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Passive Solar Design Guidelines

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BUILD-GREEN CONSULTING

Sustainability consultancy services for the built environment

Passive Solar Design Guidelines

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Introduction

Passive solar design stands for the use of the sun's energy to provide heating, cooling and lighting to living spaces. Passive solar design is applied in several countries across the world and has proved to produce buildings which have low energy use (and therefore running costs), need less maintenance, and which are comfortable and healthy to occupy.

As a general design approach, the key considerations with respect to passive design are determined by the characteristics of the building site. In order for the design to be effective, it is very important that it is based on the specific characteristics of the building site, such as the wind patterns, type of terrain, vegetation, and exposure to the sun (based on existing surrounding structures). A basic understanding of these issues can have a considerable effect on the energy performance of the building.

The term "**building envelope**" is often used in the building industry, and especially when dealing with passive design, and is also often used in these guidelines. The building envelope is used to describe the roof, walls (external and internal), windows, floors and internal walls of a building. The performance of the envelope is a very important part of the passive design, as it is the main barrier between the outdoor climate and indoor environment. In a predominantly hot climate such as the one in Mauritius, an efficiently-designed envelope should perform such that it maximises natural cooling and excludes solar gains.

Heating is generally not required in Mauritius in winter, except in regions which are high on the central plateau or prone to highly windy climatic conditions. High-density buildings such as offices do not generally require heating in winter due to the high levels of internal heat gains from people, lighting and equipment. In rare cases where heating is required, it is in domestic buildings, which are unoccupied during the day. These guidelines therefore, mainly focus on *cooling* and *reducing heat gains* by means of passive design techniques.

There are various passive solar design techniques which have been used around the world. However, it is essential that the passive design techniques used are useful and relevant in the climate where the building is located. The climate in Mauritius is predominantly hot and humid, therefore only certain passive solar design techniques will be effective. These include orientation, use of thermal mass, natural ventilation, shading, insulation and use of solar-protection glass. These techniques are covered in further detail in the chapters of this guidebook.

Emma Özsen,
December 2010

1 Designing for the local climate – key design principles

The climate in Mauritius could be called a "summer-driven climate", meaning that Mauritius prone to high outdoor temperatures for the majority of the year. One of the main concepts of passive design is it design the building for year-round comfort, therefore it is very important to focus the design on the dominant climatic conditions.

Due to its location on the globe, a warm climate prevails in Mauritius. Summers are hot and humid, with external temperatures which can go up to about 30 - 35 oC and relative humidity of about 90% or higher during peak summer days. Winters are usually not very cold, except for some days when the external temperature can drop to about 10 - 12 oC. It can therefore be said that Mauritius has a "summer-driven climate", i.e. the prevailing climate during the year is warm and humid. This makes some passive strategies, such as evaporative cooling, ineffective for Mauritius and other tropical regions. There are however a number of strategies which can be effectively applied and which can result in a significant improvement of the building in terms of energy consumption and indoor thermal comfort.

Cyclonic conditions are prevalent in Mauritius and should be kept in mind during the building design and construction. A passive building does not need to be more adversely affected by cyclones. Reinforced concrete buildings can take advantage of the thermal mass of the building to reinforce passive cooling techniques, especially when used in combination with night cooling.

In hot and humid (tropical) climates, the passive strategies which are generally found to work best are:

- The building layout should encourage the movement of air through the building (**cross ventilation**). This is ideally achieved by having layouts which are one room deep or with openings which allow flow of air through two opposite external walls.

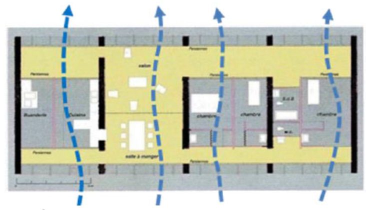


Fig. 1: Cross ventilation through a building

- Provide adequate shading of the building throughout the year. Due to the prevailing hot and humid climate in Mauritius, it is important to provide shading so that it is effective not only in summer but also in winter, in most buildings. By paying attention to the sun path, the shading can be designed such that it blocks the summer sun as well as the lower-altitude winter sun rays.

