# Spread of Innovative Solutions for Sustainable Construction

## Handbook

## 5 Energy conscious architecture - passive solutions

IS-SusCon

Co-funded by the Erasmus+ Programme of the European Union

# 5 Energy Conscious Architecture - Passive Solutions

A demand of heating and cooling energy of buildings can be reduced by passive solutions. In contrast to active methods, these solutions use only the building elements and the energy of the Sun without the need for any additional energy sources. It is a generally accepted approach that energy efficiency should be the first step towards a low energy house: saved energy is the cheapest energy. It is only worth installing active renewable energy systems if demand is already reduced by passive means.

Looking at the whole life cycle, passive measures also have the advantage that their embodied impact is usually very low or even zero – caused by the production and manufacturing of the materials-, while their saving contribution in the operational energy demand of the building. For example, a favourable building shape or a well-chosen orientation has no additional embodied impact, while thermal insulation has a relatively low impact. (see chapter 4.3 for more details).

The applicability of passive solutions depends on the climate. There are many different climate classification systems but we will use a simple and practical classification of Europe, which depends on the need for heating or cooling:

- Cold (heating-dominated climates), e.g. Finland
- Moderate (heating- and cooling-dominated (mixed) climates), e.g. Hungary
- Warm (cooling-dominated climates), e.g. the southern part of Italy

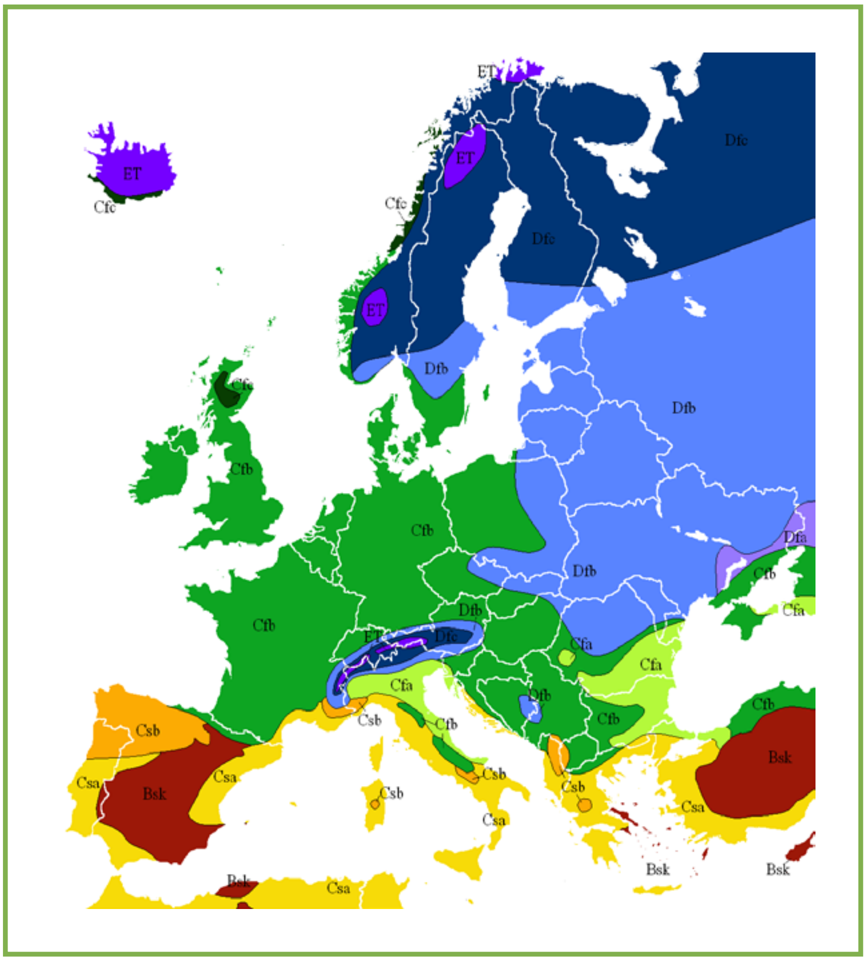



*Figure 9: Climates in Europe according to the Köppen-Geiger climate classification*[40]

Passive heating solutions are efficient in heating-dominated climates, passive cooling measures in cooling-dominated climates, while both are relevant in mixed climates.

## 5.1 The heat balance of a building

The heat balance of a building is basically the balance between heat losses and gains. In buildings, we would like to keep a certain temperature, which is called the set temperature in order to provide good thermal comfort for the residents. If heat losses are equal to heat gains, we do not need any heating. But if losses exceed gains, heating system will be needed to provide the missing energy.

40 Source: https://commons.wikimedia.org/wiki/File:Climates_of_Europe.png

Every building has heat gains. As heat gain covers a certain ratio of heat losses, we do not need to turn on the heating system immediately if the daily mean external temperature drops below 20 degrees. For example, in an average building in Hungary, most heating systems start to operate when the external temperature is below 12 °C for three consecutive days, which happens around the middle of October, because solar and internal gains cover the temperature difference. In a well-designed, low energy building, heat gains will cover a much higher ratio of losses, which leads to a shorter heating season and a lower heating energy demand. This can be achieved with a dual strategy: reducing heat losses and utilising as much solar energy as possible. Both are important in the design of an energy conscious building.

In the following chapters, we present passive heating and passive cooling solutions.

