Engineering and Technology Faculty

Building Engineering Department

Solar systems in buildings

(12310461)

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INTRODUCTION

Solar energy system

Is a stand alone system entirely powered by solar energy to harness different types of energies.

Solar energy system are divided to two types depending on the way they capture, convert and distribute solar energy which are :

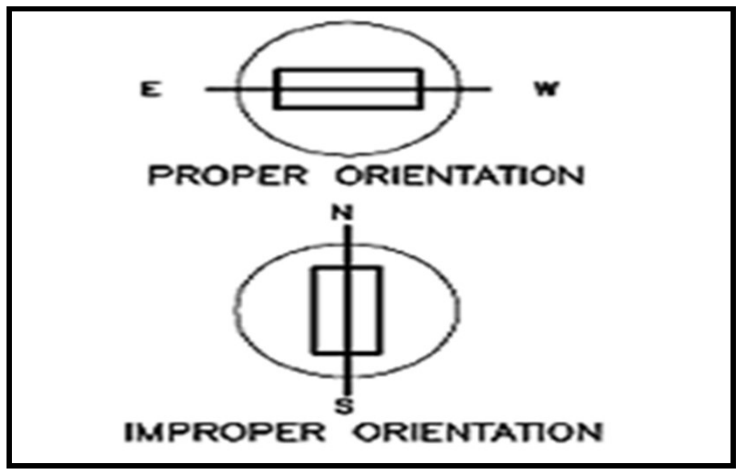
- Passive solar system: uses the elements of a building such as orientations, windows, walls, roof and floors to heat a home in winter and block the sun’s heat in summer.
- Active solar system: rely on external energy sources or backup systems, such as radiators and heat pumps to capture, store and then convert solar energy into electricity.

Passive solar system

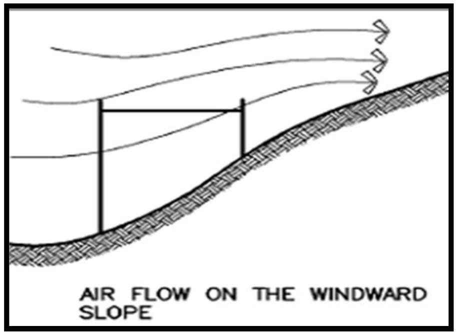
Passive solar buildings are designed to let the heat into the building during the cold winter months and block out the sun during hot summer days.

Non technical requirement for passive design:

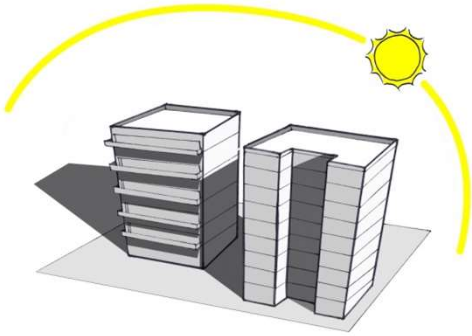
1) Land orientation: A building must face the south in order to capture the sun's energy. The long side of the house should be on an east - west axis.



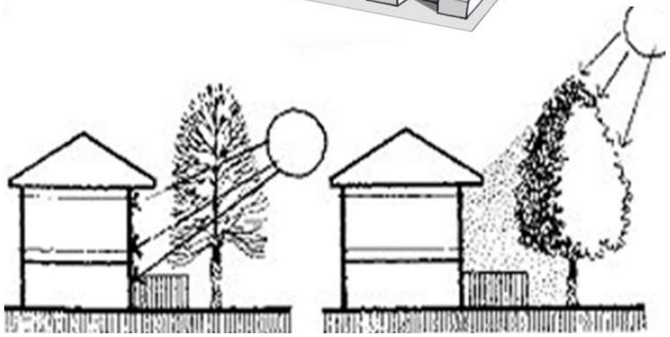
2) Topography: No nature obstacles



3) Surrounding building: change its effective weather patterns, it can block sunlight and change wind patterns.



4) Trees: work as a shading also clean the air.



5) Streets: The geometry of streets (H/W and L/w ratios) and orientation directly influence the airflow and solar access in urban canyon and therefore thermal comfort at pedestrian level.

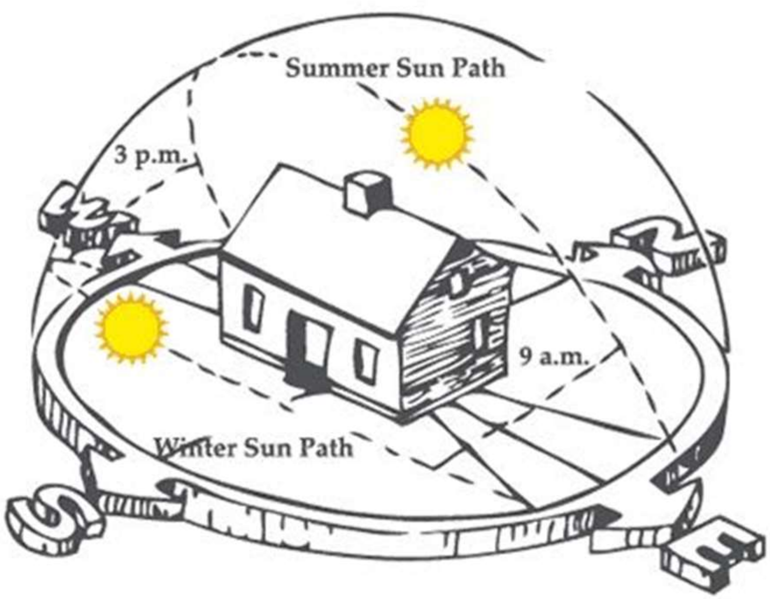
Technical requirement for passive design:

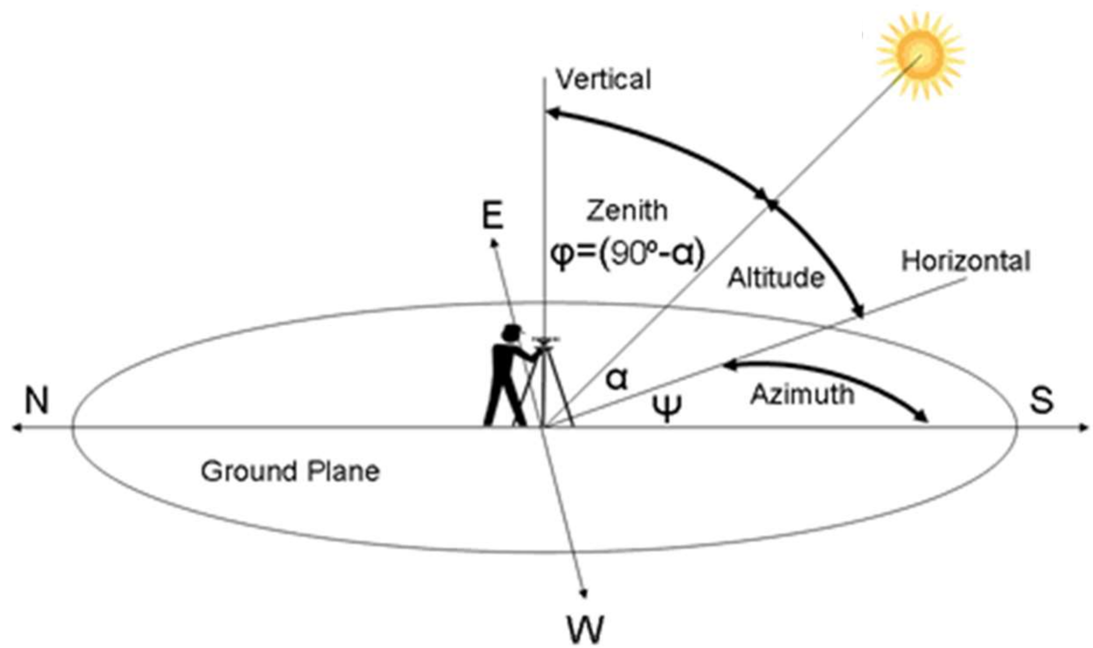
1) Large glazing areas in south side and less areas in west and east sides.
2) A good insulation in summer
3) Efficient shading for summer
4) Good ventilation in winter
5) Suitable thermal mass (2/3 of the heat gained in the day should be stored for the night)

SUN MOUVEMENT & SHADING SYSTEMS

Sun and ground

The earth movement around the sun generates sun paths that varied through the day and the year, and it is one of most crucial environmental factors to understand when designing high performance buildings. The sun moves into 2 angles azimuth and altitude angles.





1) Azimuth angle

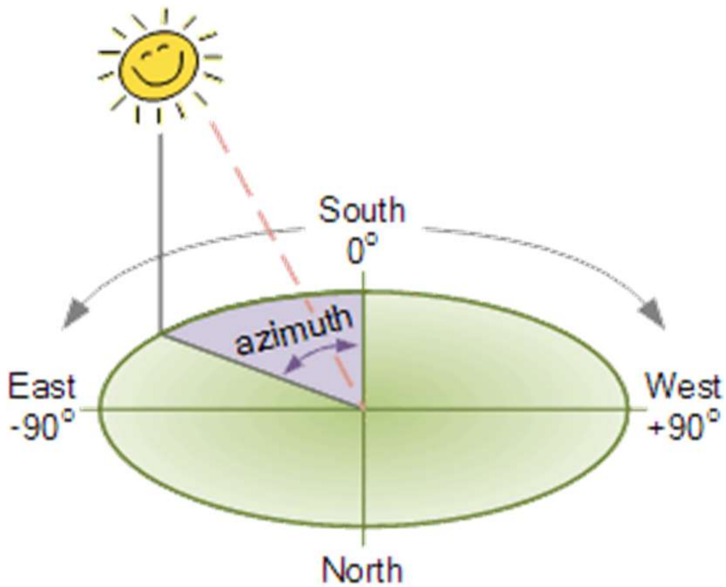
The angle between the south line and the projection line of sun on ground.

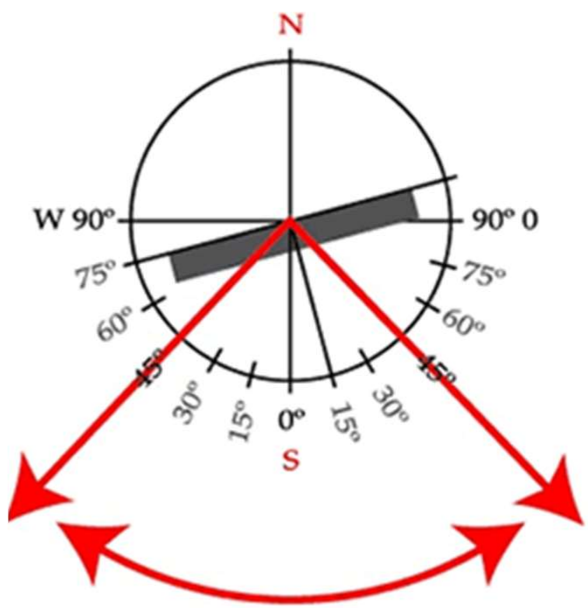
Azimuth angle everyday at noon =0^o

Maximum azimuth angle at rise and set everyday.

Maximum azimuth angle in whole year at 21/6= 126^o.

Azimuth angle at 21/3 and 21/9 =90^o





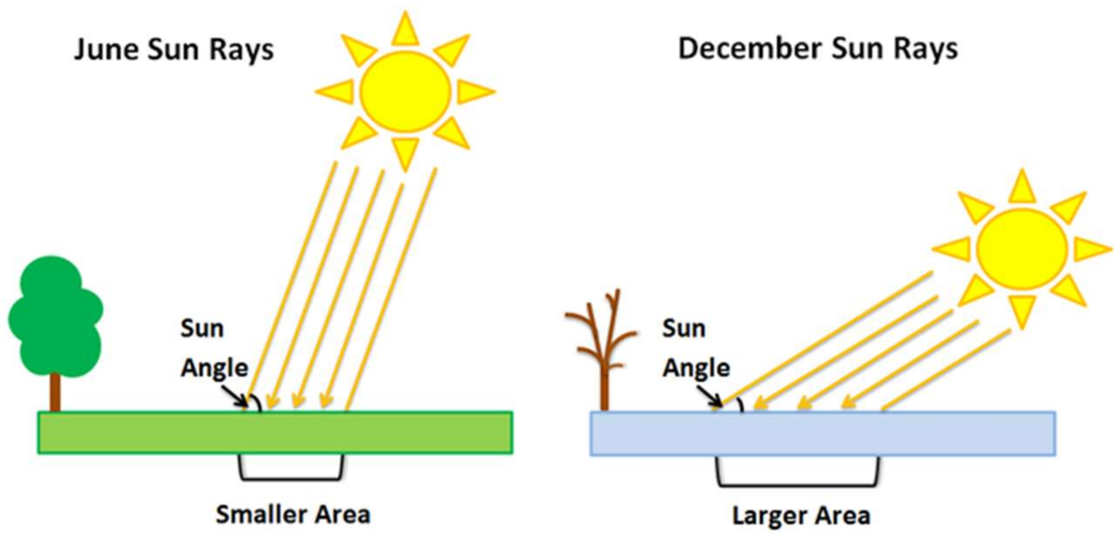
2) Altitude angle

The angle is measured up from the closest point on the horizon.

Altitude angle everyday at rise and set everyday $=0^{o}$

Maximum altitude angle whole year at noon at $21/6=81^{o}$.

Minimum altitude angle whole year at noon at $21/12=34^{o}$.



DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM
JAN 21	7	5	1.4	65.2
	8	4	12.5	56.5
	9	3	22.5	46.0
	10	2	30.6	33.1
	11	1	36.1	17.5
	12		38.0	0.0
	SURFACE DAILY TOTALS			
FEB 21	7	5	7.1	73.5
	8	4	19.0	64.4
	9	3	29.9	53.4
	10	2	39.1	39.4
	11	1	45.6	21.4
	12		48.0	0.0
	SURFACE DAILY TOTALS			
MAR 21	7	5	12.7	81.9
	8	4	25.1	73.0
	9	3	36.8	62.1
	10	2	47.3	47.5
	11	1	55.0	26.8
	12		58.0	0.0
	SURFACE DAILY TOTALS			
APR 21	6	6	6.1	99.9
	7	5	18.8	92.2
	8	4	31.5	84.0
	9	3	43.9	74.2
	10	2	55.7	60.3
	11	1	65.4	37.5
	12		69.6	0.0
	SURFACE DAILY TOTALS			
MAY 21	6	6	10.4	107.2
	7	5	22.8	100.1
	8	4	35.4	92.9
	9	3	48.1	84.7
	10	2	60.6	73.3
	11	1	72.0	51.9
	12		78.0	0.0
	SURFACE DAILY TOTALS			
JUN 21	6	6	12.2	110.2
	7	5	24.3	103.4
	8	4	36.9	96.8
	9	3	49.6	89.4
	10	2	62.2	79.7
	11	1	74.2	60.9
	12		81.5	0.0

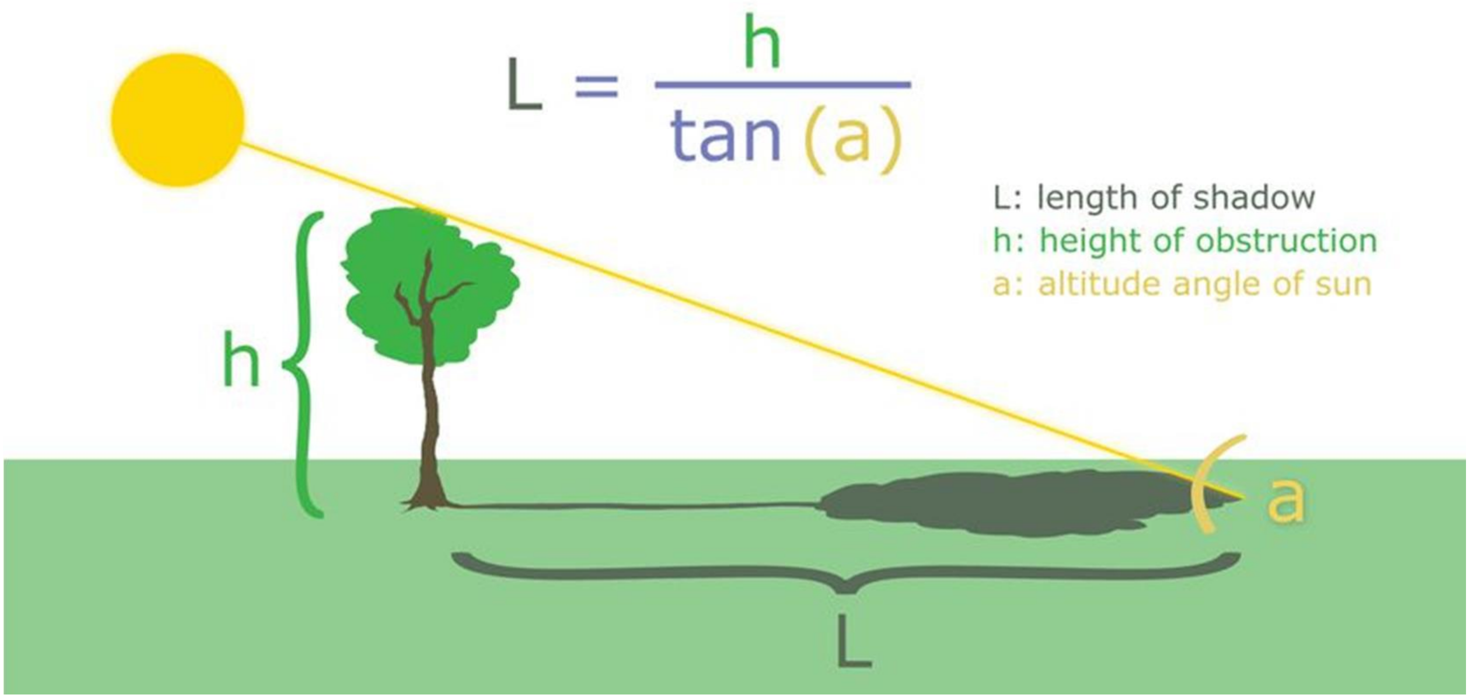
DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM
JUL 21	6	6	10.7	107.7
	7	5	23.1	100.6
	8	4	35.7	93.6
	9	3	48.4	85.5
	10	2	60.9	74.3
	11	1	72.4	53.3
	12		78.6	0.0
	SURFACE DAILY TOTALS			
AUG 21	6	6	6.5	100.5
	7	5	19.1	92.8
	8	4	31.8	84.7
	9	3	44.3	75.0
	10	2	56.1	61.3
	11	1	66.0	38.4
	12		70.3	0.0
	SURFACE DAILY TOTALS			
SEP 21	7	5	12.7	81.9
	8	4	25.1	73.0
	9	3	36.8	62.1
	10	2	47.3	47.5
	11	1	55.0	26.8
	12		58.0	0.0
	SURFACE DAILY TOTALS			
OCT 21	7	5	6.8	73.1
	8	4	18.7	64.0
	9	3	29.5	53.0
	10	2	38.7	39.1
	11	1	45.1	21.1
	12		47.5	0.0
	SURFACE DAILY TOTALS			
NOV 21	7	5	1.5	65.4
	8	4	12.7	56.6
	9	3	22.6	46.1
	10	2	30.8	33.2
	11	1	36.2	17.6
	12		38.2	0.0
	SURFACE DAILY TOTALS			
DEC 21	8	4	10.3	53.8
	9	3	19.8	43.6
	10	2	27.6	31.2
	11	1	32.7	16.4
	12		34.6	0.0
	SURFACE DAILY TOTALS			

Examples

1. What is the value of azimuth angle in 21th of March at 5pm?
2. What is the value of altitude angle in 21th of August at 17:00?
3. What is the value of azimuth angle in 21th of July at 13:30?
4. What is the value of altitude angle in 21th of November at 11:15?
5. What is the value of azimuth angle in 10th of April at 14:00?
6. What is the value of altitude angle in 18th of September at 11:15?
7. What is the value of azimuth angle in 8th of May at 15:45?
8. What is the value of altitude angle in 2nd of October at 10:20 ?