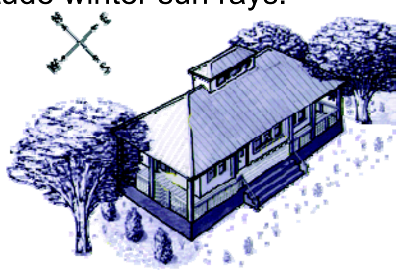


Fig. 2: Orientation of longer facade building along East/West axis

The building's longer axis should ideally be **East-West**, so that only small areas of the building envelope are affected by direct sun rays in the east and west orientations.

- Place the building on site so that it is exposed to **cooling breezes** all year round. The prevailing wind direction in Mauritius is from the South-East.

However it is important to consider the site, as wind channels may be created due to surrounding buildings, roads, etc. Once the prevailing wind direction is established, openings should be positioned such that they capture the cooling breezes.

- **Ceiling fans** should be used where required. Ceiling fans can be used to create a cooling air movement in summer.

  Although fans are a mechanical means of ventilation, they can be very useful in enhancing natural ventilation and passive cooling of buildings, especially residential buildings, thereby reducing or eliminating the need for air-conditioning. Therefore they should be considered where they can have a beneficial effect on natural ventilation and cooling, especially in rooms where the potential for natural ventilation is restricted (e.g. rooms with single-sided windows or which are not usually exposed to natural breezes).

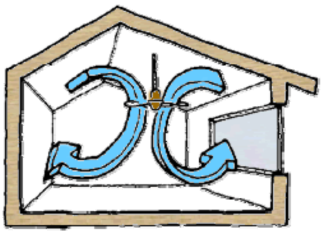


Fig. 3: Use of fans to increase air circulation

- Use **ventilated roof spaces** or use reflective insulation in roofs. The roof is the part of the building envelope which is exposed to the highest solar heat gains, and if it is not protected, the heat is transferred to the space directly below the roof.

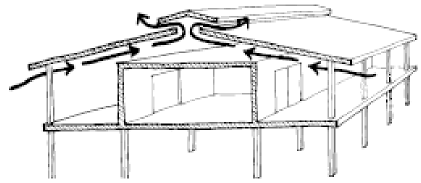


Fig. 4: Use of a "fly-roof" for shading and ventilation

- Choose white or **light-coloured painting**, or heat reflective painting, for walls and roofs. Heat reflecting paint reflect infrared and UV rays, thereby reducing the heat absorbed by the building envelope.
- Consider having **high ceiling** in the building. Hot air would move up and create a lower and more comfortable temperature at the lower (occupants) level.

2 Orientation

Good orientation increases the energy efficiency of a home, making it more comfortable to live in and cheaper to run.

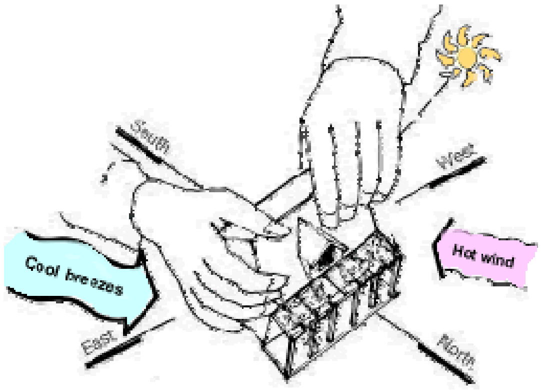


Fig. 5: General orientation in relation to wind and sun

2.1 *General Principles*

Orientation refers to the azimuth angle of a surface relative to true North.

With regards to building design, the orientation of a building can significantly affect its potential to capture of prevailing breezes and its exposure to solar radiation. The intensity of solar radiation varies depending on the orientation (see Fig. 6 below). It is therefore a very important first step towards applying good passive design strategies.