**Heat balance of a building**

Considering the case of heating, losses are due to transmission and ventilation, while the positive side of the balance is the sum of solar radiation and internal gains:

- Transmission losses arise as heat conduction and heat transfer through the structures surrounding of the building and thermal bridges
- Ventilation losses are caused by the exchange of warm internal air with external, colder air due to the need for fresh air
- Solar gains originate from solar radiation that enters the building through transparent (and non-transparent, opaque elements ) elements
- Internal heat gains are the heat outputs from internal sources whose main purpose is not heating, such as people, appliances and equipment
- Furthermore, the actual heat balance is influenced by the change of stored heat stored in the mass of building elements: heat is either absorbed or released depending on the conditions. For a longer period, the change in the stored heat is zero if changes are periodic.
- If losses overpass gains, the missing energy is given by the heating system.

The energy balance is the algebraic sum of these items.

## 5.2 Passive heating solutions

Passive heating solutions reduce heating energy demand, which is especially important in heating dominated climates. In these climates, 'defensive' strategies are used to prevail: window sizes were kept small to reduce heat losses. Recognizing the importance of energy saving and the rapid technological development of glazing in the last decades has led to the advent of solar architecture: buildings are designed to harness the energy of the Sun through large, well-oriented glazed facades and heavy structures which can store a large amount of heat. While the heating energy demand of an average conventional building in Europe is around 200 kWh/m$^2$yr, for a low energy building that is around 50-70 kWh/m$^2$yr[41] and an extremely low energy building (passive house) can be as low as 15 kWh/m$^2$yr. The strategies to reduce the heating energy demand by cutting losses and increasing gains are summarised in the following sections.

*In vernacular architecture traditionally, small windows were applied*[42]

41 https://passiv.de/former_conferences/Passivhaus_D/Aufsatz_Passivhaus_1997.htm (last access in April 2021)

42 Source: https://commons.wikimedia.org/wiki/File:Szal_paraszth%C3%A1z%2Budvar.jpg (last access in April 2021)

## a. Reduction of heat losses

The most important measures to reduce heat losses are the following: buil-ding shape, thermal insulation and airtight building envelope. It is essential to mention a very simple but efficient way to reduce heat losses: not setting the internal temperature too high. A one-degree reduction in the internal temperature results in an approximately 6-10% saving in terms of heating energy demand in a typical residential building in a moderate climate.[43] However, the temperature should be still high enough to provide adequate thermal comfort

### Building shape

***Shape matters.*** The majority of a building's energy quality is already determined when the architect draws the first sketches. A compact shape will have lower heat loss than the distributed, complicated forms. The shape of the building can be characterised by the so-called surface-to-volume ratio (A/V): that is the surface of the building envelope separating the heated interior space from outside, divided by the heated volume. A smaller surface-to-volume ratio is favourable, as the surface area in contact with the exterior is smaller for each unit of volume. An ideal building would have a spherical shape. Due to practical reasons, dome-shaped buildings are rare in terms of occurrence but cubic buildings without unnecessary protrusions are also beneficial. However, very deep floor plans should be avoided because the amount of daylight and natural ventilation may be insufficient in internal spaces. In Central Europe for example, the maximum depth penetrable by sunshine in the winter is approx. 6 m the window.[44] Slightly elongated rectangular forms work well both for heat reduction and for solar gains.

43 https://www.energy.gov/energysaver/thermostats (last access in April 2021)
44 Zöld, András; Szalay, Zsuzsa; Csoknyai, Tamás: Energiatudatos építészet 2.0

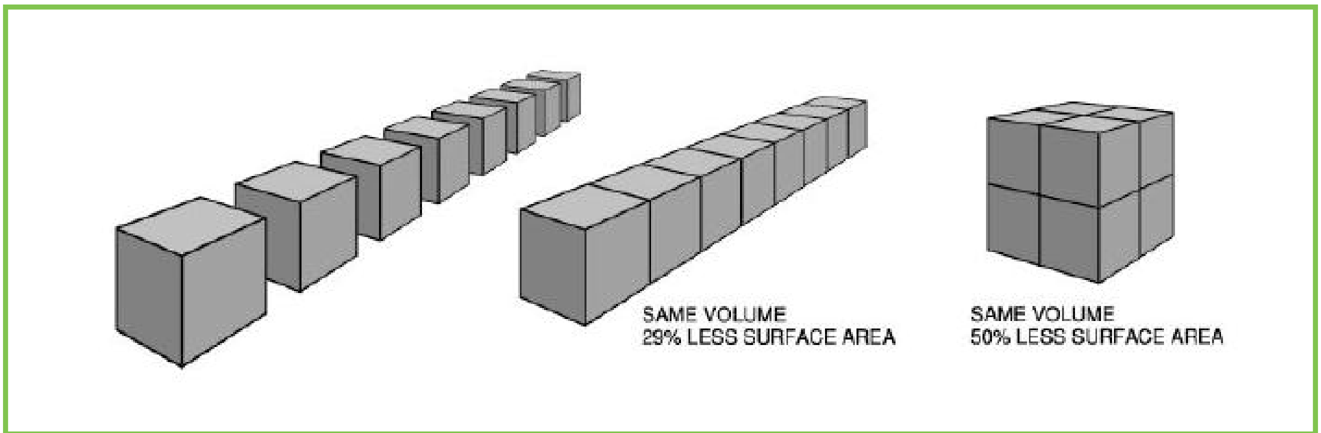



*Figure 12: Compared to the first case, the second arrangement has the same volume but 29% less surface area, while the third 50% less surface area*

***Size matters.*** While the increase in surface area is squared, the increase in volume is cubed, hence larger buildings have a lower surface to volume ratio. A large multi-family apartment house has a much lower energy demand per $m^2$ floor area than a detached house with the same insulation level! The figure below shows the specific (primary) energy demand of a building sample, with each point representing one building (this energy includes space and hot water heating, multiplied by a so-called primary energy factor describing the efficiency of the energy carrier conversion). Each building in the sample is the same regarding the insulation level, thermal bridges, airtightness, building service systems, etc., with the only exception being the size and the shape of the building. Yellow dots represent one-storey buildings with an average energy demand of 100 while the energy demand of large, 10 storey buildings may be as low as 75 kWh/$m^2$yr. There is also a big difference between buildings in the same category: the energy demand of a compact detached house is about 20 kWh/$m^2$yr less than that of a complex shape.

