

# PASSIVE DESIGN

## Introduction

Passive Design regards the particular way to construct a building using the natural movement of heat and air, passive solar gain and cooling in order to maintain a good internal comfort. Through the use of passive solutions it is possible to eliminate, or at least reduce, the use of mechanical systems and the energy demand by 80% as well as the CO<sub>2</sub> emissions.

Building a passive house takes careful planning, which includes the introduction of five basic principles:

- orientation
- overhangs and shadings
- insulation
- double or triple glazing
- thermal mass

The Passive House Concept is defined as follows: *“A Passive House is a building in which thermal comfort [EN ISO 7730] can be guaranteed by post-heating or postcooling the fresh-air mass flow required for a good indoor air quality”*.<sup>(1)</sup>

The Passive House Institute in Darmstadt has developed several Passive House building techniques to suit the Central European climate. However, it would be wrong to directly apply all the passive techniques, especially those regarding insulation, windows and ventilation from the Central European example to other parts of the world.

The standards must be adapted to the climate and geographic situation. The local building traditions and the specific climatic conditions of each region must be analysed in order to achieve the best passive solution.

Integrating passive design solutions at the very early design stage add little or nothing to the cost of the building construction. Eventually these solutions help in reducing the CO<sub>2</sub> emissions from the building and the use of mechanical systems for heat up and cool down the house.<sup>(1)</sup>

## Theory

The Passivhaus standard for central Europe requires that the building fulfils the following requirements <sup>(2)</sup>

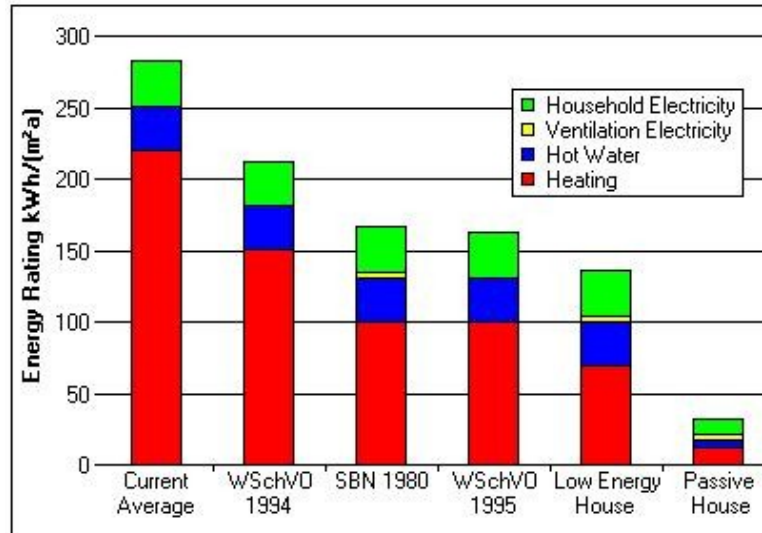
- The annual heating/cooling demand must not be more than 15 kWh/m<sup>2</sup> per year.
- Total primary energy (source energy for electricity and etc.) consumption (primary energy for heating, hot water and electricity) must not be more than 120 kWh/m<sup>2</sup> per year.

In order to achieve these standards it is necessary to follow the five basic design principles that help in reducing the energy demand till almost 80% compared to the conventional buildings.

Buildings designed to the Passive House standard require a well insulated building envelope with a ventilation system that can recover heat from the exhaust air.

In such a building, a conventional space heating system is no longer required and the small amount of space heating needed can generally be supplied through the ventilation air which is distributed throughout the building.

To achieve these low-energy targets the building design has to exceed the normal regulatory requirements for insulation and air tightness. Experience, mainly within Germany and Austria, has shown that it is possible and economic to build these particular kind of construction and that they can maintain good air quality and thermal comfort along the year. (3)



Comparison of Energy Ratings of Homes

WSchVO = German Heat Protection Regulation  
SBN = Swedish Construction Standard (5)

Following below in more detail the explanation of each passive design principle:

### Orientation

The first basic principle in a passive house is the orientation, in which the southern façade of the building should be oriented towards the equator in the northern hemisphere (and the northern façade towards the north in the southern hemisphere).