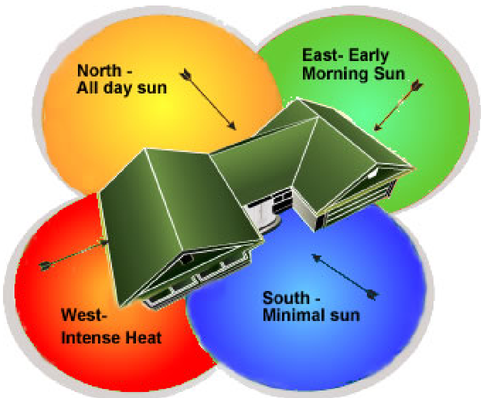


Fig. 6: Solar radiation in different orientations

An effective passive solar design should assume that the building is orientated to receive direct solar radiation only in winter (*only* in cases where heating is required in winter, such as residential buildings located high on the central plateau), and should reject as much as solar radiation as possible in summer.

Good orientation for passive cooling excludes unwanted sun and hot winds and ensures access to cooling breezes. Due to the hot and humid climate in Mauritius, both direct and reflected sunlight need to be excluded at all times around the year. Good orientation of a building is a very important initial decision and can greatly influence the solar heat gains of the building.

Due to its latitude, the sun altitude in Mauritius is very high in summer, as shown by Fig. 7 below. The highest altitude occurs on December 21st and the lowest on June 21st.

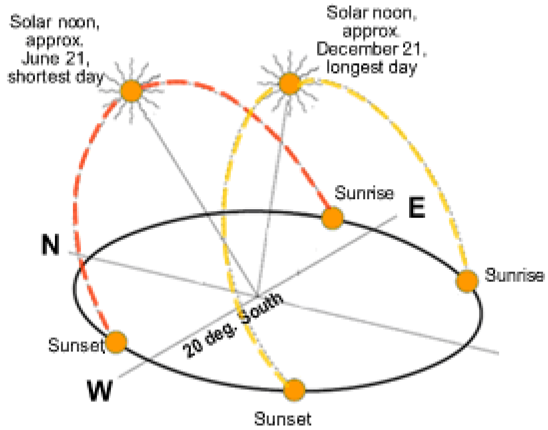


Fig. 7: Seasonal variation in solar path

In comparison, the annual sun paths in the London, United Kingdom is shown. Due to London's latitude, the highest sun altitude in summer is lower than that of Mauritius.

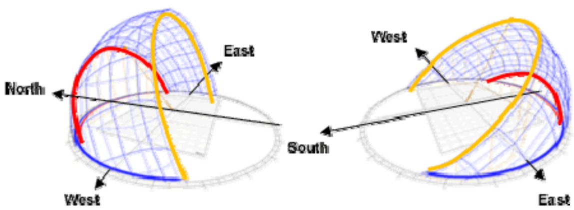


Fig. 8: Annual sun path for Mauritius (left) and annual sun path for London (right)

Sun path at summer equinox (highest sun altitude)

Sun path at winter equinox (lowest sun altitude)

The above images show that the sun's altitude is very high in summer, when the solar radiation is the strongest. Therefore, orientating the longest facade of the building towards the North makes it much easier to apply passive design strategies effectively.

Windows on the North facing facade can be more easily shaded using extending overhangs to block the high angle sun. The East and West facing facades, however, are subject to direct solar radiation in the morning and afternoon.

2.2 *Choosing a site*

When selecting a new building site, ensure that the site has good access to cooling breezes and that landscape and adjacent buildings do not block access to beneficial breezes. If feasible, select a site that would allow optimal orientation of the building, in terms of access to wind and shading potential. Optimal orientation of a building is further discussed in section 2.3 below.

A site that contains a south-facing slope can provide beneficial shade to the building (see Fig.9 below). For instance, the south is ideal for location of large windows, as south facing windows require only minimal shading from direct sun.