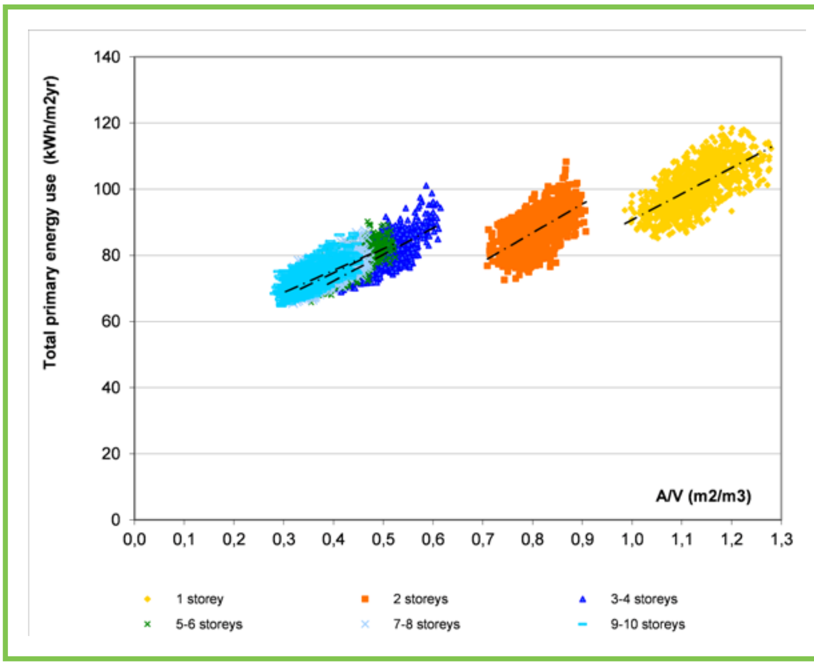



*Figure 13: Total (primary) energy demand of a building sample with uniform insulation levels but different number of storeys and shape* [45]

45 Source: Zsuzsa Szalay

***Space matters.*** It should be noted that efficient space usage also contributes to energy savings. Even the most compact, very well insulated but oversized detached house consumes energy, and saving on space also saves energy. Consider the real needs of a family when deciding on the size of a house to be established. It's also worth noting, however, that this is a complex matter with several further aspects to be taken into account. For example, housing rights and subjective considerations. The size of the building also affects the amount of land occupied, which is also an environmental indicator.

***Orientation matters.*** The orientation of the building should take into account the prevailing wind direction and should be favourable for solar energy utilisation (see chapter 5.2.b). The arrangement and zoning of the floor plan should follow the Sun: buffer spaces where lower temperature is acceptable or desirable, such as storage rooms, pantry or bathrooms should face North, while living rooms should open up to the Sun. In mixed climates, two terraces or balconies work well: one to the South and one to the North, to be used in hot weather.

## Thermal insulation

The transmission heat losses of a building are reduced in the most efficient way by applying high levels of thermal insulation. Although thermal insulation manufacturing also causes emissions and energy needs, the environmental payback time is quite short in terms of time, for the common materials, i.e. the energy saving exceeds the embodied energy in a few years (see chapter 4.3.). Insulation leads to energy savings but also ensures good thermal comfort and protects the building fabric. A side effect of insulation is that the internal surface temperatures will be higher compared to a poorly insulated structure. That influences the so-called operative temperature, which is the result of the air temperature and the radiant temperature of the enclosing surfaces. This is the temperature that humans actually feel and it is used for describing the thermal comfort. As the radiant temperature is high, the air temperature can be lower for the same thermal comfort, which results in further energy savings.

*Figure 14: Blowing of cellulose insulation into an attic*

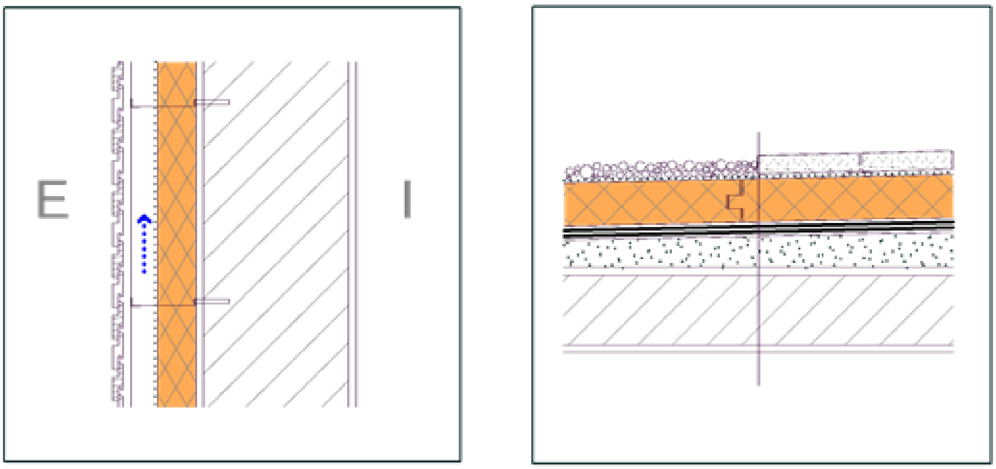



*Figure 15: External wall and flat roof with insulation*[46]

The thermal transmittance (U-value) shows how much heat is transferred through 1 $m^2$ of a building structure if there is a temperature difference between the two external surfaces, in $W/m^2K$. The lower the U-value, the better the insulation. The typical numeric values are rather low: a U-value of 1 or above indicates a poorly insulated structure, while well insulated elements have U-values of 0.1 - 0.3 $W/m^2K$. For example, in Hungary new external walls need to have a U-value of less than 0.24 $W/m^2K$, corresponding to an insulation thickness of approx. 14-16 cm if a conventional insulation material is applied.