Shadow and shading

This method has some limitations, but it is possible to calculate shadow length based on the sun's altitude angle and the height of whatever's blocking it. In short, shadow length (L) equals the height of the obstruction (h) divided by the tangent (tan) of the sun's altitude angle (a), as this illustration shows:



In general the shadow direction is North west in the morning and North east after noon, but it can be in the direction of south west in the sunrise and in the direction of south east in the sunset in summer.

At sunrise and sunset the length of shadow = ∞

The shortest shadow is at 12:00 (noon) and it cannot be= 0

Examples

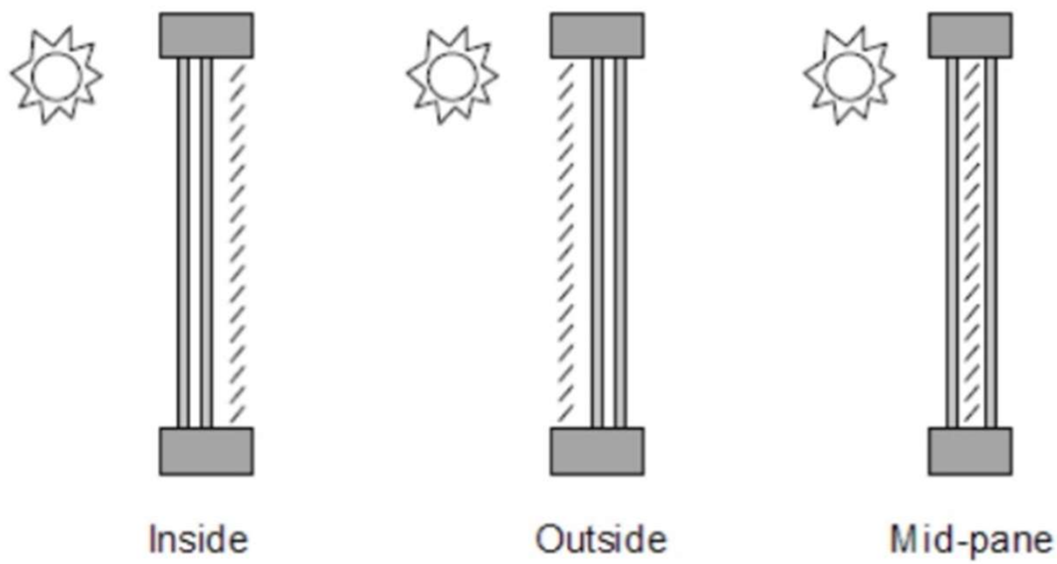
1- Draw the shadow of the pole with 6m in height at 10:00 am in 21/5.

2- Draw the shadow of the pole with 10m in height at 10:00 am in 15/1.

Sun shading devices

Sun shading devices are any mechanical equipment or textiles that are used either internally or externally or in between the internal and external building space.
The primary objective of creating a comfortable internal environment, that is cool in summer and warm in the winter.

Types of sun shading devices related to their position in building :
1. Internal
2. External
3. Mid-pane



Internal shading devices

These devices are mainly established in order to provide visual comfort by eliminating glare and usually are adjustable and allow occupants to regulate the amount of direct light entering their space.

Type of internal shading:

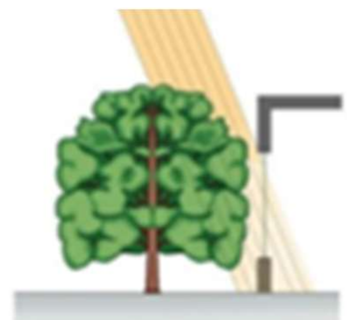
1. **Curtains**: it is the most commonly type used, mostly on residential building; it is cheaper in comparison and can found in various varieties.
2. **Venetian blind**: made of metal, plastic or wood.
3. **Vertical Louvre blinds**
4. **Roller blinds**
5. **Pleated blinds**

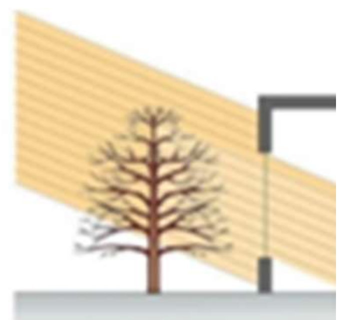
External shading devices

These devices are preferable and more effective than internal ones. This includes devices fixed to the outside of the window or attached to building envelope.

Type of external shading:

1. **Cantilever:** fixed system as balcony
2. **Umbrella**
3. **Shutters:** vertical, horizontal or egg-crate
4. **Trees:** where the leaves of these trees falls in winter such as walnut tree and royal Poinciana.



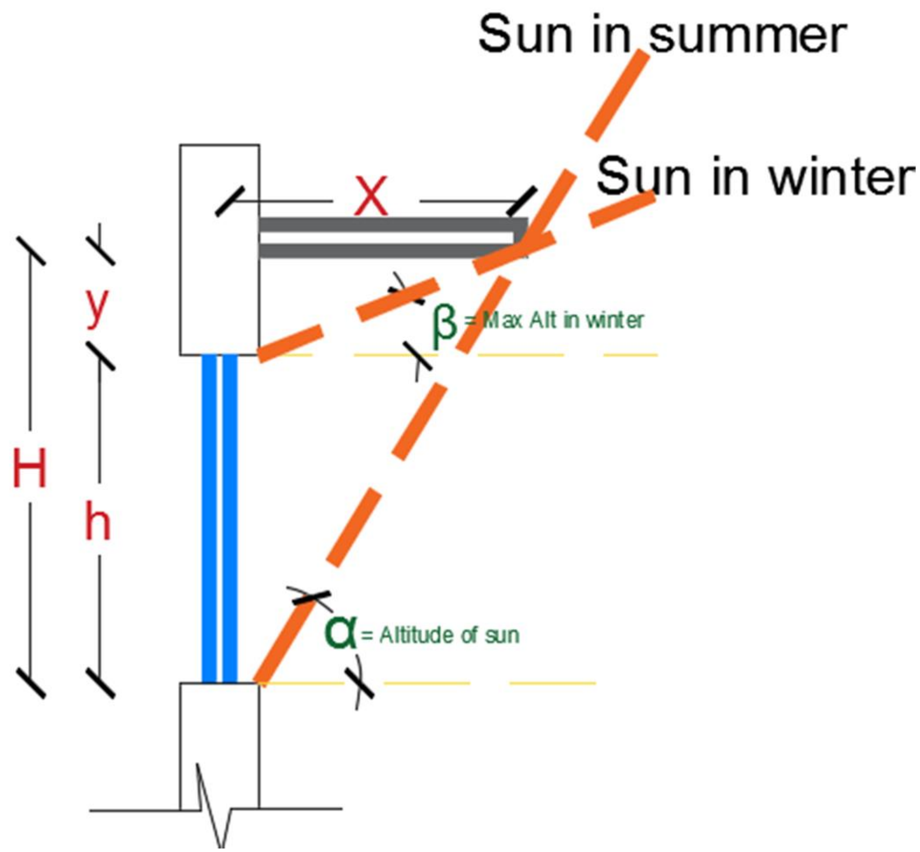


Calculation for shading devices

1) Horizontal cantilever

Example:

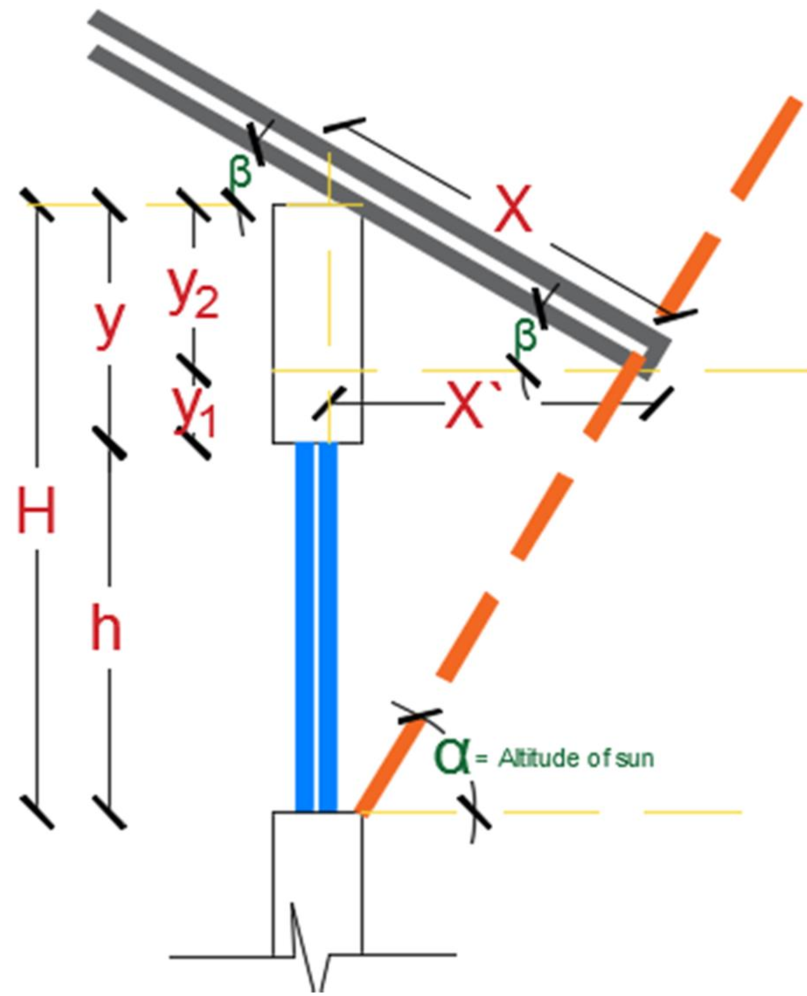
Design cantilever for full shading in summer starting at 11:00 am on 10th of May for a window in the south elevation in Palestine with height h=2m.



2) Inclined cantilever

Example:

Find the extension of an inclined cantilever for full shading at 15th of May at 11:00 am, knowing that the roof is inclined with an angle of 35° and H= 3m.



3) Horizontal shutters

If the first shutter is at the top then

$$Z = h/n$$

Where h : the height of window

N: number of shutters

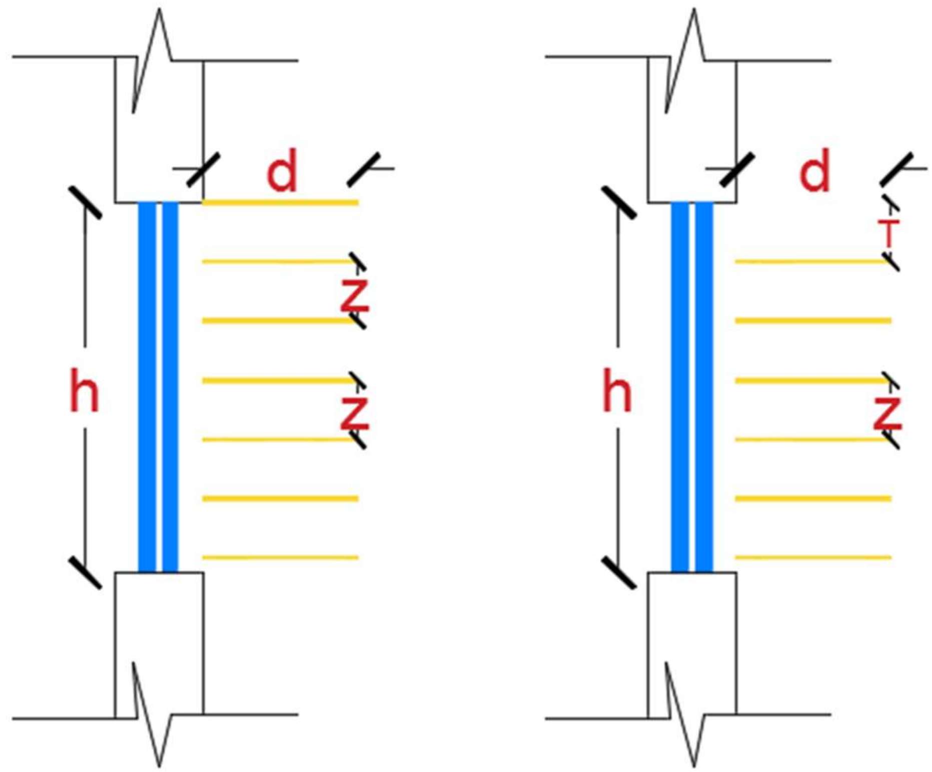
Z= the spacing between shutters

If the shutter doesn't start from the top and there is a distance T then :

$$Z = (h-T)/n$$

So the depth of shutters

$$D = Z / \tan(Alt)$$



Example:

Find shutter depth for full shading starting at 11:00 am of the 15th May, knowing that the height of the window is 2m and the number of shutters = 5.

SOLAR SYSTEMS & GAINS

Factors that affect the amount of heat falling on the window

1. Cloud coverage
2. The season (the time)

Factors that affect the amount of heat transmitted through the window:

1. Glazing area
2. Transparency
3. Glass color
4. Shading

To maximize energy savings in temperate climates with both cold and hot seasons we shall select windows with both low U-factors and low SHGC.

Solar gain for solar window

$$SG = Insolation * Glass\ area * SHGC$$

Where :

SG: Solar gain for solar window (kWh/day)

Insolation : Incident solar radiation (kWh/day/m^2)

SHGC : Solar heat gain coefficient

$$SHGC = (1-CC) * VT$$

Where :

CC: Cloud coverage

VT: Visible transmittance

$$1\ kWh/\ day/m^2 = 317\ Btu/ft^2$$

Examples

1- Find solar gain for a solar window with an area of $10m^2$ on February 21^{st}, knowing that CC=5/8 and VT= 85%.

2- Find the required glazing area for a solar window to cover 80% of heating load, knowing that the wall area = $24m^2$ and the heating load = 50 kWh/day.

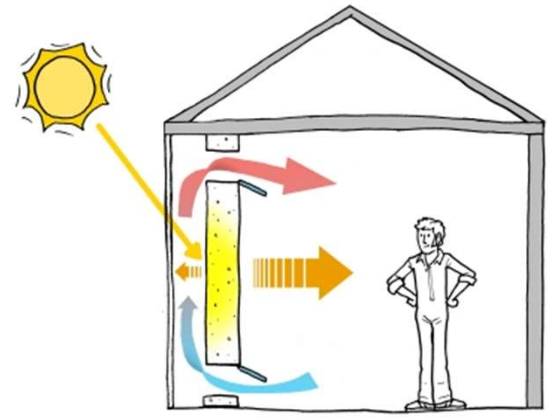
Homework

A south wall of a room has dimensions 6*4m

1- Design a solar window to cover 80% of heating load, knowing that the heating load= 30 kWh/day and VT= 85%.

2- Design a suitable cantilever for shading this window a full shading at 12:00 pm on 15^{th} May.

