does it Work?

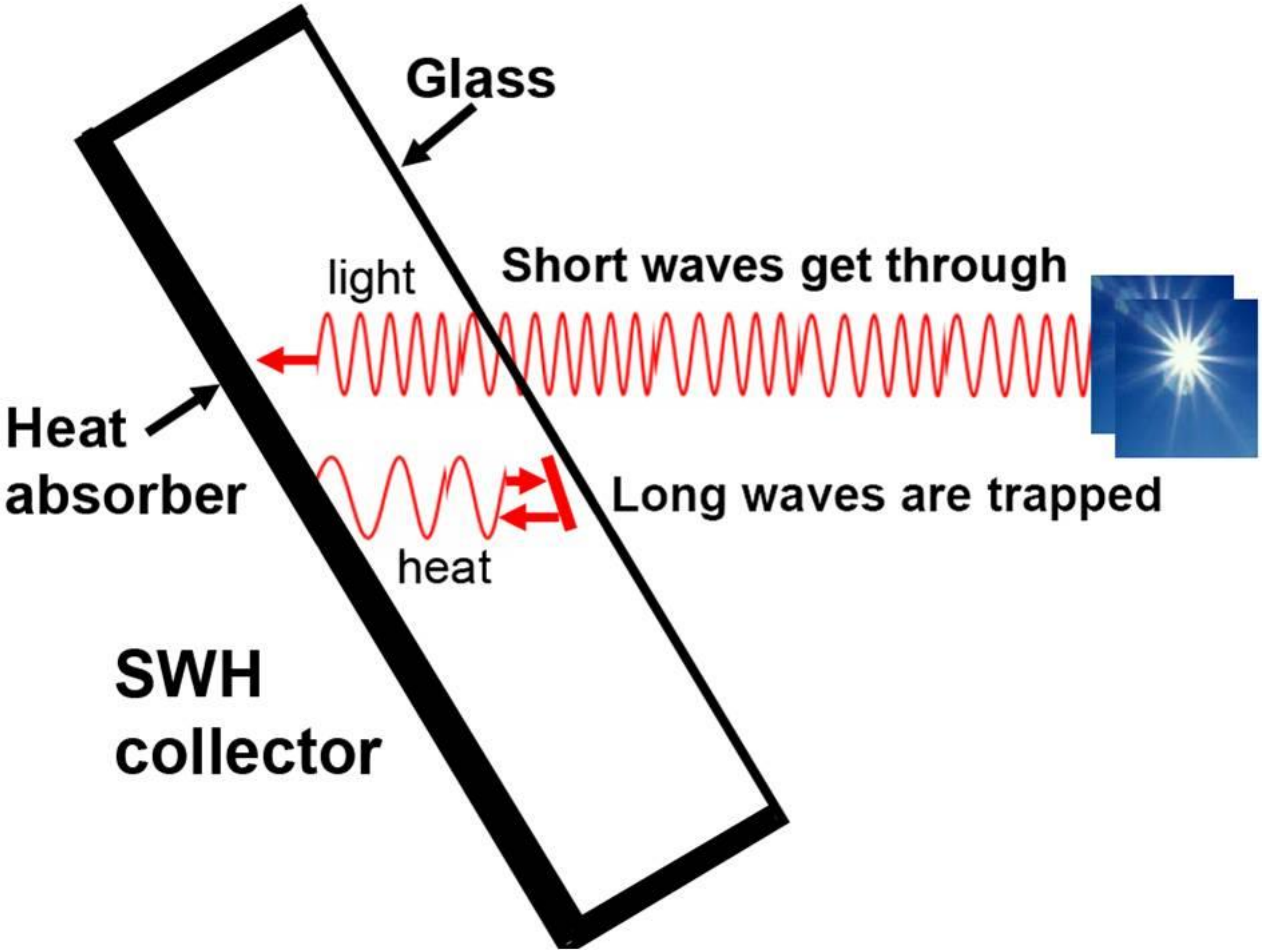


How Does it Work?



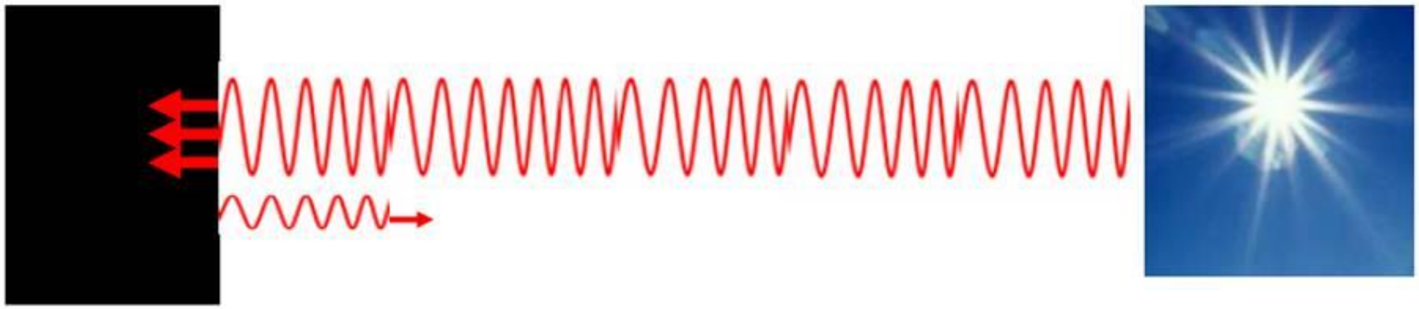
- Systems can be *passive* or *active*
- Passive systems only found in warmer climates, as they are prone to freezing
- Active: Roof-top collectors heat glycol which then passes through a heat exchanger in the storage tank to heat water
- Electric pump can be run on solar PV

Greenhouse Effect

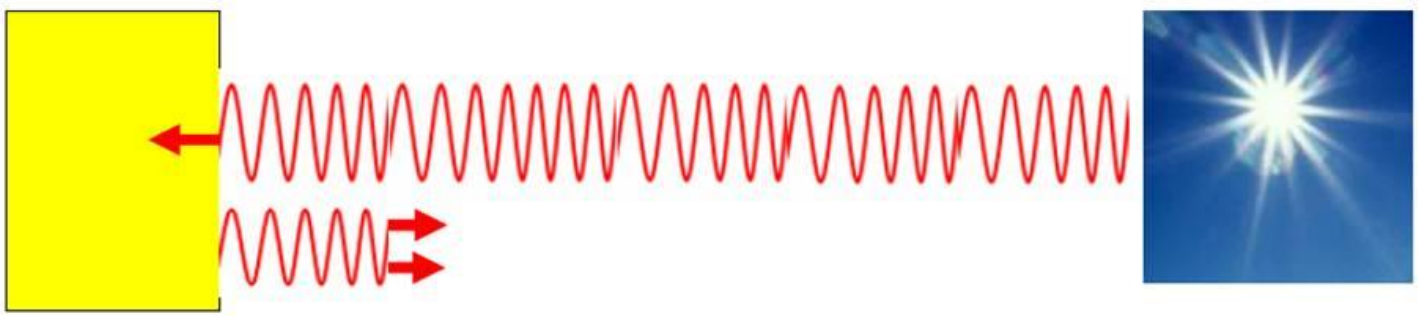


Color Absorption

Dark colors absorb a lot, reflect little

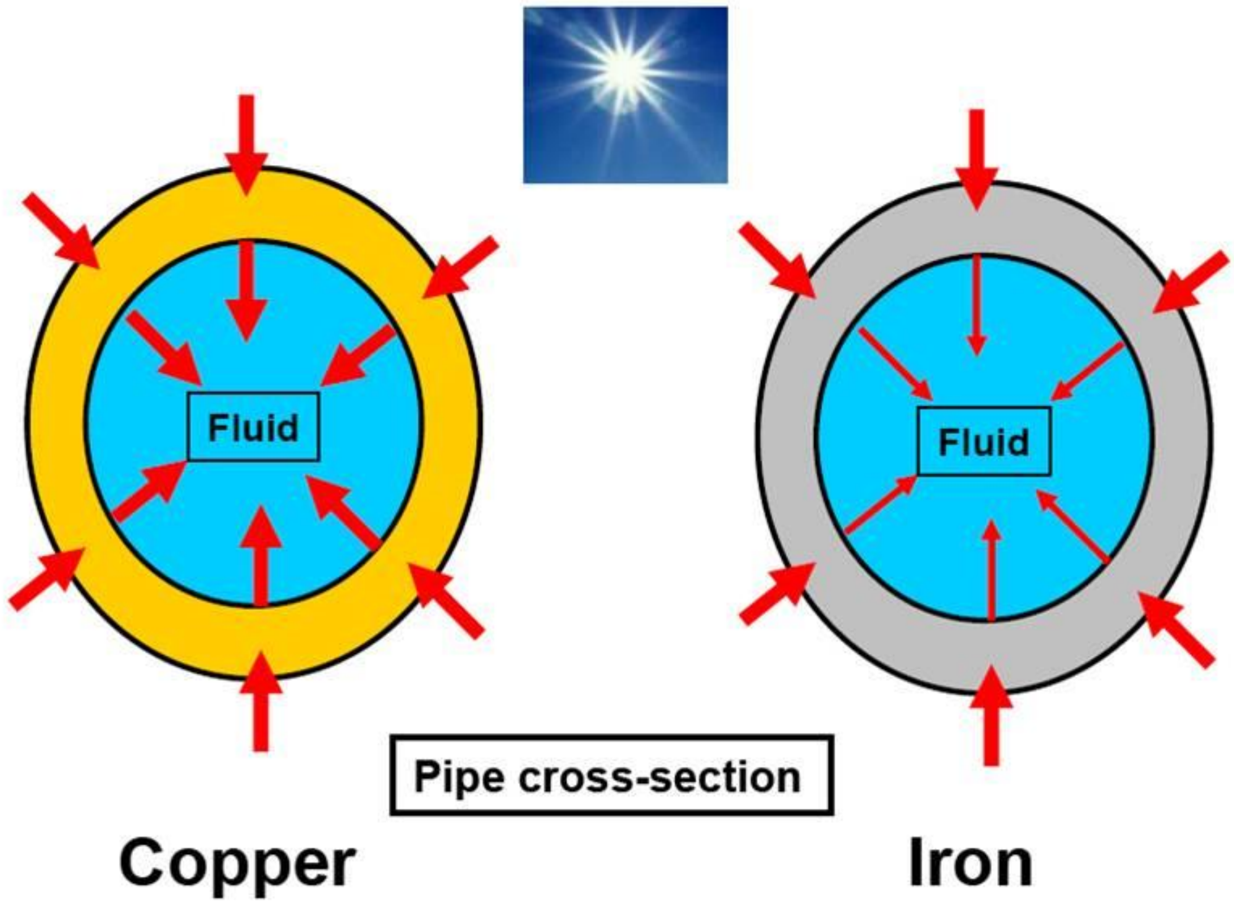


Light colors absorb little, reflect a lot



Metal Conductivity

Some metals transfer more heat than others.



Typical solar water heaters in Market

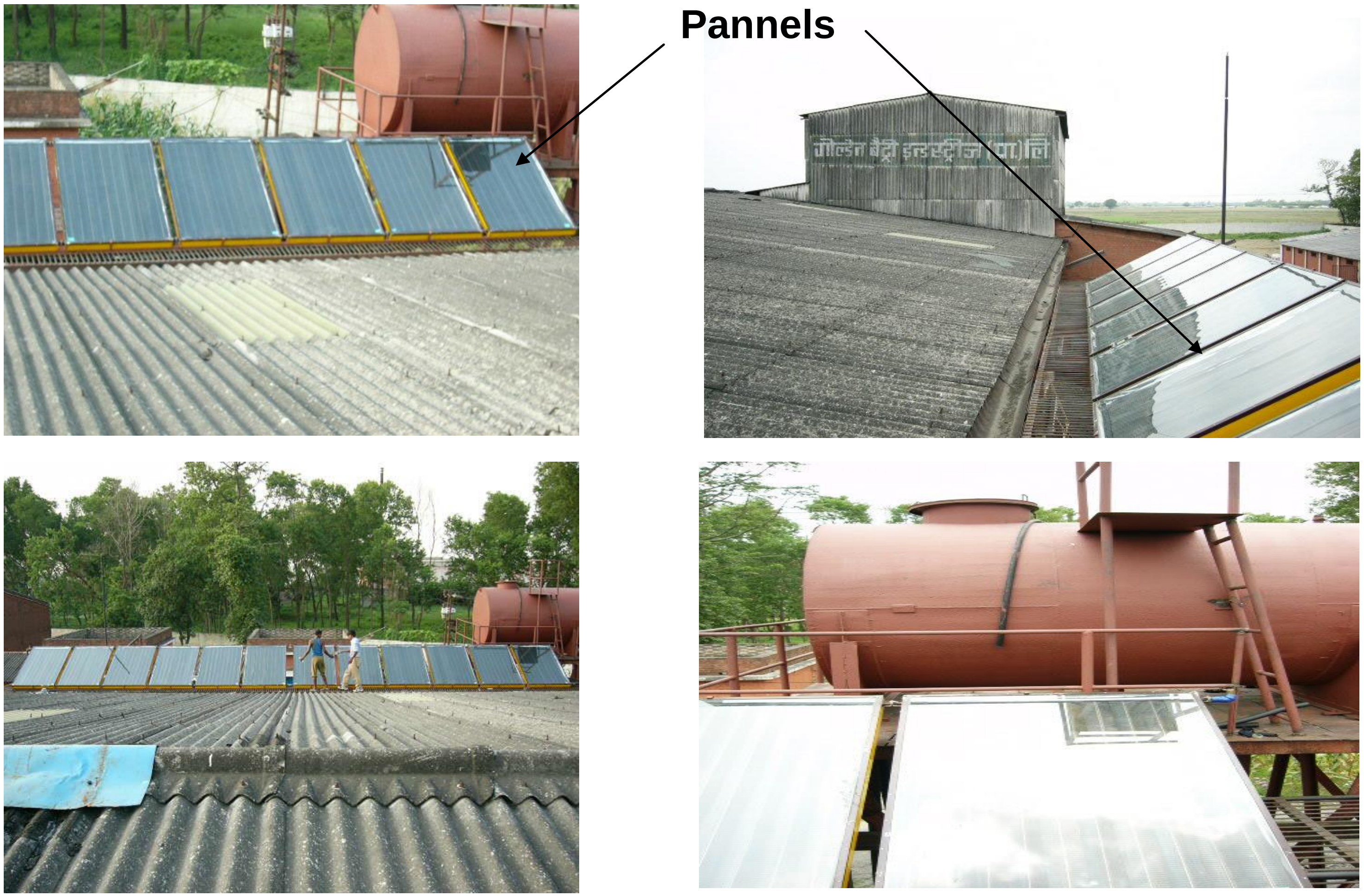
Flat plate SWH

Vaccum tube SWH

Existing Technology/in use

Locally produced SWH system

Existing Technology/in use



Cupper-fin type Collector

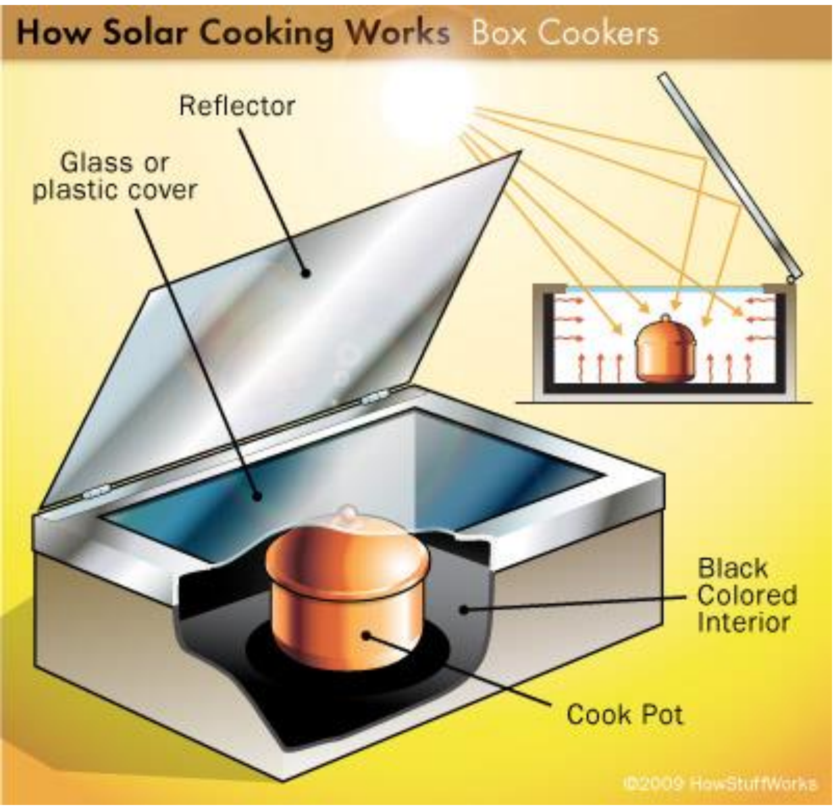
SOLAR COOKING

What is Solar Cooker ?

- A solar cooker is **a device** which **uses the energy of direct sunlight** to **heat, cook or pasteurize** food or drink
- use **no fuel** and cost nothing to operate
- help **reduce fuel costs** (for low-income people) and **air pollution**,
- **slow down the deforestation** and **desertification** caused by gathering firewood for cooking
- form of **outdoor cooking**
- **Major types:**
  - **box type cooker**
  - **Parabolic concentrator type cooker**

Box Solar Cooker

How does it works?
Box Cooker – Working Principle

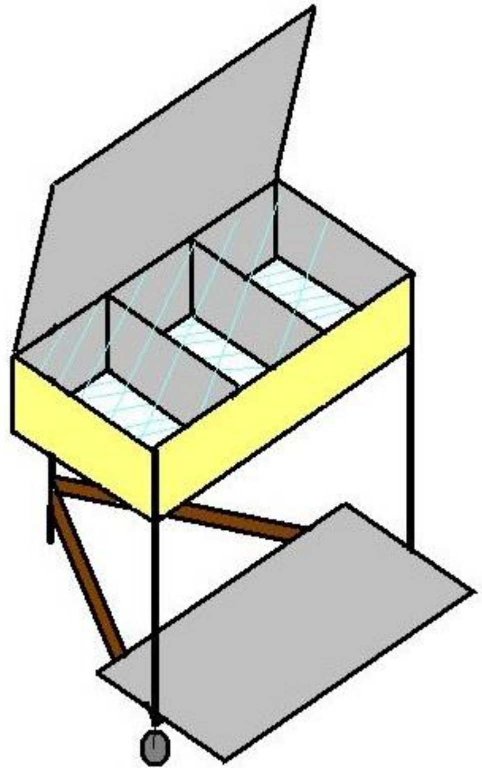


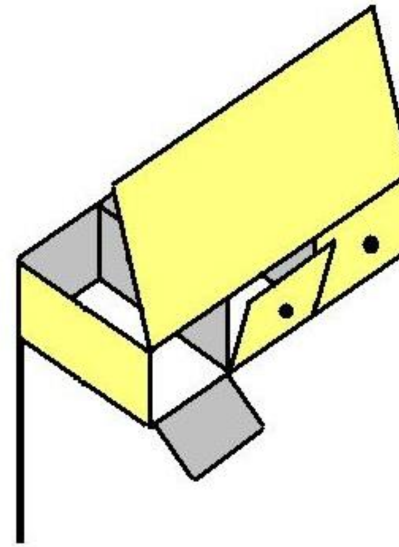
- **Concentrating sunlight:** A reflective mirror of polished glass, metal or metalized film concentrates light and heat from the sun on a small cooking area,
- **Converting light to heat:** A black or low reflectivity surface on a food container or the inside of a solar cooker improves the effectiveness of turning light into heat. Light absorption converts the sun's visible light into heat, substantially improving the effectiveness of the cooker.
- **Trapping heat:** A plastic cover or tightly sealed glass cover traps the hot air inside and reduce convection. This makes it possible to reach temperatures on cold and windy days similar to those possible on hot days.
- **Greenhouse effect:** Glass transmits visible light but blocks infrared thermal radiation from escaping. This amplifies the heat trapping effect.