By facing the longer axis of the building in the east/west direction, the longer dimension of the home faces will be more likely to gain the maximum solar radiation. For that reason, areas which are most frequently used, such as the kitchen and the living room, must be located into this part of the building.

This orientation is also advantageous for summer cooling conditions because it minimizes the east-west façades to morning and afternoon sunlight.

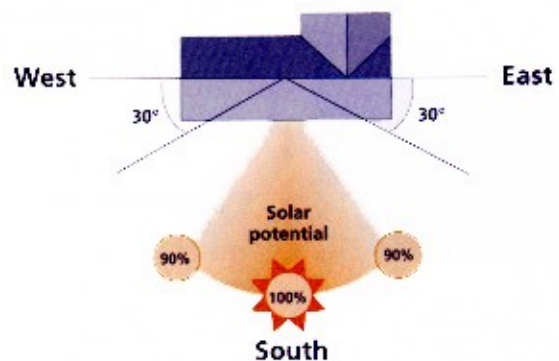
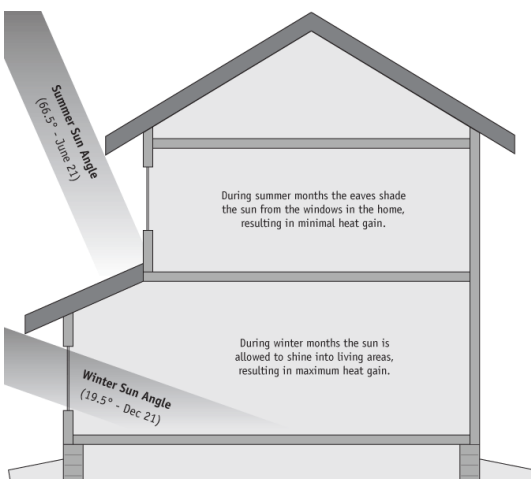


Fig: Orientation and solar gain

### Overhangs and Shading

Overhangs and shadings are important devices in a passive house because they help in reducing overheating during the summer season. Therefore, it is very important that the devices are properly sized. The southern façade through which the sun mostly comes inside must be correctly shaded, or equipped by sized overhangs, in order to prevent overheating and to keep the house cool during summer months. However, a careful design of the device must be made in order to guarantee that the size and sloped (if necessary) can meet the need to let the sun in during the winter and to shade the building during the summer. The type of shade and its degree is always linked with the position of the sun and the geometry of the building. For instance, simple overhangs are very efficient for shading the building in the south façade during the summer when the sun is high in the sky. However, this type of shading device is not efficient for the south-west façade at blocking the sun entering inside during morning and afternoon hours, when the sun is low in the sky. It is very important to understand that in summer the peak sun angles comes in June on the 21<sup>st</sup> during the solstice, but peak temperature and humidity come mostly in August. Therefore, include a fully shade south façade during the summer will also shade the window in autumn and spring, when actually the passive solar heat is needed for heat up the building and keep the house with a comfort temperature.

Having say that, for designing a proper shading device it is necessary to understand how the sun moves along the year and which effect its angles have on the building. The altitude and azimuth angles represent the position of the sun in the sky.

Because shading devices can have a huge impact on the building appearance as well as reducing the cooling demand, they must be considered and evaluated at the early stage of the design process, in order to be effective for both technical and visual aspect for being well-integrated in the whole architecture.