Heat gain for trombe wall



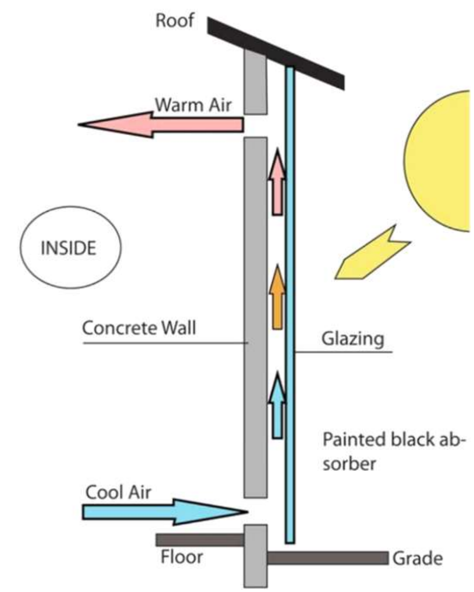
SG = Insolation * Glass area* SHGC

SHGC = (1-CC) * Transparency

Where :

CC: Cloud coverage

Transparency: Average transparency in solar wall is between (55-70%)



The efficiency of the trombe wall depends on many factors such as color, air gap ,etc….
Losses in solar wall will be less than in losses in solar window

Example: Design a solar wall to cover 80% of heating load =20kWh/day

Heat gain for solar chimney

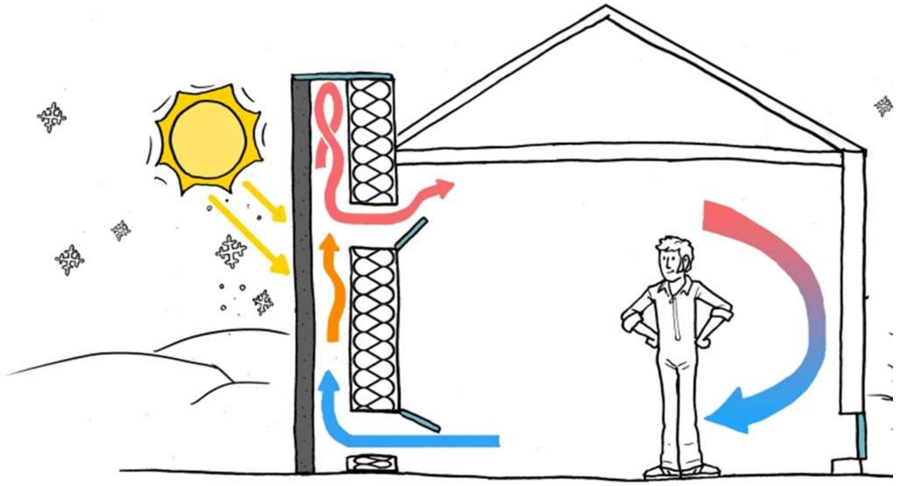
SG = Insolation * Glass area* SHGC

SHGC = (1-CC) * Transparency

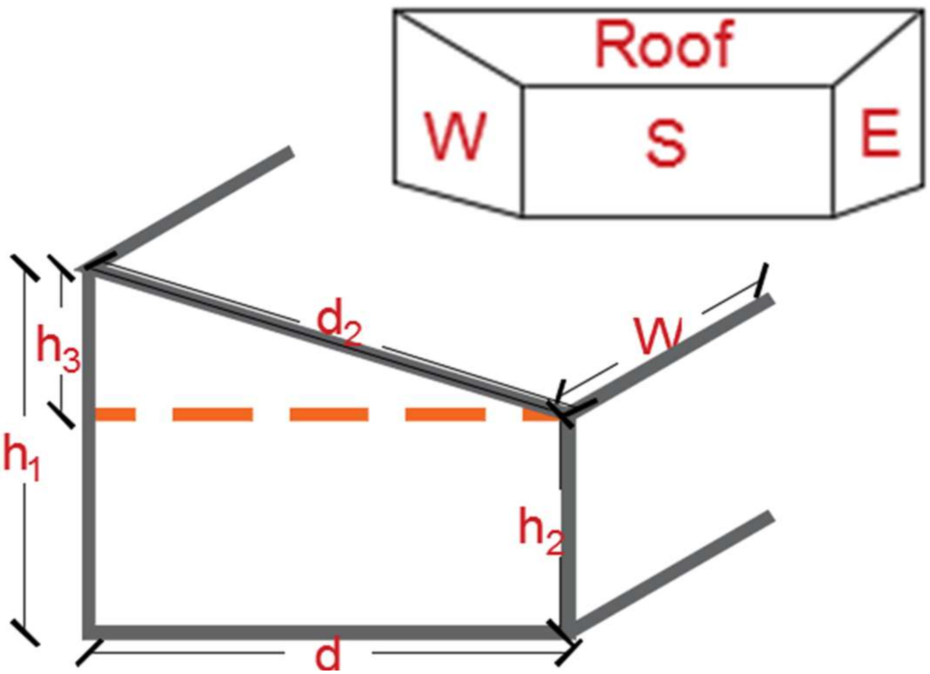
Where :

CC: Cloud coverage

Transparency: Average transparency in solar wall is between (50-60%)



Solarium gain



$\alpha = \tan^{-1}\left(\frac{h_3}{d}\right)$

$h_3 = h_1 - h_2$

$d_2 = \sqrt{h_3^2 + d^2}$

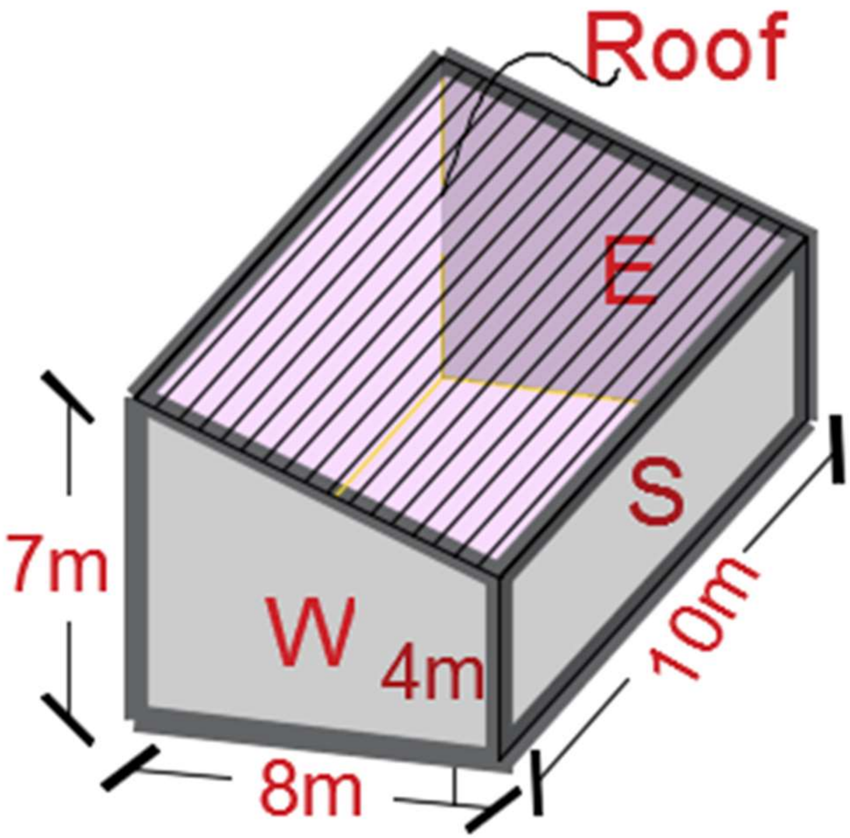
Area (South) = $h_2 * W$

Area (East) = Area (West) = $d * h_2 + \left(\frac{1}{2} d * h_3\right)$

Area (Roof) = $d_2 * W$

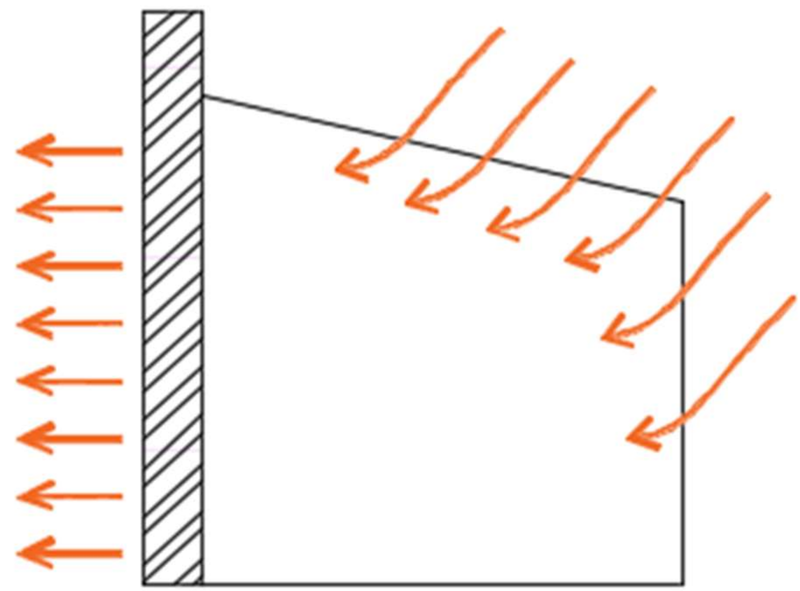
Example:

Find the solar gain in winter then in summer for the solarium shown below



Transferring heat from solarium to attached building

1) Radiating wall



Advantages

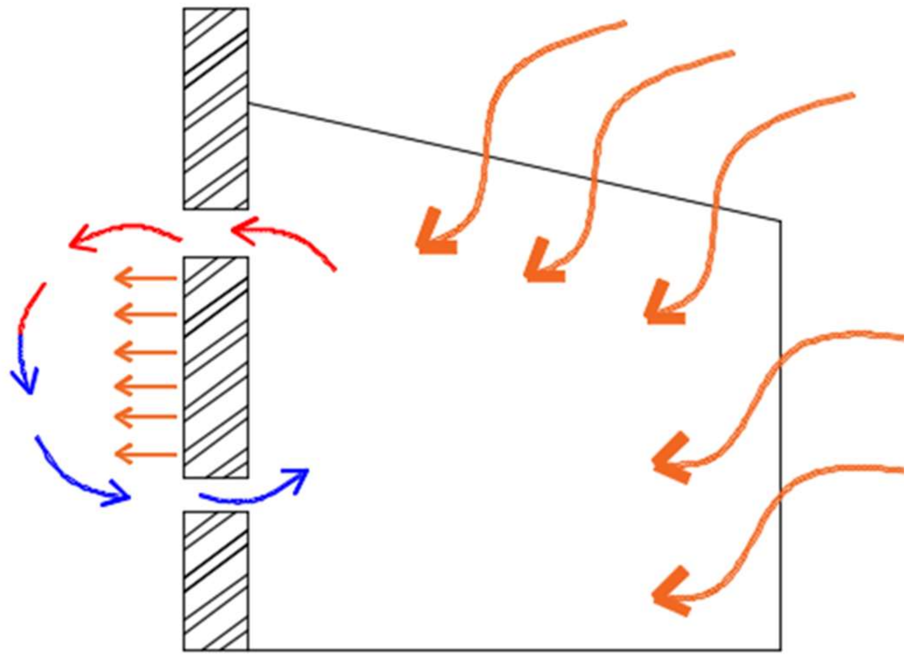
1. Storage for night time
2. No extra cost

Disadvantages

1. Only for adjacent room
2. Not uniformal distribution of radiation
3. Losses at night very high through the glass
4. In summer the gain is disaster for the room (excessive heat will be produced)

2) Radiating wall and circulation

The same idea of trombe wall



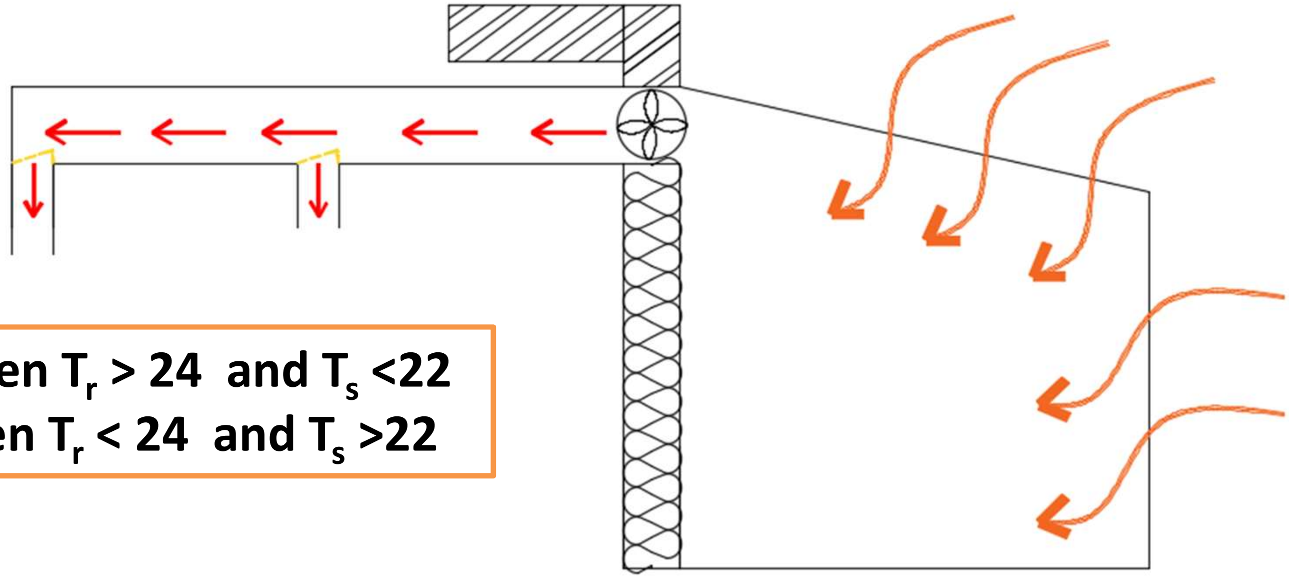
Advantages

1. Fast operation
2. More uniformed distribution
3. We can avoid excessive heat
4. Not only for adjacent room by using ducts

Disadvantages

1. Reverse circulation at night (we be solve by closing the vents
2. Uncontrolled operation

3) Forced circulation without radiation



System OFF when T_r > 24 and T_s <22
System ON when T_r < 24 and T_s >22

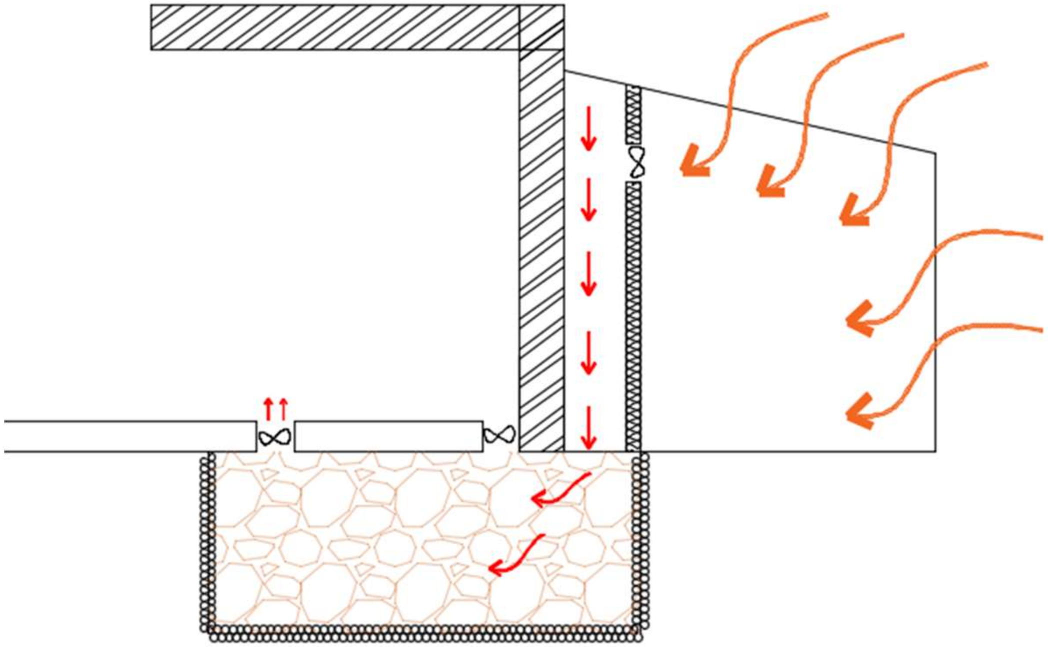
Advantages

1. Very uniformal distribution
2. The temperature is guaranteed in the solarium
3. It can be use for any room in the building

Disadvantages

1. No storage of heat (we need storage strategy for the solarium and rooms)

4) Underground stone bid



System ON when
T_s > 26 and T_s >22

<u>Advantages</u>

1. Good storage
2. Insulated with no radiation
3. Controlled operation
4. Good distribution and uniformed temperature
5. Low cost

<u>Disadvantages</u>

1. Can be used only for small houses
2. Operation is a bit complicated

AIR FLOW & THERMAL MASS

Air flow in solar chimney

Air velocity (V): is the rate of motion of air in a given direction in meters per second

Air flow (Q) : is the movement of air from one area to another in meters cube per hours

Natural air change per hour (NACH): is a measure of how many times the air within a defined space is replaced in times per hour

Air velocity in chimney depends on :

1. Height of the glass which affect on the distance between the inlet and outlet
2. The difference in temperature which is occurred by heat gain in the glass (when the gain and the difference between the inside and outside air in heat are higher then the velocity of air will increase)

This is an empirical formula

$$V = 486\sqrt{\frac{h(To - Ti)}{T_i + 460^o}}$$

V : velocity of air (fpm)

H : height between upper and lower openings (ft.)

T_o: air temperature at outlet (F^o)

T_i: air temperature at intlet (F^o)

To convert the units from Celsius to Fahrenheit use the following equation:-

$$F^o = \frac{9}{5} C^o + 32$$

T_o: It is a test number that can't be controlled, but it will be assumed because it depends on the heat gain.

We will assume T_o = 100 F^o in summer

$T_i = T_{ambient}$ =75 F^o in summer

$T_i = T_{room}$ =70 F^o in winter

Description of air depending on the velocity	
Breeze	0-2 m/s
Light wind	2-5 m/s
Windy	> 5 m/s

Example: Estimate air speed in solar chimney in a summer day where h= 10ft.