Box Cookers

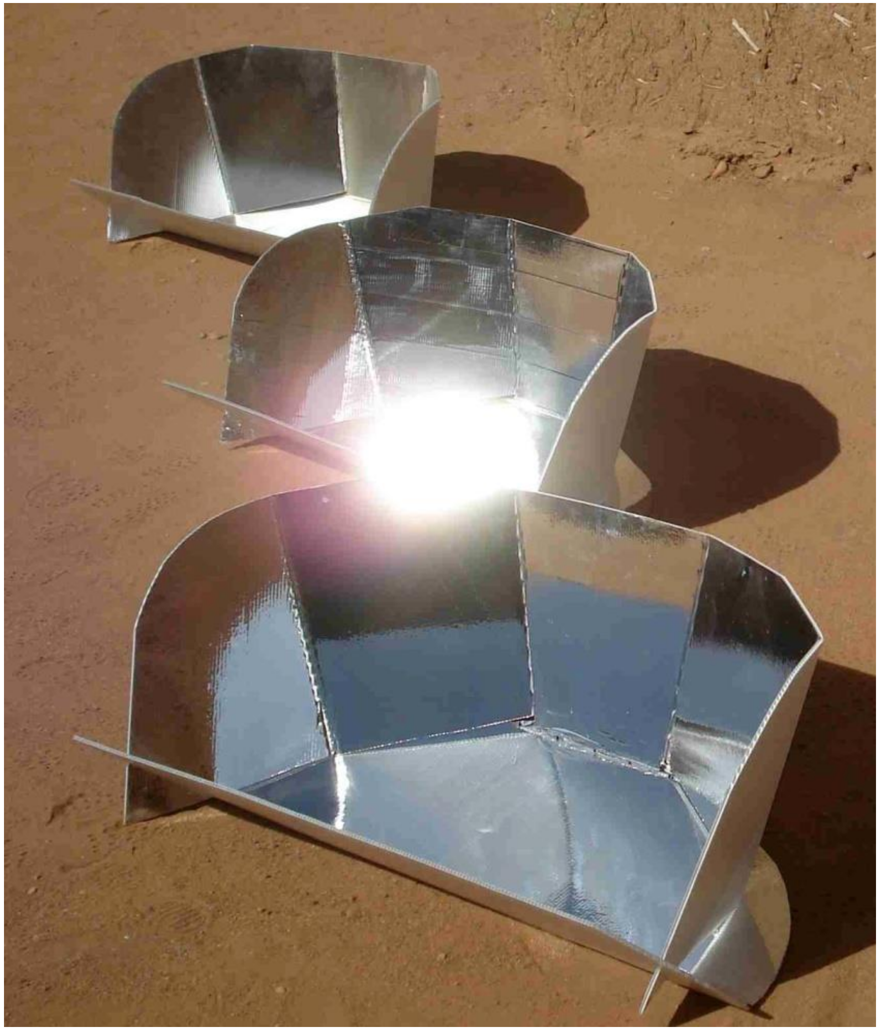
Box Cookers

Box Cooker (Modified)





Panel Solar Cookers



Source: www.simplyeff.com

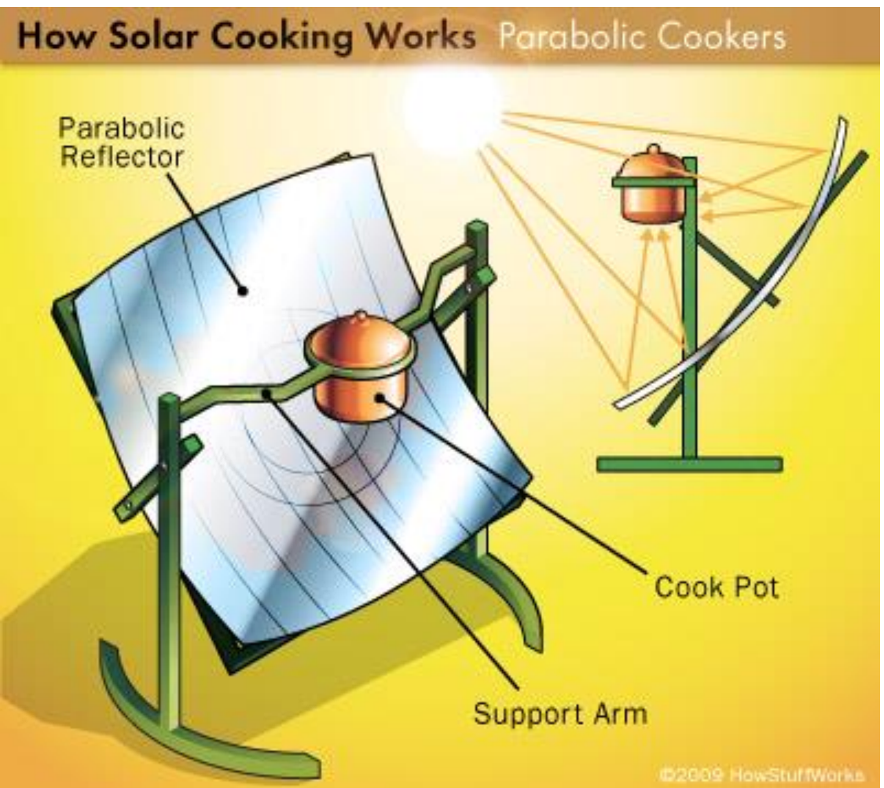
Other Cookers

A cardboard box cooker

A basket cooker at the Centre for Rural Technology in Nepal

Parabolic Solar Cooker

How does it works? Parabolic Cooker



Working Principle

- **Concentrating sunlight:** A reflective mirror of polished glass, metal or metalized film concentrates light and heat from the sun on a small cooking area, making the energy more concentrated and increasing its heating power

Parabolic Cooker

SK-14 is a parabolic solar cooker

Source: http://solarcooking.wikia.com/wiki/SK-14

- invented by Hans Michlbauer of Germany.
- **It can cook for 10-15 people per day with only 2-3 hours of sunlight.**
- **Using a pressure cooker** dramatically **reduces the cooking time**
- *Size: reflective area of 1.5 m2*
    - ground area 1.5 x 1.5 m2
- *Material balance:*
    - iron 23 kg
    - coated aluminium 3 kg
    - cement 1 kg
    - paint 0.1 kg (estimation)
- *Expected life span:*
    - reflector plates at least 10 years
    - frame 12 years
- ***Power: 700 W*** *at 700 W/m2 insolation*

Parabolic Cooker

- The **SK-14** solar cooker being promoted in Beldangi-I as a complementary device to the kerosene supply by Vajra Foundation Nepal

Parabolic Cookers

Parabolic Cookers

Parabolic Cookers

Parabolic Vs. Box Cooker

Parabolic Cooker	Box Cooker
Very high temperatures (200 to 500 deg C)	Only 80 – 100 deg C.
More like a BBQ or Grill	Cooking takes much longer
Easy to see it cooking quickly	Not too sure it is working! (WAPI – 65 deg C)
Needs frequent adjustment	Adjust once an hour.
More likely to be dazzled by reflected light.	Much less reflected light.
concentrate direct insolation on a cooking pot	use both direct and diffuse solar radiation
Unstable	Very stable

Advanced Solar Cooker

Challenges for acceptance of Solar Cookers

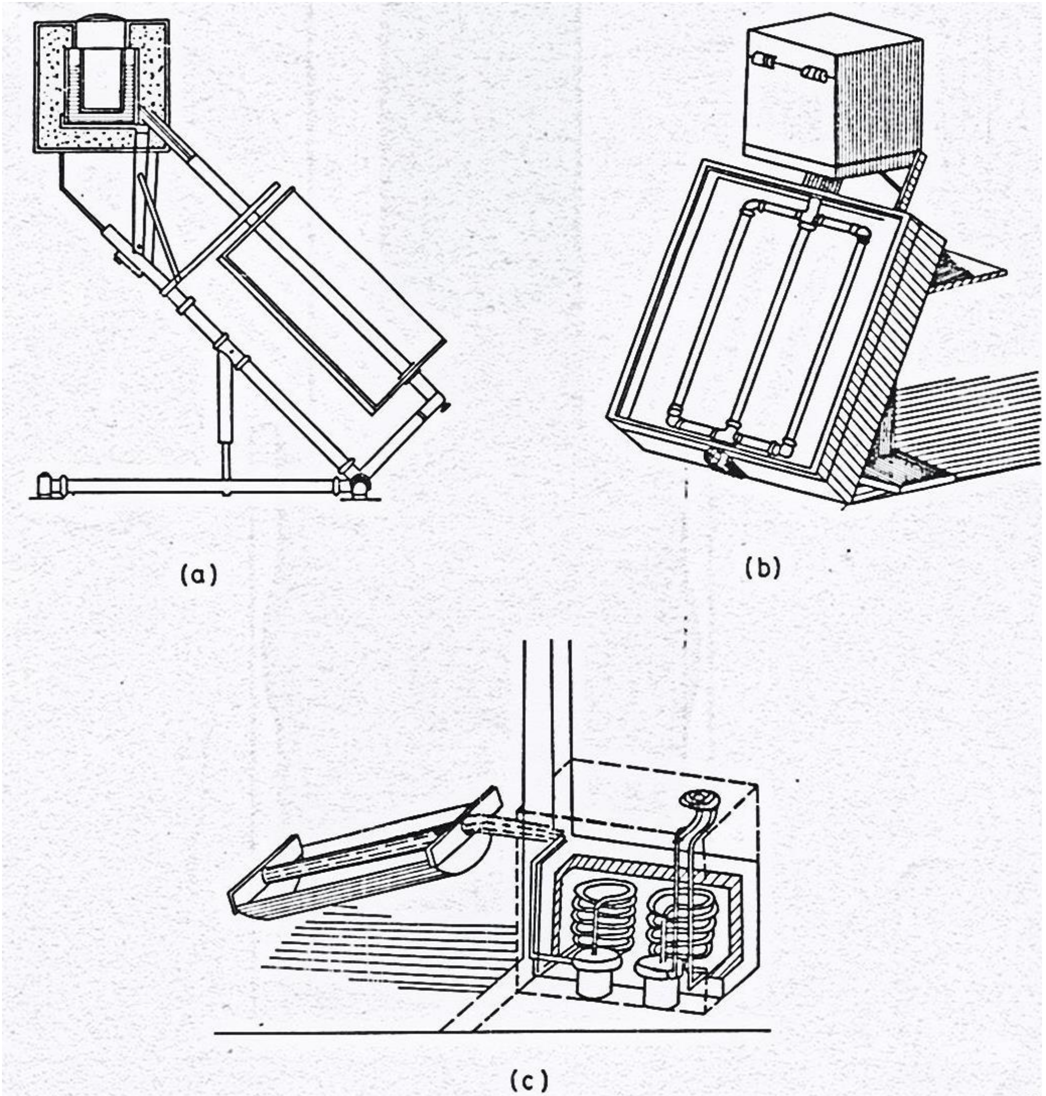
- **Too expensive** for individual family ownership
- **Incompatible** with traditional cooking practices
- too **complicated** to handle
- cooking can be done only in the direct sun
- can **not cook at night**
- can not cook in cloudy weather
- can **not cook indoors**
- danger of getting burned or eye damage
- are **not locally available**
- less durable; needs repair or replacement of parts which are not easily available
- The cooker needs frequent adjustment towards the sun and exposure of the cooking pot to the blowing dust and sand effected the food taste
- Easy availability of alternative cooking fuels like wood and fuel wood
- There is **no provision of storing the heat** therefore cooking of food was not possible where there are clouds or sun is not strong
- **No proper education, training and involvement** of women folk

Source: Garg (1992)

Advanced Solar Cookers

- Cooking can be done indoors
- Storage of heat is possible
- Frequent tracking required / not required
- Temperature achieved up to 350°C
- User – single family / community
- Flat plate collector, cylindrical or large mosaic parabolic reflector/concentrator which focuses the solar heat and transfers to the cooking vessel or heat storage device

Advanced Solar Cookers



Heat Storage and Indoor Cooking type solar cookers:

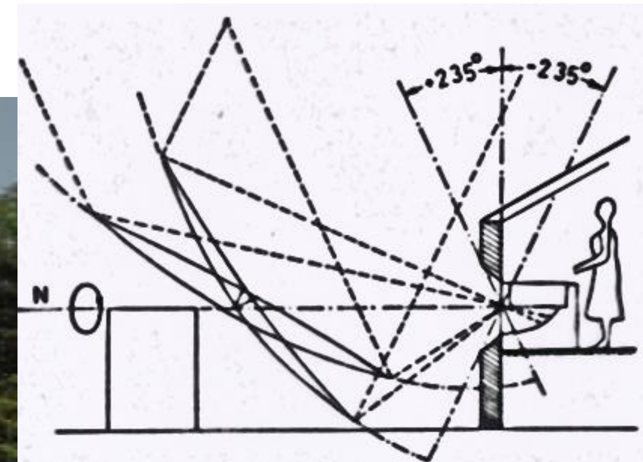
(a)and (b) Flat plate collector type

(c) Parabolic reflector type

Source: Garg (1992)

Advanced Solar Cookers

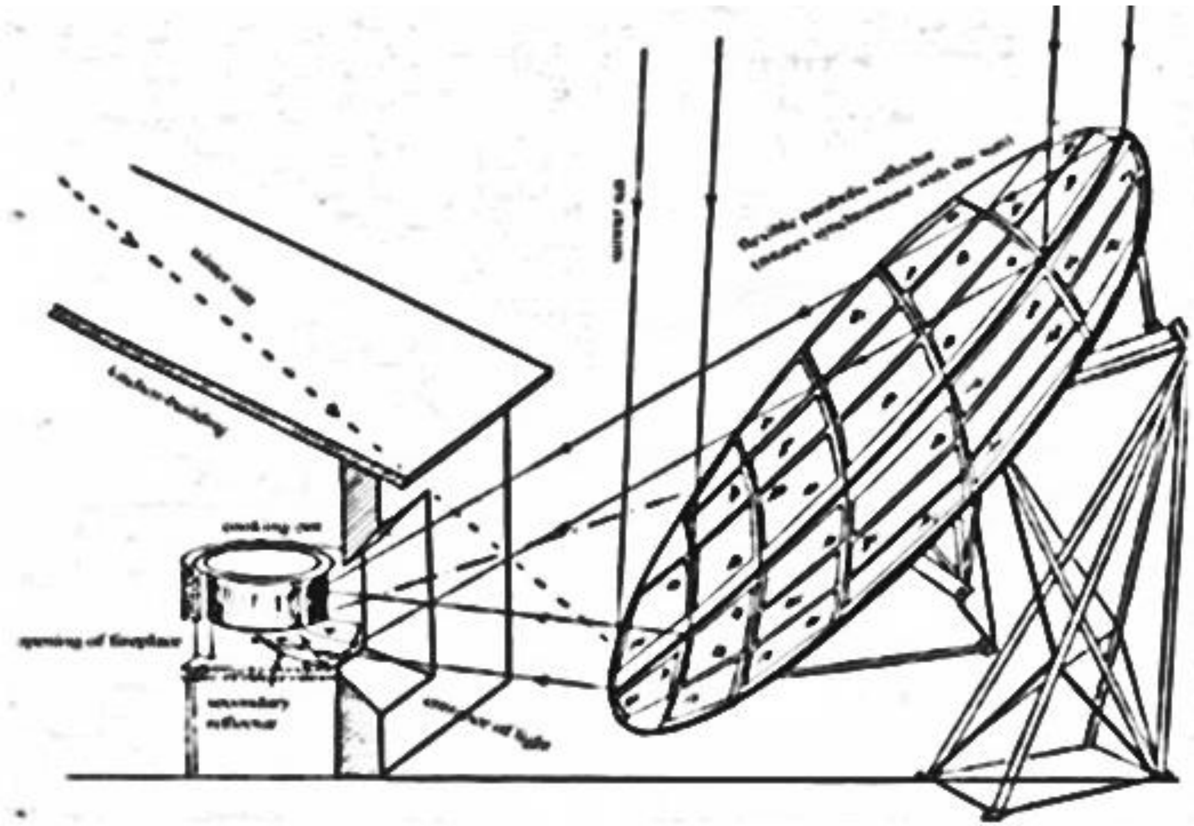
Scheffler Community Solar Cooker : 7 sq m Primary Reflector concentrating the sun's rays onto a Secondary Reflector

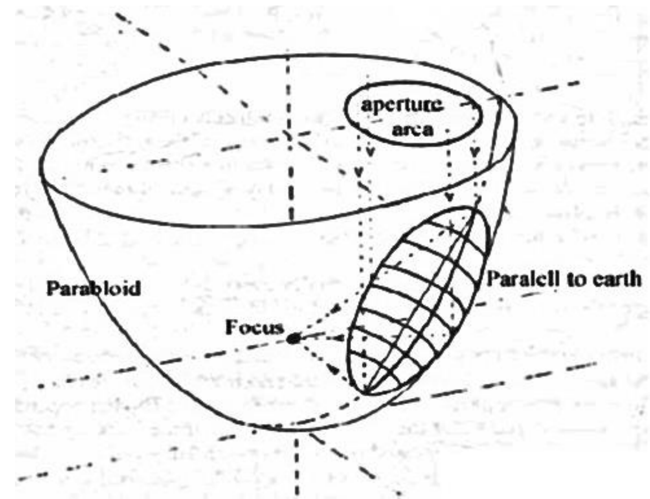


Source: Garg (1992)

Advanced Solar Cookers

Scheffler Community Solar Cooker : 7 sq m Primary Reflector concentrating the sun's rays onto a Secondary Reflector

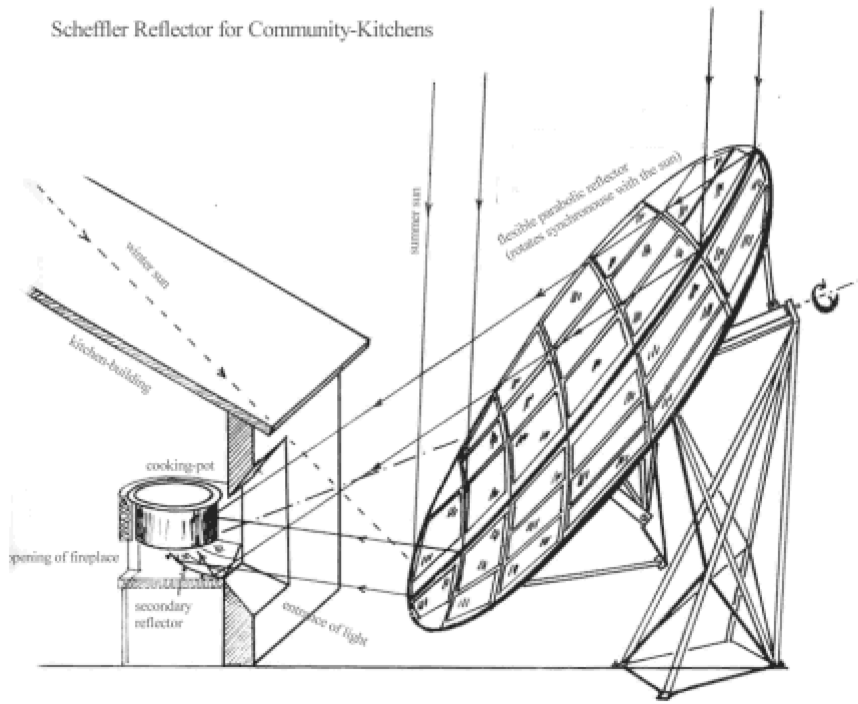




Source: Barli Development Institute for Rural Women

Commercial Application

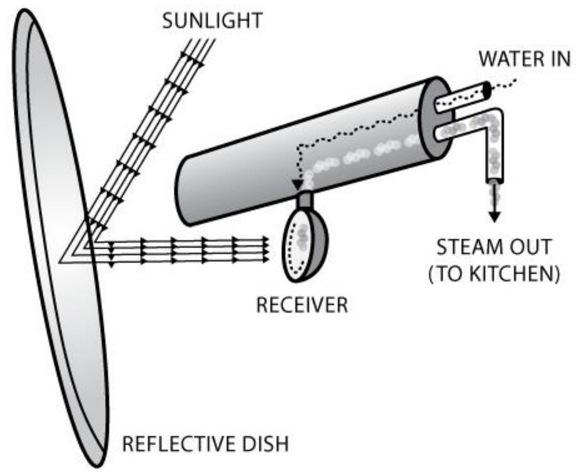
Scheffler Community Cooker Design : Community Kitchen - India



Scheffler Community Solar Cooker : Deep Frying is possible (Frying Purees)

Advanced Solar Cookers

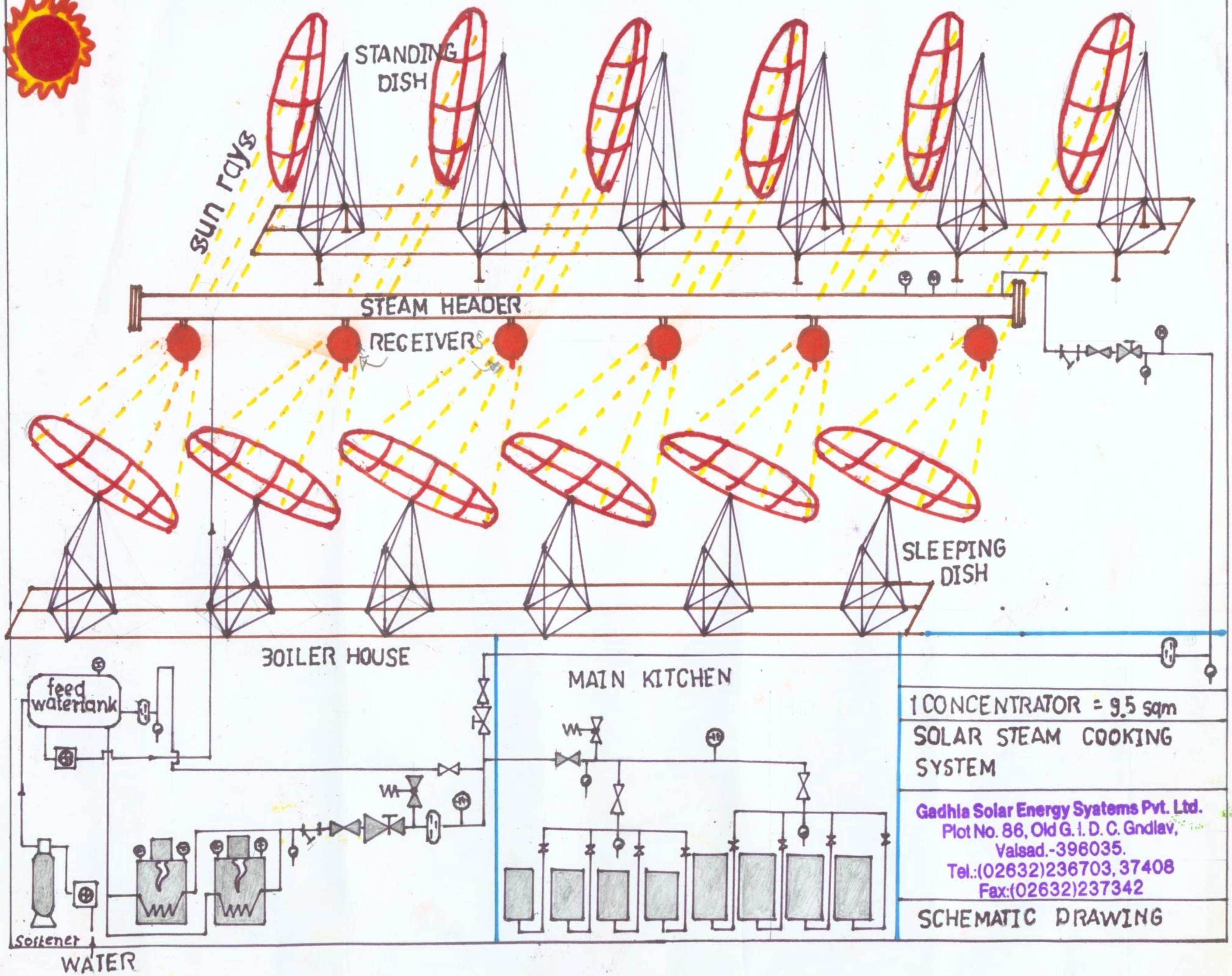
Solar Steam Cooking System at Talheti, Mount Abu, Rajasthan