A very important indicator of the insulation capacity in case of the building structures, is the so-called U-value or thermal transmittance.

46 Source: Zsuzsa Szalay

The U-values of windows are typically higher than the U-values of opaque elements (for modern windows 0.7-1.6 W/m$^2$K), but we should not forget that windows contribute not only to heat losses but also to heat gains: glazing transmits solar energy to the room behind and this reduces the heating energy demand (see chapter 5.2.b). For example, the overall winter energy balance of a south-oriented window in a moderate climate is positive: that means that more energy is transmitted through the glazing than the total heat lost through the window in the heating season. When selecting a window, it is essential to pay attention to the fact that many manufacturers indicate only the U-value of the glazing, which is usually better than the U-value of the frame. The U-value of the whole window is the surface weighted average of the frame and the glazing. In cold climates, triple glazing with special coatings and gas filling is required, while in warm climates double glazing may be sufficient.

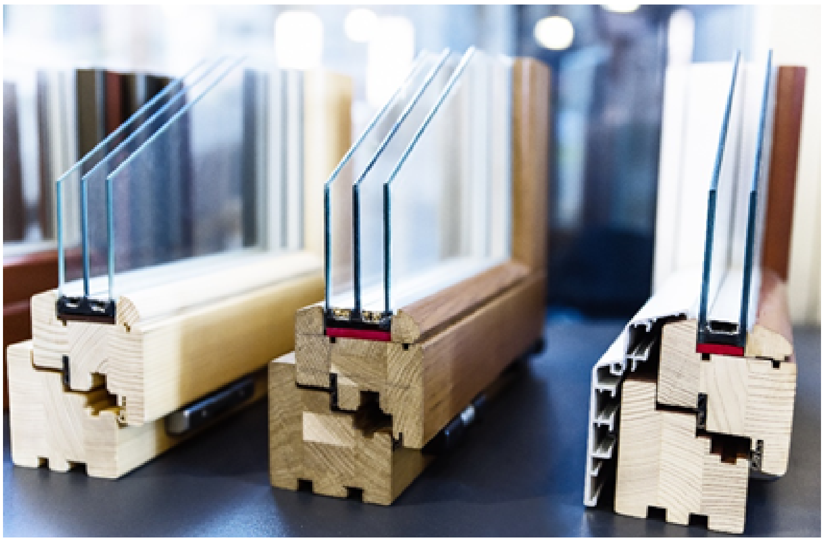


*Figure 16: Wooden windows with double or triple glazing*

## Thermal bridges

Thermal insulation of the surfaces is very important but special attention should be paid to the details of the building. Additional heat losses may occur at every junction and at every change in the building elements. These are called thermal bridges. Let's think about the simplest thermal bridge that is present in every building: wall corners. When we look at the wall corner from the inside, we only see a line. From the outside, there is a large surface corresponding to this line, hence the heat losses at the 'line' are much larger than on the general surface.

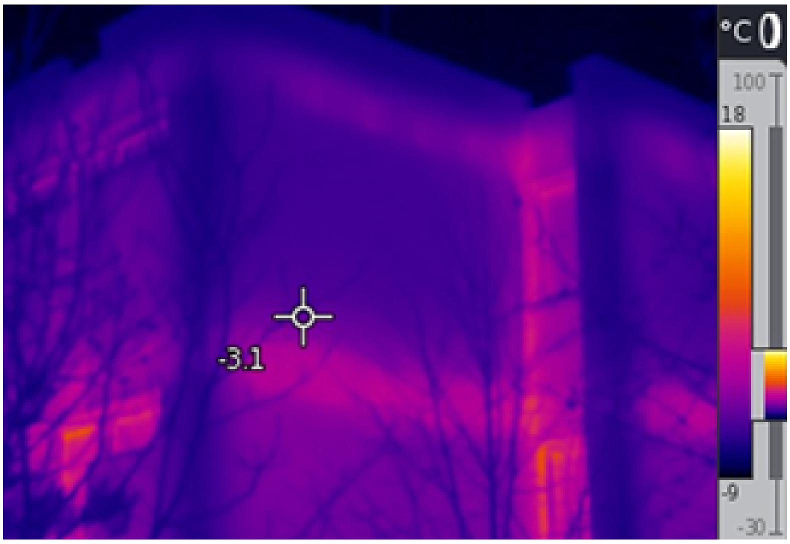
This type of thermal bridge is called a 'geometric' thermal bridge. Geometric thermal bridges occur in every building and it is practically impossible to avoid them. Other types of thermal bridges are, for example, due to the change in the material use, e.g. load-bearing reinforced concrete pillars in a brick wall or the junction of a reinforced concrete slab with a brick wall. Even wooden rafters in a roof are thermal bridges compared to the infill insulation in a heated attic, as the insulation capacity of wood is about three times lower than that of the insulation. It is important to install additional thermal insulation at these types of thermal bridges not only to minimize the heat losses but also to avoid the reduced internal surface temperature. If the internal surface temperature drops below a critical value, the risk of condensation and mould growth significantly increases.