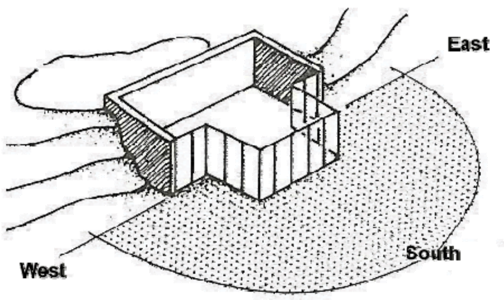


Fig. 9: Maximising glazing on south orientation and using benefit of a sloped site for shading facades exposed to direct sun

Solar access is however also beneficial, for example for solar water heaters, clothes drying (in residential buildings) and gardens. Therefore, when placing a building on site, solar access should be considered where it is beneficial.

Sometimes, sites with poor orientation or no access to cooling breezes have to be selected by default. In these cases, an energy-efficient building can still be achieved by applying good design principles. For instance, high level windows or vents can aid in the formation of convective currents for cooling, where access to cooling breezes is limited.

The building shape and the landscape around it can also be designed such that it can control the flow of natural breezes or to block unwanted sun.

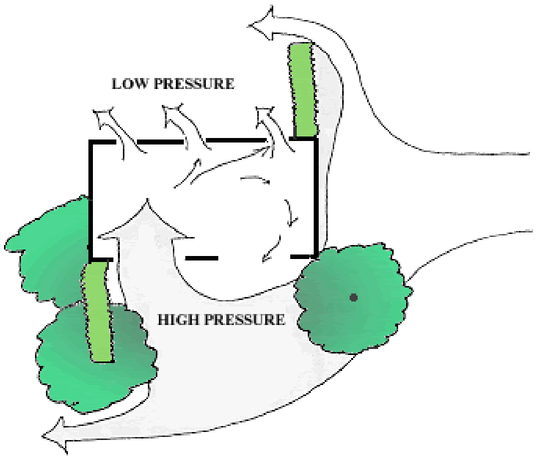


Fig. 10: Example use of landscape to control flow of breezes into a building

2.3 *Optimal orientation*

With regards to passive solar design, for optimal orientation the building's East and West facades should be as small as possible, and have either no windows or very small windows. Rooms which face East and West can also be designed to be used storage areas or areas which are not often occupied.

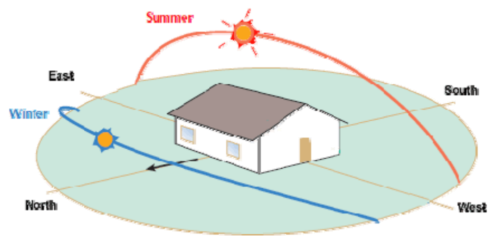


Fig. 11: Building orientation on East-West axis

Fig. 11 above shows a building with its longer facade facing North, and the smaller facades facing east and west, in order to minimise the east and west exposure to solar heat gains.

Long, unshaded walls on the east and west sides of a building can significantly contribute to an overheating problem.

On the north facing wall, the sun can be quite easily blocked using eaves (roof overhangs), as the sun altitude is high.

However, when the sun is lower in the sky in the morning and afternoon, overhangs will not be effective to protect the east and west facing walls.

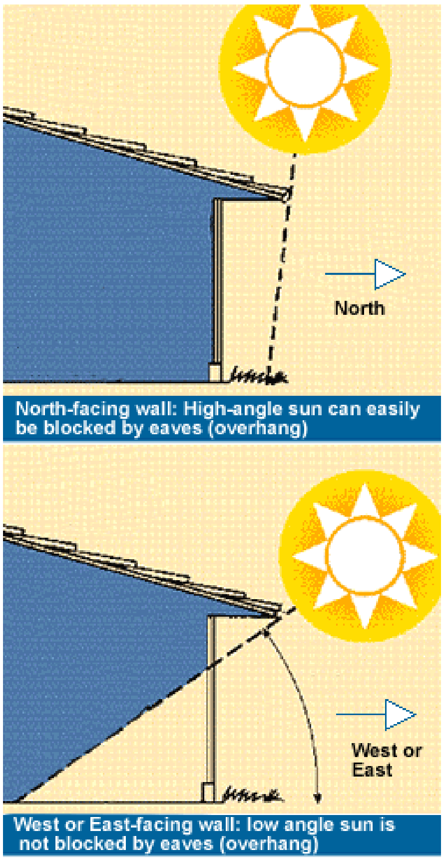


Fig. 12: Effectiveness of shading by overhangs

East and west walls and windows can be shaded using plants and high trees and by using vertical shading on windows which face east and west.