There are several type of shading devices, but it is very difficult to make a generalization of their design. However, some general recommendations have been listed just below:

- to control direct solar radiation in the south façade use fixed overhangs
- limit the number of east and west windows because they are very difficult to shade compared to the south side. Maybe some consideration of the surrounded landscape, such as type of tree that might be used to shade
- north façade can be out of shading as it receives very little direct solar radiation
- interior shading devices, such as Venetian blinds or vertical louvres, might be used in order to control glare, however exterior shadings must be included since the interior ones have already admitted the solar gain in. (4)

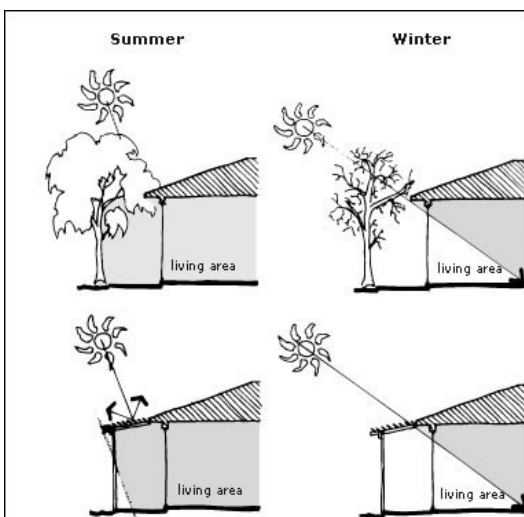
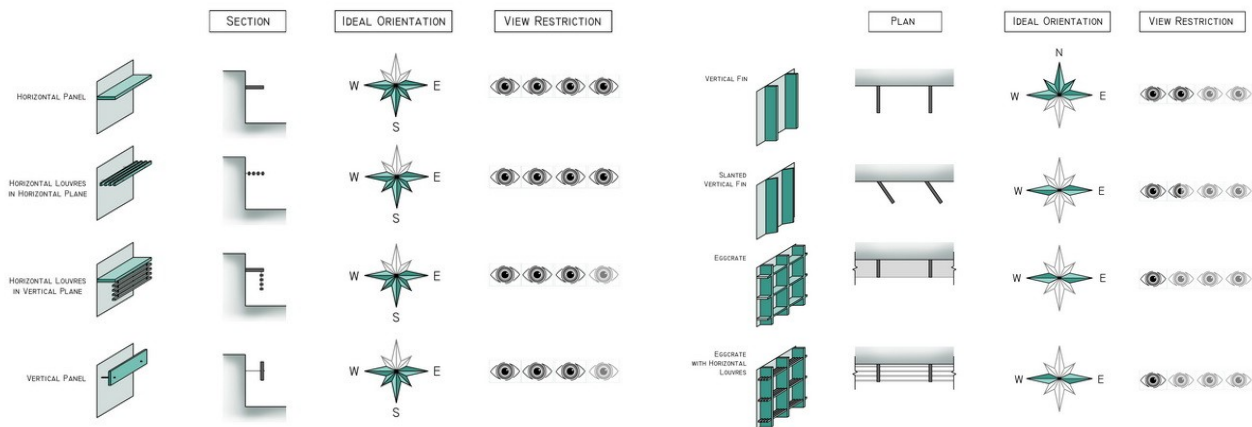


Fig: Shading concept

## Concept of shading devices



## Insulation

A well insulated building helps in reducing heat loss during the winter and keeping the house cool during the summer. Insulated materials, so called because they are poor conductors of heat, form a barrier between interior and exterior spaces, by means between warmed interior and cool exterior, and cool interior and hot exterior according to the season.

Since insulation is important in warm climate as well as in cold climate, less energy is required to heat houses in cold conditions or cool houses in warm condition which results in a good interior temperature along the whole year.

Regarding insulation, the heat loss through the construction (walls, floor, basement, ceiling or the roof) is represented by the thermal heat loss coefficient or U-value, which represents how much heat in Watts is lost per m<sup>2</sup> at a standard temperature difference. Insulation materials are normally used in walls, floors and roof because they work by resisting heat flow, which is measured by an R-value (the higher the R-value, the greater the insulation).

The R-value changes according to the material type, its density and thickness and it is affected by thermal bridging. *Thermal bridging* represents the unwanted heat flow that comes inside the building through joints, studs and rafters. Therefore, in order to achieve the best insulation thermal bridges must be avoided.