*Figure 17: Mould growth after window change, due to thermal bridges and insufficient ventilation*[47]

Handling thermal bridges is especially challenging when existing buildings undergo renovation, as it is often difficult to insulate some of the building elements and junctions. For example, insulating a slab on the ground would mean that the floor construction must be completely rebuilt and the change in the ground floor level would affect all adjoining structures. In this case, a perimeter insulation along the footing is effective for reducing the ground heat losses but this also requires a lot of groundworks. Even relatively small insufficiencies in the insulation layer may contribute to significant losses. For example, insulation should be turned in to cover the vertical soffit at the edge of the window, even if its thickness is limited by the window frame. The best option is if windows are installed in a way that they are connected to the surface insulation or they are in the plane of the insulation. Deficiencies in the insulation layer can be controlled with the help of infrared thermography.

47 Source: Martin Marosvölgyi

*Figure 18: Thermal bridges can be detected with the help of infrared thermography*[48]




People need fresh air for their health and comfort. However, it is important to distinguish between ventilation and infiltration. Ventilation is the deliberate movement of air to remove odours and contaminants, and it can be provided through opening the windows or a mechanical ventilation system. Infiltration, on the other hand, is an unintentional air exchange between inside and outside through the cracks in the building fabric. It is unwanted as it leads to uncontrolled heat losses. To minimise infiltration, an airtight building envelope is needed.

In general, the 'pencil rule' applies: if we take a look at the cross section of a building, we should be able to follow the airtight building envelope without lifting a pencil. It is easier to fulfil airtightness in solid masonry or concrete buildings, where the building envelope can be sealed through internal plastering. In lightweight constructions such as in a timber frame wall or a pitched roof, airtight membranes should be installed. Again, special attention should be paid to the details: even small holes, such as plug sockets or piping penetrations may contribute to very large air leakages. Through these gaps, moist internal air may penetrate the structure and may lead to serious damage in the fabric. While modern windows are usually very airtight, window joints are typical weak points: the joint between the wall and the window must be sealed with an airtight tape.

48 Source: Zsuzsa Szalay

Providing fresh air is still necessary in a very airtight building but this can be conducted in a controlled way. If ventilation is provided through a window opening, it is important to ventilate the apartment well at least twice a day or even more often depending on the use. In wet rooms, humidity-controlled trickle vents can be applied that automatically open if humidity levels exceed a certain level. Ventilation may be provided artificially as well. This has the advantage if a heat recovery unit is also installed that heat loss is reduced this way significantly. (see chapter 6.1).

Blower door test

The airtightness of a building can be tested with a so-called blower door test where a fan creates a pressure difference between the inside and outside. The airtightness of the building, indicated by the air changes per hour at 50 Pascal pressure difference (ACH50 or n50), can be calculated from the rate of airflow. Old buildings may have a value of n50 over 10, typical new buildings around 2-5, but the requirement for a passive houses is 0.6 $h^{-1}$. This test is compulsory for new buildings in some countries as this test can help filter construction errors.

## b. Increase of heat gains

Heat gains reduce heating energy demand. The two main types of heat gains are solar gains and internal gains from residents, appliances and equipment. As the operation of appliances consumes electricity, it should not be wasted for heating purposes only, it is worth buying energy efficient machine with high efficiency. Solar energy, on the other hand, is ‘free’ and can significantly contribute to heating.

### Solar gains

Every building with window uses solar gains in a passive way. Obviously, solar gains depend on the orientation of the surface. In the Northern hemisphere, surfaces oriented towards the south with an inclination roughly corresponding to the latitude, receive the maximum incident solar radiation. For example, in Hungary, the total solar radiation on a surface oriented towards the south with an inclination of 45° is about 450 kWh/$m^2$ in the heating season, while for a vertical surface it is around 400 on a South, around 200 on an East/ West surface and around 100 kWh/$m^2$ on a North facing surface. As heat gains exceed heat losses for a modern South facing window in the heating season, a high window ratio is beneficial on the South façade but steps must be taken to provide shading in the summer to reduce the risk of overheating. (see chapter 5.3.a)

The phenomenon of greenhouse effect

To understand how solar gain contributes to heating, it is important to remember first what the greenhouse effect is. The energy of the Sun is transmitted through the atmosphere and some of this energy is absorbed by the surface of the Earth. Heat then radiates from Earth towards space but some of this heat is trapped by greenhouse gases in the atmosphere and warms the Earth itself. Why is this heat trapped? Because greenhouse gases transmit most of shortwave radiation coming from the Sun, while they block most of the longwave radiation of the Earth. The same phenomenon is observed on a building scale: most of the solar energy is transmitted through the glazing, it is then reflected, absorbed and re-radiated by the surfaces until it heats up the whole room. It is trapped in the room, as glazing, similarly to greenhouses gases, has a very high solar transmittance for shortwave radiation but its transmittance dramatically decreases in the longwave range, which is radiated by the surfaces of the room. The solar transmittance value of the glazing is characterised by the g-value.

### Thermal mass

Thermal mass helps reducing temperature fluctuations inside a building. This is beneficial both in winter and summer. In winter, solar radiation is absorbed by the thermal mass during the day and later released when the temperature drops. This results in a higher utilisation of solar gains and hence plays an important role in passive solar heating systems. Also, installing a heating system of lower capacity will be sufficient in such an instance. High thermal mass is an advantage in buildings that are continuously in use, such as homes, but it may be counterproductive in a rarely used holiday house where it takes longer to heat up the structure. The relevance of thermal mass in summer is explained in chapter 5.2.