Green canopies can also be used to act as shading on west and east facades, as shown below.

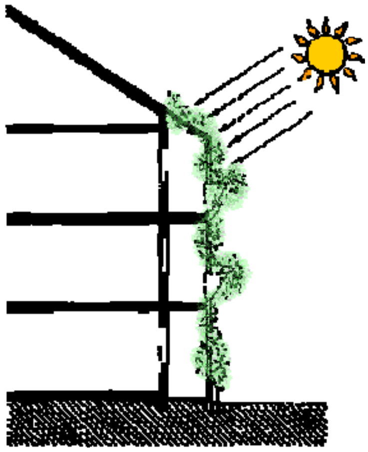


Fig. 13: Using plants for shading on multi-storey buildings

3 Natural Ventilation

Natural ventilation refers to a set of principles by which the circulation of air in a building is increased by natural means, or in other words, without the use of mechanical systems.

3.1 *Basic Principles*

Air movement is a very important aspect which needs to be considered for passive cooling of buildings. Air movement increases cooling by increasing evaporation rates. Cross ventilation is generally the most effective means of natural ventilation for cooling buildings through air exchange, whilst fans are useful for enhancing air movement for cooling of building occupants (although fans are a mechanical means of cooling).

There is a physiological cooling effect that occurs when still air is moved at a certain speed, causing occupants to feel less hot than they would otherwise. Due to the high humidity levels in Mauritius, the airspeeds required to achieve adequate cooling benefits need to be higher than in dryer climates.

For instance, an air speed of 0.5m per second equates to a 3 degree drop in temperature at relative humidity of 50%.

Natural ventilation is either driven by the climatic forces of the wind (**wind effect ventilation**) or by temperature difference (**stack effect ventilation**).

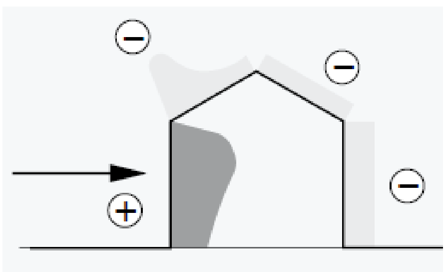


Fig. 14: Wind effect (pressure driven) ventilation

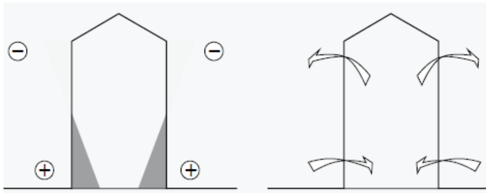


Fig. 15: Stack effect (temperature driven) ventilation

3.2 *Single-sided ventilation*

When openings for natural ventilation are available only on one side of a room which is to be ventilated, this is referred to as “single-sided ventilation”.

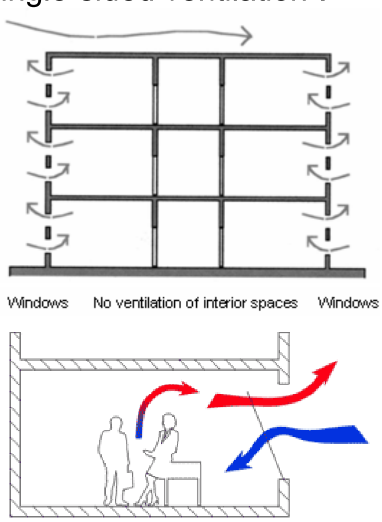


Fig. 16: Examples of single-sided ventilation

In single-sided ventilation, cooler outside air enters and warm inside air leaves the building through the same opening.