Therefore, the building envelope must be greatly insulated, especially to what concern external structural walls, because by doing so:

- thermal bridges are eliminated because there are no longer interruptions caused by floor slabs
- heat gained from the sun is dissipated in the cavity and ventilated throughout openings
- temperature swings are drastically reduced

There are many type of insulation material which might be used in a passive house, such as cellulose, cotton, fiberglass, polyurethane, mineral wool, perlite and sheep's wool.

- Cellulose Insulation is made by plant fibre and paper products (recycles as well) that might be used in walls and roof cavities in order to separate the internal climate from the exterior and it is also an eco-friendly insulation material. Cellulose insulation has very high thermal performance because it provides an R-value of circa R-3.5 per inch of thickness. (5)



Fig: Cellulose Insulation

- Cotton insulation is made from post-industrial recycled cotton clothes, such as jeans and it comes in batts that are comparable to fiberglass in ease of installation, fire resistance, and energy efficiency. It actually requires less energy for being produced compared to other insulation materials. It has good thermal capacity because it can provide a R-value of R-13 for standard wall with a 3 1/2-inch-thick "bat" of cotton. (6)



Fig: Cotton Insulation

- Fiberglass insulation is the most common insulated material used in construction. It is characterized for having good insulation properties and it is made by molten glass and shaped in batts or rolls placed in sheets. Fiber glass insulation has a R-value that ranges from R-11 to R-38. (7)



- Polyurethane insulation is formed by panels with a polyurethane foam core sandwiched between two layers of roofing felt (or aluminum foil) and it has extremely low thermal conductivity. (8)

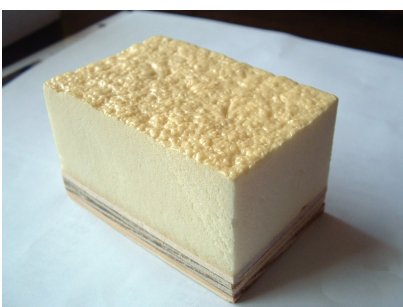


Fig: Polyurethan

- Mineral wool insulation is made from molten glass, stone or slag that is spun into a fiber-like structure and it has a higher density, which could provide also a good acoustical insulation compared to fiberglass. However, since this particular insulated material is not still so common in the construction sector, its price is quite often higher than than the price of fiberglass. (9)



Fig: Mineral Wool Insulation

- Perlite insulation is used as a loose-fill insulation in masonry construction. It is poured into the cavity of concrete block providing thermal insulation, fire protection as well as reducing noise transmission. Perlite is not an expensive insulation material and it is easy to install. (10)



Fig: Perlite Insulation

- Rockwool insulation is a particular insulation made from actual rocks and minerals and it has the great ability to block the flow of sound and heat. It has an R-value of R-30 (heavier than fiberglass). (11)



Fig: Rockwool Insulation

- Sheep wool insulation is one of the most effective eco-friendly and renewable insulation material. It is breathable, by means that it can absorb and release moisture without reducing thermal performance compared to fibreglass. It can come in the shape of batts or rolls and it has an R-value approximately between 3.5 to 3.8 per inch of material thickness. (12)



Fig: Sheep wool insulation

### *Windows*

Glazed surfaces play an important role in a passive house because they serve as solar collectors bringing in light and heat while also providing natural ventilation.

The way how windows are positioned, in relation to the landscape, the wind and the movement of the sun can effectively increase the energy efficient and provide a good internal comfort.

The basic role regarding windows in a passive house is the southern position because it allows them to collect warm solar energy when heat is needed, or vice versa to let fresh air in when is needed.

Locating the majority of glazed surfaces on the southern façade helps in achieving the maximum solar gain and reduce the ones in the northern façade helps for the insulation of the building against winter cold.

Also the type of glazing is a key feature considering insulation issues. For that reason, the Passive House standards recommend to use double (or triple if needed, according to the location) glazing which helps in reducing heat losses through the windows. (12) The glazing must have a low emissivity glass (low-e), which includes a metal oxide coating, in one of the internal panes, next to the gap. Through that, the glazing can let in the sunlight and heat, while at the same moment blocks the heat from leaving the interior space, otherwise there would be heat loss.