Thermal mass is a function of the density and specific heat capacity of building materials. (The heat capacity describes the amount of heat to be supplied to a given mass of material to produce a unit change in its temperature.) Heavy materials such as concrete, brick and stone have a high thermal mass. The production of these materials require typically rather energy intensive procedure and this needs to be taken into account in the evaluation of their whole life cycle performance. The effective thermal mass of the building depends on the materials near the internal surfaces of the building elements. Heat absorbed in a single day does not penetrate into the deeper layers: the effective thickness for a one-day period is approx. 10 cm. However, insulating layers close to the internal surface will cut off the mass behind. For example, an internal insulation or even a carpet or a false ceiling could have an adverse effect on thermal mass.

In very well-insulated buildings, the role of thermal mass is less pronounced because the reaction time of the building to outside changes is in direct proportion to the heat capacity and indirect proportion to the heat transfer coefficient. As the heat transfer coefficient is greatly reduced in well insulated buildings, these will respond slowly to any weather changes (the so-called time constant will be high).

## c. Innovative passive heating solutions

There are many other innovative passive solar solutions. Some of these have been around for 30-40 years but most of them are still in research phase and their practical usage is limited.

### Sunspace

A sunspace is a glazed area outside of the heated building envelope facing South without any heating device. The sunspace collects sunshine during bright periods and due to greenhouse effect, it gets heated up. This heat is transferred inside by transmission through the common wall and by ventilation through vents, which can be opened. The heat storage capacity can be increased by implementing a rock store where heated air from the sunspace is mechanically channelled into and later heat is given off by radiation and conduction. If there is no sunshine, the sunspace functions as a buffer space, reduces heat losses and protects the building against wind and rain. In favourable weather conditions, it provides living space. As sunspaces can easily overheat in the summer, mobile shading is necessary. Placing operable vents to the exterior at the top and bottom of the sunspace will help remove heat by ventilation.

### Trombe wall

A Trombe wall is a basically a dark-painted heavy wall facing South that absorbs solar radiation. The wall is covered with glazing from the outside, with a small air gap behind the glazing, which functions as a greenhouse. The heat from solar radiation is stored in the wall, and the room behind is heated by radiation and a controlled air exchange through small vents. The operation of the vents depends on the season and the time of the day: in winter, vents are open during the day to help solar-heated air enter the room but they are closed at night to avoid cooling the space. Summer overheating of the structure must be reduced with an operable shading device.

*Figure 19: Trombe wall in France*[49]

49 Source: https://commons.wikimedia.org/wiki/File:Trombe_Wall_by_Felix_and_Michel.jpg

### Transparent insulation

Transparent insulation combines the function of glass and opaque insulation: it has a good insulation capacity but can also transmit solar energy and daylight. The typical construction is made out of glass or plastic, arranged into the formulation of a honeycomb or capillaries. Transparent insulation materials have been already been applied to windows, walls and solar collectors, among others. They can also be combined with a Trombe wall.

*Figure 20: Transparent insulation for the retrofit of a façade (Villa Tannheim, Freiburg*[50]

### Phase change materials

Phase change materials help increasing the thermal mass of a building. These materials have a low melting temperature, around the thermal comfort limit of humans. When the temperature increases, the material changes from solid to liquid and this reaction absorbs heat. Later, when the temperature drops at night, the material changes from liquid to solid and releases the heat. These substances are already available in commercial products, for example in plasters and gypsum plasterboards but their use is not yet widespread.

*Figure 21: Trombe wall with phase change material (Ebnat-Kappel, Switzerland)*[51]

50 Source: https://commons.wikimedia.org/wiki/File:Villa_Tannheim_in_Freiburg -Vauban,_Sitz_der_International_Solar_Energy_Society_(ISES).jpg
51 Source: https://www.schwarz-architekten.com/project/solarhaus-iii/

### Solar wall

In a solar wall, a perforated dark metal cladding is installed in front of a South facing wall as an external cladding. There is a ventilated air layer behind the metal, which rises as it heats up due to the incident solar radiation. The system is connected to the building HVAC system and ventilation fans are used to draw the warm air into the building and distribute it via air ducts. This is a relatively simple and inexpensive technology, which can be successfully applied, for example, in industrial buildings.

# 5.3 Passive cooling solutions

Passive cooling solutions may greatly reduce or totally eliminate energy demand of cooling in a building. It is possible to reduce or remove the cooling load by passive means., which is summarised in the following chapters.

## a. Reduction of loads

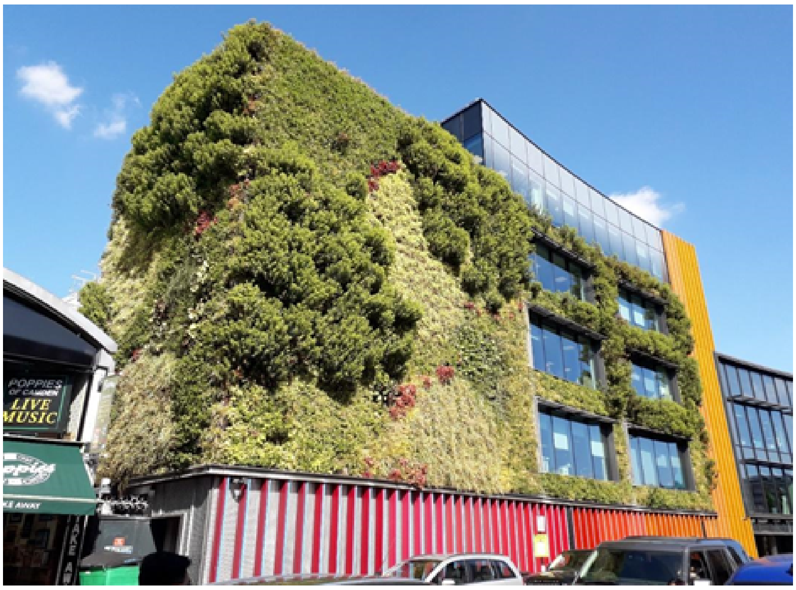
While sunshine is desirable in winter, it should be blocked from the building when external temperatures are high in cooling dominated and mixed climates. Shading can be provided by vegetation, building elements, dedicated shading devices or special glazing.