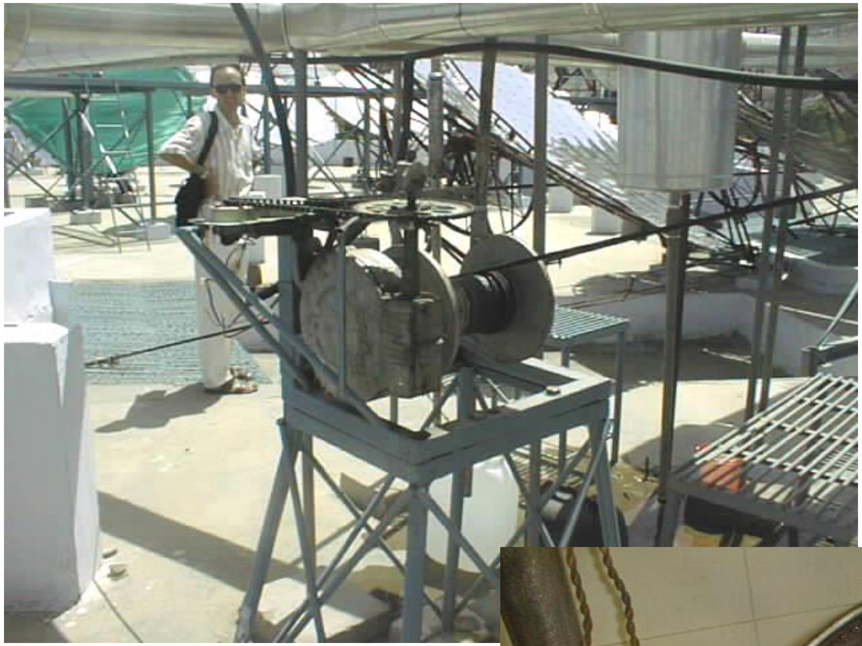
Source: Garg (1992)

Solar Steam Cooking System for 15’000 people

Tirumala Tirupati Devasthanams (TTD) Andhra Pradesh, India


STANDING DISH
sun rays
STEAM HEADER
RECEIVERS
SLEEPING DISH
BOILER HOUSE
MAIN KITCHEN
feed watertank
Softener
WATER
1 CONCENTRATOR = 9.5 sqm
SOLAR STEAM COOKING SYSTEM
Gadhia Solar Energy Syatems Pvt. Ltd.
Plot No. 86, Old G. I. D. C. Gndlav,
Valsad.-396035.
Tel.:(02632)236703, 37408
Fax:(02632)237342
SCHEMATIC DRAWING

Solar Steam Cooking System



Tracking system

Kitchen for steam cooking system

Steam cooking pot

Solar in food processing industry

Solar Bakery

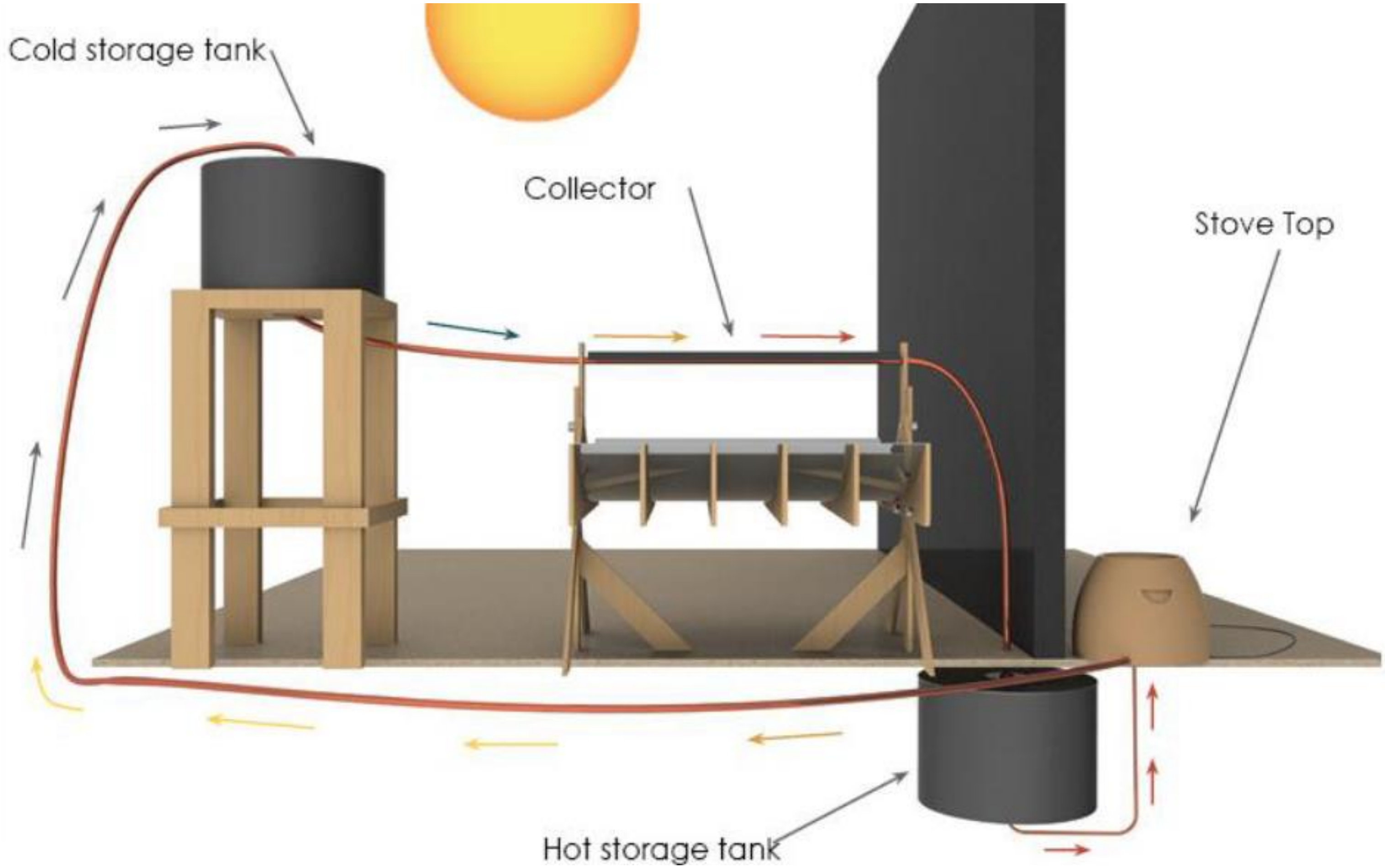
Drinking water from Sea Water

Waste incineration

Solar crematorium

Energy Storing Cooker

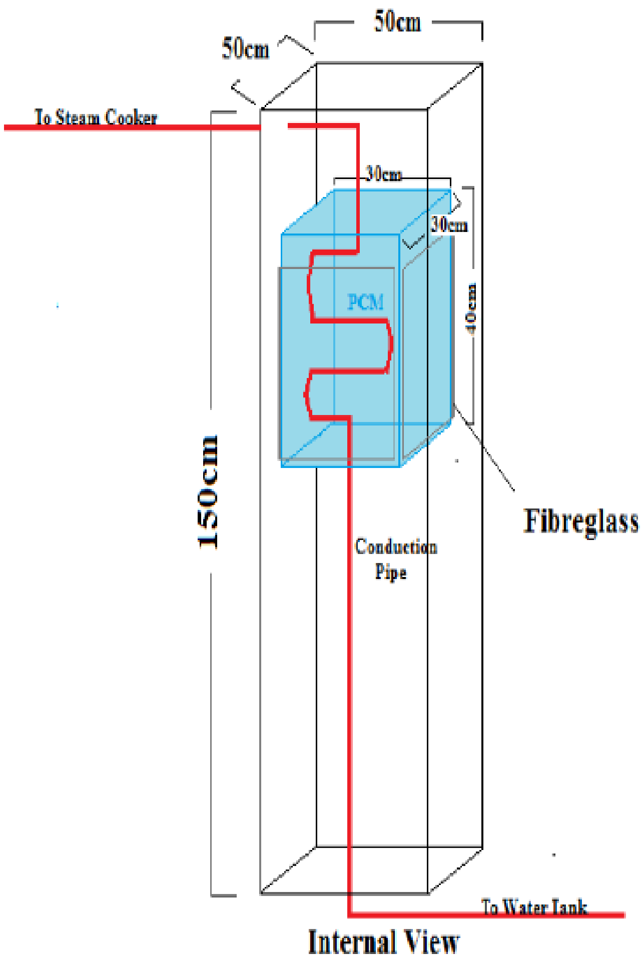
Solar cooker with oil

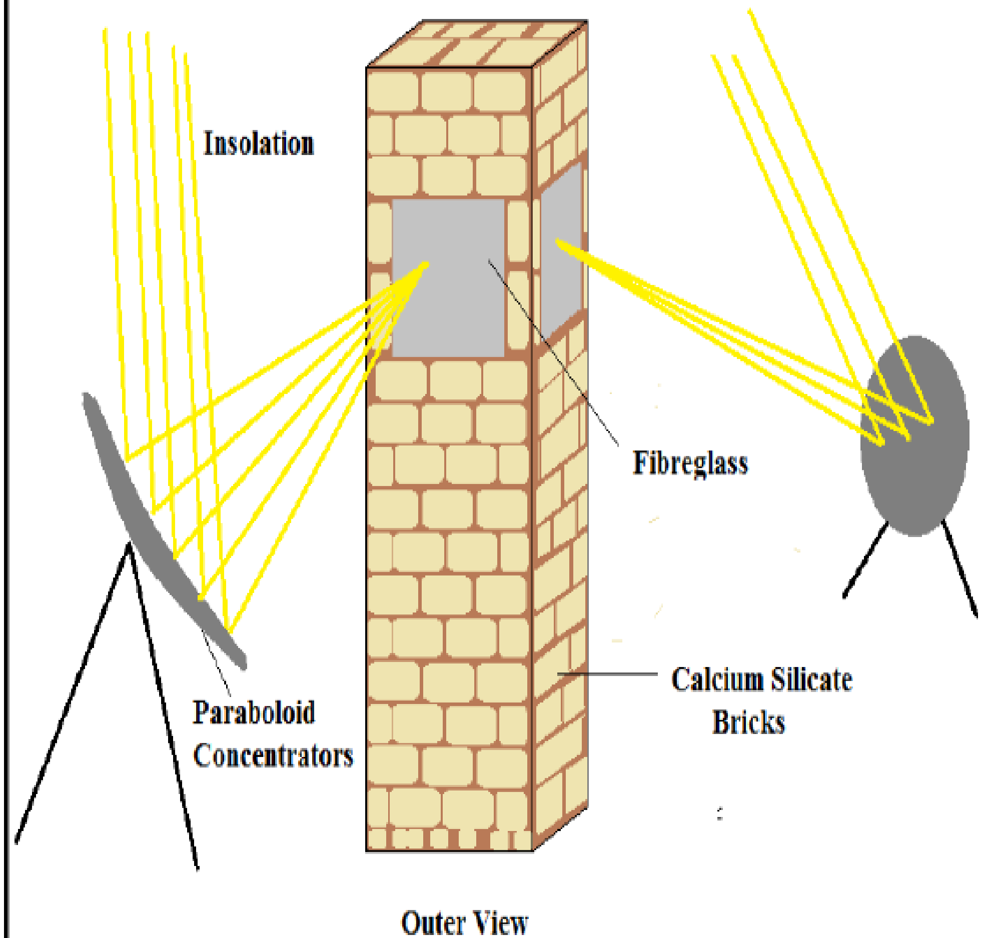


Source: https://www.engineeringforchange.org/whiteboard/view/450

Energy Storing Cooker

Molten-salt solar cooker

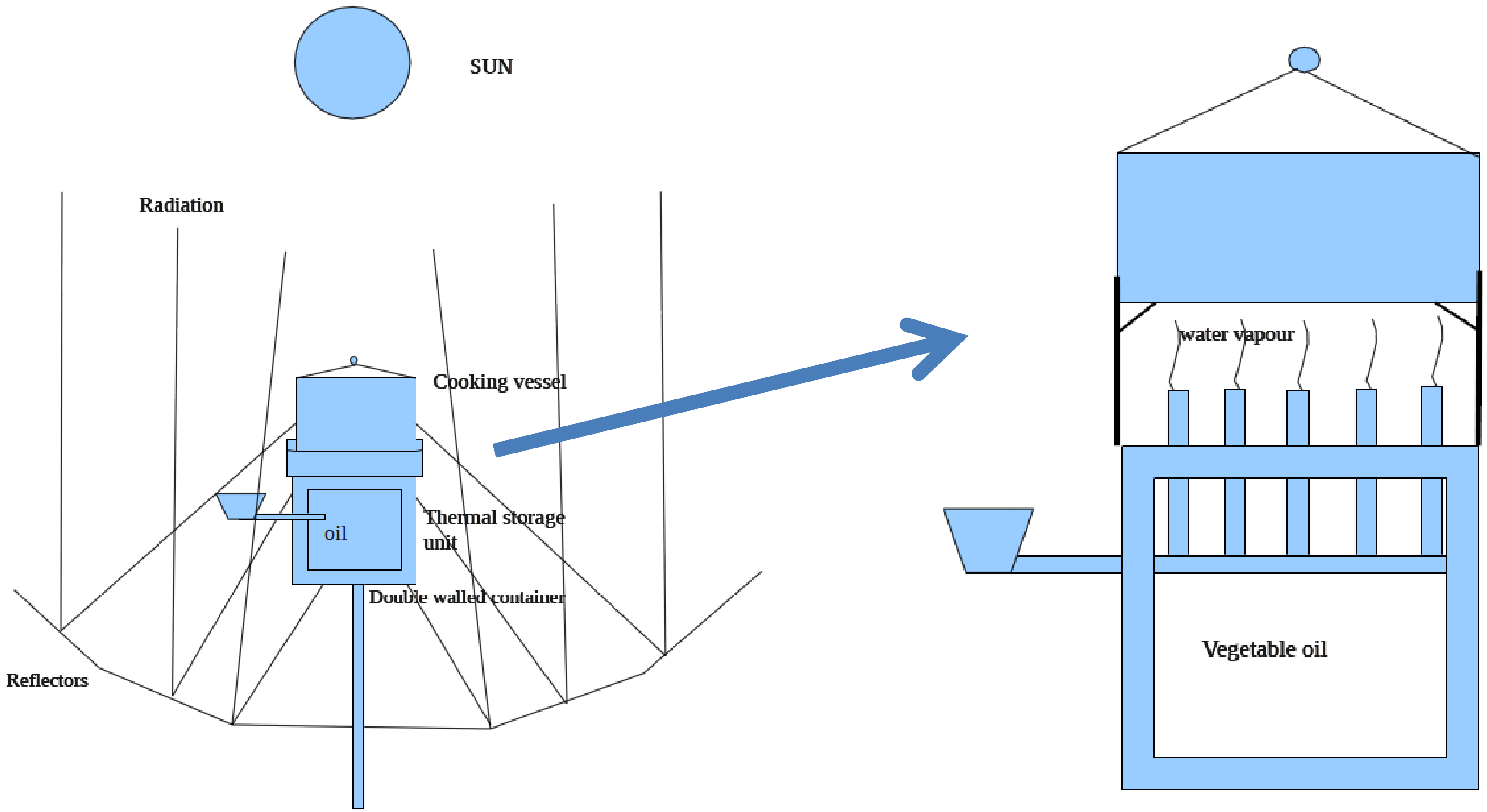




Source: https://www.engineeringforchange.org/whiteboard/view/449

Energy Storing Cooker

Parabolic solar cooker with steam



Source: https://www.engineeringforchange.org/whiteboard/view/446

SOLAR DRYERS

Solar Dryers Developed by RECAST

1. Solar Box Dryer
2. Solar Cabinet Dryer
3. Solar Tunnel Dryer
4. Hybrid Solar Biomass Cabinet Dryer

Hybrid Solar/Biomass Cabinet Dryer

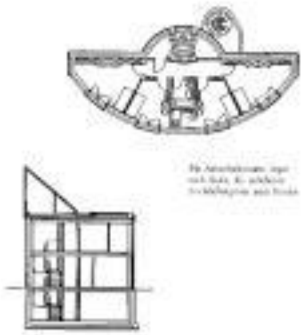
Solar Cabinet Dryer

Solar Tunnel Dryer

Solar Box Dryer

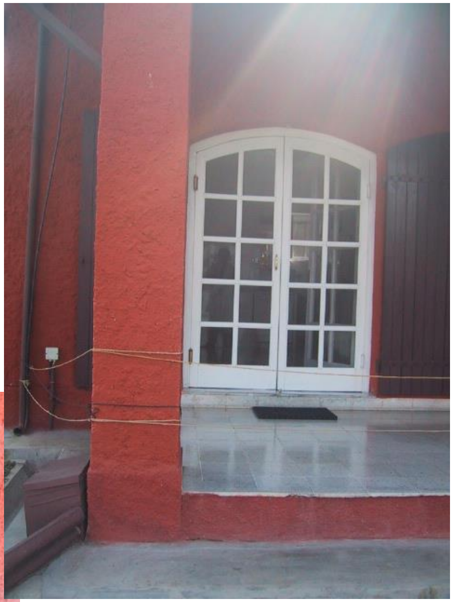
Solar space heating

Zero-energy house,
Freiburg, Germany



Bruchhagen, Germany

Solar space heating



Private house, Kathmandu

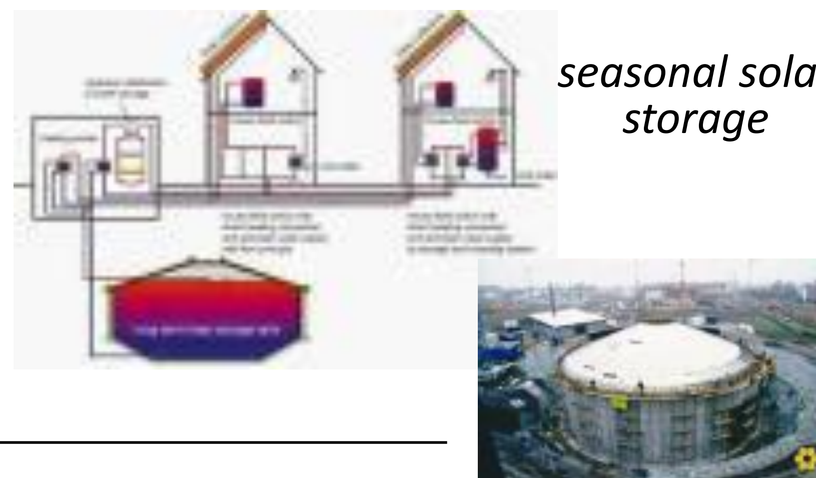
Solar district heating

boilerhouseGötti ngen, Germany

solar field, Denmark

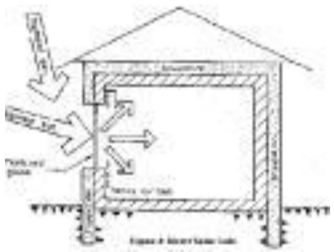
solar roofs

industrial pre-heating

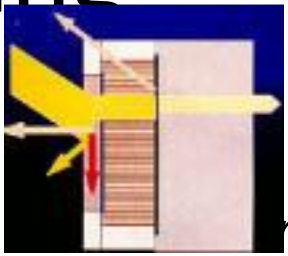


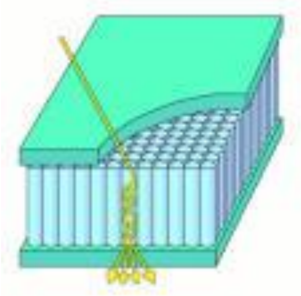
seasonal solar storage

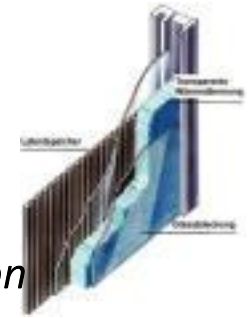
passive solar heating



passive solar heating - scheme





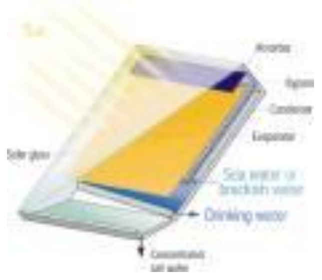


ransparent insulation

Heliotrop Freiburg, Germany

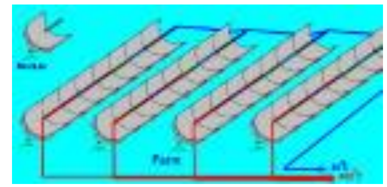
air collector

Solar desalination & purification

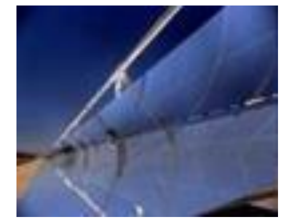


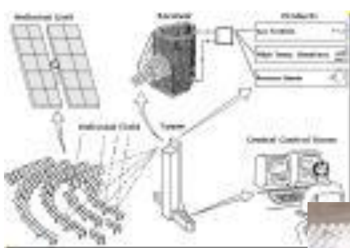
Solar thermal electricity

parabolic dish

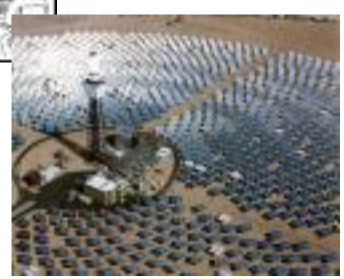


parabolic trough





Heliostat



Solar Water Heater Design

Simple integral type SWH

Source: http://www.associatedcontent.com/article/283635/
66_beer_bottles_land_son_in_hot_water.html?cat=16