This equation is used just when the lower opening = upper opening

$$Q = 540\ A\sqrt{h(T_1 - T_2)}$$

Q : air flow in ft^2/hr

A : area of inlet opening (lower opening) in ft^2

T_1: average temperature in chimney in F^o

T_2: average inlet temperature (equal T_{amb} in summer) in F^o

$$T_1 = \frac{T_i + T_o}{2}$$

If the upper opening is bigger than the lower opening then the coefficient 540 will change according to the following table:

A_o/A_i	**Coefficient**
1	540
2	680
3	720
4	740
5	745

If the upper opening is smaller than the lower opening then the coefficient 540 will change according to the following table:

A_o/A_i	Coefficient
$^3/_4$	455
$^1/_2$	340
$^1/_4$	185

Example:

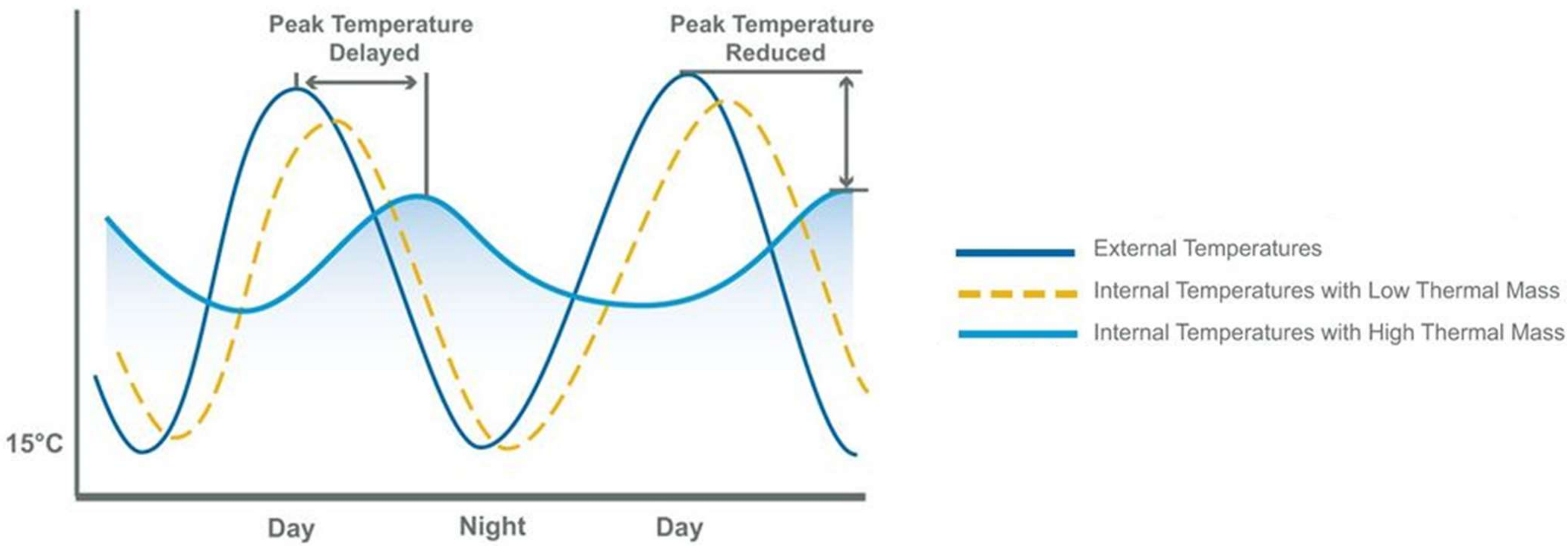
1. Estimate air flow rate of a solar chimney where Ai = 4ft^2, Tamb =28^{o}C, Tout = 60^{o}C and A_o=2A_i.
2. If the volume =320m^3 find the value of NACH.

Thermal mass

Thermal mass is a concept in building design that describes how the mass of the building provides "inertia" against temperature fluctuations.

Insulation and thermal mass

They both slow down the movement of heat between exterior and interior. Insulation to maintain a temperature different between exterior and interior but thermal used to slowly take on heat and then slowly release it.



Thermal mass depends on many factors:

1. Specific heat capacity (SHC)

Physical material's capacity to store heat for every kilogram of mass contained in that material is measured in J/kg.K (high thermal mass has a high SHC).

2. Density (ρ)

The mass or weight per unit volume of a material and is measured in kg/m^3. (material with high ρ has high thermal mass).

3. Thermal Conductivity

The ease with which heat can travel through a material is measured in W/m.K. (For a good thermal mass we should have a low thermal conductivity).

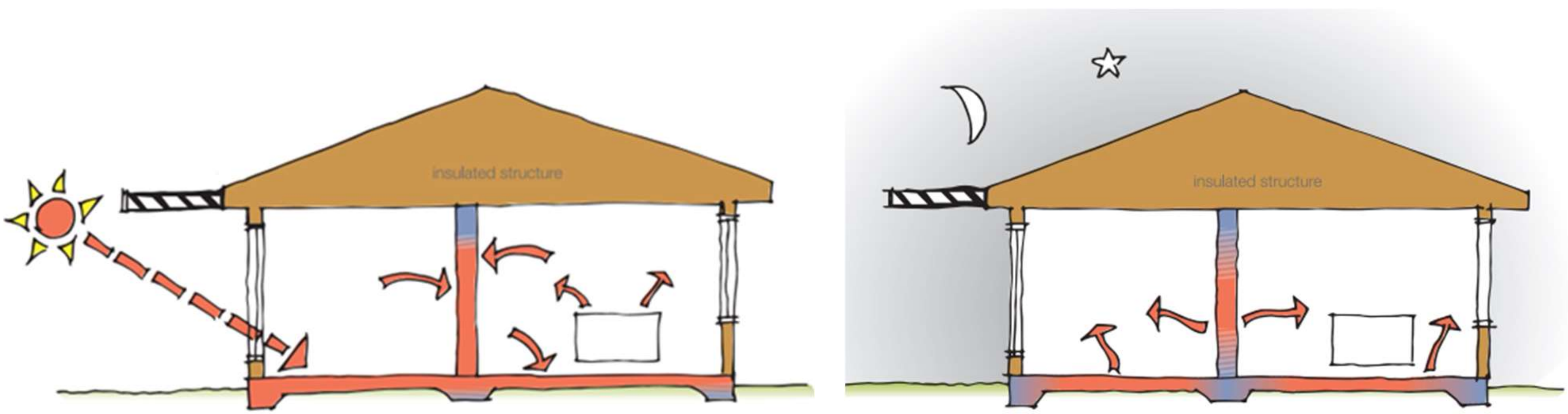
4. Thickness

Increasing the thickness of the material it couldn’t mean increasing the thermal capacity

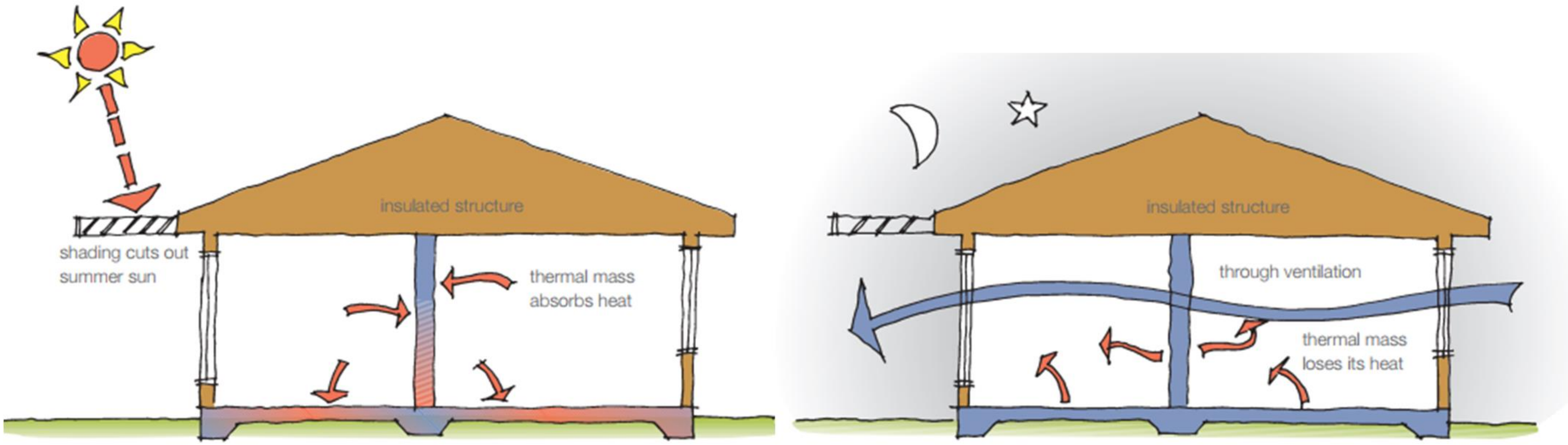
For good performance, thermal mass must be considered in conjunction with other passive design features such as insulation, location, orientation and layout, window sizing, and shading.

For example, if thermal mass is being used for passive heating, it should receive maximum exposure to sunlight during cooler months, but minimal exposure to sunlight during summer.

In winter, thermal mass will absorb heat from the sun during the day, as well as from supplementary heat sources, and release that heat as temperatures fall at night, as shown in figure below



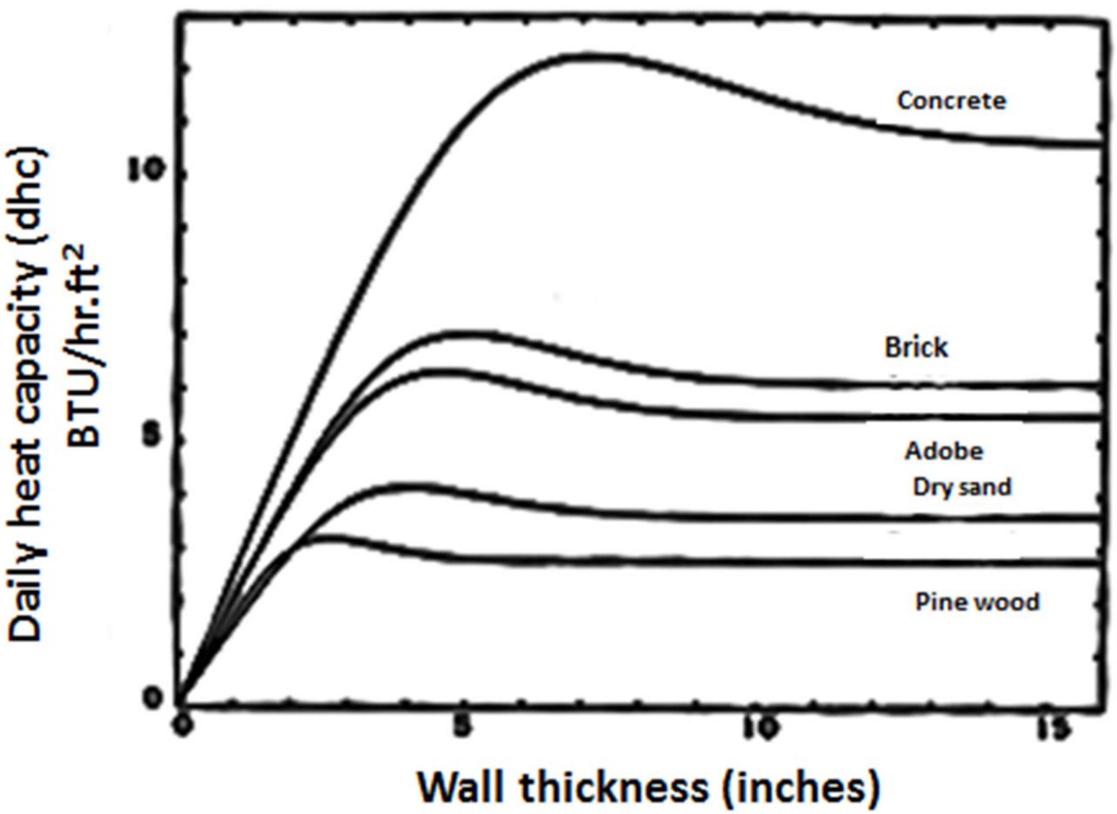
<u>In summer</u>, thermal mass absorbs the ambient air heat while being shaded from direct sunlight to help reduce overheating. At night, the house can be ventilated to allow any excess heat to be lost into the cooler night air. Ideally, excess solar gain should be prevented from entering the house by use external shading systems – otherwise overheating may occur.



Daily (diurnal) heat capacity (dhc)

Is a measure of the building's capacity to absorb solar energy coming into the interior of the space and to release the heat to the interior during the night hours

1 $BTU/hr.ft^2$ = 5,678 $Whr/^oC.m^2$



Properties of material

Material	Density (kg/m^3)	Specific heat ($kCal/^oC.kg$)
Granite	2676	0.20
Concrete	2300	0.21
Masonry	2250	0.21
Lime stone	2450	0.22
Hard wood	720	0.30
Water	1000	1.00

$$\Delta T_{swing} = \frac{Q_s.A + Q_i/2 - \{(T_r - Ta) * TLC/2\}}{DHC}$$

Q_s : Daily solar gain / unit glass area in Whr/day. m^2

Q_i : Daily internal gain in Whr/day

A : Total glazing area in m^2

T_r: room temperature in ^oC

T_a: ambient temperature in ^oC

TLC : Total heat loss coefficient of building in Whr/^oC.day

Q_s = Insolation * SHGC

TLC = Σ U.A + 0.33* n *Volume

DHC= Σ $dhc_i A_i$

Example:

A room with TLC = 600 Whr/^oC/day has a solar gain =18 kWhr/day knowing that T_r= 22^oC, T_a= 8^oC and internal gain = 15 kWhr/day.

Find required DHC for ΔT_{swing}= 4^oC

If the room dimensions 6*4*3m and the floor is the only storage with dhc = 54W/$^oC.m^2$. Then find the actual ΔT_{swing}

Example:

If you have a room with the following dimensions 6*6*4m.

Knowing that T_r= 22°C, T_a= 6°C, TLC= 90 Whr/°C.day and you have :

6 lamps 40 W for 8 hours with an efficiency of 0.8.

2 PC's 80 W for 10 hours

2 persons 90 W for 10 hours

If no auxiliary heating system is used then we use the following equation

$$\Delta T_{swing} = \frac{Q_s . A}{2DHC}$$

In the previous examples there was a heating system so the temperature of the room was constant.

Example:

If you have a room with the following dimensions 5*4*4m, where the south wall 4*4m and you have a solar window 3*3m , the thermal mass is in floor and E and W walls, dhc_{floor} =54 W/°C.m^2 and dhc_{wall} =51 W/°C.m^2

Knowing that, T_a= 6°C, TLC= 80 Whr/°C and you have :

6 lamps 40 W for 12 hours with an efficiency of 0.8.

2 PC's 80 W for 8 hours

3 persons 160 W for 8 hours

Thermal mass depends on building type or usage

1) Building used for 24 hours such as residential buildings
2) Building used till midnight(for 16 hours) such as restaurant
3) Building used at night only for 8 hours such as wedding hall
4) Building used at daytime only for 8 hours such as office buildings

→ *We will try to fulfill the day time requirements from sun and lets the night loads to be from storage or other system of heating.*
So in winter we have 8 hours (daytime) and 16 hours (night time)

$$\textbf{Thermal capacity (Whr/}^{o}\textbf{C) = Volume (m}^3\textbf{)*}\rho\ \left(\frac{kg}{m3}\right)\textbf{* SHC}(\text{Whr}/^{o}\text{C.kg})$$

$$\textbf{Storage energy(Whr) = Volume (m}^3\textbf{)*}\rho\ \left(\frac{kg}{m3}\right)\textbf{* SHC}(\text{Whr}/^{o}\text{C.kg})\ \textbf{*}\ \Delta T_{swing}\ (^{o}\text{C})$$

Units converter

1 BTU = 0.293 Whr
1 kCal = 1.163 Whr
$1 lb/ft^3 = 16.02\ kg/m^3$
1 Btu/ ^{o}F. Lb = 1.16 Wh /^{o}C.kg

Example: For a given building , the heating load is 240,000 BTU/day, a solar wall may cover 80% of heating load, ΔT_{swing}= 5,5 find the suitable thermal storage size.

Solution : -

Solar wall gain = 80%*240,000 = 192,000 BTU

You will still need 240,000-192,000= 0,2*240,000=48,000 BTU

Daytime needs = $\frac{1}{3}$* total daily heating load = 80,000 BTU

Energy to be stored(minimum)= total gain – daytime needs =192,000-80,000= 112,000 BTU

Energy to be stored(maximum)= $\frac{2}{3}$* total daily heating load = 160,000 BTU

Storage energy = Volume *ρ * SHC* ΔT_{swing}

→ Min. Volume = $\frac{112,000 * 0,293}{2,300 * 0.21 * 1.163 * 5,5}$ = 10.62 m^3 → Max. vol =15.17 m^3

Suppose the solar wall have an area of 13*4 m^2

then the suitable thickness is between 20-29 cm

Where to locate thermal mass

To determine the best location for thermal mass you need to know if your greatest energy consumption is the result of summer cooling or winter heating.

Heating:

- Locate thermal mass in areas that receive direct sunlight or radiant heat from heaters.

Heating and cooling:

- Locate thermal mass inside the building on the ground floor for ideal summer and winter efficiency. The floor is usually the most economical place to locate heavy materials, and earth coupling gives additional thermal stabilization in both summer and winter in these climates.
- Locate additional thermal mass near the center of the building, particularly if a heater or cooler is positioned there.

Cooling:

- Protect thermal mass from summer sun with shading and insulation if required.
- Allow cool night breezes and air currents to pass over the thermal mass, drawing out all the stored energy.

Specific climate responses

Climatic consideration is critical in the effective use of thermal mass.

1) Hot humid (tropical) climates

Use of high mass construction is generally not recommended in hot humid climates due to their limited diurnal range. Passive cooling in this climate is usually more effective in low mass buildings.

Thermal comfort during sleeping hours is a primary design consideration in tropical climates. Lightweight construction responds quickly to cooling breezes. High mass can completely negate these benefits by slowly re-releasing heat absorbed during the day.

2) Warm humid and warm/mild temperate climates

The predominant requirement for cooling in these climates is often suited to lightweight, low mass construction. High mass construction is also appropriate but requires passive design to avoid overheating in summer.

3) Hot dry climates

Both winter heating and summer cooling are very important in these climates. High mass construction combined with passive heating and cooling principles is the most effective and economical means of maintaining thermal comfort.

Diurnal ranges are generally quite significant and can be extreme. High mass construction with high insulation levels is ideal in these conditions.

4) Cool temperate and alpine climates

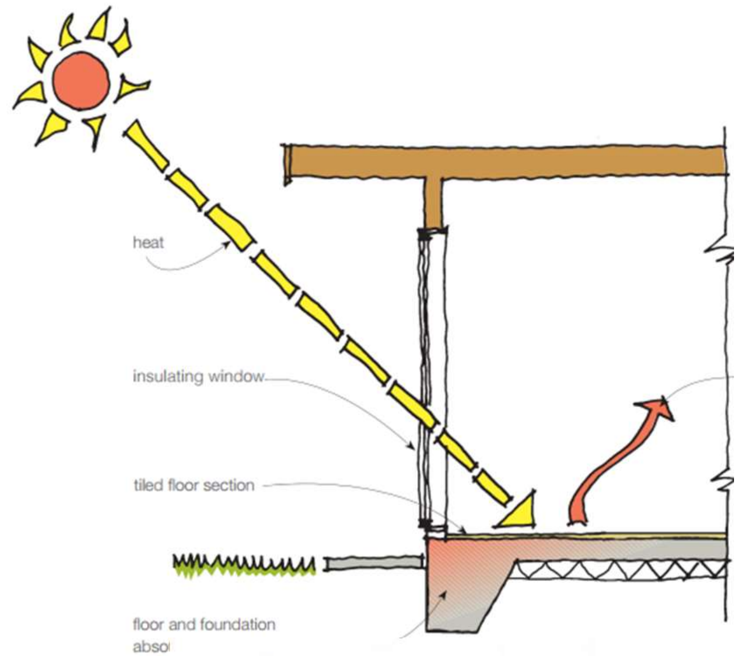
Winter heating is the main need in these climates although some summer cooling is generally required. Ceiling fans usually provide adequate cooling in these low humidity climates.