- Double glazing: has two layers of glass with a gap between them of around 16 mm (argon gas filling).
- Triple-glazing: has three layers of glass, with argon or krypton gas filled between glazings, and low-conductance edge spaces. It has a very low heat loss rate (low U-factor). It will give greater sound insulation and energy saving

In terms of U-values, the main difference that exists between a good double-glazed and triple-glazed is not so huge. Normally it is just over 1W/m<sup>2</sup>K to what concerns a double-glazed, and circa 0.8W/m<sup>2</sup>K for a triple. However, the Passive House Institute refers to the U-value speaking about the whole window, which means the glazing parts included the frame that does not have to exceed 0.85 to 0.70 W/m<sup>2</sup>K.

Regarding the frame type, it can be made from different materials, such as wood, aluminium or pvc. However, the better choice for the frame material seems to be wood, because it is environmental-friendly, requires little energy to manufacture and it has good insulation properties.

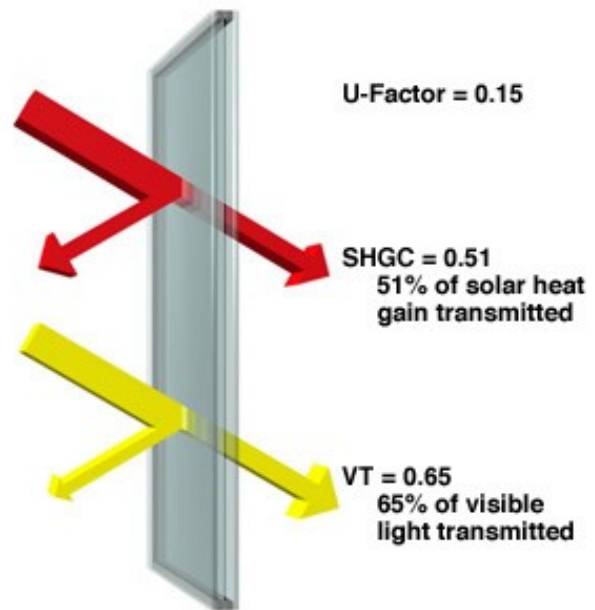
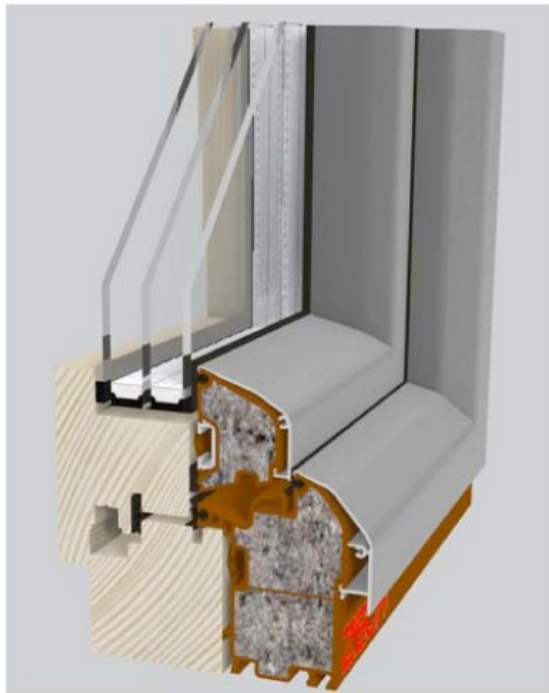


Fig: Typical triple-glazing

### *Thermal mass*

The concept of thermal mass regards a solid or liquid material which absorbs and store warmth and releases it when is needed. By means that, the excess solar heat gain can be stored and used when the sun is not shining or where there is no sun at all, as during the night. It actually works as a battery because during the summer season it absorbs heat keeping the house comfortable, while in winter it stores the heat gained and gives it back at night keeping the house warm. Basically in a passive house a thermal mass can work in two ways: by direct solar gain or by indirect solar gain.

A thermal mass could moderate the temperature of internal spaces, reducing the need for mechanical cooling and winter heating requirements and the most cost effective method normally is to take advantage of thermal mass in the building structure.