Typical solar water heaters in Market

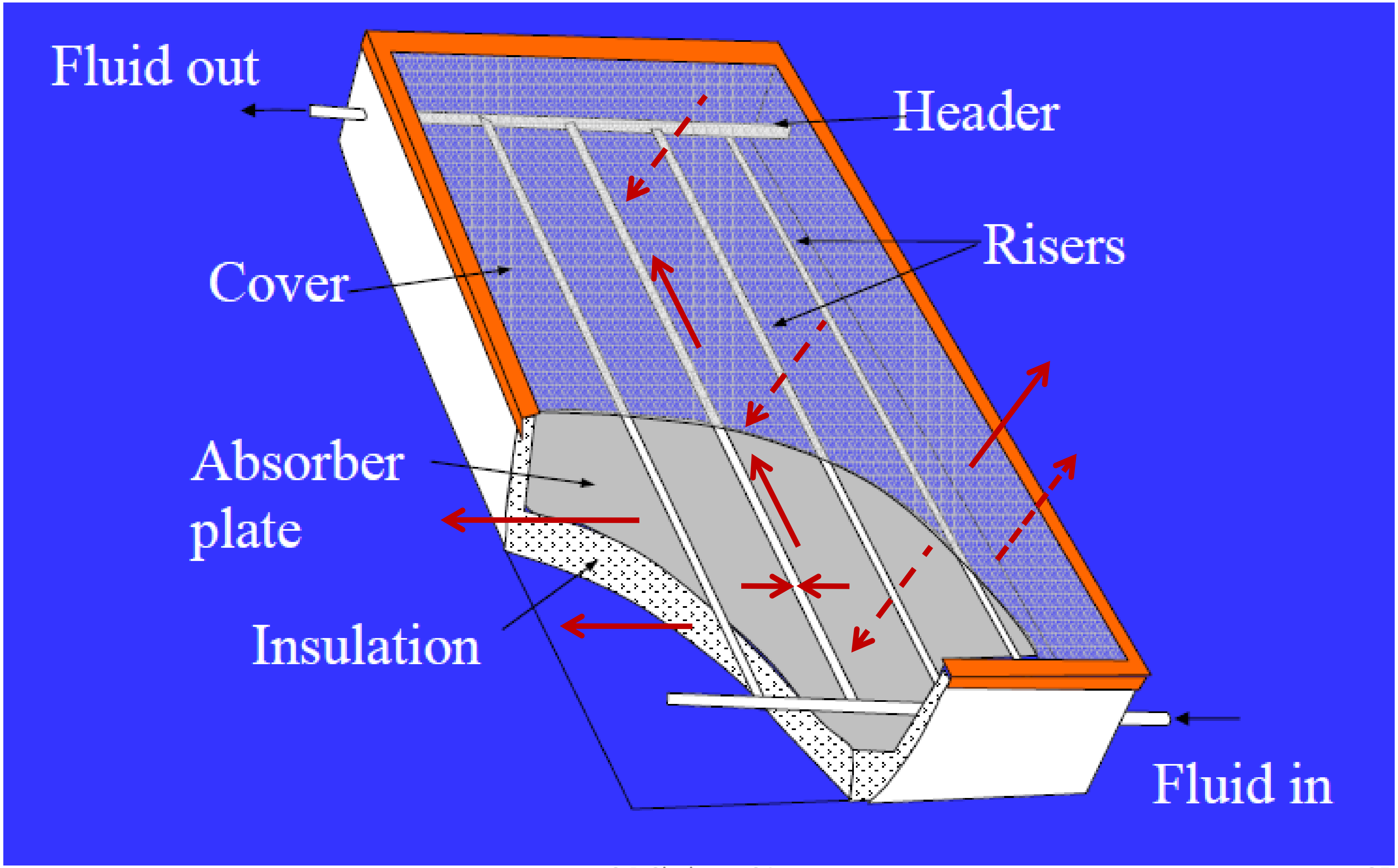
Flat plate SWH

Vaccum tube SWH

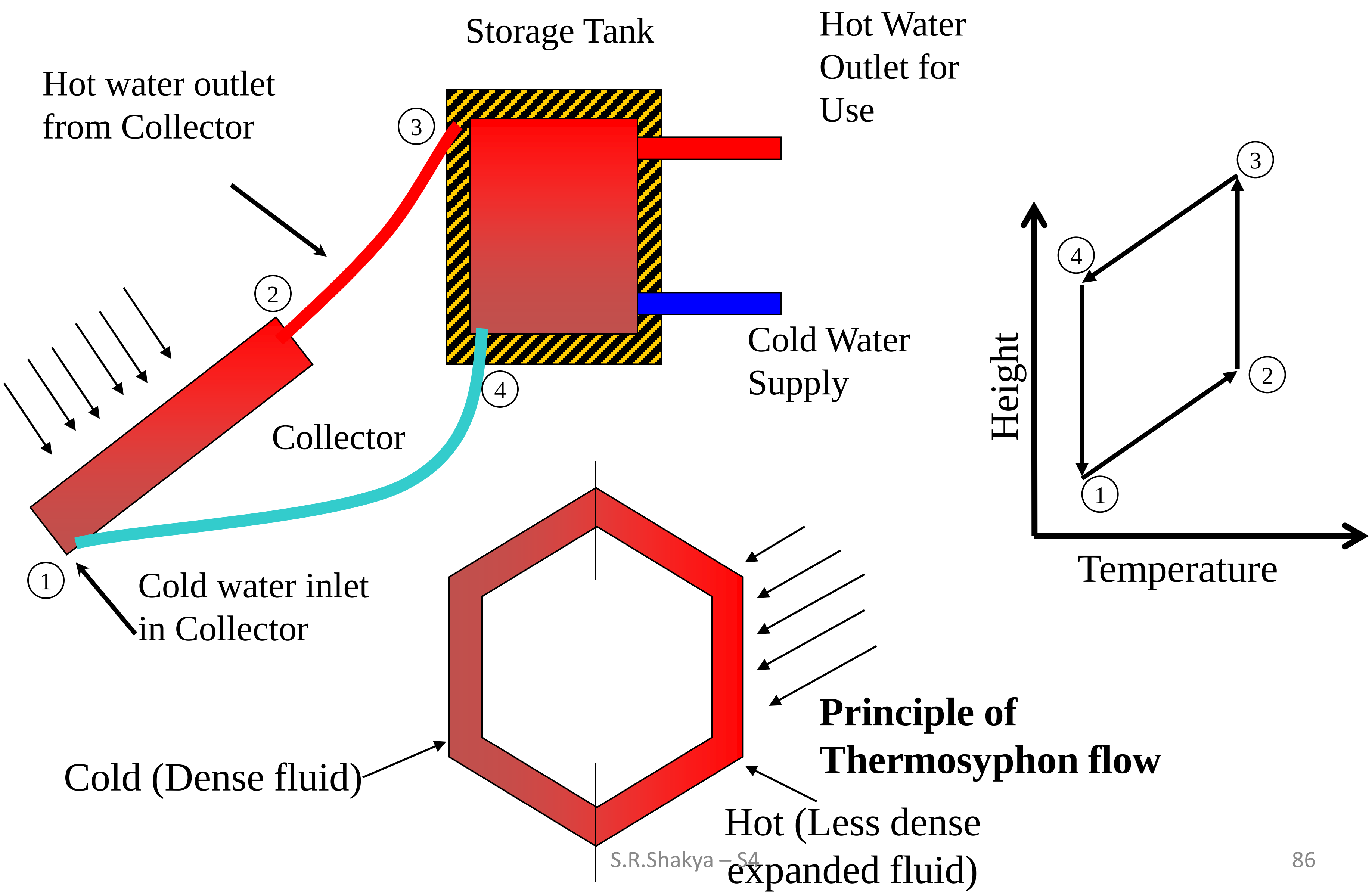
How does the heat transfer takes place in SWH?

- Radiation
  - Transmission through cover plate
  - Incident radiation absorbed by the absorber plate
- Conduction
  - Heat transfer from absorber plate up to riser tube
  - Heat losses from plate to surroundings
- Convection
  - Heat transfer within fluid in the riser pipe
  - Heat loss from the absorber plate to the surrounding
  - Heat loss from the insulation to the surrounding

How does heat transfer takes place in SWH?



Working Principle of SWH



Energy Balance

Hot water requirement

- Energy gained = Energy Loss:

$$m_1C(T_c-T_m) = m_2C(T_h-T_m)$$

i.e.= Mass of water (kg) x Specific heat of water x Temperature diff. (K).

- – Specific heat of water = 4.2kJ/kg.K
- – Assume: 1 kg water = 1 liter water

Energy Balance Contd.

- Eg. A family with 5 people has hot water requirement for bathing purpose.
- Assumption:
  - required water temp=30°C
  - Required water quantity = 100 liters per person.
  - SWH can raise the water temp to 60 °C=
  - Cold Water inlet temperature = 20 °C
- Now, we have by energy balance for each person:
  - 100*C*(30-20) = m_2*C*(60-30)
  - then m_2 = 33liter: For other uses, add 5 liter ≅ 38 liter.
  - Recommend: 38 liter * 5 person = 190 ≅ 200 liter hot water storage tank system

Collector Area sizing Thumb Rule

collector	*area*	*reservoir size*
3.0 m²	**(2 panels)**	**150 l reservoir**
4.5 m²	**(3 panels)**	**250 l reservoir**
7.5 m²	**(5 panels)**	**400 l reservoir**
10.5 m²	**(7 panels)**	**600 l reservoir**

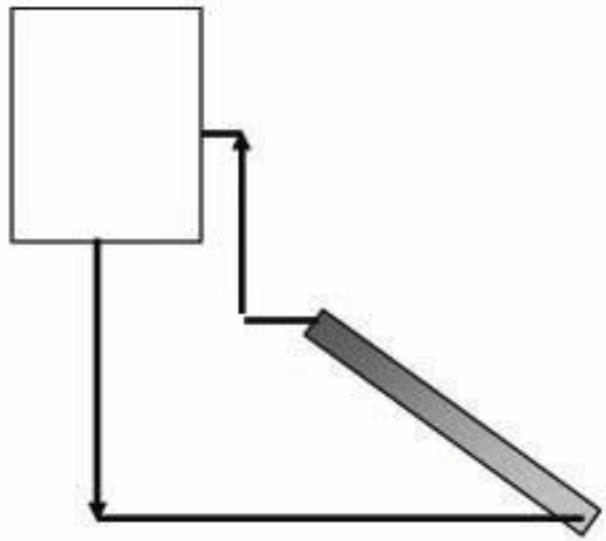
Energy Balance Contd.

- **Exercise:**
  - Recommend SWH system for a family with 3 people having requirement of hot water.
- Assume:
  - required water temp = 40°C
  - Required water quantity = 100 liters per person.
  - SWH can raise the water temp to 65 °C
  - Cold Water inlet temperature = 25 °C

SWH Sizing

Purpose	Medium Consumption per day per person	Maximum Consumption per day per person
Modest domestic	20-40	30-60
Comfortable standard	40-60	60-90
High Standard	60-120	90-180
Children hostel	40-60	60-80
Hospital (town)	70-100	100-150
Hostel (Luxury)	Up to 200	Up to 300

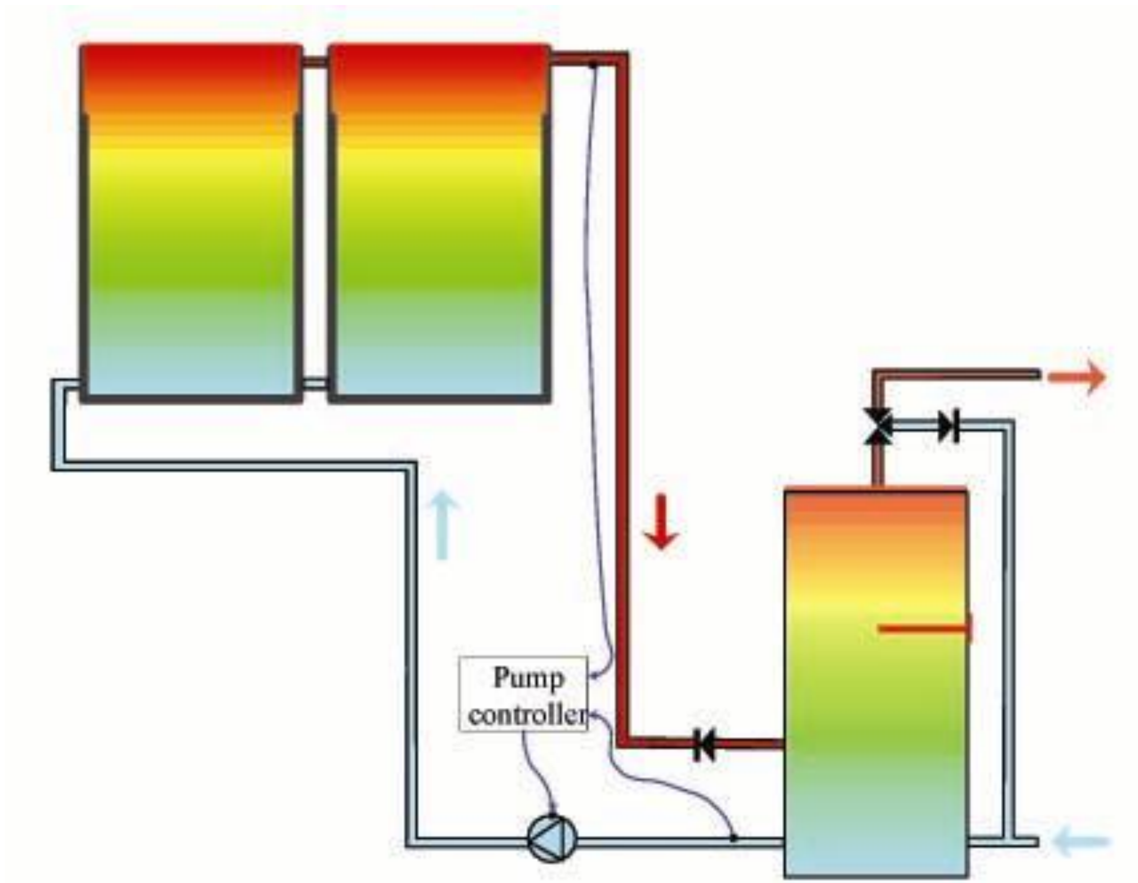
Different SWH systems



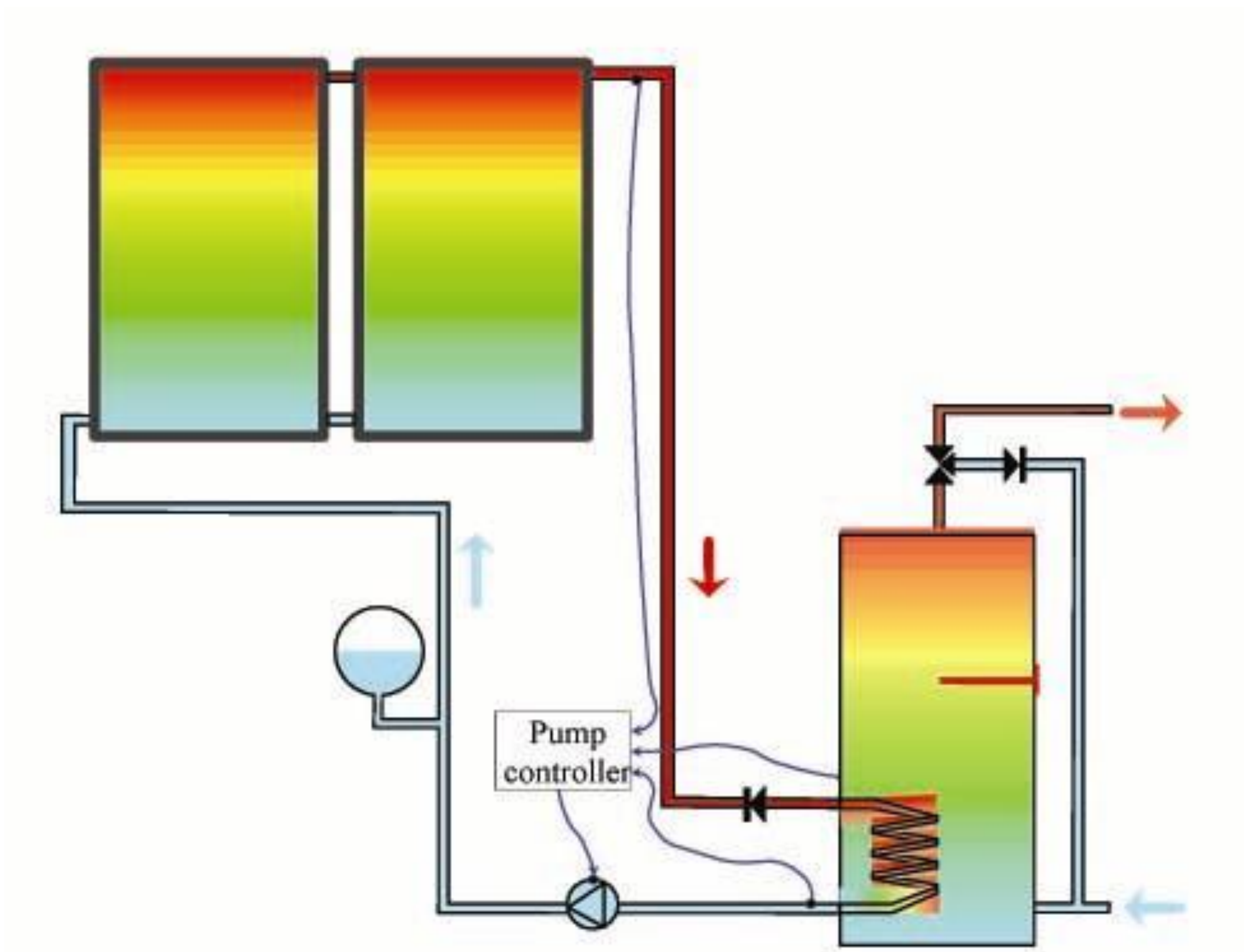
Separate tank and collector

Close coupled tank and collector

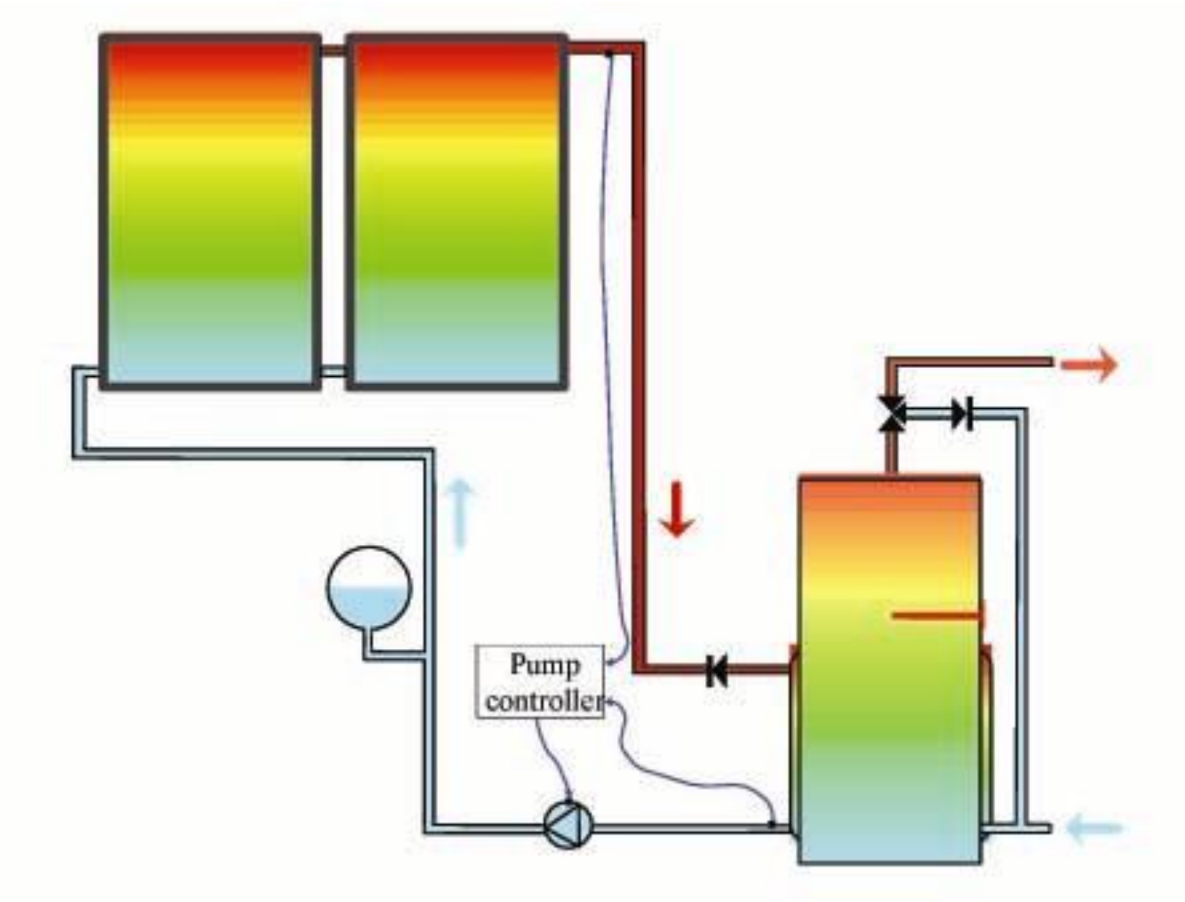
Pumped circulation between tank and collector