High mass construction combined with passive solar design and high level insulation is an ideal solution.

Floor requirements to provide thermal mass for heating

A concrete slab floor provides excellent thermal mass. For maximum heat absorption, the surface should:

1. Be exposed or be covered with a high density material such as tile or slate
2. Have a mid to dark color or a textured or matt finish
3. Be 100–200 mm thick
4. Be insulated underneath the slab so that heat moves up into the interior space rather than into the ground
5. Have slab edge insulation to reduce heat loss from the slab perimeter to the outside air.
6. Materials with high thermal resistance (such as carpet etc,) should never be laid over concrete floors that are to provide thermal mass.



Wall requirements to provide thermal mass for heating

While floors are more commonly used to provide thermal mass (because they usually receive more sun and are therefore more effective), in the right situations walls can also be used.

Walls to provide thermal mass should be concrete, concrete masonry, stone or earth. They should:

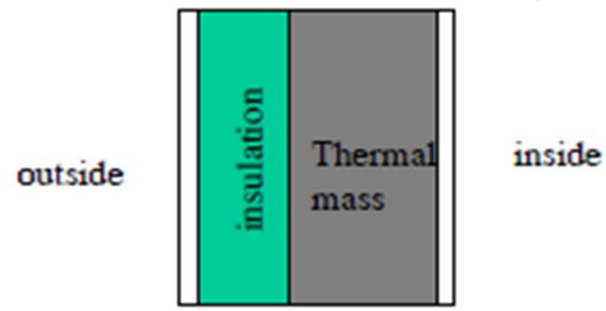
1. Be exposed to direct sunlight if possible
2. Be of a mid to dark matt color
3. Be 100–150 mm thick to provide sufficient mass for optimal heat storage
4. Have insulation on the exterior face of external walls.
5. Dense or heavy materials such as concrete masonry located outside the insulation do not add thermal mass to a building .

Insulation position

1) Exterior insulation

Building which is externally insulated with internal exposed mass. Here DHC is high.

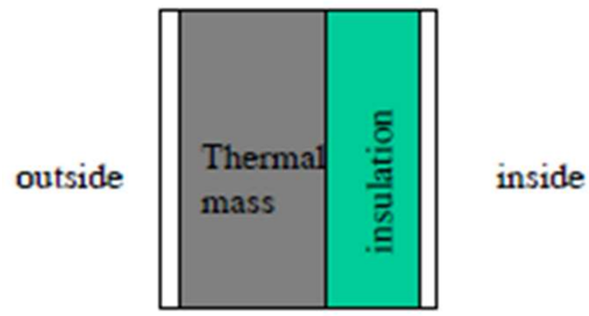
When the building is ventilated at night and closed during the day, it can absorb the heat in the mass with relatively small indoor temperature rise. Best for hot-dry regions.



Easier to install, least disruptive for occupants and existing finishes, has no effect in internal building services and overcomes thermal bridging.

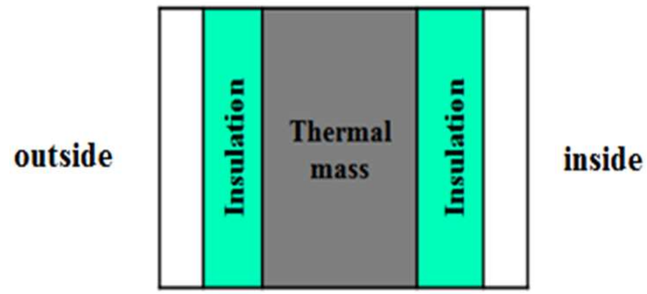
2) Interior insulation

Building with mass insulated internally. Here DHC is low.
The mass will store energy and release energy mostly to the exterior, and the thermal response is similar to a low mass building.
Best for hot, warm humid regions.



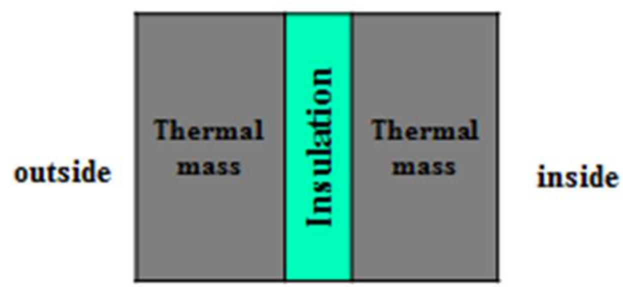
3) Mid insulation

Building with high mass insulated externally and internally. Here, the building has a negligible DHC, as the interior insulation separates the mass from the interior.



4) Cavity or core insulation Air flow and thermal mass

Building with core insulation inside two layers of mass. Here DHC is a function on the interior mass. The external mass influences heat loss and gain by affecting the delta T across the insulation.



SOLAR WATER HEATERS

Solar water heaters (SWH)

Solar water heaters use solar energy (sun light) to generate heat which used to heat water.

Advantages:

1) Renewable source of energy (free)
2) Reduce our dependence on fossil fuels
3) Very low maintenance costs
4) Highly cost effective (especially in sunny and warm places)
5) Nature friendly

Applications:

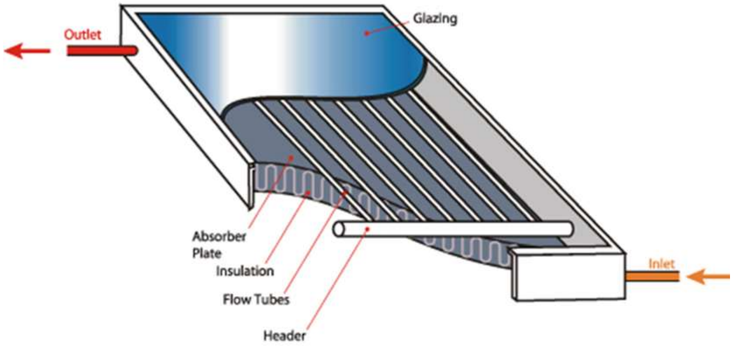
1) Domestic uses(bath, kitchens, laundries, etc) or industrial uses
2) Heating spaces
3) Swimming pool

Main parts of SWH:

1) *Solar collectors* : a device designed to absorb incident solar radiation and to transfer the energy to a fluid passing in contact with it, usually liquid or air.
2) *Storage tank*

Solar collectors types :

1) Flat plate collector
2) Tube collector
3) Parabolic collector



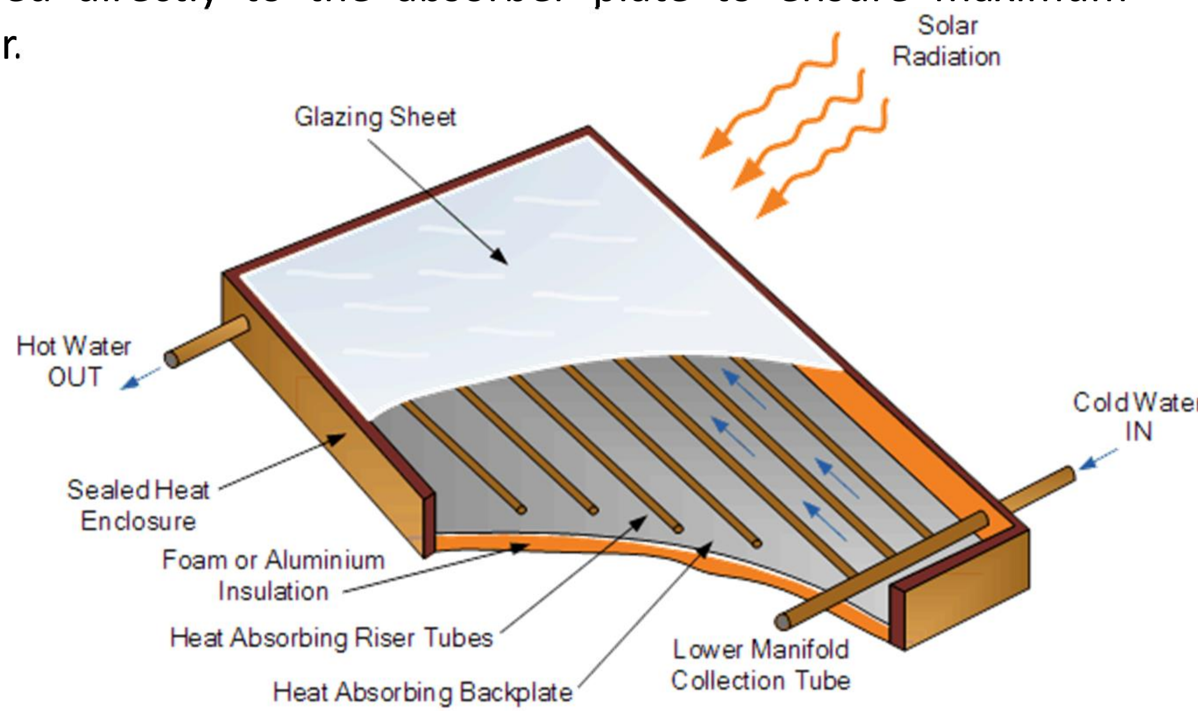
1) Flat plate collector

It consists of a large heat absorbing plate, usually a large sheet of copper or aluminum as they are both good conductors of heat, which is painted (generally black) to absorb as much solar radiation as possible for maximum efficiency.

This blackened heat absorbing surface has several parallel copper pipes or tubes called risers, running length ways across the plate which contain the heat transfer fluid, typically water.

These copper pipes are soldered directly to the absorber plate to ensure maximum surface contact and heat transfer.

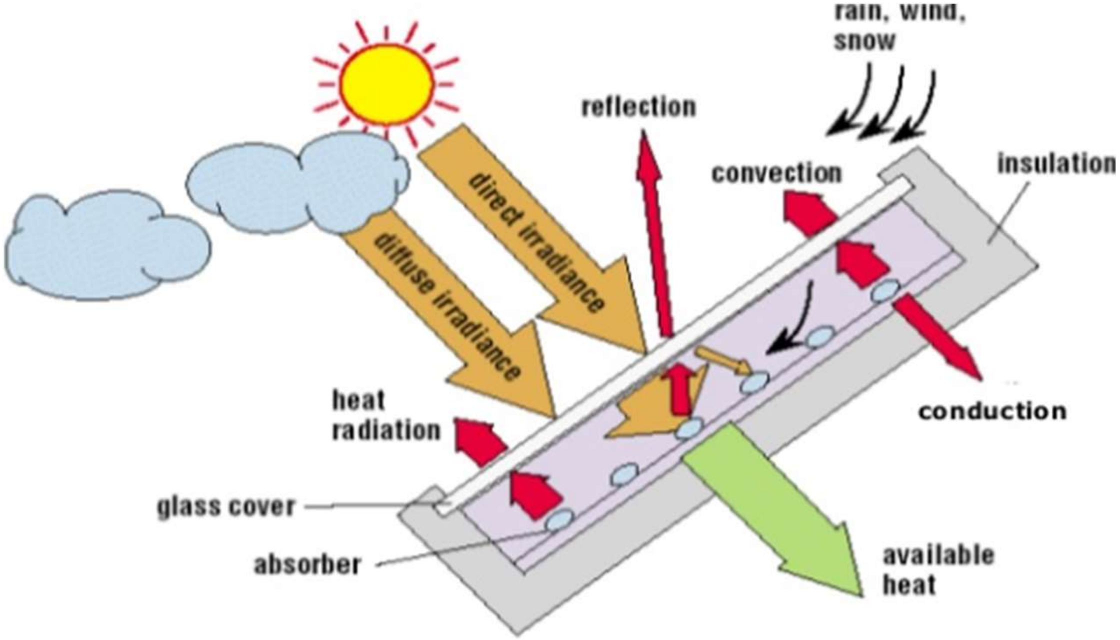
Sunlight heats the absorbing surface which increases in temperature.
As the plate gets hotter this heat is conducted through the risers and absorbed by the fluid flowing inside the copper pipes which is then used by the household.

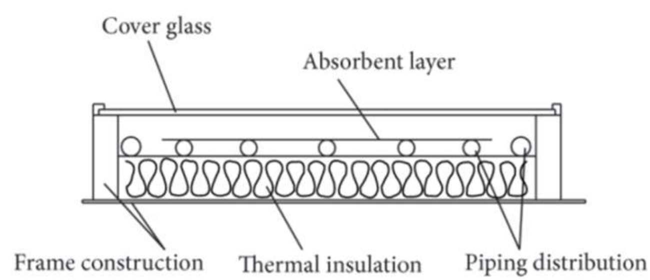


The pipes and absorber plate are enclosed in an insulated metal box with a sheet either glass or plastic on the front to protect the enclosed absorber plate and create an insulating air space.

The air gap between the plate and glazing material traps this heat preventing it from escaping back into the atmosphere. As the absorber plate warms up, it transfers heat to the fluid within the collector but it also loses heat to its surroundings.

To minimize this loss of heat, the bottom and sides of a flat plate collector are insulated with high temperature rigid foam or aluminum foil insulation.





Advantages of flat plate collectors:

1) Very simple and low in cost
2) Can be manufactured locally
3) Low maintenance cost and long life

Disadvantages of flat plate collectors:

1) High losses (by radiation and convention)
2) Efficiency depends on $\Delta T = T_{plate} - T_{amb}$ (Low efficiency in cold weather)
3) Heavy
4) Not suitable for high temperatures
5) Need large areas

Efficiency of flat plate collector is between 38-50%
Annual depreciation of efficiency from the previous year is 5-15%

Factors increases the plate temperature :

- Water flow is slow
- ΔT between input and output water is small
- The number of pipe is small

Solar water heaters systems

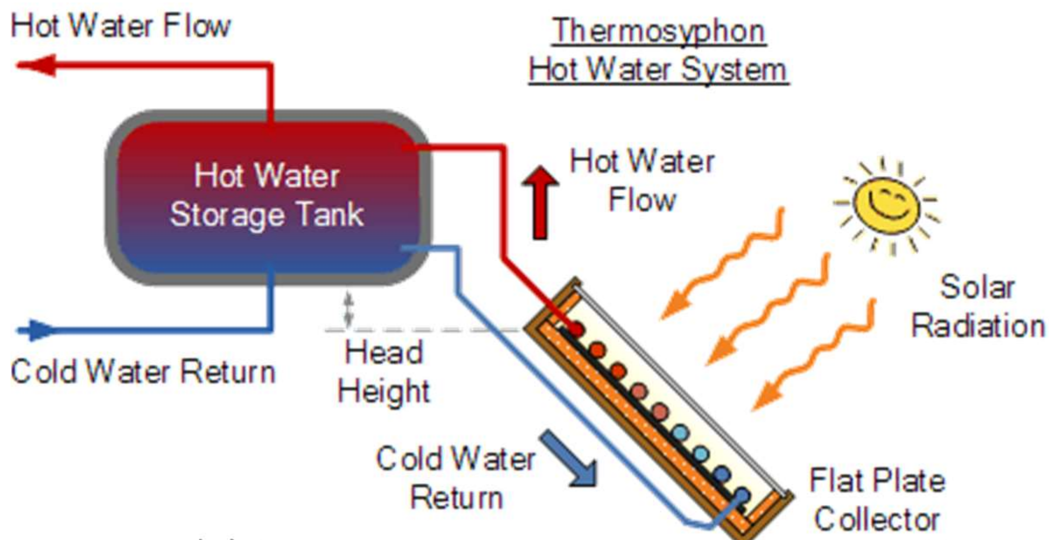
1) Open-loop system (Thermo-syphon System)

This system use the natural force of gravity to help circulate the water around the system and uses a solar flat plate collector combined with a horizontally mounted storage tank of some kind located immediately above the collector.

The water heated by the sun rises naturally using convection through the solar collectors pipes and enters the storage tank situated above. As the heated water enters the storage tank above, the cooler water is forced out and flows down to the bottom of the collectors aided by gravity as cold water is more dense than hot water.

This cycle of hot water rising and cooler water falling is known as a “thermo syphon flow” and continuously repeats unaided while the sun is shining.

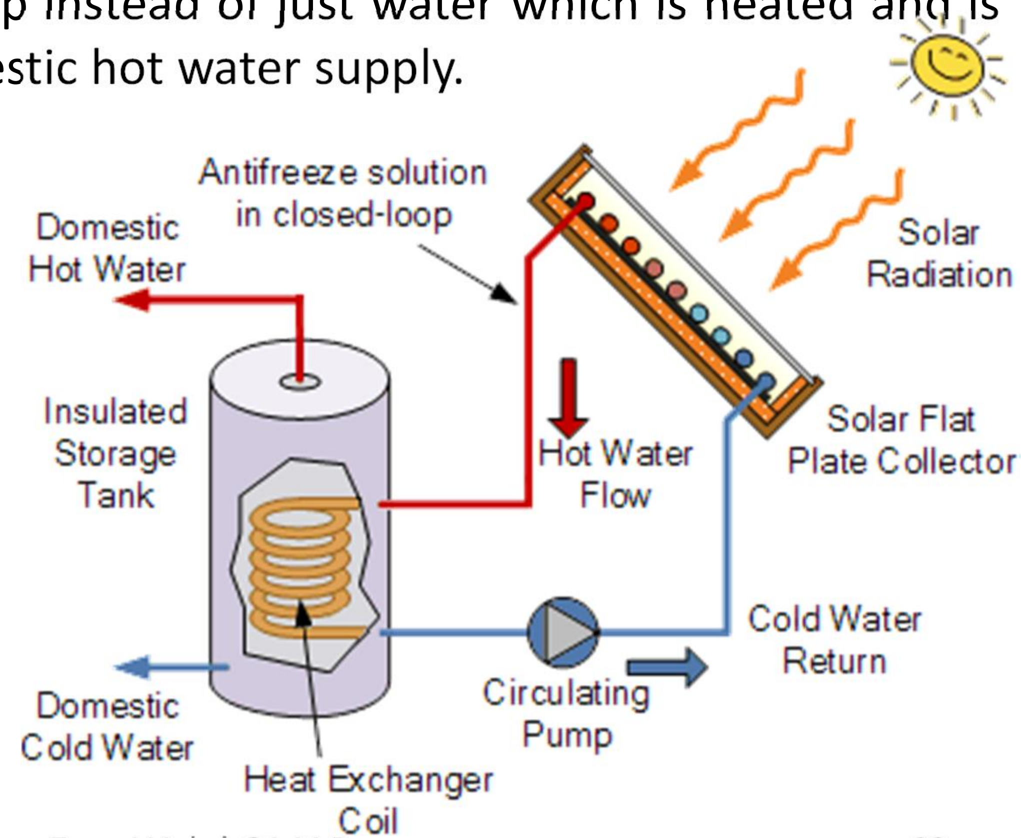
The base of the water tank must be situated at least (30 to 50cm) above the top of the collectors for the thermo syphoning process to work correctly. This distance is also known as the systems “head height”.