### Vegetation/Greenery

Planting trees in a clever way can help controlling internal temperature. Evergreen trees are recommended only on the Northern side to protect the building from wind. On the South side, deciduous trees function well. They shade the building in the summer months, but in winter, after the leaves fall, they do not obstruct sunshine from entering inside. Vegetation also has the advantage that it provides evaporative cooling (see chapter 5.3.c).

Vegetation can also be planted on the building such as, on the façade, on the roof or even inside the building. Green facades usually have a substructure mounted to the façade. Leaves will shade the façade and provide evaporative cooling if plants are regularly watered. Green roofs with a thick soil layer and larger plants (intensive roofs) have a similar effect but even if the thickness of the soil layer is limited and plants are smaller (extensive roof it will reduce the heat load due to its thermal mass.

*Figure 22: Green wall (London, UK)*[52]




## Shading

Protruding shading element elements work very efficiently if well designed. For south-oriented windows, horizontal elements such as roof overhangs or balconies above the window can be applied.

The movement of the sun and the change in temperature are not perfectly aligned in the summer, as the Sun is the highest in June but the strongest heat usually occurs in July/ August. Hence the shading should be designed so that it protects from the sunshine even in August. Overhangs possess an advantage as they do not block daylight, allowing it into the building even in the summertime. For East and West facing windows, horizontal overhangs are not very effective as the sun angles are low in the morning and afternoon. Vertical fins or separate shading devices work better in this case. These devices have an advantage that is they do not block entirely the light of sun, and therefore, natural lightning will be sufficient.

52 Source: Zsuzsa Szalay

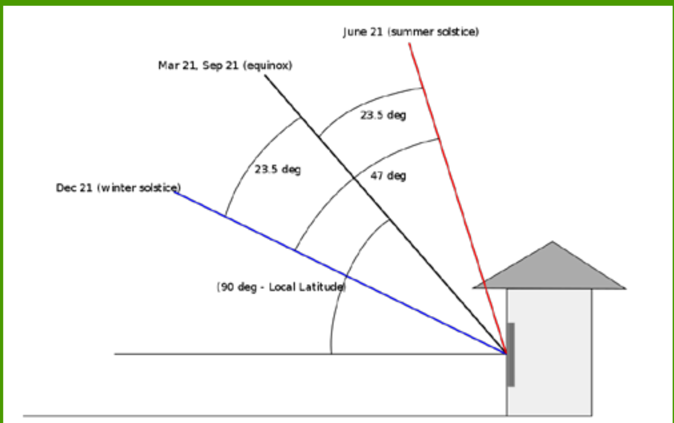
## Designing the length of an overhang

The length of the overhang should be designed so that it provides shade during summer when the Sun is high but does not obstruct sunshine during winter at lower sun angles. For example, in Hungary at a latitude of 47° North, the sun altitude at exact noon is:

at the equinox (March 21/ Sept 21): (90° – latitude) = 43°

at summer solstice (June 21): (90° – latitude + 23.5°) = 66°

at winter solstice (Dec 21): (90° – latitude - 23.5°) = 20°




Source of the picture: https://commons.wikimedia.org/wiki/File:Solar_altitude.svg

For the protection of windows, there are several shading devices such as shutters, blinds, screens, awnings, roll ups, etc. In general, external shading devices are more effective as they block the sun before reaching the window. Heat that is transmitted through the glazing and absorbed by an internal shade is already inside the room and will contribute to warming the space. Internal shades are only effective if their solar reflectance on the side facing the window is high. There are also adjustable shades available that are placed between the glass panes. These shades are still quite effective and they are also protected from wind effects. Operable shades that can be opened or closed have the advantage that their use can be adapted to the changes depending on the position of the sun during the day and during the year. Shading devices are also beneficial against glare. The reduction factor indicating the percentage of solar gain that enters the room is shown for some mobile shading devices in the table below.

A common issue with shading devices is that most of them also reduce the incoming light and may increase the need for electric lighting. Shutters with adjustable slats are a good solution that enable lighting, visual connection with the exterior and ventilation, while shading the room.

| Shading device | Reduction factor | |
|---|---|---|
| | if placed internally | if placed externally |
| Roller shutter | - | 0,1 |
| Venetian blind, light | 0,45 | 0,15 |
| Venetian blind, dark | 0,80 | 0,35 |
| Textile blind, light | 0,55 | 0,35 |
| Textile blind, dark | 0,85 | 0,6 |
| Aluminium-coated textiles | 0,2 | 0,1 |
| Curtain, light color | 0,8 | - |
| Curtain, dark color | 0,95 | - |

*Figure 23: Reduction factors for some mobile shading devices*[53]

## Special glazing

Shading may also be provided by the glazing itself. A large variety of glazing with different films and coating are available. The most important properties of glazing are the solar energy transmittance (g-value or SHGC) and the visible light transmittance (VLT). While a high VLT is always desirable, a high g-value is preferable in the winter and a low value in the summer. Normal glazing cannot adapt itself to the changing conditions, so in a residential building a combination of glazing and operable shading devices is more suitable than a non-adjustable solar control glass that may also change the colour of the light.