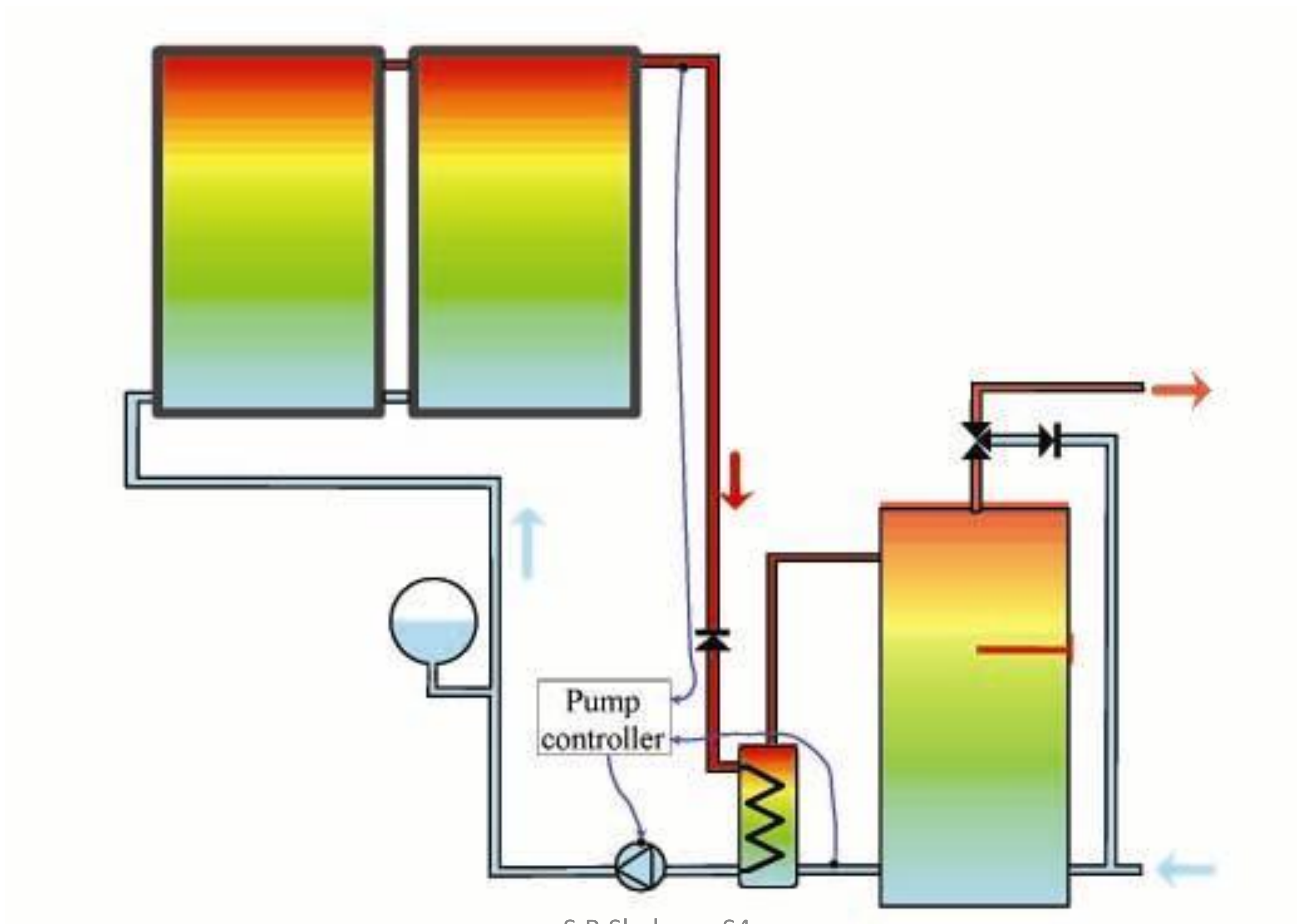
Closed loop with internal heat exchanger



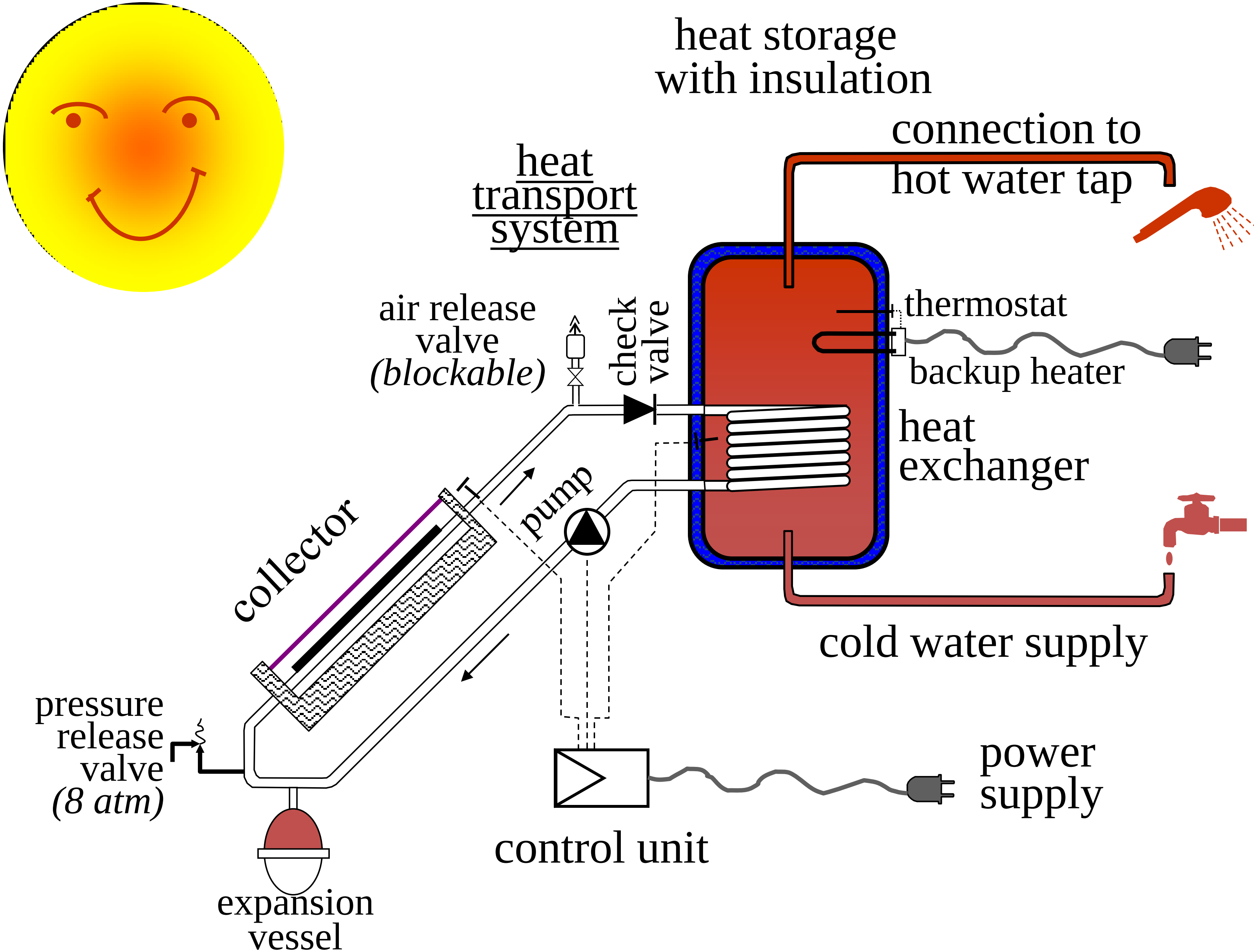
Closed loop with jacket



Pumped circulation and natural circulation from tank



Components of Good SWH



heat storage
with insulation
connection to
hot water tap
heat
transport
system
air release
valve
(blockable)
check
valve
thermostat
backup heater
heat
exchanger
collector
pump
cold water supply
pressure
release
valve
(8 atm)
power
supply
control unit
expansion
vessel

Forced-flow versus natural circulation SHW systems

forced flow

+ better performance
+ can be installed in large systems
+ allows independent location of collector and hot water tank
– requires more components
– needs electrical energy for pumping and control
– is more expensive

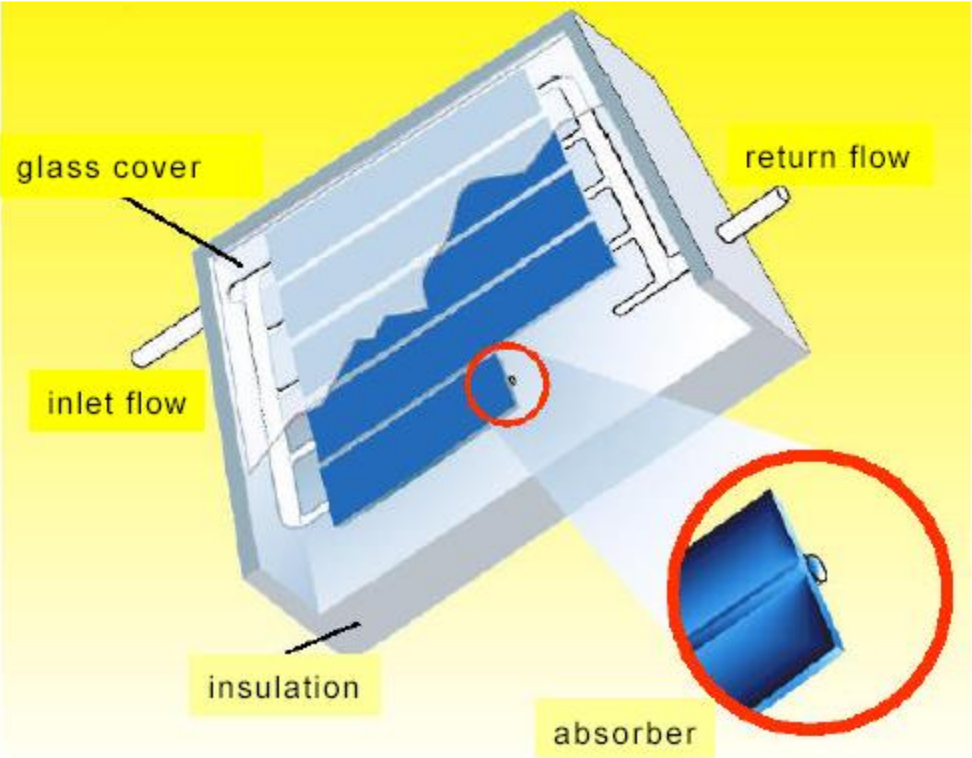
natural circulation (thermosiphon)

+ simple and require less components
+ work without active control equipment
+ cheaper
– not suitable for large systems
– less efficient
– storage tank must be located above the collectors

Flat-plate collectors

Elements of a flat plate collector:

- absorber
- collecting tubes
- transparent cover
- insulation of the absorber
- casing



SWH System Locally Made

Storage tank

Collector

Locally made SWH

Open- versus closed-loop SHW systems

Closed loop

- \+ better performance – avoids air bubbles
- \+ Prevents siltation of the collectors
- \+ allows use of antifreeze
- – Some temperature loss
- – needs significantly more components
- – more expensive
- – more difficult to manufacture

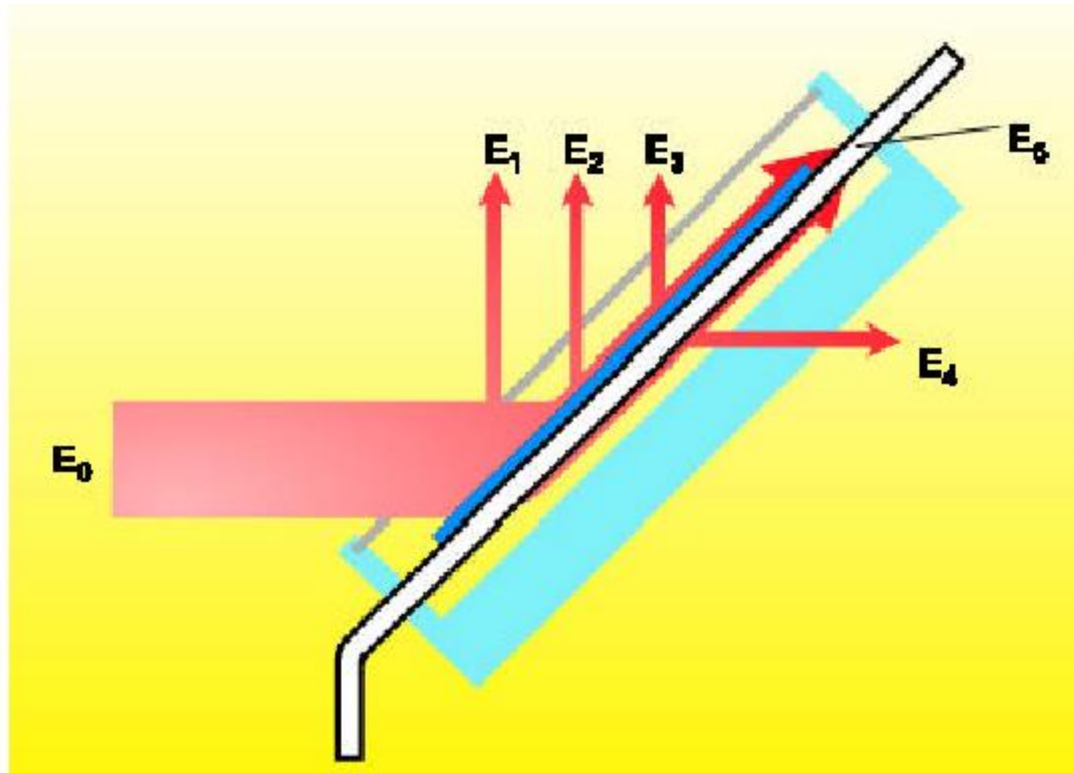
Open loop

- \+ simple and require less components
- \+ Requires less tecnical skill
- \+ Cheaper and less sensitive to flaws
- – not suitable for frost area
- – not suitable for poor quality water

Energy flow in the collector from the radiation to the hot water:

Sources of energy losses:

- E_0: incident radiation
- E_1: reflection at the glass cover
- E_2: reflection at the absorber surface
- E_3: heat loss through the front cover
- E_4: heat losses through the back insulation
- E_5: heat transferred to the fluid
- heat losses at the pipe connections
- thermal bridges (piping, housing)

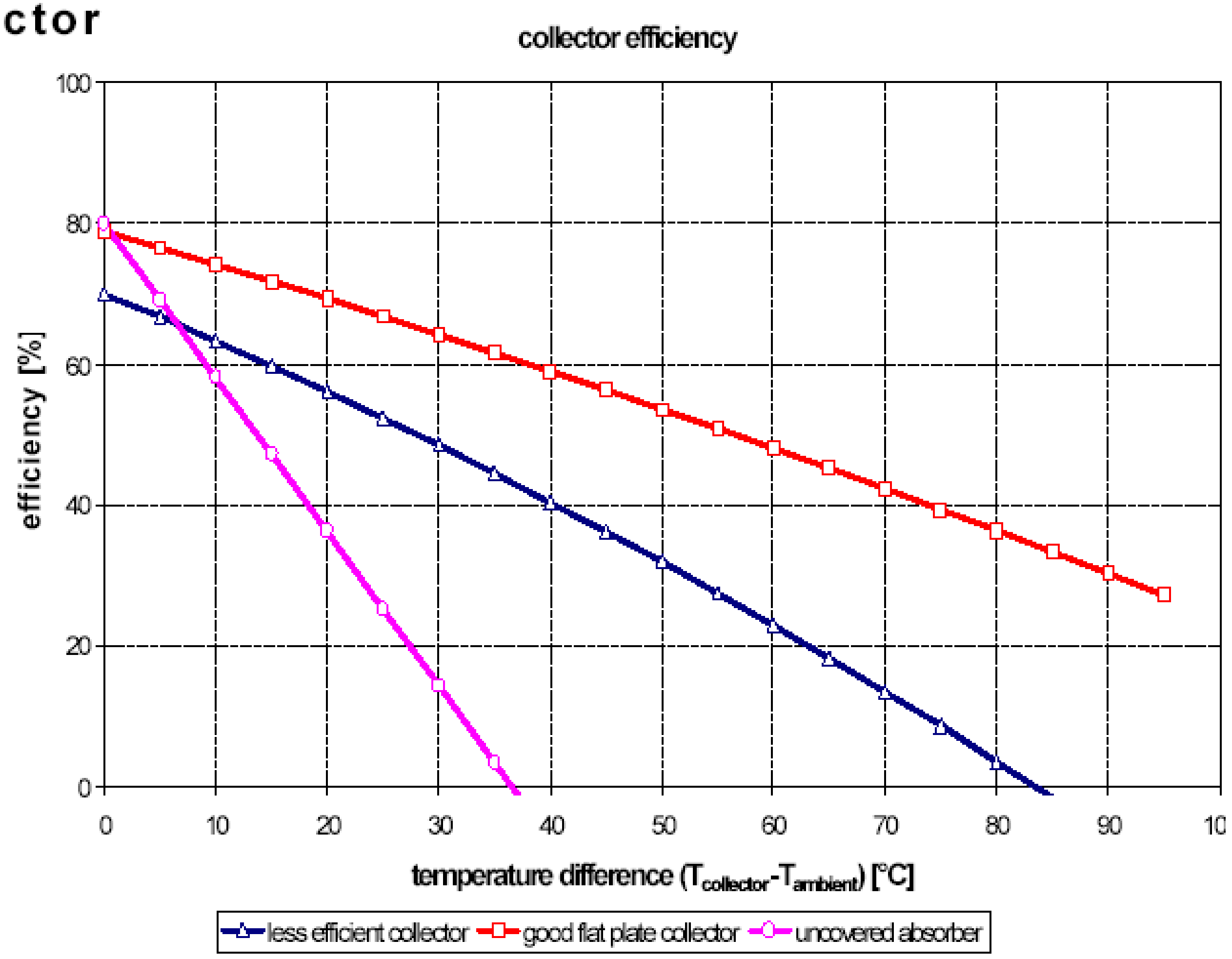


Efficiency of a collector

The efficiency of a collector depends on:

- the characteristics of the collector (efficiency curve)
- the collector temperature
- the ambient temperature
- the radiation power

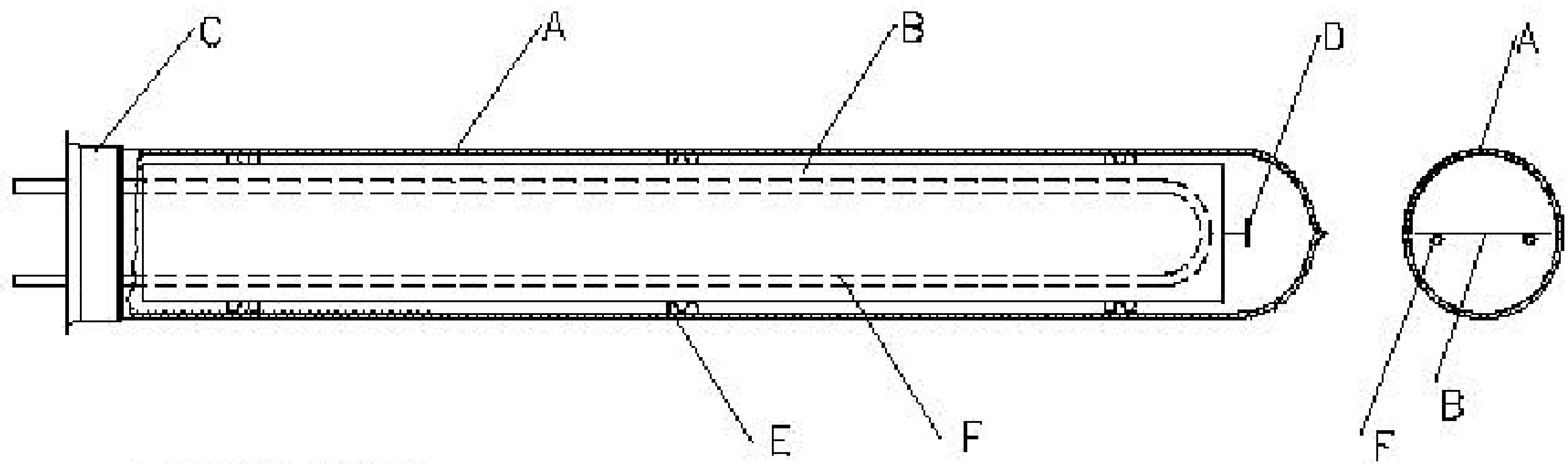
(800 W/m²)



High efficiency collectors for process heat applications

Evacuated tube collector

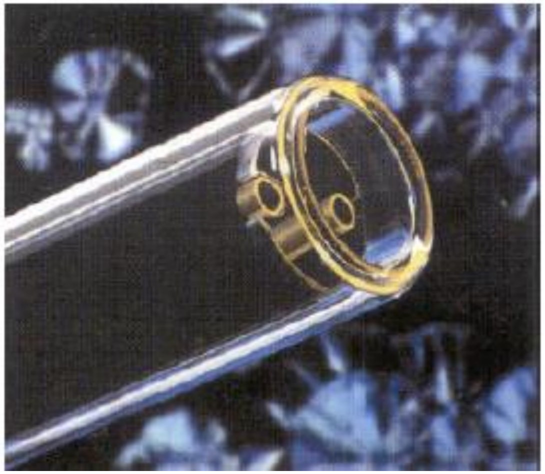
3.1. Vacuum tube collector [4]

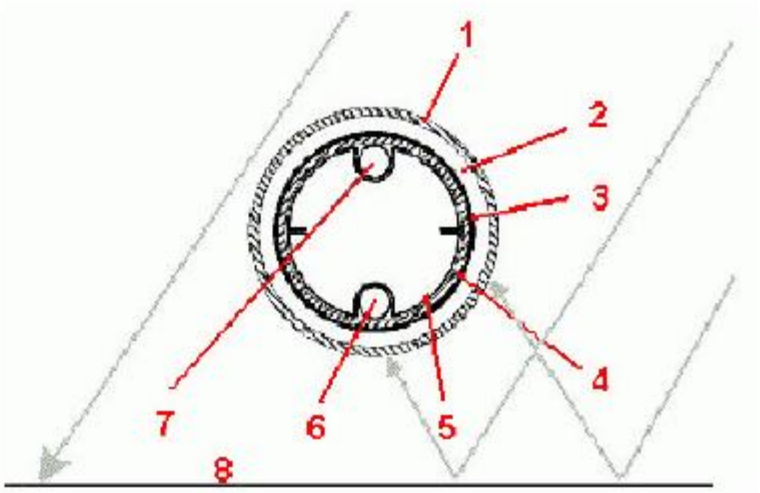


A - evacuated glass tube
B - absorber
C - metal header
D - getter
E - support spring
F - copper U-tube

The evacuated tube collector - examples

- consists of a concentric double glass tube
- the absorbent coating is applied to the internal tube
- the inter-tube space is evacuated
- a heat transfer sheet of metal holds flow and return tube