2) Closed-loop system

It uses a heat exchanger that is separate from the solar flat plate collector to heat the water in the storage tank and require pumps to circulate the heat transfer liquid around the closed-loop system from the collector to the heat exchanger in the tank.

The system contains an antifreeze solution, typically a 50% Glycol/water mixture, in the primary closed-loop instead of just water which is heated and is kept separate from the main domestic hot water supply.



2) Evacuated tube collector

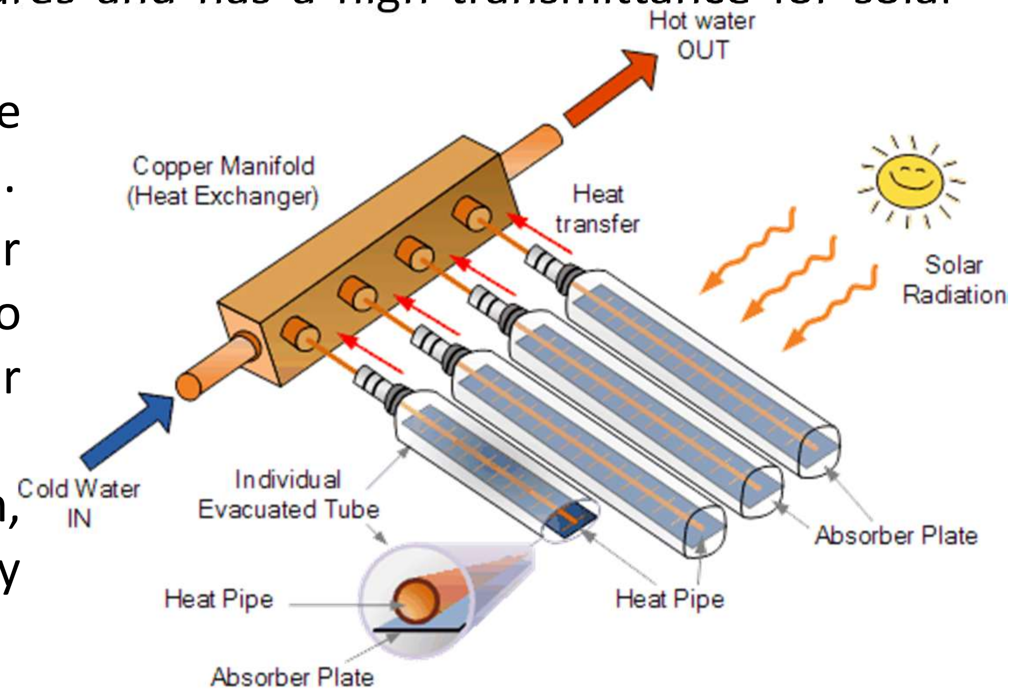
They are made up of a single or multiple rows of parallel, transparent glass tubes supported on a frame. Each individual tube varies in diameter from between (25 to 75mm) and between (1500 to 2400mm) in length depending upon the manufacturer.

Each tube consists of a thick glass outer tube and a thinner glass inner tube, “twin-glass tube” which is covered with a special coating that absorbs solar energy but inhibits heat loss. The tubes are made of borosilicate or soda lime glass, which is strong, resistant to high temperatures and has a high transmittance for solar irradiation.

Air is evacuated from the space between the tubes, forming a vacuum.

This vacuum acts as an insulator reducing any heat loss significantly to the surrounding atmosphere either through convection or radiation.

With the assistance of this vacuum, evacuated tube collectors generally produce higher fluid temperatures.



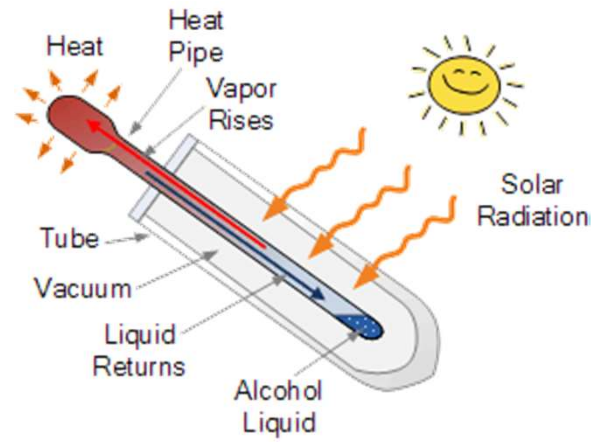
Advantages :

1) Useful in areas with cold, cloudy wintry weathers.
2) Low in weight
3) Suitable for high temperature and quick heat generation
4) Heat losses are negligible
5) Shed snow very poorly

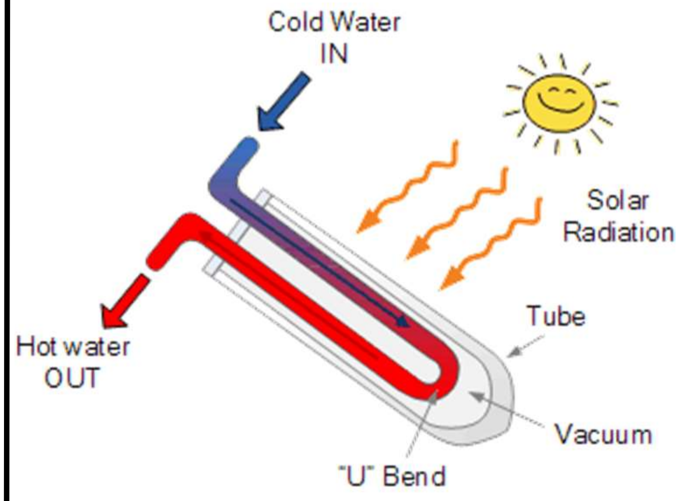
Disadvantages :

1) More expensive (10-15% more expensive than flat plates)
2) Not suitable for warm weather
3) Lower lifetime

Efficiency of evacuated tubes collector is between 65-70%



Heat Pipe Evacuated Tube Collectors



Direct Flow Evacuated Tube Collector

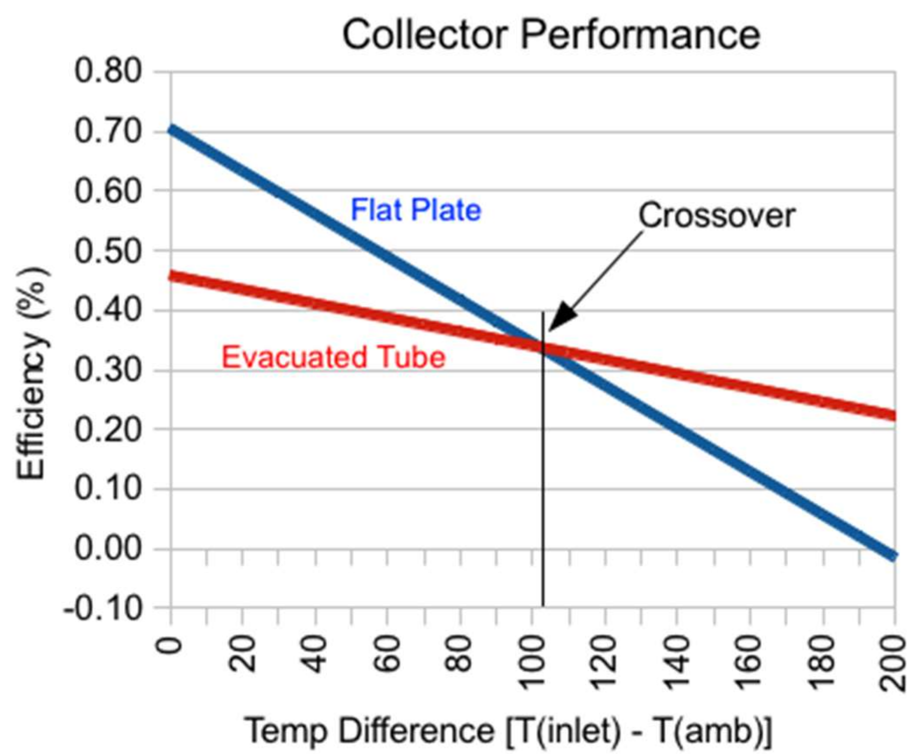
Who has the best performance??

The answer is… it depends!

They both work. If designed correctly, you're not going to see a huge difference between one or the other in most cases.

If both types of collectors are placed side by side on the same roof, the performance is based on the difference between the entering water temperature that you're heating and the ambient temperature.

In other words, the performance depends on the temperature of the water coming from the storage tank compared to the ambient temperature, i.e. the temperature of the surroundings. As the variance increases (i.e. you're in colder temperatures), evacuated tubes become more efficient. **As shown in the graph.**



Differences between flat plat and evacuated tube collector

	Flat plat collector	Evacuated tube collector
1	Slow heat generation	Quick heat generation
2	Low efficiency in cold weather	High efficiency in cold weather
3	High losses	Low (negligible) losses
4	Low in cost	10-15% more expensive than flat plates
5	Heavy	Light weight
6	Temperature reached 30- 90^{o}C	Temperature reached up to 140^{o}C

3) Concentrating collector

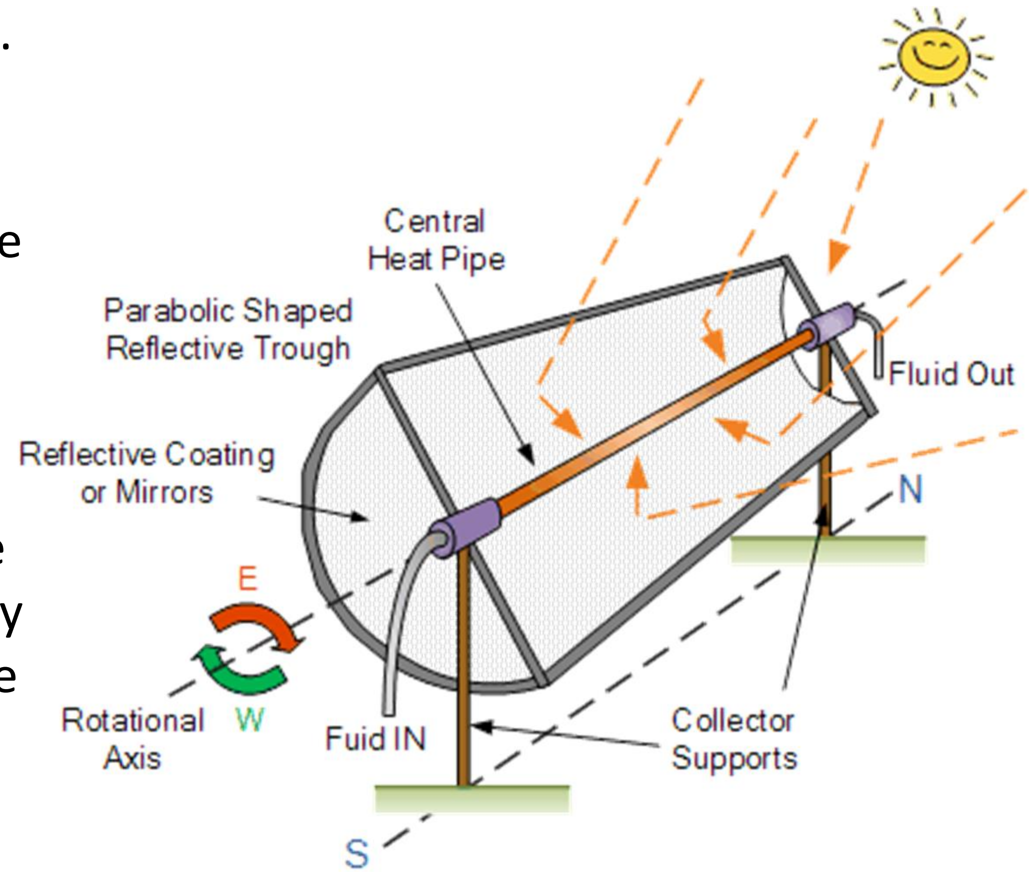
It is constructed as a long parabolic reflecting mirror which is usually painted a reflective silver, or made from polished aluminum, or uses mirrors which extends linearly into the trough shape. A metal black heat tube inside a sealed glass tube which can also be evacuated is used to reduce heat losses.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

<u>Advantages :</u>

1) Gives water at high temperature even steam

<u>Disadvantages :</u>

1) Requires tracking system
2) Small amount of water in the pipe
3) Works only with clear sky condition and with direct sunshine



<u>Gains of solar water collectors depends on :</u>

1. Angle of inclination
2. Efficiency
3. Area of collector

Number of collectors = $\frac{\textit{Total area of glass}}{\textit{Glass area per collector}}$

<u>Examples</u>

1) We found that we need a glazing area of $24m^2$ of flat plate collector to cover the requirements of hot water, knowing that the area of each collector 80*200 cm, how many collectors do we need?

2) If you have 5 collectors in Nablus with an inclination of 42^{o} , find the total gain of these collector in the 21 of December if you know that the glass surface of each collector 90*220cm and the efficiency = 40% .

The table below indicates hot water consumption per occupant or person in typical buildings:

Type of building	Consumption per occupant	
	liter/day	*gal/day*
Factories (no process)	22 - 45	5 - 10
Hospitals, general	160	35
Hospitals, mental	110	25
Hostels	90	20
Hotels	90 - 160	20 - 35
Houses and flats	90 - 160	20 - 35
Offices	22	5
Schools, boarding	115	25
Schools, day	15	3

Energy need to heat water(Whr/year)= Cons.* ρ_{water} *SHC_{water} * ΔT (^{O}C)

Where:

Cons. : Total hot water consumption of occupants (m^3/year)

ρ_{water} : Density of water = 1,000 kg/m^3

SHC_{water} : Specific heat capacity of water = 1 kCal/kg. ^{O}C

ΔT : Difference between the inlet and outlet water (^{O}C)

Example

If we have a house of $100m^2$ with 3 occupants (present 360day/year), how many collectors do we need? Knowing that the efficiency = 45%, ΔT between the inlet and outlet water = 45 °C

Solution:

Consumption = # of occupant* Consumption per occupant * # of presence day = 3 * 90*360 = 97,200 ltr/ year= 97.2 m3/year

Energy need to heat water= 97.2* 1000*1*1.163* 45 = 5,086,962 Whr /year = 5,087 kWhr/ year

If the average solar insolation in Palestine = 2,450 kwhr/ m2/year

*Glass Area of collectors = Energy needed to heat water / (Solar insolation * efficiency) = 5,087 / (2450*0.45) = 4.61 m2*

*If the area of the collector was 80*200 cm how many collector we have*

*Collector glass area = 0.85*2*0.8 = 1.36 m2*

# of collector = 4.61/1.36 = 3.4→ we will need 4 collectors

Swimming pool example

A swimming pool (dimensions 7*4*1.4), water temperature in winter (21/Jan) = 10°C and required water temperature for swimming is 25°C
Estimate the necessary area of solar collectors to cover 100% of this issue. Knowing that the efficiency of collector used =40% and will be inclined 42°

Solution:

To cover 100% → Total heat water energy = solar gain

Volume* ρ_{water} *SHC_{water} * ΔT = Insolation*A * (1-CC)* efficiency

(7*4*1.4)* 1000*1*1,163*(25-10) = (2118*1000/317) *A* (1- $-\frac{5}{8}$) * 0.40 =

683,844 = 1,002 *A → A = 682.48 m^2

If the glass area of one panel = 2m^2 →# of panel = $\frac{682.5}{2}$ = 342 panels

If the cost of 1 panel = 120$ → panel cost = 120*342 = 41,040 $

If one liter of diesel cover 11,720 Whr of heating water energy and the combustion efficiency = 75% and the price of diesel = 1.5 $
Suppose we need to heat water for 80 days/ year

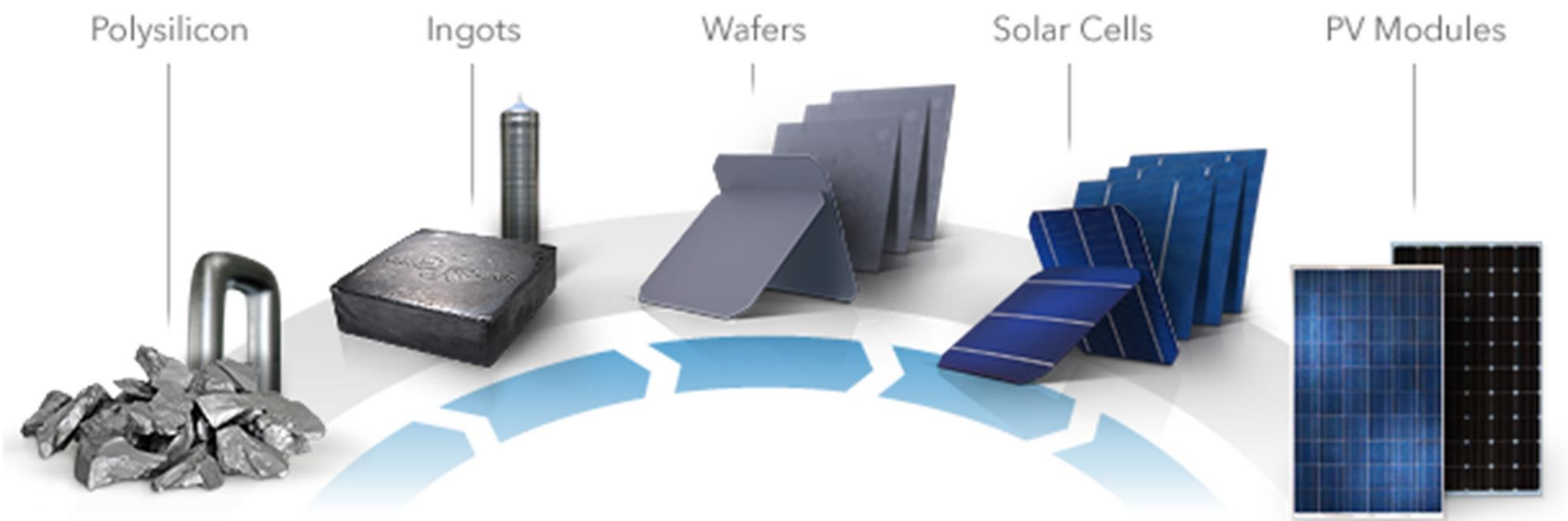
Cost of diesel = $\frac{683,844}{11,720*0.75}$ * 1.5 =116.7 $/ day = 9,336 $/year

Recovery time = $\frac{41,040}{9,336}$ =4.4 years (this value is approximately estimated we have depreciation for solar panel)

PHOTOVOLTAIC

DEFINITION OF PHOTOVOLTAIC

Photovoltaic (PV) cells convert light energy into electricity. The term 'photo' is derived from the Greek word 'phos', which means 'light'. 'Volt' is named for the scientist Alessandro Volta (1745-1827) who pioneered the study of electricity. Photovoltaic literally means light-electricity. PV cells are also commonly known as 'solar cells'.