Single-sided ventilation is only useful up to a certain room depth. According to rules of thumb, the maximum room depth for effective single-sided ventilation is **2.5 times the floor-to-ceiling height** and an **openable area which is at least $^{1}/_{20}{}^{th}$ of the ventilated floor area** (see Fig. 17).

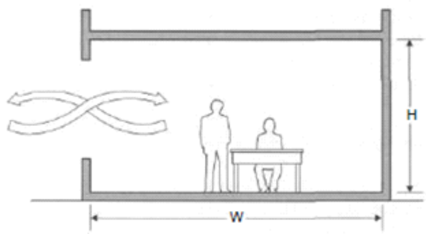


Fig. 17: Wind effect (pressure driven) ventilation:
Single-sided ventilation (wind-driven)
Maximum depth of room (W) ≈ 2.5H and window area approximately $^{1}/_{20}$ floor area
Image courtesy of BRE Digest 399

3.3 *Cross ventilation*

Cross-ventilation refers to natural ventilation of space/building through openable windows on both sides of the space/building.

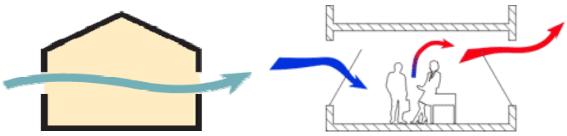


Fig. 18: Examples of cross-ventilation

Cross ventilation occurs due to the pressure difference between the side of the building that faces the wind (windward side) and the side that faces away from the wind (leeward side).

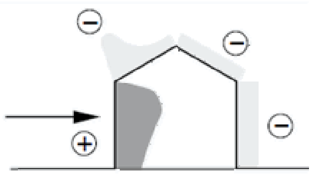


Fig. 19: Pressure on windward and leeward sides

The positive pressure on the windward side and/or the negative pressure (vacuum effect) on the leeward side of the building cause air movement through the building, with air entering the building at the windward side and exiting at the leeward side.

There can sometimes be problems of drafts which can be disruptive in offices. To prevent or reduce this problem and to obtain an optimal airflow, the openable area of windows on the windward side should less than on the leeward side.

According to **rules of thumb**, the maximum room depth for effective cross-ventilation is **5 times the floor-to-ceiling height** (see Fig. 20 below).

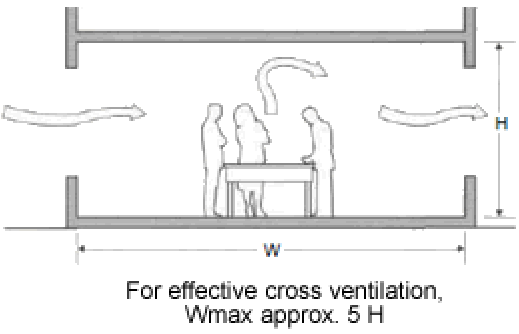


Fig. 20: Cross-ventilation effective room depth
Image courtesy of BRE Digest 399

3.4 *Stack-effect ventilation*

The case of stack ventilation is somewhat similar to smoke ventilation, where the natural tendency of hot air to rise is used to allow ventilation through high-level openings. Cooler fresh air enters the building through lower openings.

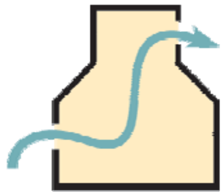


Fig. 21: Principle of stack ventilation

Stack ventilation can be enhanced by different innovative measures, such as using a “solar chimney” or using an atrium (see Fig. 22).