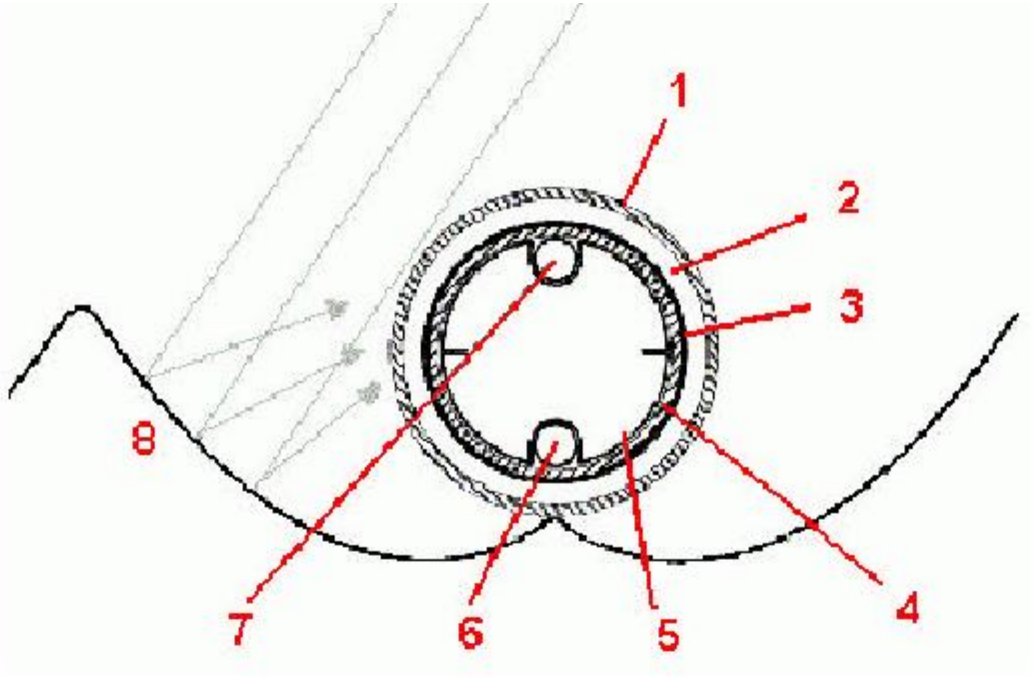




Legend
1 Outer glass tube
2 Evacuated volume
3 Coating
4 Inner glass tube (absorber)
5 Heat-conducting metal sheet
6 Inlet
7 Return
8 White reflector

Evacuated tube collectors - examples

Compound parabolic concentrator (CPC) combined with evacuated tube



Legend
1 Glazing
2 Evacuated volume
4 Absorber
5 Heat-conducting metal sheet
6 Inlet
7 Return
8 Reflector

Installation includes:

- collector installation
- plumbing and connecting techniques
- components of the hydraulic cycle
- filling and leakage testing
- electrical installation
- setting in operation
- troubleshooting and control of operation

Layout of Pipelines:

- Connection of hot water storage tank and collector should be shortest as possible
- Pipes should not be exposed if possible
- All connections must be of good quality
- Air valves and drainage valves must be accessible places
- Layout must allow complete drawings of the entire system

Pipe Diameter:

- Consumptions
- Duration of user total quantity
- Length
- Materials

Connection:

Thumb Rule of sizing:

- Surface of a standard collector is approximately 1.4 m^2

- Per m^2 of collector count approx. 50 litre

Capacity in ltr	No. of collectors	Riser pipe	Down pipe
100	1	1”	1”
125	1 – 2	1’	1”
150	2 – 3	1”	1”
200	2 - 3	1”	1”

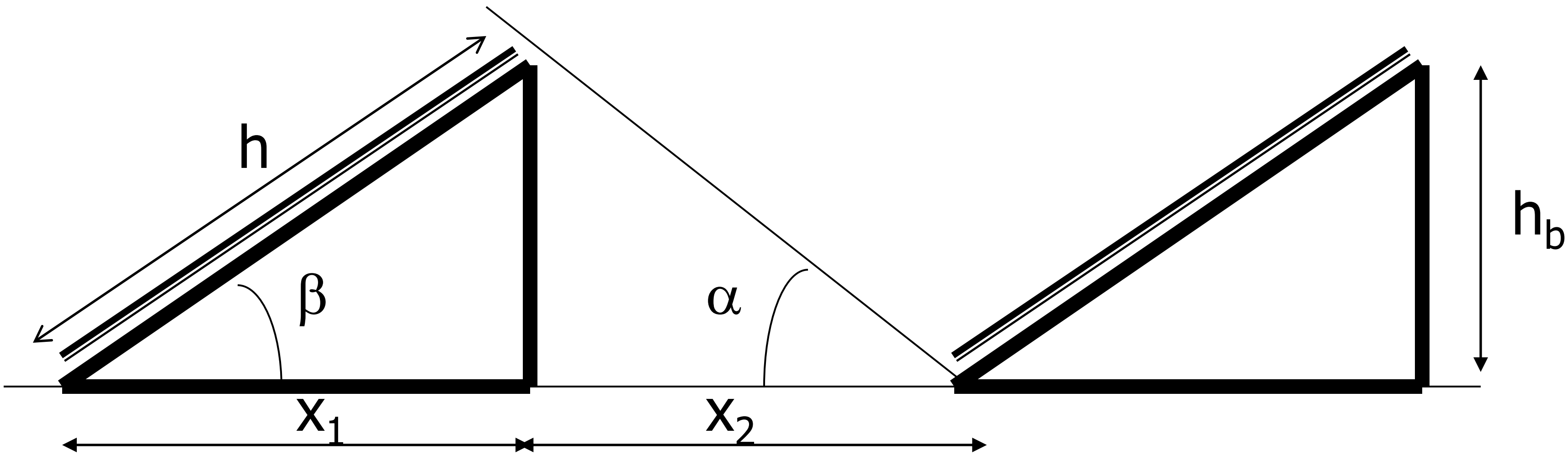
Layout and Plan:

- The cold water supply tank (overhead tank) has always to be higher than the SWH system
- Thermo-syphon system – Collector must be below than the hot water storage tank
- Keep sufficient spacing between the riser and bottom of the hot water storage tank
- Keep easy access to collectors and the solar system for maintenance and repair

Layout of Pipelines:

- Connection of hot water storage tank and collector should be shortest as possible
- Pipes should not be exposed if possible
- All connections must be of good quality
- Air valves and drainage valves must be accessible places
- Layout must allow complete drawings of the entire system

Collector spacing:



X_1=h cos β $\quad$ X_2=h_b tan α $\quad$ h_b=h sin β

Collector Installation - mounting

Collector Installation - mounting

Preparation of Collectors for glazing:

- clean off dust and dirt from the absorber plate
- glass cleaning, the inner surface of the glaze must be cleaned before installing
- place the glazing on the collector with proper rubber gasket
- cleaning glaze from outside
- In case of need of protection from hailstones, collectors should be protected by using galvanized wire netting about 80 mm above the collector surface.

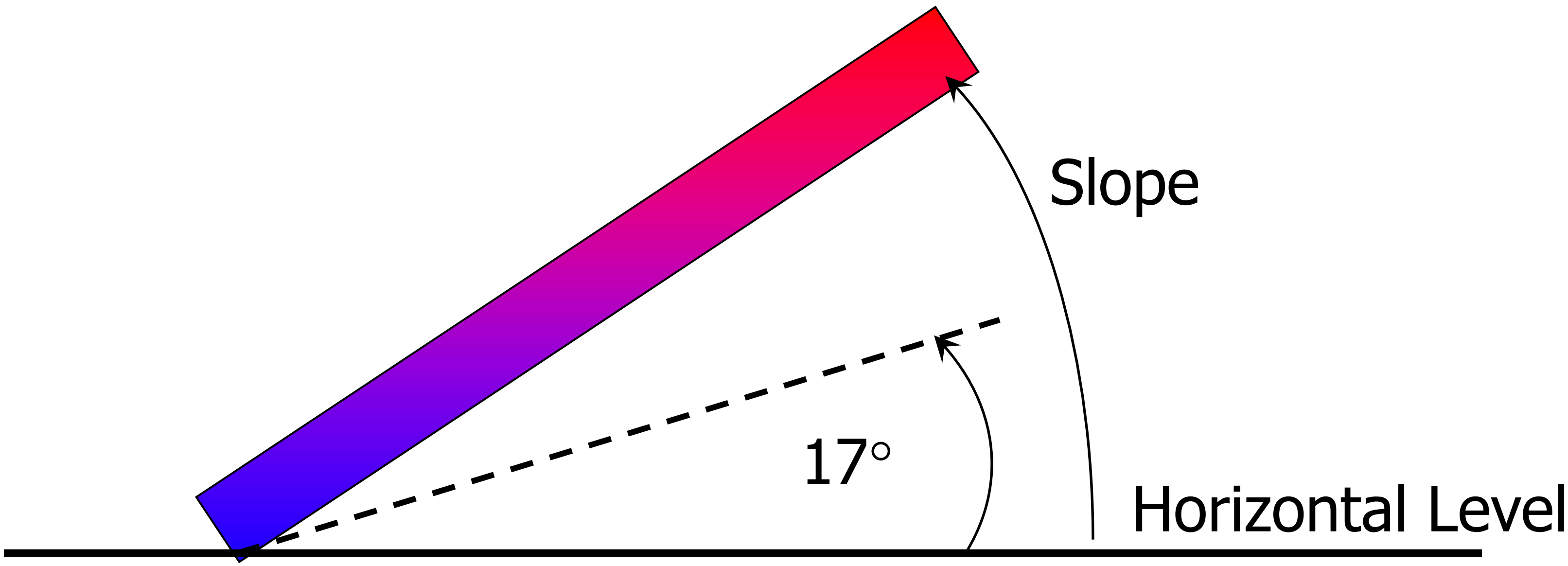
Angle and direction of Collectors:

- directly facing South in Northern Hemisphre (and due North in the Southern Hemisphere), deviation 15 to 20 degrees, slightly to the West

- Example

  The latitude of Kathmandu is about 27°
  Therefore, 27°+10° = 37°
  So, an angle of 37° is recommended for Kathmandu

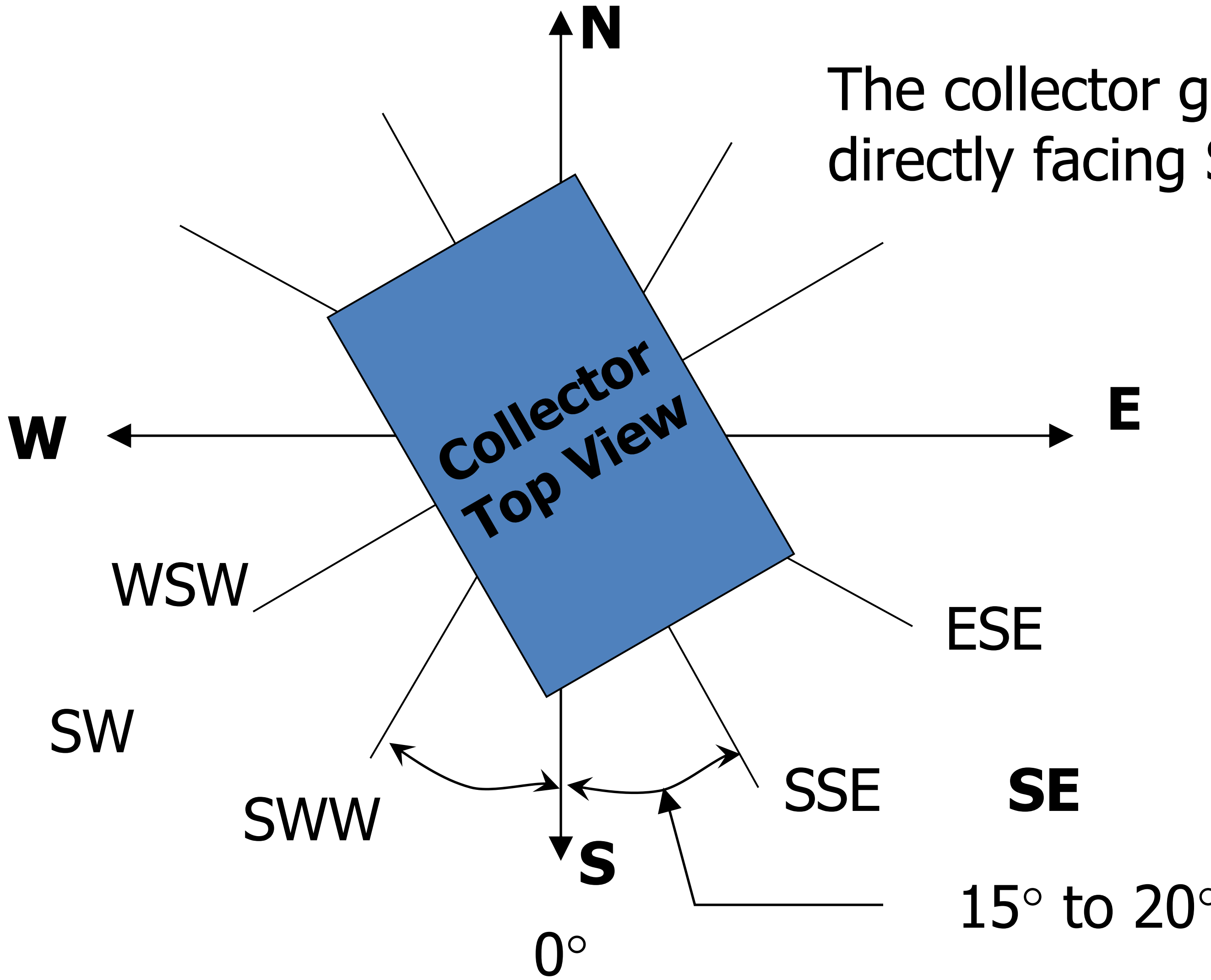
Angle of Collectors



- Slope for Bhutan: Latitude of Bhutan + 10°C is recommended
- Eg: for Kathmandu: 27°+10° = 37° is recommended!

- However, minimum slope should be 17°.

Direction of Collectors

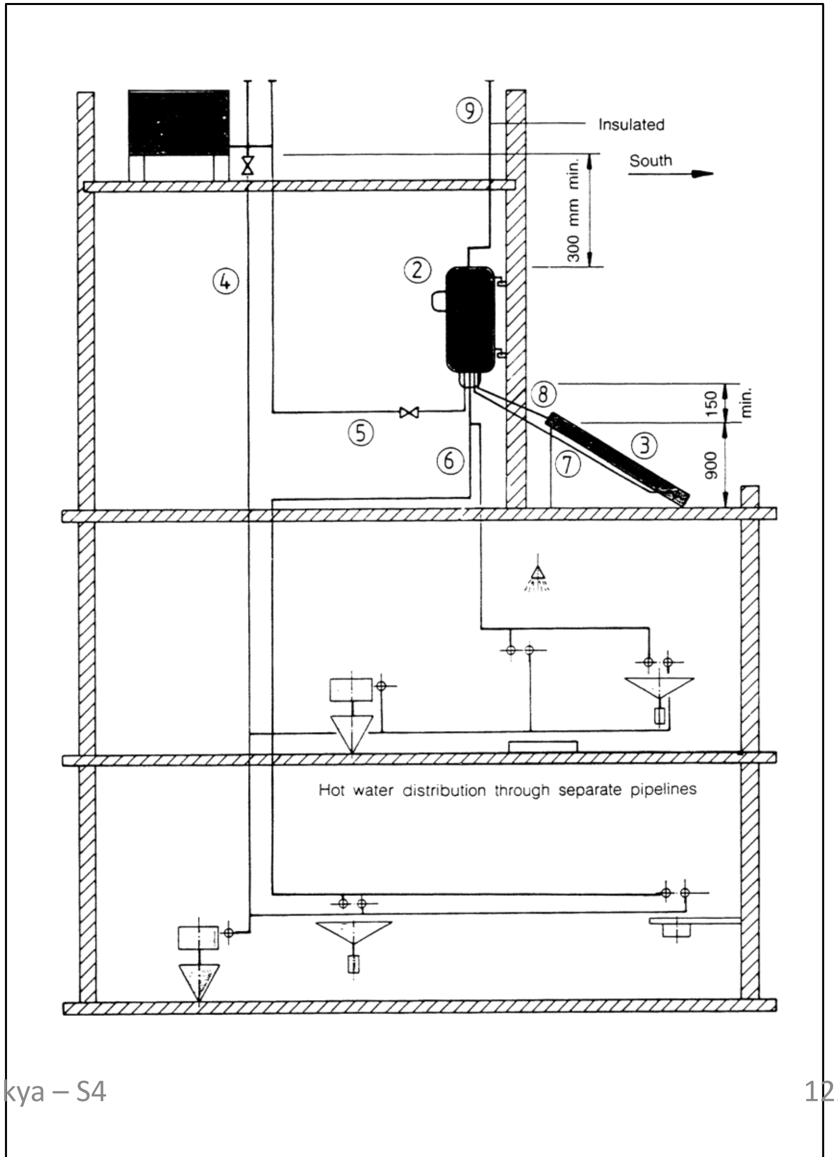


The collector glass directly facing South

Either side of South

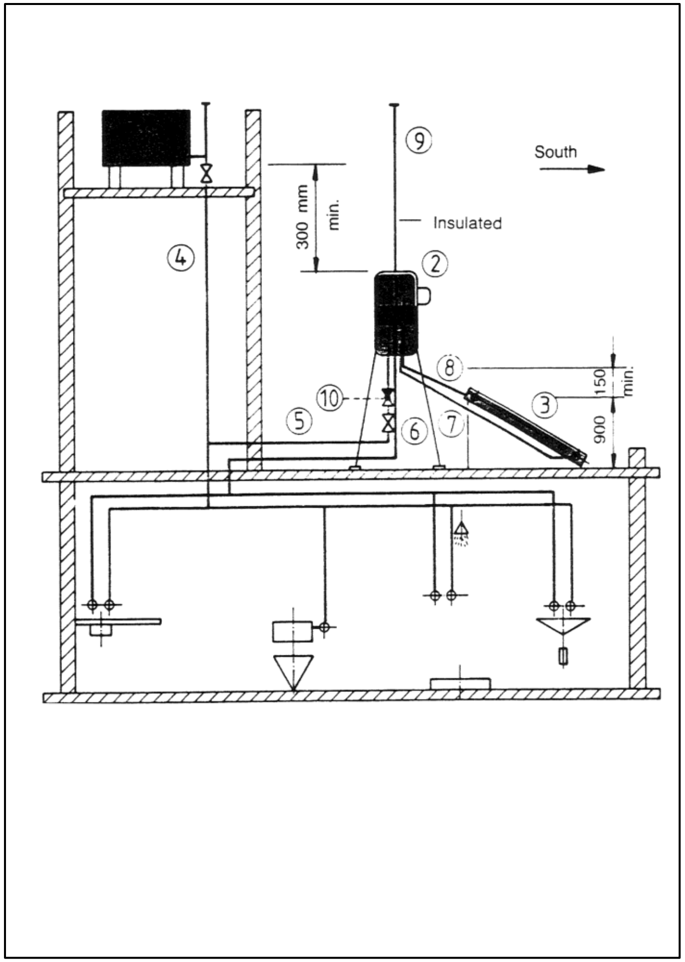
Thermo-siphon System Example No.1

1. Cold storage tank
2. Hot storage tank
3. Collector
4. Coldwater pipeline
5. Coldwater to hot tank
6. Hotwater to the taps
7. Circulation pipe to collector
8. Circulation pipe to hot tank
9. Vent pipe



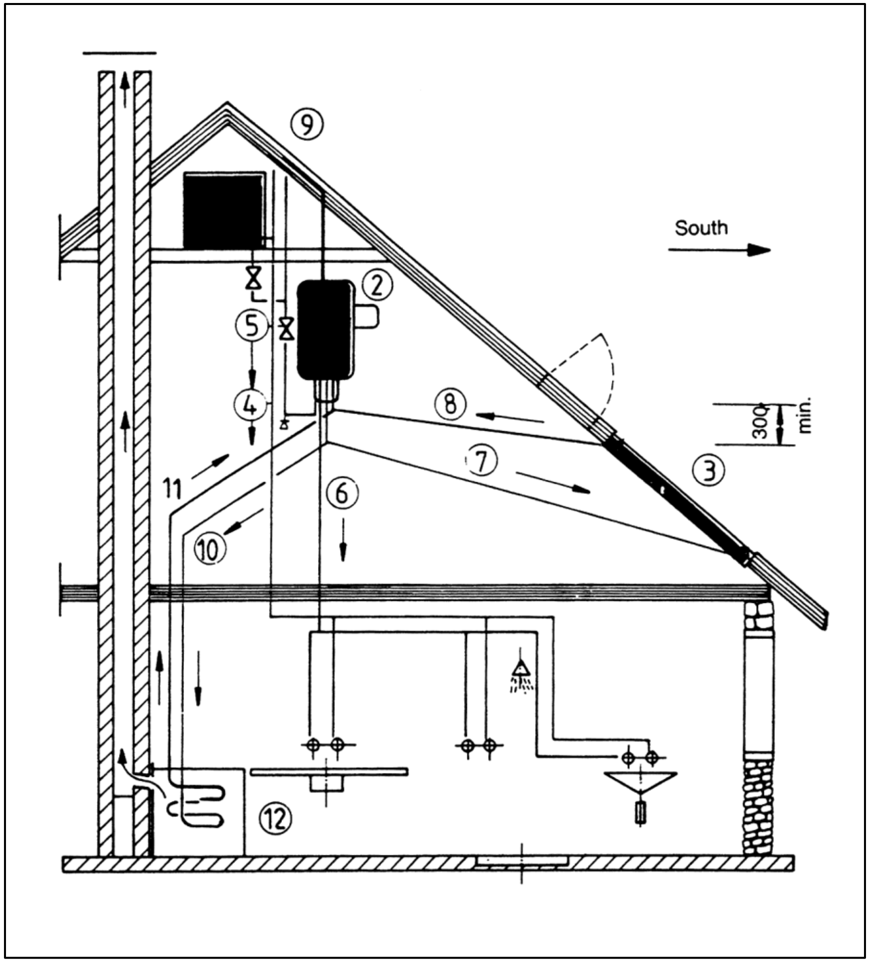
Thermo-siphon System Example No.2

1. Cold storage tank
2. Hot storage tank
3. Collector
4. Coldwater pipeline
5. Coldwater to hot tank
6. Hotwater to the taps
7. Circulation pipe to collector
8. Circulation pipe to hot tank
9. Vent pipe insulated
10. Check valve (non return valve)