PHOTON TO ELECTRICITY

PV cells consist of a junction between two thin layers of dissimilar semiconductor materials known as ‘p’ (positive) type and ‘n’ (negative) type semiconductors.

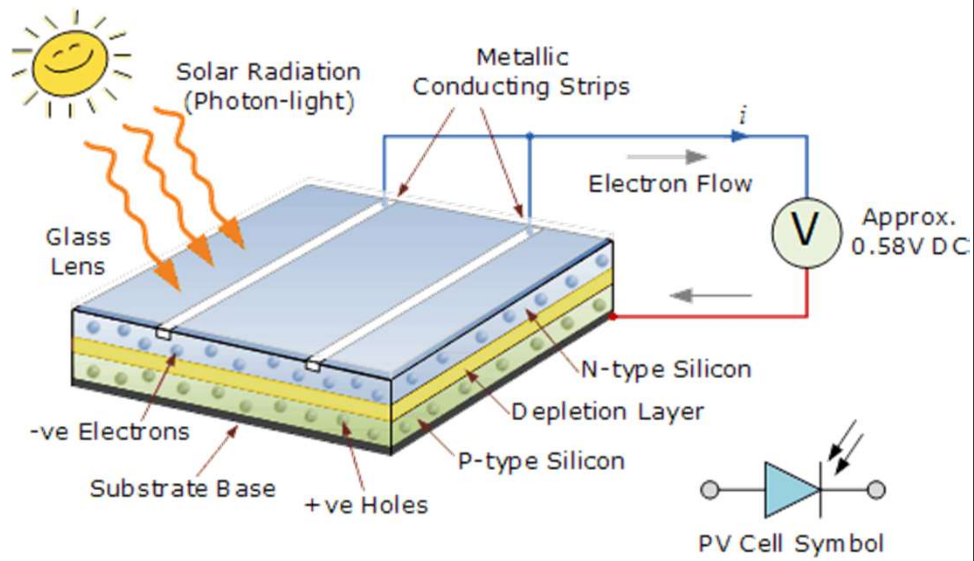
In a PV cell, wafer thin (0.2 to 0.3 mm thick) layers of both these materials are brought together to form a P-N junction that creates an electric field.

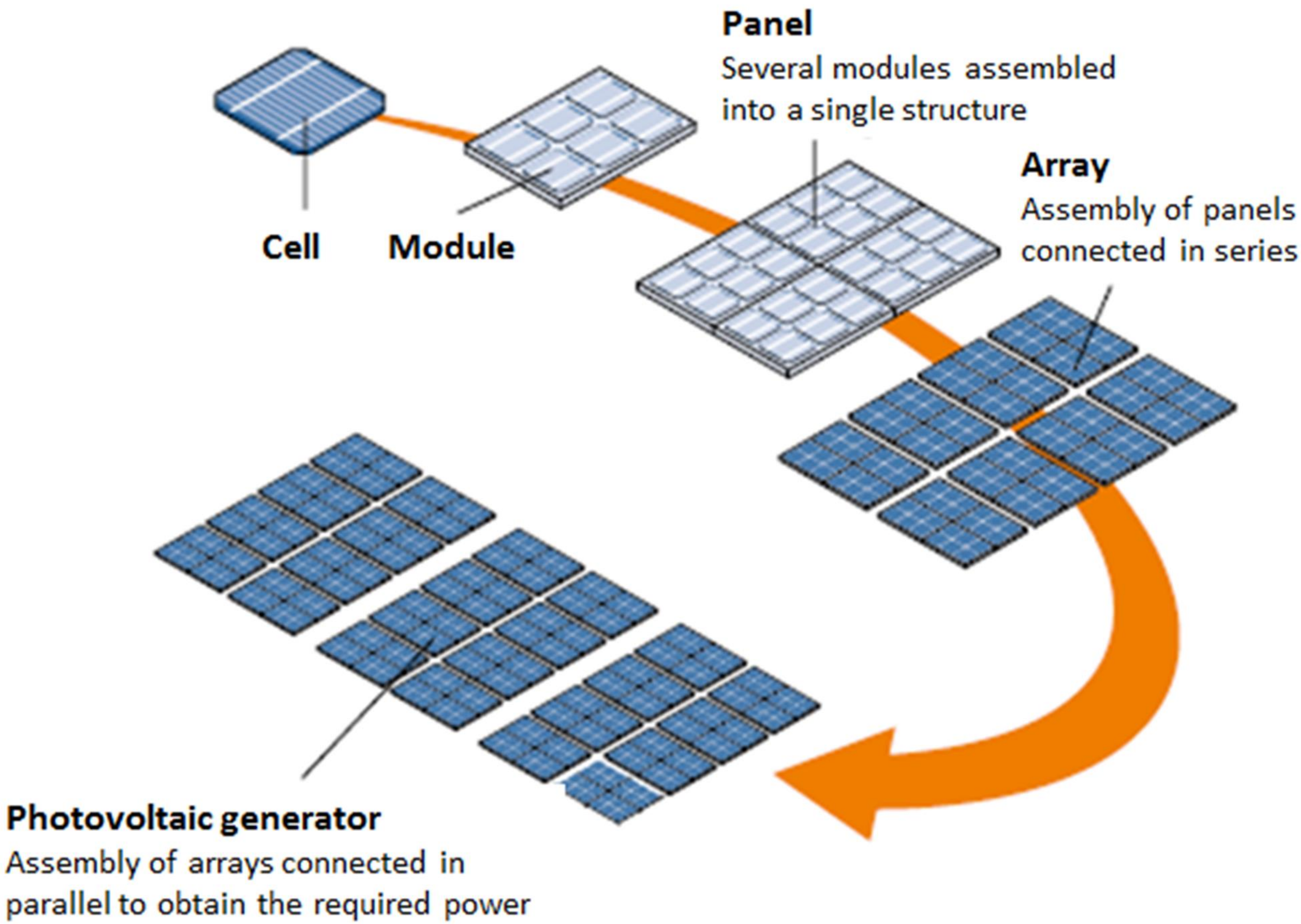
When sunlight shines on a photovoltaic cell, photons of light strike the surface of the semiconductor material and liberate electrons from their atomic bonds.

During manufacture certain doping chemicals are added to the semiconductors composition to help to establish a path for the freed electrons. These paths creates a flow of electrons forming an electrical current which starts to flow over the surface of the photovoltaic solar cell.

This electron is attracted by a neighboring positively charged hole.

Electricity is thus produced as a result of the flow of electrons triggered by Photons.




Panel
Several modules assembled into a single structure
Cell
Module
Array
Assembly of panels connected in series
Photovoltaic generator
Assembly of arrays connected in parallel to obtain the required power

A solar cell is the basic semiconductor device that converts light energy into electric energy. Solar cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels.

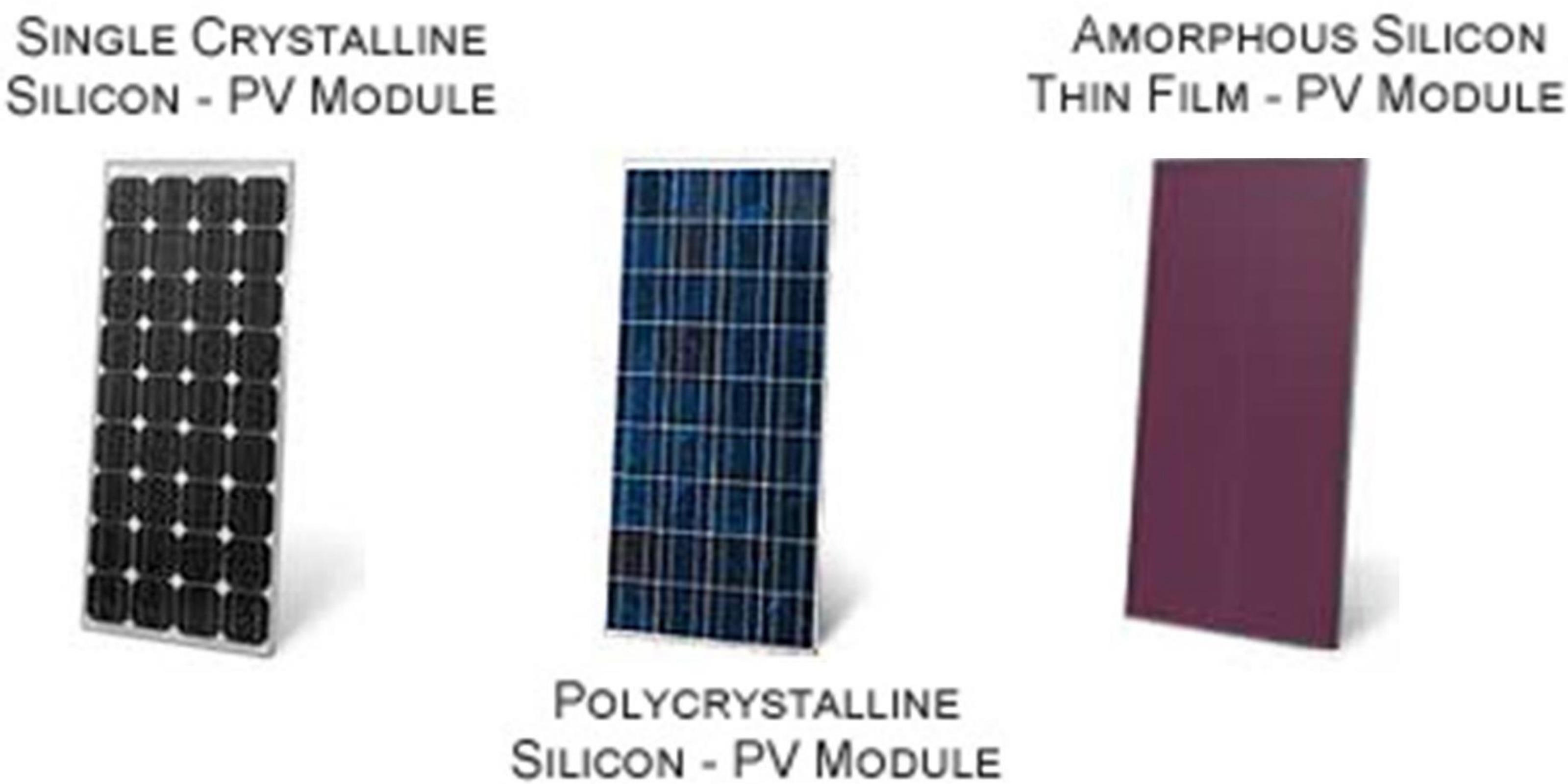
Photovoltaic module consists of PV cell circuits sealed in an environmentally protective laminate and are the fundamental solar PV units available to customers. (Usually in a module 36 cells are connected together)

Panel is a group of modules (containing usually 2-3 modules) that can be packaged and pre-wired off-site.

A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels

PV types

1) Monocrystalline silicon solar panels
2) Polycrystalline (or multi-crystalline) solar panels
3) Amorphous/thin film solar panels



1) Monocrystalline silicon solar panels

They are produced from a single crystal of silicon (grown from highly pure molten silicon). This crystal is then cut into thin wafers between 0.2mm and 0.3mm thick, which then form the basis of the solar PV cell. These solar PV cells are the most efficient, however, they also tend to be the most expensive to produce. They are rigid and are mounted in a rigid frame for protection.

Advantages

- They have the highest level of efficiency at 15-20%
- They require less space compared to other types due to their high efficiency
- Manufacturers state that this form of solar cell lasts the longest, with most giving them a 25-year warranty
- They perform better in low levels of sunlight, making them ideal for cloudy areas

Disadvantages

- They are the most expensive solar cells
- Increase in temperature affect on the efficiency
- There is a lot of waste material when the silicon is cut during manufacture

2) Polycrystalline silicon solar panels

They are made from a slice cut from a block of silicon and contain multiple silicon crystals. This gives them a blue marbled appearance (rather than the much darker color of Monocrystalline solar PV cells). These solar PV cells also need to be stored in a rigid protective frame

Advantages

- The manufacturing process is cheaper and easier than the Monocrystalline cells
- It avoids silicon waste
- More attractive in warmer areas because of high temperatures have less negative effects on efficiency compared with Monocrystalline cells

Disadvantages

- They need more space
- Less efficient due to low levels of silicon purity.

3) Amorphous/thin film solar panels

They are a type of ‘thin film solar cells’ and are made from a thin film of amorphous (non-crystalline) silicon. The silicon material is not structured or crystalized on a molecular level, as many other types of silicon-based solar cells are.

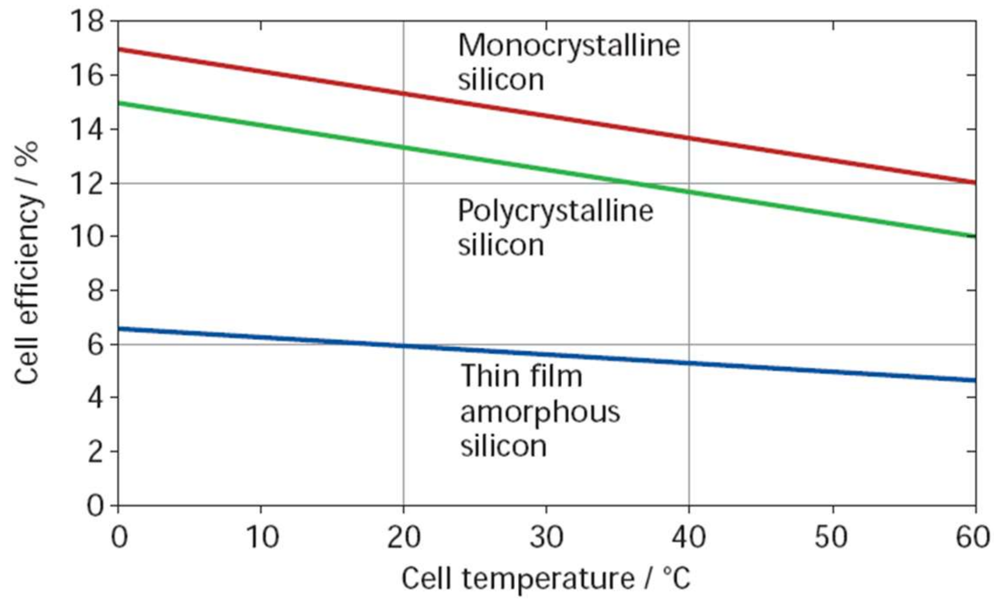
Advantages

- Lower manufacturing costs, which makes these cells very cost competitive.
- Requires much less silicon.
- Flexible and lightweight enables us be more creative when it comes to applications
- Perform relatively well under poor lighting conditions and are not affected as much by shading issues

Disadvantages

- Have lower efficiency rates
- They need much more space

CELL EFFICIENCY AS A FUNCTION OF TEMPERATURE



Optimum weather conditions

Solar irradiance – 1000W/m^2

Temperature – 25ºC

Air mass – 1.5

Watt peak (W_p) : is the maximum power or output of a module

A 60W_p module can produce a maximum of 60W under the above conditions.

A PV module will always produce a bit less than its peak power, especially in hot climates.

At temperatures greater than 25°C (temperature of the cell itself), power output will decrease by 0.5% for each degree rise in temperature of the PV module.

Example:

Determine the loss in output from a 60W_p PV module operating at a temperature of 50°C.