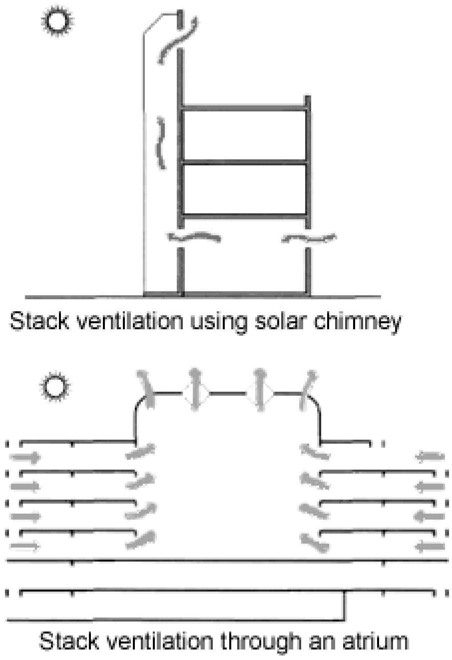


Fig. 22: Stack ventilation examples
Image courtesy of BRE Digest 399

The use of double facades (as in the example of the solar chimney) is an ideal solution for buildings which are adjacent to roads of areas affected by high acoustic emissions. The principle behind the solar chimney is to create a column of air at higher temperature which causes pressure differences that give rise to the stack effect.

Stack ventilation is also effective in removing heat and pollutants or odorous air at source. For instance, in some industrial buildings, very high sources of heat or pollution are located at specific points in the buildings. In those cases, stack ventilation can be effective in removing the heat and pollutants directly through the rising hot air.

3.5 Night cooling

The use of thermal mass (refer to Chapter 5) can be useful to absorb heat gains during the day, thus reducing peak temperatures. However, the heat absorbed by the thermal mass needs to be taken out of the building so that it can absorb more heat the following day. Due to the slow absorption of heat by the thermal mass, it can take time for it to cool down. Night cooling is very effective in removing heat gains from the thermal mass at night, when the external temperature is cooler. Increased night time ventilation can therefore greatly help in removing heat that is stored in the building structure during the daytime, to avoid high internal temperatures in summer.

Night cooling can be very successful, and can reduce daytime temperatures in the building considerably, so that it is lower than the peak external temperature. However, the ventilation techniques must be applied correctly. For example, when the external temperature is high, daytime ventilation rates should be reduced, and solar gains blocked with adequate shading. Night ventilation then removes any heat stored in the thermal mass and heat gains inside the building (see Fig. 23 below).

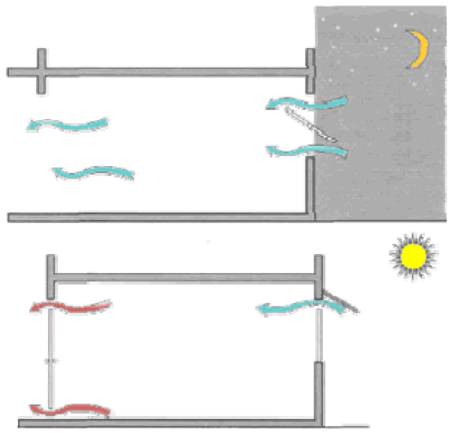


Fig. 23: Stack ventilation examples
Image adapted from BRE Digest 399

Other innovative solutions include using the thermal mass of the by passing air through the building structure, for example, through hollow core slabs or using a combination of roof venting and stack effect ventilation to enhance night ventilation (see Fig. 24 below).

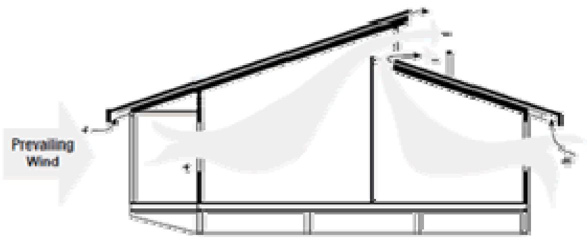


Fig. 24: Example of roof venting and stack ventilation

Night cooling is a very effective way to allow the building envelope to dissipate at night, heat that has been absorbed during the day. In Mauritius, high summer daytime temperatures often cause heat gains to be stored in high thermal mass buildings. Without night cooling, the heat is trapped inside the building, preventing the thermal mass from be effectively used for passive cooling during the following day. A good passive night cooling strategy simply relies on good window design to allow ventilation at night, and should definitely be considered where possible.

4 Shading

Shading can reduce summer temperatures by blocking up to 90 percent of direct sunlight and therefore helps improve comfort and save energy.