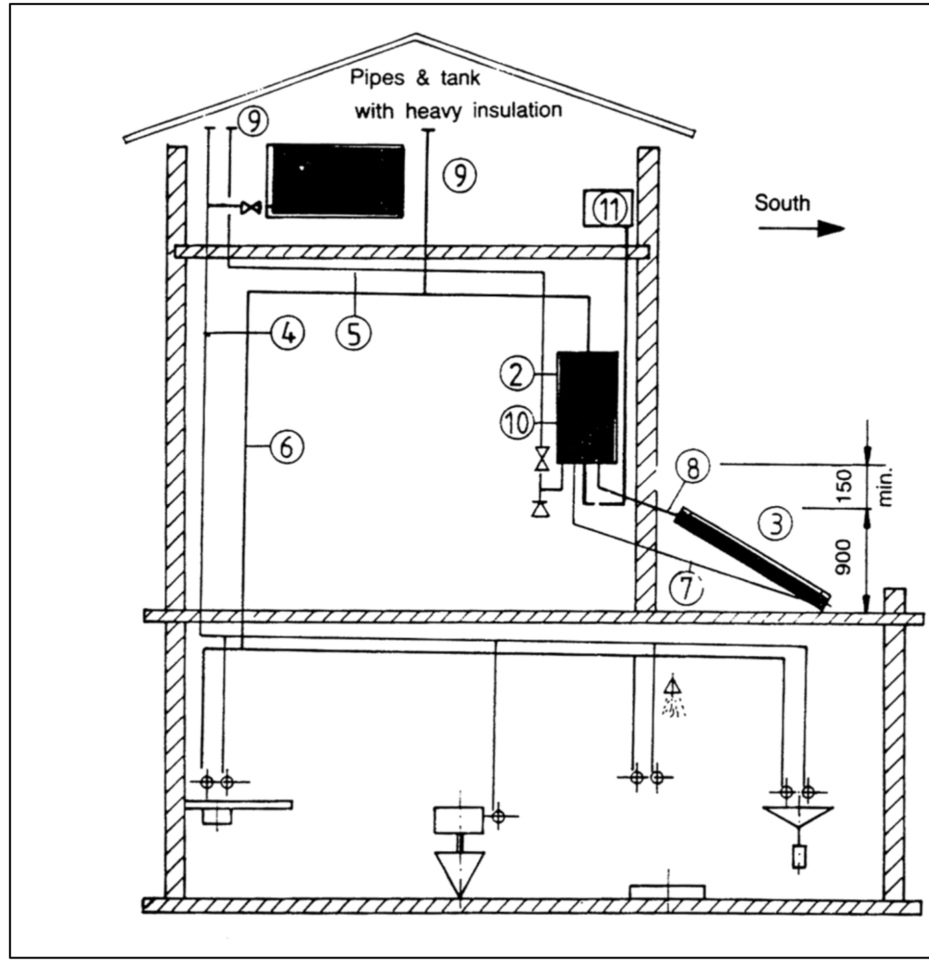
Thermo-siphon Antifreeze System Example No.3

1. Coldwater storage tank
2. Hotwater storage tank
3. Collector
4. Coldwater line
5. Coldwater to the boiler
6. Hotwater to the taps
7. Circulation pipe to collector
8. Circulation pipe to boiler
9. Vent pipe
10. Circulation pipe to the combustion cooker
11. Circulation pipe to boiler
12. Slow combustion heater



Thermo-siphon Anti Freeze System Example No.4

1. Coldwater storage tank
2. Hotwater storage tank
3. Collector
4. Coldwater pipeline
5. Coldwater to hot tank
6. Hotwater to the taps
7. Circulation pipe to collector
8. Circulation pipe to hot tank
9. Vent pipes insulated
10. Heat exchanger
11. System for top-up and expansion, containing anti freeze and anti-corrosion fluid



Plumbing and Connecting Techniques:

For long distances and collector link, compensation of dilatation necessary

- ❑ welding - steel
- ❑ soldering - copper
- ❑ screw - steel
- ❑ flange – steel

No plastic pipes in the collector field !!!

Typical Installation Mistakes

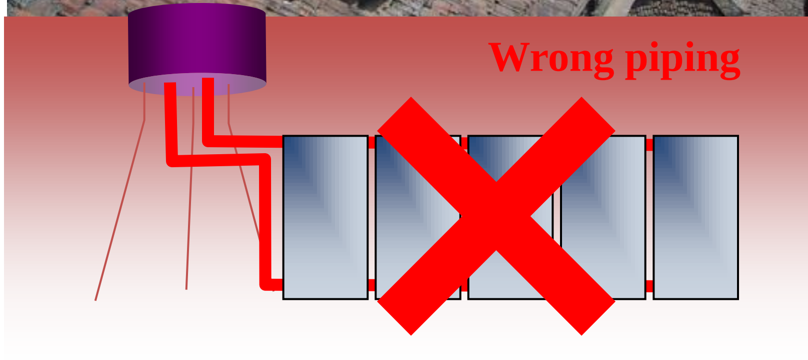
- interchange of advance and return
- interchange of sensors
- air in the system
- low flow rate
- dirt in the strainer
- Position of heater
- Hydraulic short circuits
- Size of the reservoir

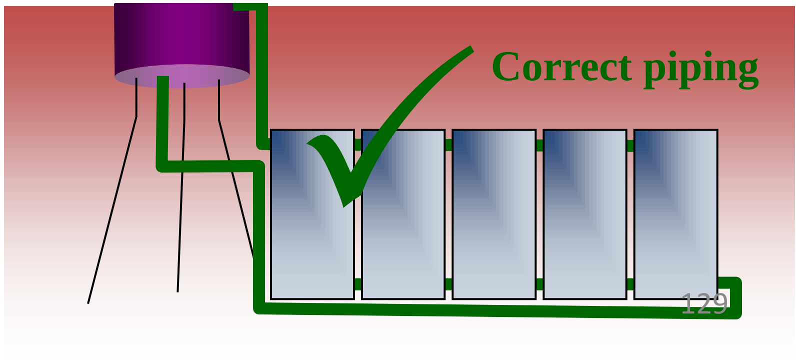
Position of the electric immersion heater

- Most common and disasterous mistake
- Reduces the solar efficiency to below 20%
- Simple geyser would be more efficient.
- <u>REMEMBER</u>: Only the water below the electric rod can be heated by solar.

Hydraulic short circuits

- **Water always flows the shortest way**
- **Hydraulic shortcuts render farther collectors useless**
- **all collectors must face the same hydraulic resistance**
- **<u>REMEMBER</u>: cold end in at the farthest point, hot end out at the closest point to the tank**



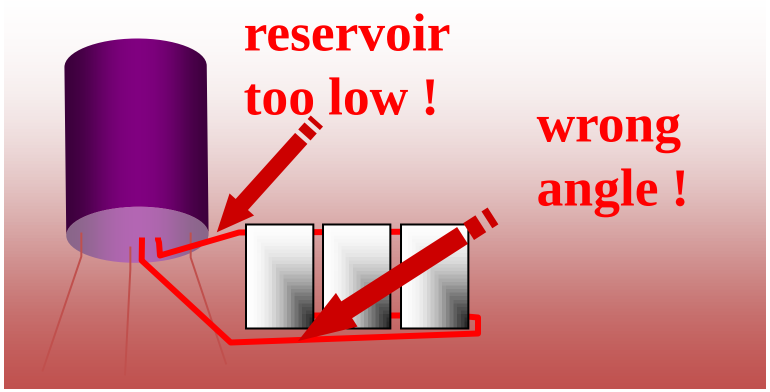


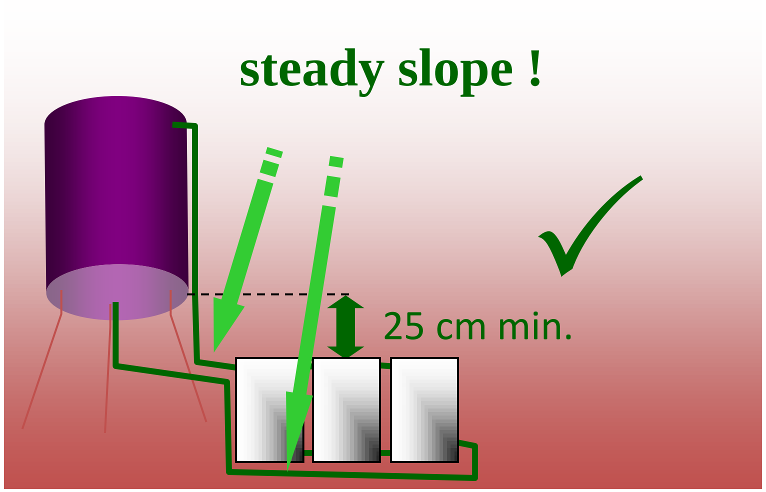
Insulation matters!

- Glasswool is a standard, PU-foam also recommendable
- Reservoir: minimum 10 cm on the sides and the top
- Insulation must be tight fitting to avoid chimney effect
- Pipes: all pipes with at least the same insulation thickness as pipe diameter
- Weatherproofing important

Connecting the collectors to the reservoir

- Thermosiphon systems need proper piping
- All pipes must be under a constant angle
- The lower end of the tank must be at least 25 cm above the upper edge of the collector
- Supply and return pipes must be of large diameter (at least 1.5“)





Fittings and Piping in a Closed Circuit

- pump
- safety valve
- expansion vessel
- heat exchanger
- air breather
- non return valve

Solar Dryer Design

Introduction

- **Majority of population** live in rural areas engaging in agriculture
- There is **lack of appropriate preservation and storage system** which causes **considerable losses**, thus reducing the food supply significantly.
- **Sun drying of crops** is most widespread, oldest method of food preservation but it has **some drawbacks** like **contamination of food by dust, insect attack, enzymatic reactions and infection** by micro-organisms. It is also **labour and time intensive** since the crops have to be covered at night and during bad weather and crops have to be protected from attack by domestic animals, birds.
- **Non-uniform and insufficient drying** also leads to **deterioration of the crop** during storage during humid condition and rainy season.

Fruits and vegetable production

Fruits: 444.65 MT (FAO, 1999)

- China: 59.5 MT (13.4%)
- India: 38.56 MT (8.7%)
- Brazil: 8.45%
- USA: 6.4%
- Italy: 4.3%

Vegetables: 628.75 MT (FAO, 1999)

- China: 250 MT (39.8%)
- India: 59.4 MT (9.45%)
- USA
- Turkey
- Italy

Losses: **Water loss and decay account for most of their losses**, which are estimated to be more than **30–40% in the developing countries** in the tropics and subtropics due to inadequate handling, transportation, and storage facilities. Apart from physical and economic losses, serious losses do occur in the availability of essential nutrients, notably vitamins and minerals.

Pretreatment for drying

- **Alkaline dip:** A sodium carbonate or lye solution (≤0.5%) is used at a temperature ranging from 93-100C. It facilitates drying by forming fine cracks in the skin of fruits.
- **Sulfiting:** sulfur dioxide treatments are widely used in fruit and vegetable as SO_2 is by far the most effective additive to avoid nonenzymatic browning. It acts an antioxidant in preventing loss of ascorbic acid (vitamin C) and protecting lipids, essential oils, and carotenoids against oxidative deterioration during processing and storage.

Drying techniques and equipment

- **Dehydration:** It involves the application of heat to vaporize moisture and some means of removing water vapor after its separation from the fruit and vegetable tissue. Hence it is a combined and simultaneous heat and mass transfer operation for which energy must be supplied.
- 3 basic types of drying processes are:
  - sun drying and solar drying
  - atmospheric drying including batch (cabinet dryer) and continuous (tunnel dryer) processes
  - subatmospheric dehydration (vacuum shelf belt/drum and freeze dryers)

Drying techniques and equipment - Solar drying

- **The ambient air is heated with the help of solar air collector** and **sent to the drying chamber**. The **hot air coming in contact with the products carry away the moisture** and the **required dehydration is achieved**.
- Drying is an excellent way to preserve food and **solar food dryers** are an **appropriate food preservation technology** for a sustainability in food.
- The **flavor and most of nutritional value is preserved** and concentrated. Vegetables, fruits, meat, fish and herbs can all be dried and can be preserved for several years in many cases.

Benefits of Solar Dried Food

- "Dried foods are **tasty, nutritious, lightweight, easy-to-prepare, and easy-to-store and use**. The energy input is less than what is needed to freeze or can, and the storage space is minimal compared with that needed for canning jars and freezer containers.
- "The **nutritional value of food is only minimally affected by drying**. Vitamin A is retained during drying; however, because vitamin A is light sensitive, food containing it should be stored in dark places. Yellow and dark green vegetables, such as peppers, carrots, winter squash, and sweet potatoes, have high vitamin A content. Vitamin C is destroyed by exposure to heat, although pretreating foods with lemon, orange, or pineapple juice increases vitamin C content.
- "Dried foods are **high in fiber and carbohydrates and low in fat**, making them healthy food choices. Dried foods that are not completely dried are susceptible to mold.
- "**Microorganisms are effectively killed** when the internal temperature of food reaches 145 degrees Fahrenheit (F)."

Source: http://solarcooking.org/drying/Whitfield-drying1.htm

Solar drying

- To **design** a solar dryer for drying fruits and vegetables, **two important stages** are to be considered:
  – to **heat the air by the radiant energy from sun** and
  – to **bring this heated air in contact with the material** inside a chamber **to evaporate moisture**.
- Solar dryers are generally classified according to their heating modes or the manner in which the heat derived from solar radiation is utilized.
- Sun or natural dryers
- Solar dryers – direct
- Solar dryers – indirect
- Hybrid dryers
- Mixed dryers

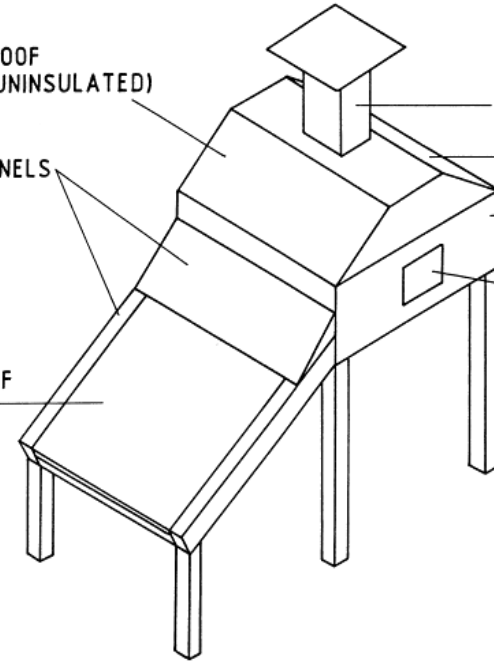
Sun or natural dryers

Solar or natural dryers make use of the action of solar radiation, ambient air temperature, and relative humidity and wind speed to achieve the drying process.

Solar dryers - direct

- In direct solar dryers the material to be dried is placed in an enclosure with a transparent cover or side panels.
- Heat is generated by absorption of solar radiation on the product itself as well as on the internal surfaces of the drying chamber. This heat evaporates the moisture from the drying product.
- In addition it serves to heat and expand the air, causing the removal of the moisture by the circulation of air.

Solar dryers - indirect



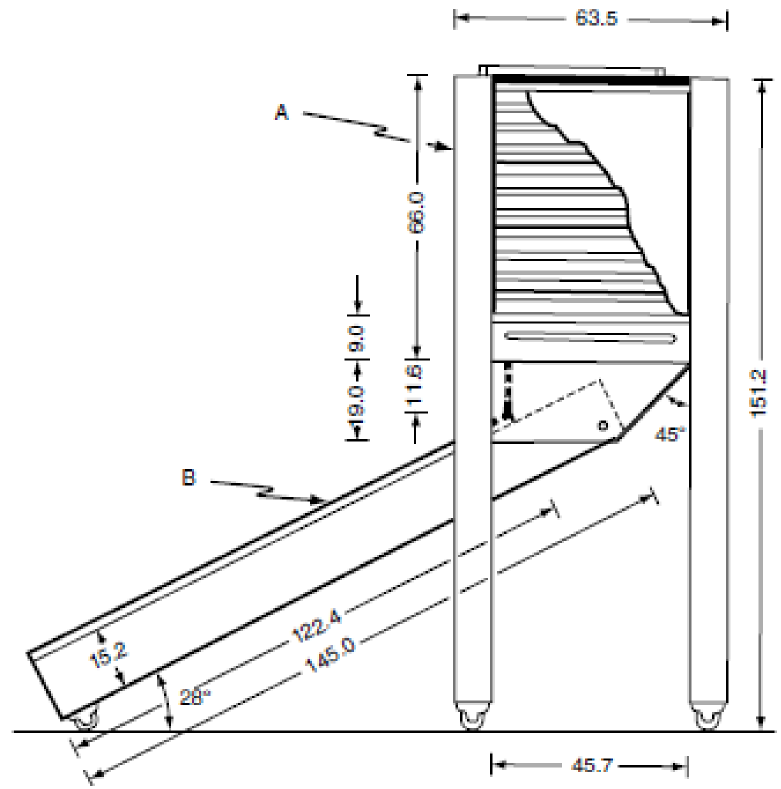
- Air is heated in a solar collector and then ducted to the drying chamber to dehydrate the product. Generally flat-plate solar collectors are used for heating the air for low and moderate temperature use. Efficiency of these collectors depends on the design and operating conditions.
- The main factors that affect collector efficiency are heater configuration, airflow rate, spectral properties of the absorber, air barriers, heat transfer coefficient between absorber and air, insulation, and insolation.
- By optimizing these factors, a high efficiency can be obtained.

Hybrid systems

Hybrid systems are dryers in which another form of energy, such as fuel or electricity, is used to supplement solar energy for heating and ventilation.

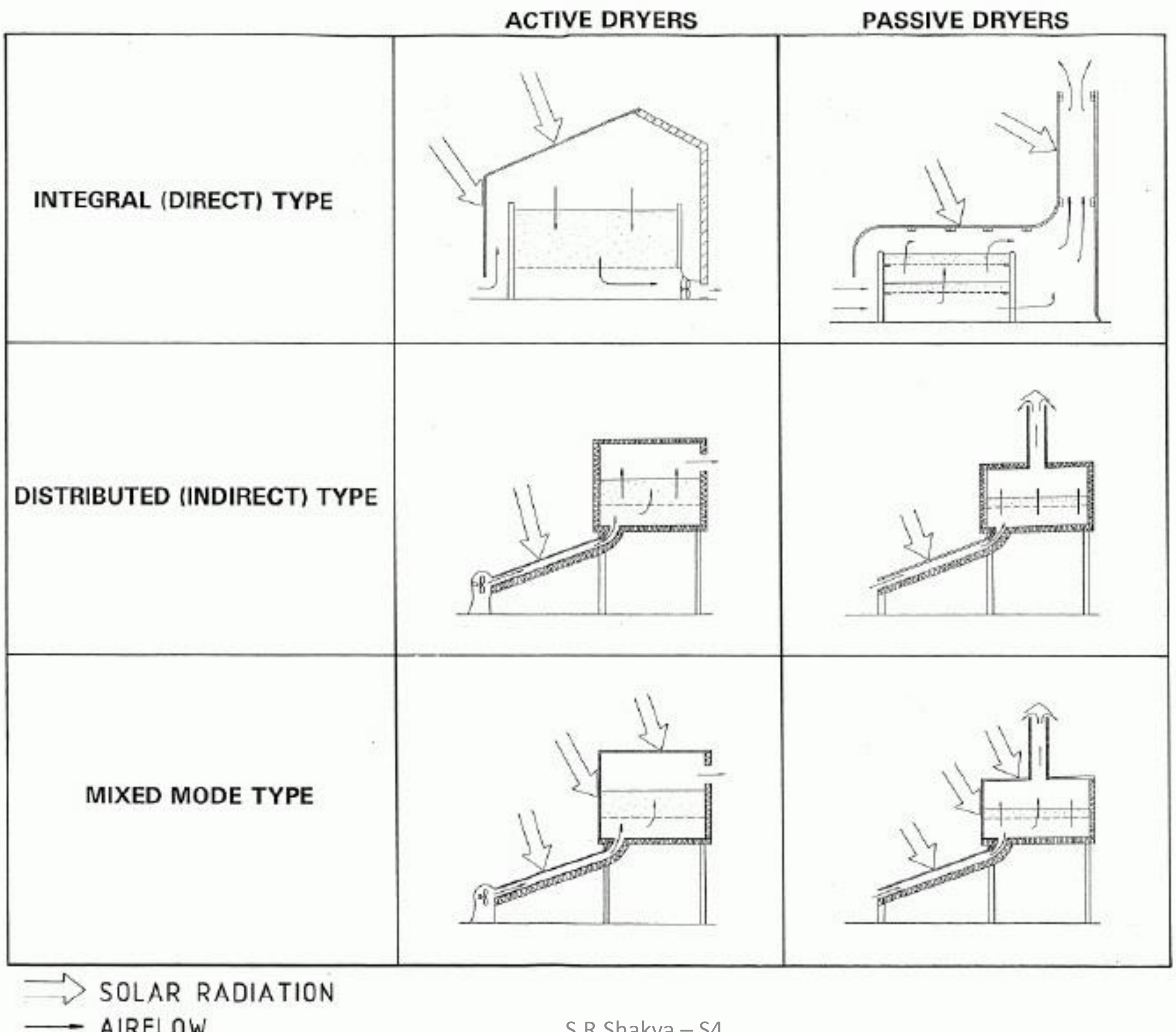
Mixed systems

- Mixed systems include dryers in which both direct and indirect models of heating have been utilized.
- Several experimental methods were evaluated for the solar dehydration of fruits (apricots):
  - wooden trays;
  - solar troughs of various materials designed to reflect radiant energy onto drying trays;
  - natural convection, solar-heated cabinet dryers with slanted plate heat collectors;
  - dryers incorporating inflated polyethylene (PE) tubes as solar collectors; and
  - PE semicylinders either incorporating a fan blower to be used in inflated hemispheres or incorporating a similar dome used as a solar collector, the air from which is blown over fruit in a cabinet dryer.



Active and passive dryers

- Active solar drying systems depend only partly on solar energy. They employ solar-energy and/or electrical or fossil-fuel based heating systems and motorized fans and/or pumps for air circulation. A typical active solar dryer depends solely on solar-energy as the heat source but employs motorized fans and/or pumps for forced circulation of the drying air.
- Passive solar drying systems (natural circulation solar energy dryers) depend entirely on solar energy for their operation. These dryers are called passive in order to distinguish them from systems that employ fans to convey the air through the crops. These dryers are most attractive option for use in remote rural locations. They are superior operationally and competitive economically to natural open to sun drying.