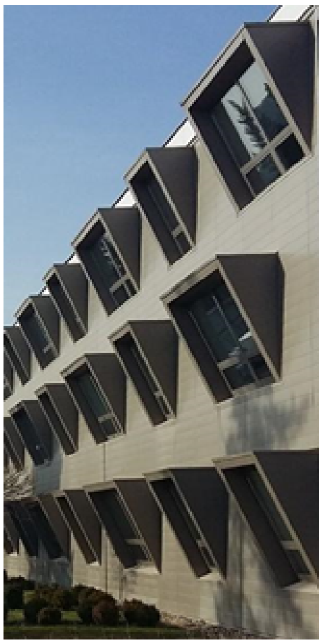


*Figure 24: Shading with tilted windows (ÉMI, Szentendre, Hungary*[54]

53 Source: MSZ EN ISO 13790: 2008
54 Source: Zsófia Deme Bélafi

There are also some innovative but rather expensive special glazing techniques available that can dynamically change their properties depending on the outside conditions. Photochromic glazing darkens under sunlight, similarly to automatically darkening sunglasses. However, as they adjust to light, they may darken even on a cold but sunny day when heat gains would be welcome. Thermochromic glass responds to heat and the tint of the window darkens with more intense sunlight. Thermotropic systems change their light-scattering properties depending on the temperature. Electrochromic glazing undergoes a reversible change if light falls on it. The advantage is that they can also be controlled manually.


*Figure 25: Electrochromic glazing (Washington)* [55]

### Thermal mass

In summer, thermal mass leads to a reduction of temperature peaks and a time lag compared to the outside peak. Thermal mass accumulates the heat from the Sun and internal gains during the day and releases the heat towards the exterior by natural ventilation when the external temperature becomes lower than the internal one. For further details, see chapter 5.2.b.

55 Source: https://www.sageglass.com/en/article/what-electrochromic-glass

## b. Removing heat loads

### Ventilation/aeration

Heat loads and heat stored in the thermal mass can be most efficiently removed by ventilation when the external air has a lower temperature than inside. This is usually valid at night in summer. Ventilation rates can be increased via cross ventilation by opening windows on different façades and internal doors. During hot periods in the daytime, ventilation should be kept at a minimum to avoid further heat load. Simple fans can be used to create air movement instead of letting hot air inside.

Ventilation inside building elements helps decreasing the heat load on building elements. A ventilated air layer behind the external façade cladding or roof covering functions as an 'umbrella' against rain and as a 'parasol' against sunshine. Heated air moves faster in the air gap and this enhanced natural ventilation removes heat from the surface facing the air layer.

## c. Innovative passive cooling solutions

### Evaporative cooling

Evaporative cooling has been traditionally applied in hot and dry climates of the Middle East and in Mediterranean architecture, in order to cool the outdoor air. Air should be in contact with water on a large surface, for example a fountain or pool of water. In the process, air heats up the water, the water starts to evaporate and the temperature of the air is lowered without changing the amount of heat in the air. This type of cooling increases the relative humidity of air so it only works well if the outside air is dry enough.

*Figure 26:*
*Evaporative cooling with plants and fountains (Alhambra, Granada)*[56]

56 Source: https://commons.wikimedia.org/wiki/File:Alhambra_Generalife_fountains.jpg

## Wind catchers

Wind catchers or wind towers have been traditionally used and built in hot and arid or humid areas such as the Middle East and Egypt. Their main role is to enhance natural ventilation and provide cooling by leading external air into the building. The wind catcher is on the top of the roof where wind velocities are higher with openings facing the prevailing wind. Air can be pulled through the basement or over water surfaces to precool the air before it enters the rooms. The extraction can be enhanced by installing a Venturi plate on the tower. Venturi effect is the principle that a velocity of a fluid increases and the static pressure decreases if it passes through a constricted pipe.

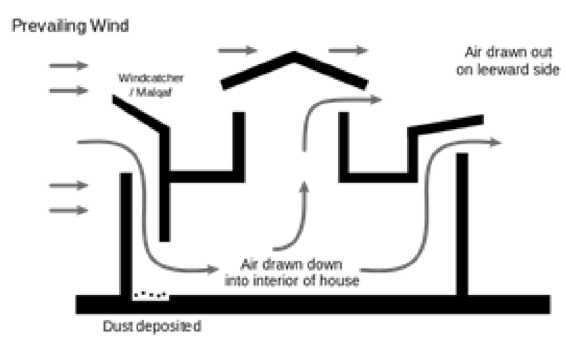



*Figure 27: Wind is forced down on the windward side and leaves on the leeward side in a pair of windcatchers*[57]

*Figure 28: Venturi plate on the Hungarian nest+ project for enhancing natural ventilation and passive cooling*[58]

57 Source: https://www.wikiwand.com/en/Windcatcher
58 Source: http://www.sde2019.hu/hungarian_nestplus.html

### Solar chimney

A solar chimney provides natural ventilation and passive cooling. It is a dark-painted chimney with a glazing cover facing South, placed outside of the building while being connected to it. Upon exposure to solar radiation, the air in the solar chimney heats up and the large temperature difference causes air to lift up and out of the chimney (stack effect), pulling external air inside through the building and creating a draft inside. A staircase or multi-storey atrium may also work like a solar chimney.

### References and further reading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