In order to let the thermal mass work correctly, it must be integrated with other passive technique, such as insulation and passive solar gain, in order to moderate the internal temperature and minimize the need for mechanical cooling as well as reducing winter heating requirements.

Thermal mass can be a brick, tile or thick concrete floors (called *Solar Slab*). It can also be a large brick or stone internal fireplace or an interior wall made of adobe or brick. A masonry or concrete wall (called a *Trombe Wall*) or water filled containers (called a *Tube Wall*) can also be used to absorb heat and cool. This type of system must have southern exposure and receive direct sunlight for working properly.

The main properties of a thermal mass are its high density (the more dense the material the higher its thermal mass), good thermal conductivity (it must allow heat to flow through it) and low reflectivity (dark or textured surfaces absorb and release more energy than light or reflective surfaces).

Below a brief list of some thermal mass material that might be used in a passive house according to their thermal capacity (volumetric heat capacity, KJ/m<sup>3</sup>K):

- water = 4186 KJ/m<sup>3</sup>K
- concrete = 2060 KJ/m<sup>3</sup>K
- sandstone = 1800 KJ/m<sup>3</sup>K

- compressed earth blocks = 1740 KJ/m<sup>3</sup>K
- rammed earth = 1673 KJ/m<sup>3</sup>K
- brick = 1360 KJ/m<sup>3</sup>K
- earth wall (adobe) = 1300 KJ/m<sup>3</sup>K

High thermal mass materials, as brick or concrete, work well as thermal storage for both heat and cold as they heat up and cool down quite slowly.

In warm climate conditions, such as in the Mediterranean countries, high thermal material should be used in order to help the building structure operate as a “thermal storage” and it must be combined with proper insulation of the external envelope. This combination reduces internal temperature and guarantees thermal comfort conditions during the summer months.

Thermal mass under door is normally a concrete underneath insulated slab that is in direct contact with the ground, or other options include brick or suspended concrete slab, with external insulation. The actual location and area needed for the integration of thermal mass into the building structure requires attention to solar architecture as well as heat flow engineering details. (13)



Fig: How

thermal mass works

## Key Points

The Passive House Institute has developed a list of specific features for a passive house, regarding in particular values of insulation, glazing, thermal bridge, air tightness, appliances. The institute has given some specific value for each categories in order to meet the requirement of keeping the space heating/cooling at 15 kWh/m<sup>2</sup>/year or less and the total primary energy demand at 120 kWh/m<sup>2</sup>/year. The values are:

- thermal heat loss coefficients of external walls, roof and slabs to the ground: U-Value = 0.1 to 0.15 W/mK
- thermal bridge free construction: coefficient lower than 0.01 W/mK
- air tightness n<sub>50</sub>-airchange-values must be less than 3 h<sup>-1</sup>, with ventilation systems 1.5 h<sup>-1</sup>
- windows must have high R-Value (low U-values, typically 0.85 to 0.70 W/m<sup>2</sup>K including the frame). These type of windows are usually made by the combination of triple-pane insulated glazing (with low-emissivity coating, high solar heat-gain coefficient, argon or krypton gas filled in , and 'warm edge' insulating glass spacers)

- mechanical heat recovery ventilation system in order to maintain air quality and to recover enough heat to distribute with a conventional central heating system. In addition, in a cold climate condition the warmed air works also well in preventing from the formation of ice in the heat recovery system's heat exchanger
- using high-efficiency electrical appliances, such as solid-state lighting and fluorescent lamps to minimize the total primary energy demand. (14)

## **Passive Standards in a warm climate**

Most of the Passive House examples are available from Central Europe, which is characterized by a temperate/cold climate, with very cold winters and pleasure summers. However, nowadays the main challenge is to verify if it is possible to apply the the passive approach in a warmer climates of South Europe.