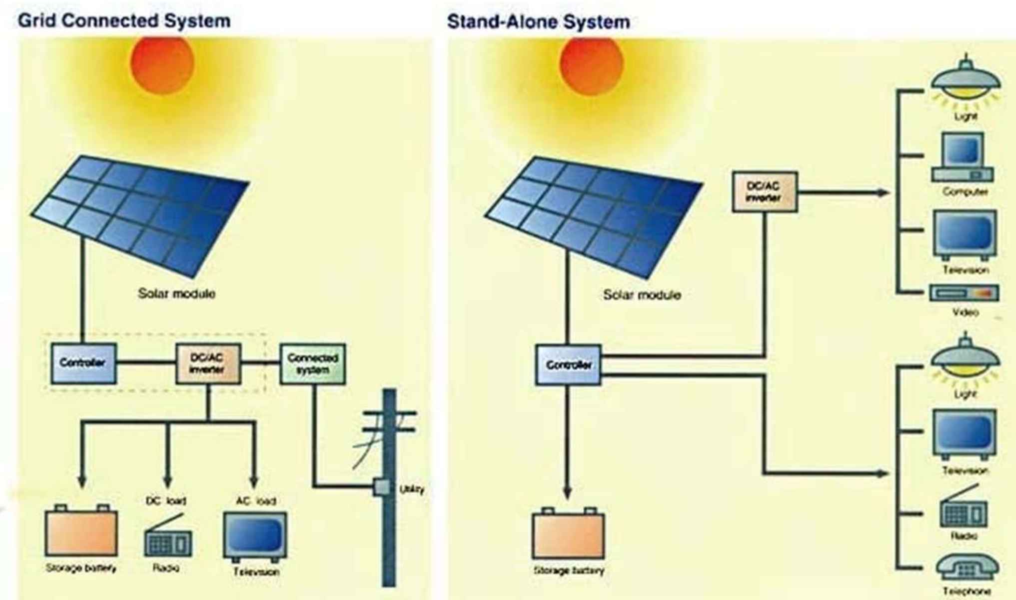
Loss in output = 60 x 0.005 x (50-25) = 7.5 W

Solar photovoltaic systems types

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. The two principal classifications are:

1) **Stand-Alone System**
2) **Grid-connected system**

The primary difference between the standalone and grid connected systems comes from the storage feature, which is direct consequence of their connection with the grid.



While the standalone PV systems usually have a provision of energy storage or deficit energy produce by the PV source in grid connected systems is supply or drawn from the grid.

Solar photovoltaic systems components

1) Charge controller (CC) or regulator

- It regulates the fluctuating voltage (due to cloud cover, rain etc) from solar PV to protect the battery unit.
- Provide information and warnings to the user on the state of the system’s battery, PV array currents and load currents.
- Protects a battery from overcharging and complete discharging.
- Sometimes provide secondary functions such as disabling lighting circuits during the hours of daylight.
- Prevents backflow (with the help of a backflow resistor) of current to PV panel.

2) Inverter

- It converts DC (direct current) into AC (alternating current)
- It is required to run any mains appliance
- The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as your battery.

- Inverter size should be 25 - 30% bigger than total Watts of appliances

3) Batteries

They are needed to store energy and they are the most vulnerable part of the PV system.

They are usually specified as voltage and capacity in Amp-hours (E = V x capacity)

A 12V 100Ah battery stores up to 1200 Wh, enough energy to run a 10W light bulb for 120hours

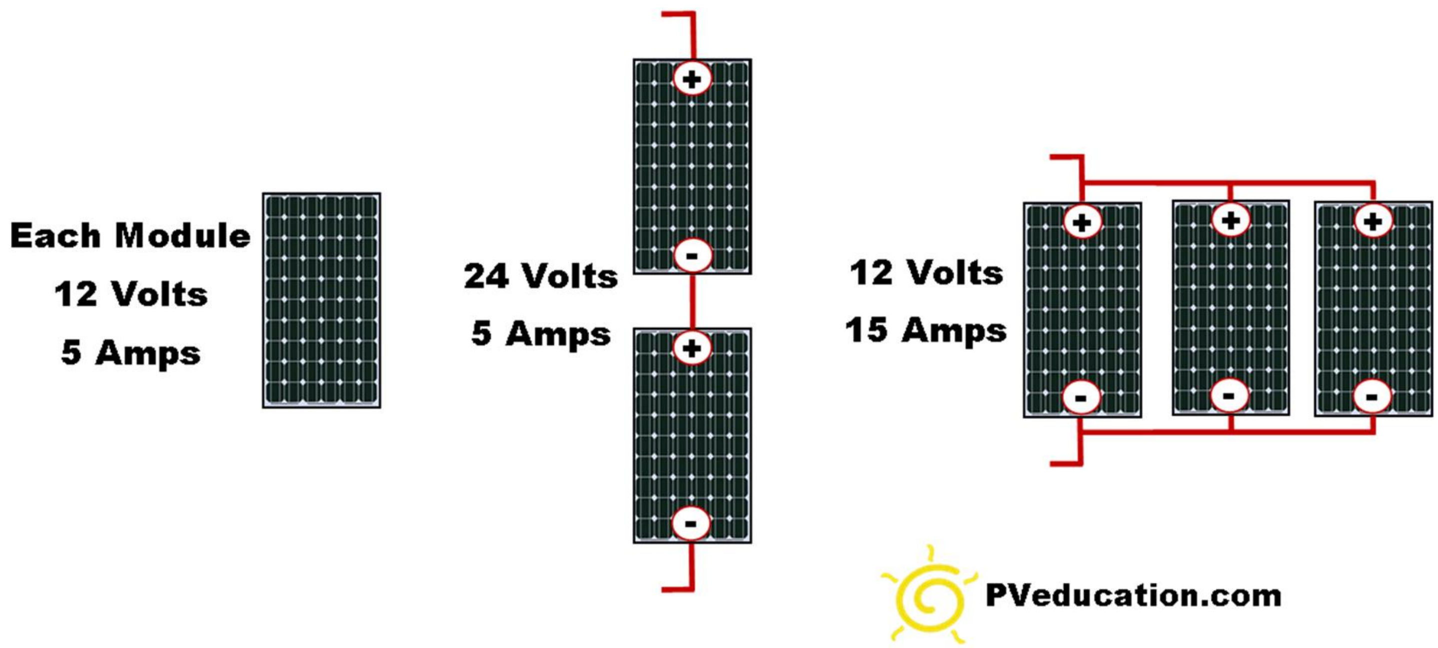
A state of charge (SOC) of 100% corresponds to a completely charged battery and an SOC of 0% corresponds to a completely discharged battery.

Depth of discharge (DOD) is the converse of SOC. If a battery has a DOD of 80% this corresponds to a SOC of 20%.

DOD + SOC always equals 100%.

Series and parallel connections

PV modules can be connected in series or parallel depending upon the battery/load requirements.
For example, 12V modules should be connected in parallel if the battery voltage is also 12V.
If the battery voltage is 24V, these panels are to be arranged in series to deliver 24V power to the battery.



Orientation of PV modules

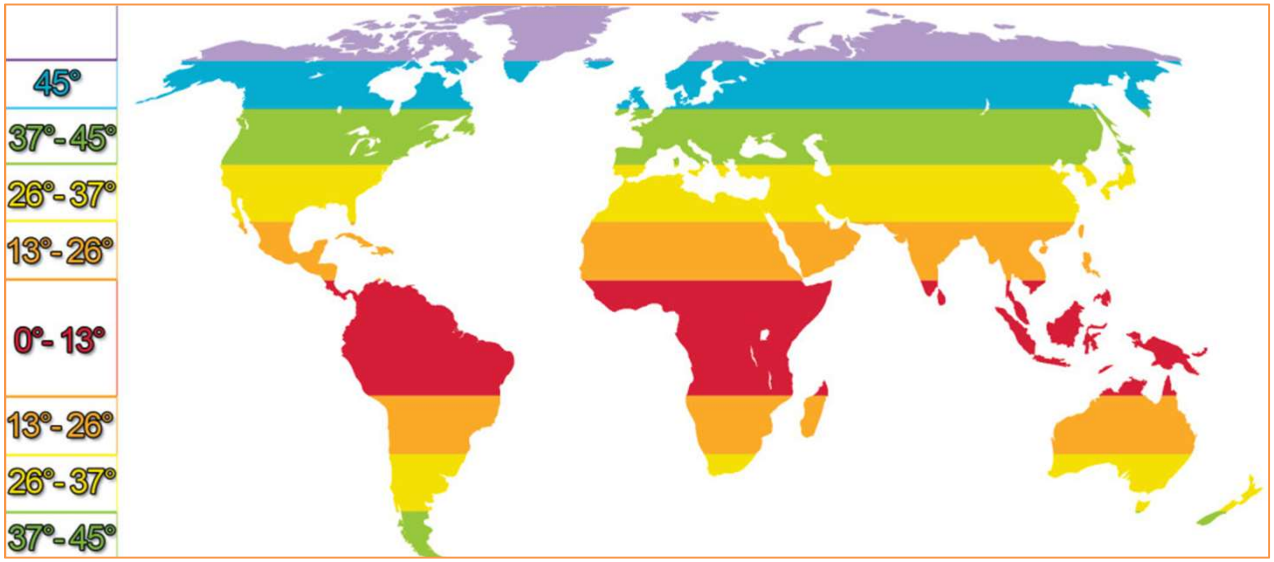
1- Fixed tilt angle

For panels that you will want to use all year and not have to touch once they are installed, you will want to install at a solar panel angle optimized for just that.

On the Picture below is a easy to understand map. Showing with clear colored lines what is your most optimal angle for your solar energy installation.

For a more exact tilt angle you will need to make a little calculating as follow:

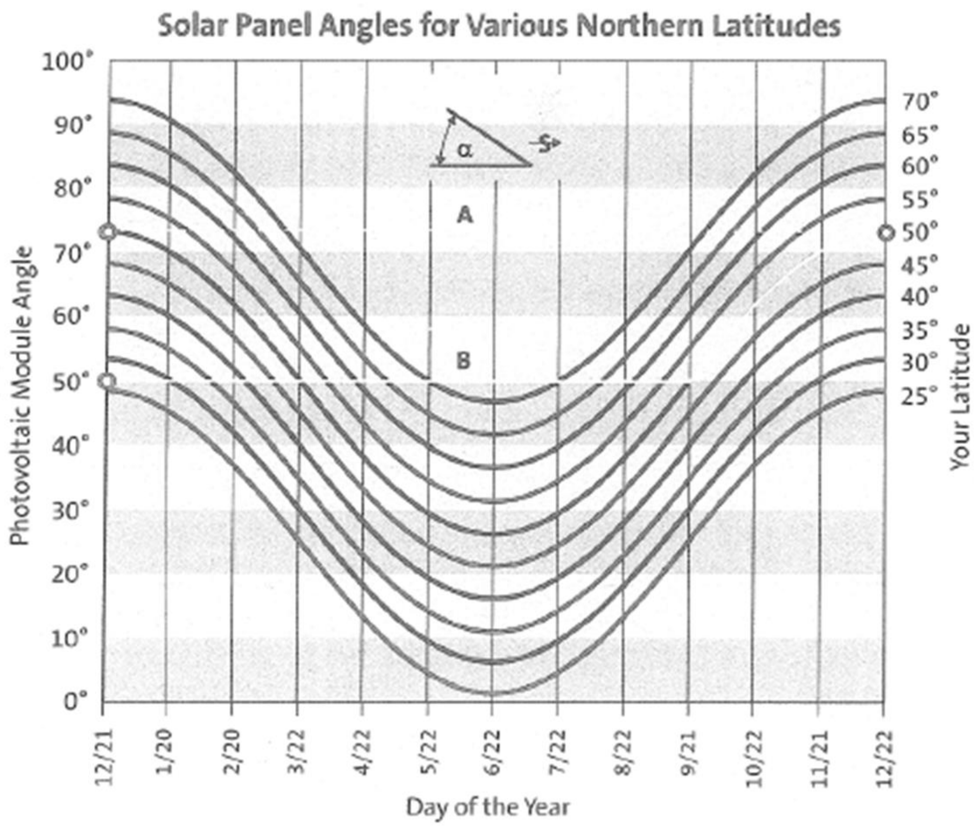
- for a latitude up to 25° take your latitude and multiply it by 0,87.
- for a latitude between 25° to 50° take your latitude multiply by 0,87 after that you will add 3,1 degrees.
- for a latitude over 50° the most ideal angle will end up being approximately 45° degrees.



__2- Movable and adjustable solar panels__

If you would like to get the absolute best performance from your solar panels you should put them up on movable scaffolding, or on special movable panel holders or frames. This way you could adjust the tilt angle and direction of the solar panels to an optimal level.

Adjusting the tilt four times a year is often a good compromise between optimizing the energy on panels and optimizing time and effort spent in adjusting them.



Solar PV system sizing

1. Determine power consumption demands

The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system as follows:

1.1 Calculate total Watt-hours per day for each appliance used

Add the Watt-hours needed for all appliances together to get the total Watt-hours per day which must be delivered to the appliances.

1.2 Calculate total Watt-hours per day needed from the PV modules

Multiply the total appliances Watt-hours per day times*1.3 (the energy lost in the system) to get the total Watt-hours per day which must be provided by the panels.

2. Size the PV modules

Different size of PV modules will produce different amount of power. To find out the sizing of PV module, the total peak watt produced is needed. The peak watt (W_p) produced depends on size of the PV module and climate of site location.

2.1 Divide the total peak watt by average annual solar insolation hours/day

Assume the average annual solar insolation is 5.5 $kWh/m^2/day$ and the solar irradiance is 1000 W/m^2.

2.2 Calculate the number of PV panels for the system

Divide the answer obtained in item 2.1 by the rated output Watt-peak of the PV modules available to you.

Increase any fractional part of result to the next highest full number and that will be the number of PV modules required.

3. Battery sizing

3.1 Calculate total Watt-hours per day used by appliances.

3.2 Divide the total Watt-hours per day used by cables and inverter efficiency for battery loss.

3.3 Divide the answer obtained in item 3.2 by depth of discharge (DOD).

DOD is an alternate method to indicate a battery's state of charge (SOC). The DOD is the complement of SOC: as one increases, the other decreases. As a battery may actually have higher capacity than its nominal rating, it is possible for DOD value to exceed the full value (e.g.: 55 Ah or 110% for a 50 Ah one).

3.4 Divide the answer obtained in item 3.3 by the nominal battery voltage.

3.5 Multiply the answer obtained in item 3.4 by days of autonomy to get the required Ampere-hour (Ah) capacity of deep-cycle battery.

Days of autonomy (DA): the number of days that you need the system to operate when there is no power produced by PV panels

Battery Capacity (Ah) $= \dfrac{Total\ watt * DA}{Battery\ voltage * DOD * Eff_{\ inverter} * Eff_{\ cables}}$

Example: Design a PV system for a house has the following electrical appliance usage:

Appliance	Wattage (Watt)	Quantity	House usage (hour)
Energy saver	18	1	4
Fan	60	1	2
Refrigerant	75	1	12

Knowing that the system will be powered by 12Vdc , 130Wp PV module. The targeted day of autonomy is 3 days and the allowed battery DOD is 60%, and the efficiency of the inverter and cable are 90% and 94% respectively.

Solution :

1. Determine power consumption demands

Total Watt-hours per day= (18*1*4) + (60*1*2) + (75*1*12)= 1,092 Whr/day

Total PV panels energy needed = 1,092 x 1.3 = 1,419.6 Whr/day

2. Size and number the PV panel

Total W_p of PV panel capacity needed = 1,419.6/ 5.5= 258.1 W_p

Number of PV panels needed = $\frac{258,10}{130}$ ≈ 2 **>>>** then 2 panels are required

3. Inverter sizing

Total Watt of all appliances = 18 + 60 + 75 =153 W

For safety, the inverter should be considered 25-30% bigger size

The inverter size should be = 153*1.3 = 198.9 W or greater

4. Battery capacity

Total energy of the batteries needed for this system = $\frac{1,092*3}{0.6*0.90*0.94}$ =6,453.9 Whr

Battery capacity = $\frac{6,453,9}{12}$ = 537.82 Ah

So the battery should be rated 12 V 600 Ah for 3 day autonomy. For 24 VDC input we need 300Ahx2 batteries or other suitable battery bank

Example:

If you know that the maximum investment = \$35,000, the available shade-free roof area = 51m^2 (L =8.5, W=6m) oriented due south with an inclination of 45°, the estimated net installed cost =\$5,500/kW_p, the selected cell type = mono crystalline (require 9m^2/kW_p) and where the site temperature range = -10°C to 40°C and the module operating temperature range = -10°C to 70°C.

Module specifications on the data sheet

Dimensions	L=1.61m, W=0.81m		
Maximum power	W_p		=165W_p
MPP-voltage	V_{MPP}	(at 25C)	= 35.35V
MPP-current	I_{MPP}	(at 25C)	= 4.67A
Open circuit voltage	V_{OC}	(at 25C)	= 43.24V
Short circuit current	I_{SC}	(at 25C)	= 5.10A
Voltage temperature coefficient	Tc	(V_{OC})	=-168.636mV/C
Current temperature coefficient	Tc	(I_{SC})	= 2mA/C
Power coefficient	Tc	(P_N)	= -0.42%/C

Find the maximum number of modules that can be installed and the possible operating voltage range for these modules?

1) The maximum number of modules that can be installed

Max. system that can be bought from the available investment = $\frac{35,000}{5,500}$ =6.36kW$_p$

Max. system the available roof area can have =$\frac{51}{9}$ = 5.67kW$_p$< 6.36kW$_p$

→ The largest possible system is within the budget limit!

No. of modules required = $\frac{5,670}{165}$= 34.4 modules

→ The initial estimate suggests 34 modules of a max. capacity 34 x 165 = 5.61kWp

Can 34 modules fit on the roof???

Modules arrangement / layout

Modules in landscape format:

Roof length/modules length = 8.5m/1.61m = 5.27

Roof width/module width = 6/0.81 =7.41m

Maximum modules = 5 x 7 =35 modules

Modules in portrait format:

Roof length/modules width = 8.5m/0.81m = 10.49

Roof width/module length = 6/1.61 = 3.73m

Maximum modules = 10 x 3 =30 modules

→ 35 modules thus can be used but in landscape format

2) The possible operating voltage range for the modules

Voltage design

Module operating temperature range = -10°C to 70°C
V_{OC} (at -10C) = 43.24 – (25+10)*-168.636/1000= 43.24V + 35(0.168636V) = 49.14V
V_{MPP} (at -10C) = 35.35V + 35(0.168636V) = 41.25V
V_{MPP} (at 70C) = 35.35V - 45(0.168636V) = 27.76V

→ The highest voltage V_{OC} will be at -10C i.e. 49.14V and the voltage range at MPP will be between (27.76V - 41.25V).

FUNDAMENTAL MEASUREMENTS

Capacity of battery (Ah) = current (A) x time (h)

Power (W) = voltage (V) x current (A)

Energy (Wh) = power (W) x time (h)

Maximum capacity of PV system (W_P) =No. of modules x max. power (W_P)

$$\text{Peak power } (W_P) = \frac{\text{Energy (Wh)}}{\text{solar gain (Wh)} * \text{efficiency}}$$