ACTIVE DRYERS
PASSIVE DRYERS
INTEGRAL (DIRECT) TYPE
DISTRIBUTED (INDIRECT) TYPE
MIXED MODE TYPE
SOLAR RADIATION
AIRFLOW

Dryers in use

Factors affecting solar drying

- **Solar radiation/insolation**: solar radiation determines drying air temperature and air flow rate through the dryer in natural convection.
- **Ambient temperature**: moisture evaporation rate will be low at lower ambient temperature due to saturated air. Generally, the temperature difference between ambient air and solar dryer temperature is maintained at 15-20ºC.
- **Relative humidity**: the drying potential is lower (lower drying rate) with the higher relative humidity.
- **Moisture content of the product**: the amount of moisture of the product is dictated by the expected storage period of the dried product. The lower final moisture content, the higher the expected storage life of the product.
- **Air-flow rate**: the higher the air-flow rate the higher will be the drying effectiveness (e.g., forced convection type dryer has a faster drying rate). Speed, v = 1 m/s

Cabinet dryer

Tunnel dryer

Source: CRE, 2012

Drying duration

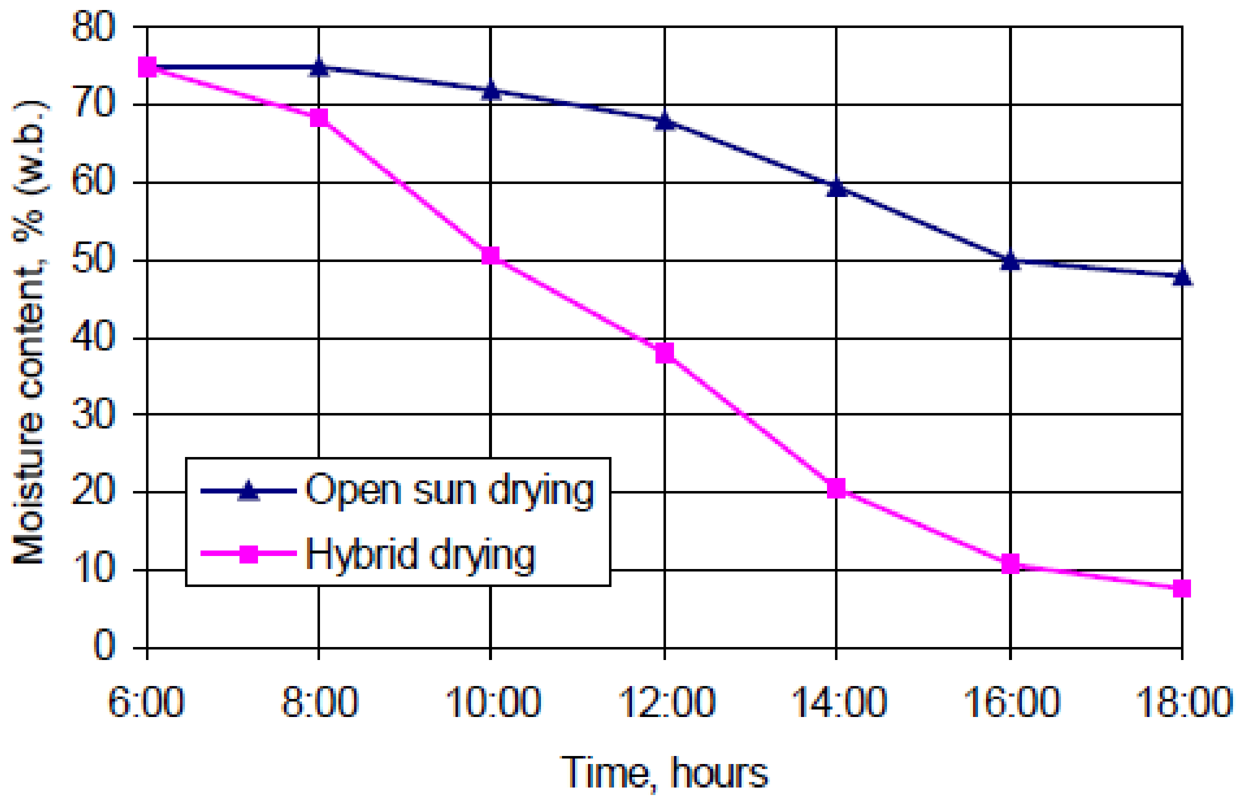


Figure 8: Drying curves for chilli with hybrid drying compared to open sun drying

Source: Gauhar et al, 1999, Experimental studies on a hybrid dryer, AIT

Drying time comparison

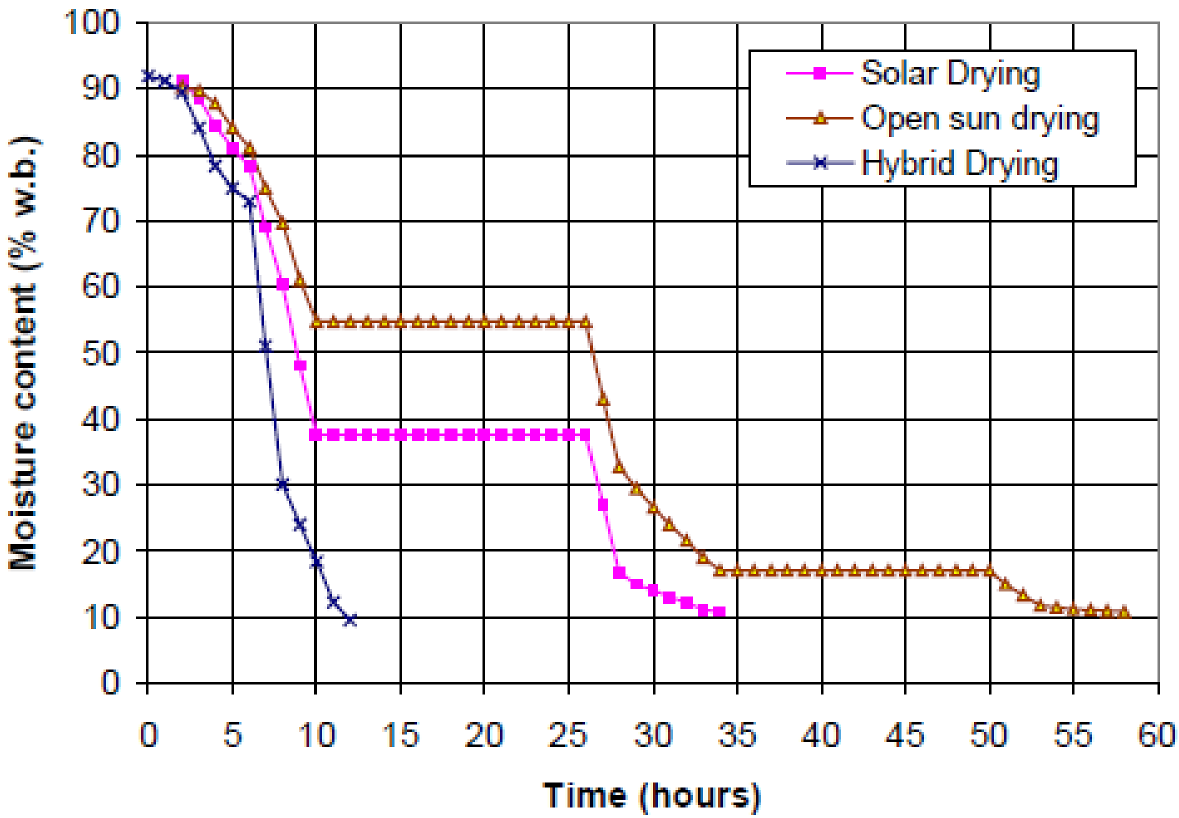


Figure 9: Drying curves for 'ear-lobe' mushroom dried in the hybrid tunnel dryer compared to solar drying and open sun drying

Source: Gauhar et al, 1999, Experimental studies on a hybrid dryer, AIT

Industrial solar dryer

Fish dryer

NRG has provided this dryer as an demonstration project, again with University of Mumbai, in a seaside locale with a large fishermen population, so that they can actively take free trials on the dryer. A lot of fishermen took trials of various types of fish, prawns etc in the dryer. Many of them were really impressed by the fact that the drying took only 6-7 hours instead of the usual 4-5 days in the open sun! A few of them have already approached us to help them set up similar plants for them.

Source: http://www.nrgtechnologists.com/Solar_Dryer_Solution/nrg_solar_dryer_fish.html

Industrial solar dryer

- For this range of solar drying systems, we use UV Stabilised Transparent PE Sheets, which is used as the Top of the Chambers, where the Copra, Chilly, Spices, and agricultural commodities are dried. The temperature maintained inside the chamber is 20 degree more than the normal outside Temperature.
- By using these systems we can reduce the drying cost as well as production cost up to a greater extent. With efficient drying these systems never incur any harm to the items taken for drying. Even in the night the temperature remains hot inside the chamber.

Source: http://www.arjunenergy.com/solar-dryers.html

Industrial solar dryer

- Fish dryer
- Mushroom dryer
- Ginger dryer
- Tea leaf dryer
- Fruit dryer
- Vegetable dryer
- Coffee dryer

Advantages of Solar Dryer

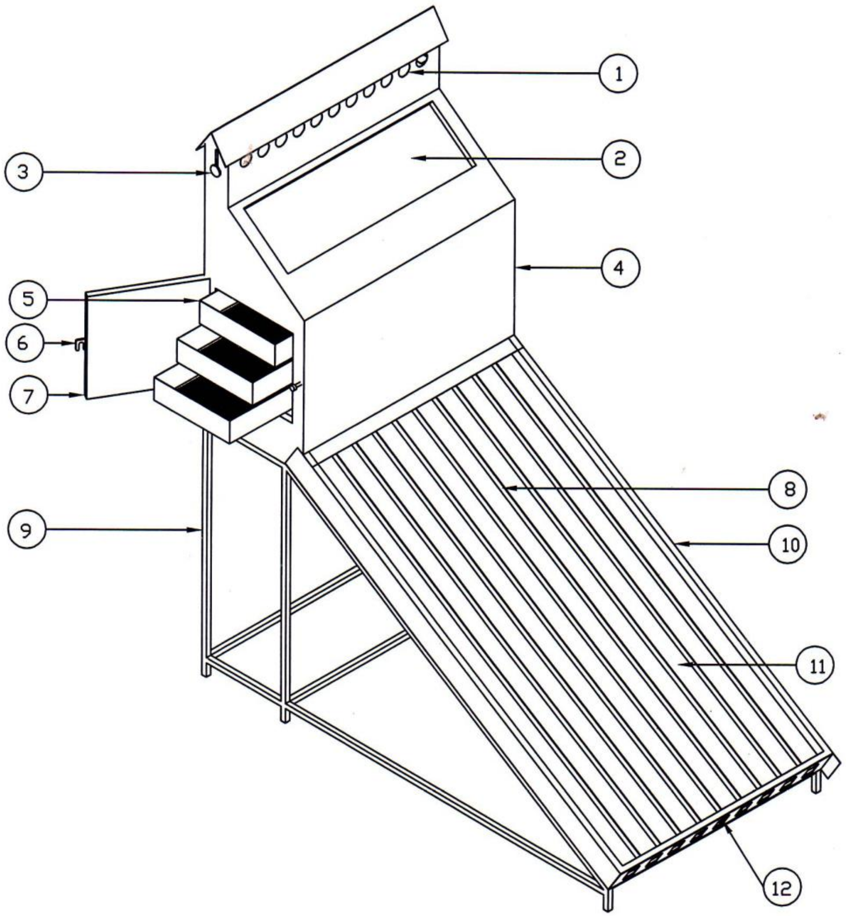
- **Savings in time**
- **Increased production possible**
- **Less space requirement for drying**
- **More hygenic than drying outside in the sun**
- **Cost Effective**
- **Negligible maintenance costs**
- **Free and Clean energy**
- **Just one time investment, after that the energy is Free!**
- **Quick Return on Investment (ROI) - just 3 years**

Solar dryer design

Standard guidelines recommended for the construction of typical solar cabinet dryers:

- The length of the cabinet should be at least three times its width to minimize shading effects of the side panels;
- An optimal angle of slope for the glazing as a function of the local latitude (applicable to sites both north and south of the equator);
- The interior walls should be painted black;
- The crop trays should be placed reasonably above the cabinet floor to ensure a reasonable level of air circulation under and around the product;
- The top cover glazing should be treated against degradation under UV radiation; and
- The choice of construction materials should be determined by local availability and the desired level of dryer sophistication.

[Solar dryer design-Example.docx]

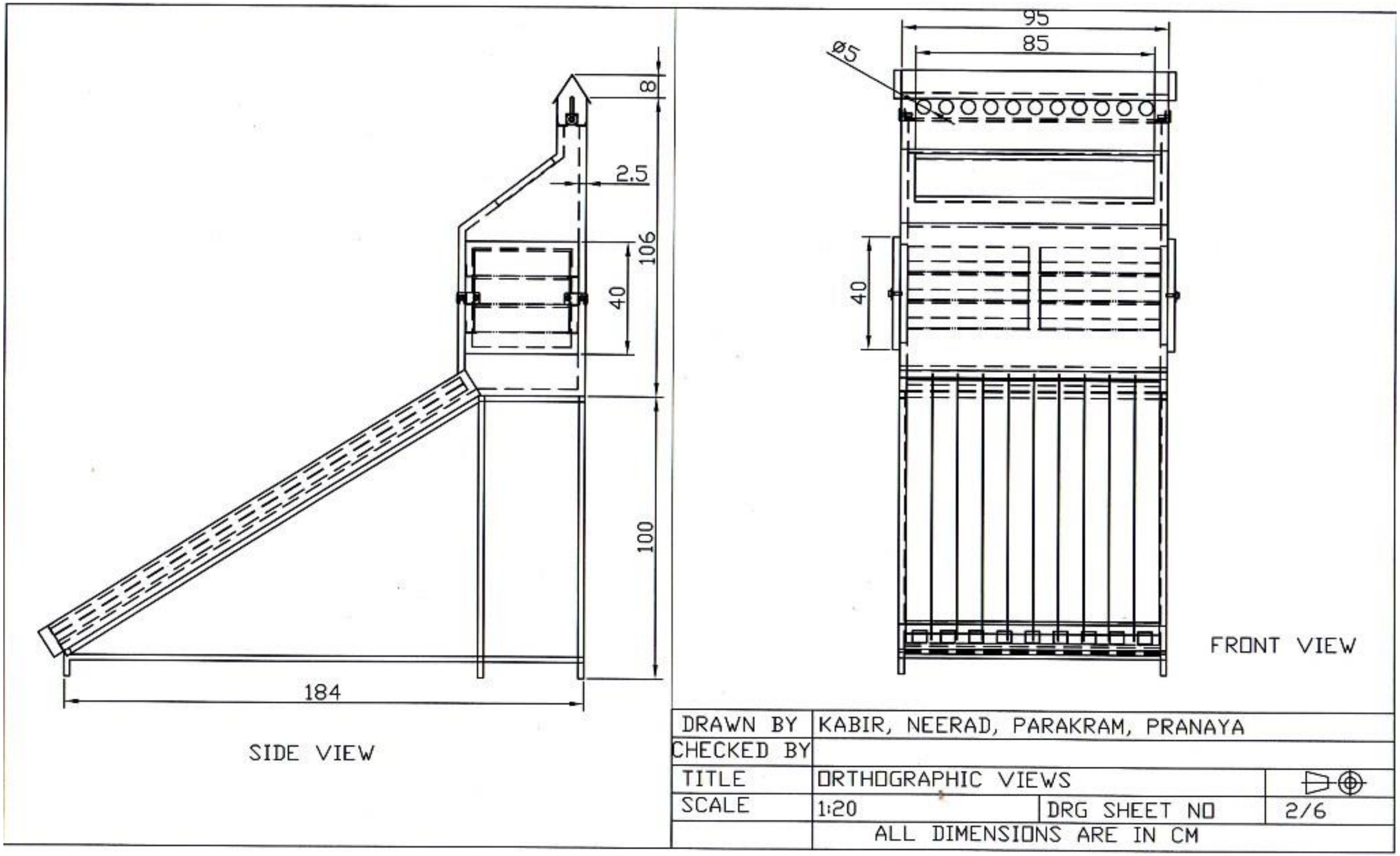


S.N.	PARTICULARS	S.N.	PARTICULARS
1	CHIMNEY VENT	7	DOOR
2	UPPER COLLECTOR	8	FIN
3	CHIMNEY SHUTTER	9	STAND
4	DRYING CHMABER	10	COLLECTOR BOX
5	TRAY	11	ABSORBER
6	DOOR LOCK	12	INLET OPENING

Indirect rack type solar dryer

- Introduced by BYS in 1984 at Department of Herbarium, Godawari, Patan.
- Improved version of 2 units are placed at Manichaur near Sankhu and at Tistung.
- BYS fabricated rack solar dryer was put into operation at Sabai International Pvt. Ltd, a fruit juice manufacturer in Kathmandu.

Source: RECAST, 2001



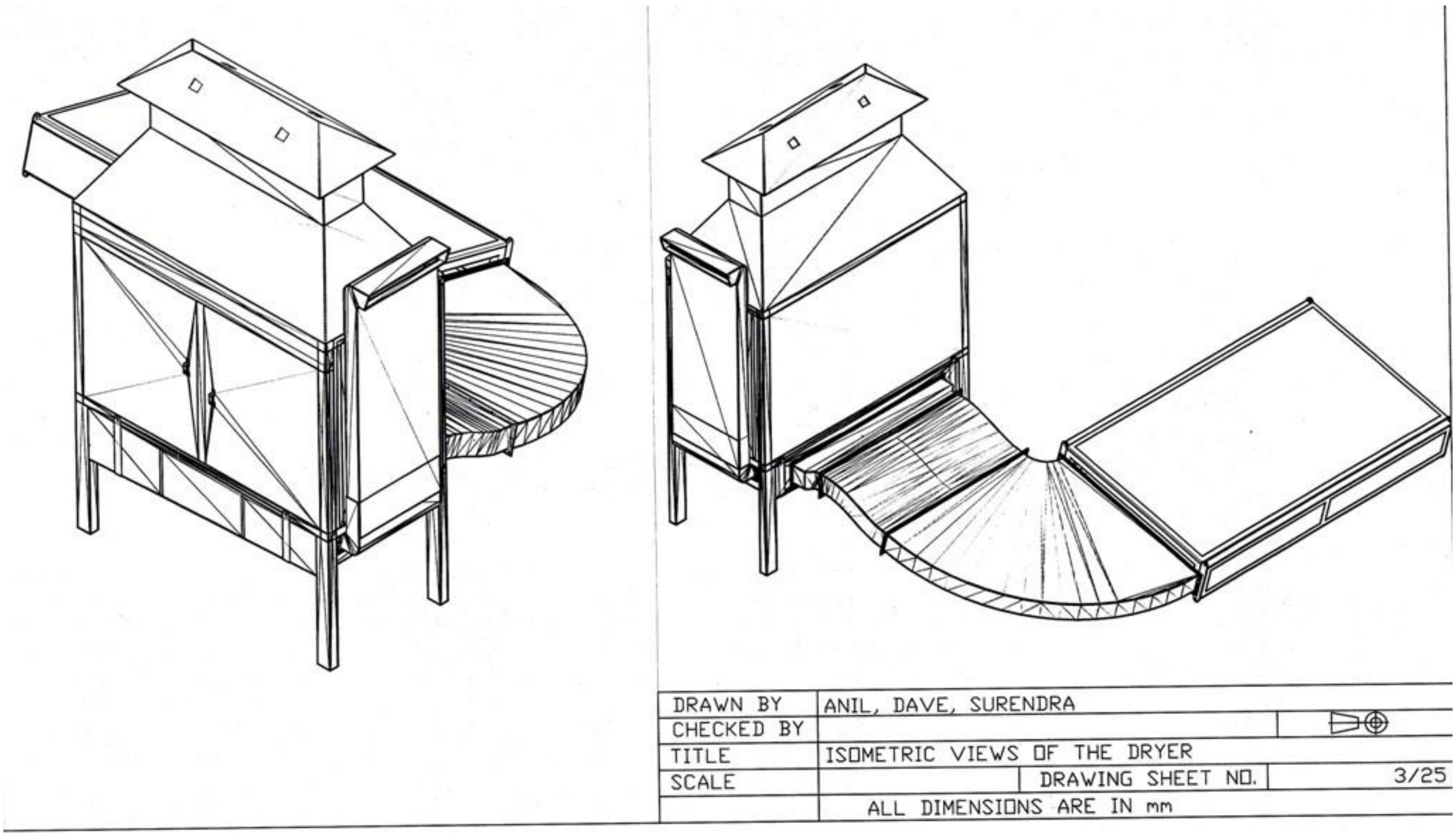
Source: BE Project, 2008

Hybrid tunnel dryer

- Tunnel dryer is wisely used for the mass production of dry products.
- Tunnel dryer was first introduced in Marpha in Mustang,Nepal by a team of teachers and students from University of Munich, Germany in collaboration with RECAST in 1993.
- Now this type of solar dryer is installed in many districts of Nepal for drying cash/spice crops.

Source; cei, Biratnagar

Modular type hybrid solar dryer



Source: BE Project, 2009

Drying time of fruits and vegetable drying

Crops	Drying air temp,ºC (at 11am-3pm)	Initial moisture content, % wb	Final moisture content, % wb	Drying duration**, days
Kanya mushroom	50-55	75 - 95	3 - 4	1- 2
Ginger	55-60	80 - 90	10 – 11*	2
Carrot	55-60	80 -90	10 – 11	1 - 2
Large cardamom	50 - 55	75 - 80	10	3
Cauliflower		90	10	3

*Less than 7% moisture content for long term storage

** depend on porosity, texture, slice thickness, sugar content

Opportunities and challenges

Opportunities	Challenges
• Fruits and vegetables losses are minimized, preserved and can be sold at reasonable price even during off season. • Malnutrition is reduced. Rural people can have nutrient diet. • Small scale business can be established (job creation). • …	• Solar dryers are expensive for farmer. No provision for loan ! • Solar dryers are usually custom made. • Transportation cost is high. • Difficult to get enough raw materials for industries. • Limited market. Needs exploration. • Cooking behavior – awareness ! • …..

Thank you !

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