Like in Central Europe, even in most of the Mediterranean climates the space heating is the major energy demand in addition to the strongly growing of air cooling requirement. For instance, to what concern the winter season in southern Europe there is a higher level of solar radiation compared to northern Europe. Therefore, a single glazing is already enough to achieve the solar gain on the south façade. However, for a good internal thermal comfort a double low-e glazing seems to be the right option, while triple glazing is not recommended from the south of the Alps. Even the building orientation towards the sun plays an important role as well in the Southern European countries, because it can rise the solar gain and considerably reduce the heating demand.

Thermal mass can significantly effect the heating demand as well as providing natural ventilation during the summer.

To what concern the cooling demand, a good thermal insulation can provide high thermal comfort during the summer period in all the Mediterranean climate zone, in particular if it is applied in the roof in order to reduce the fluctuations of the temperature. The building shape must be compact and the use of double low-e glazing protects also against heat transfer in summer.

However, a proper shading device is indispensable to control solar access, but a careful designing must be done in order to avoid extra heat demand during the winter.

An addition option to reduce the cooling demand in such kind of warm climates is to use the so-called cool colours for the exterior walls, by means colours with low heat absorption to reduce the solar load during the summer period. In fact, even if the building is well insulated, the integration of such painted colours can quite reduce the cooling demand and the peak cooling load. (15)

### ***Reflective Coating***

The heat reflective coating paint is an important tool to use in order to reduce the cooling demand because inside the paint there are small particles, often made in glass, that are excellent at reflecting the sun's rays. By cutting the majority of these rays from letting inside the building, it is possible to achieve a reducing of the cooling demand and the cost of the bills. Some type of heat reflective paints can also act as a natural insulator and they can be used in the exterior walls as well as in the roof to re-radiate 90% of solar infra-red and 85% of ultraviolet rays back into the atmosphere, which effectively stop the heat transfer through the exterior walls or the roof. Working as an insulation, the reflective coating paint can actually help a lot in reducing the overheating during the summer season in most of the warm countries. (16,17)

## Renewable Energy Systems Integration

Another important issue regarding sustainable building is the integration of renewable energy systems into the building at the very early stage of the design process. By means that, it is very important to consider which technologies will be more suitable according to the site conditions and the building structure.

A renewable system integrated into the building, such as PVs and Solar Collector, represents a good practice that has many advantageous aspects, such as:

- it works as both building envelope material and energy generator
- it saves in materials and energy costs
- it drastically reduces CO<sub>2</sub> emissions
- it actually adds architectural value to the building as well as providing a public expression of sustainable commitment.

Basically, a integrated renewable system into the building is used to replace conventional materials on the building envelope, such as the roof, façade or skylights. The integrated systems is increasingly becoming a good practice because the initial cost can be offset by reducing the amount of cost spent for producing and installing building materials. In fact, the systems, mostly PV and in some case Solar Panels, are used to construct part of the building and they are available in several forms. (18)

According to the envelope in which they will be integrated, they can be available in different types, such as:

- a thin film solar cell integrated into a flexible polymer roofing membrane suitable for flat roofs
- modules roof tiles, solar shingles and panels normally used in pitched roofs
- solar modules mounted on the façade of the building
- (semi)transparent modules used to replace architectural components made with glass, such as windows or skylights, that can work as well as shading.



Fig: Thin film solar cell integration for flat roofs



Fig: Integration module roof tiles



Fig: Integration module roof tiles



Fig: Integration of pv into a metal structure



Fig: Integration of pv into façade

Fig: Integration of PV as shading

The International Energy Agency IEA has fixed some architectural parameters to better define an integrated energy system into the building. In particular to what concern the integration of PVs , it suggests that the system:

- must be naturally and architecturally integrated into the building context
- must be adapted at the building modular system and being in harmony with it in order to create a well material composition. (19)

A well designed integration means that the renewable energy system is turned into a part of the roof/façade, becoming a weatherproof skin of the building itself and working as insulation as well. Building Integration PV system(BIPV), for example, is becoming a common practice because it can drastically reduce the overall cost of the construction because the panels are perfectly integrated into the building and mounting racks are no longer required. The system as also the advantage to be turned into an aesthetically pleasing energy generator system that is does not require roof penetration and that can give a new image to the whole building.

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