Fig. 25: Shading example
(image courtesy of Levolux)

4.1 General Principles

Radiant heat from the sun can easily pass through glass into the building. Building elements and furnishings absorb and then re-radiate this heat at a different wavelength, which means that this heat cannot pass back out through the glass.

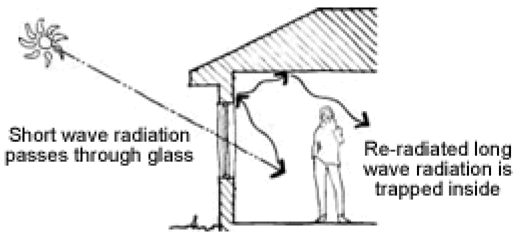


Fig. 26: Heat transmission through windows

It is very important that windows are adequately shaded. Shading protects the building from the “trapped” radiant heat effect by preventing the heat from entering the building through glass.

Additionally, shading glass also has the benefit of reducing glare by blocking direct sunlight penetration and allowing through diffuse daylight.

Shading of walls and roof surfaces is also very important, especially because of the latitude of Mauritius and thus the high altitude of the sun in summer. Through appropriate orientation (refer to Chapter 2), the shading strategy can be more easily defined. For instance, orientating the longer sides building along the East-West axis will facilitate the shading design, as north-facing windows and walls can be more easily protected from direct sunlight using overhangs (eaves) or louvers. Lower angle sun (east and west) is more difficult to control, and requires vertical shading, which can obstruct views and reduce the availability of daylight.

Wide overhangs can be useful but only in the early afternoon and mid-morning when the sun angle is not very low.

Some common shading strategies are shown below:

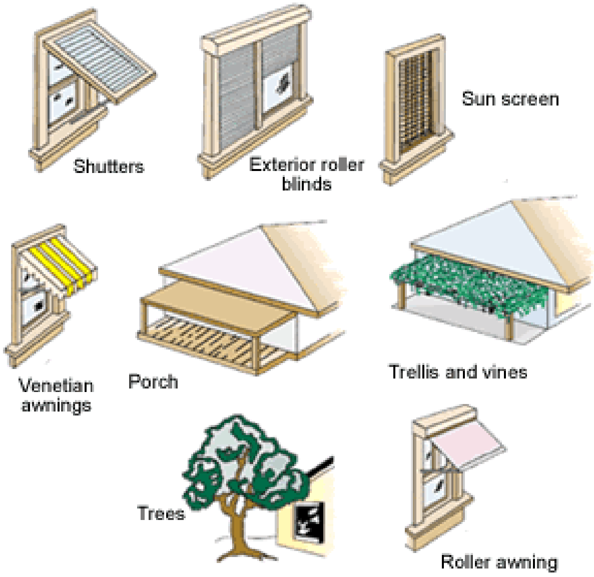


Fig. 27: Examples of shading strategies

Other simple and cost-effective strategies which can be used for shading the east and west facing sides of the building are shown below:

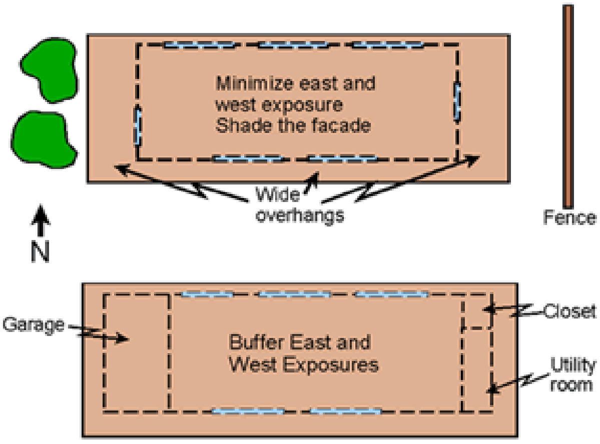


Fig. 28: Cost effective east/west shading strategies

The use of trees or vegetated fences can be useful in blocking low angle sun rays, and also allow some diffuse daylight to go through.

Designing east and west facing areas to be used as unoccupied or non-air-conditioned spaces serves as buffering or insulating zones.

4.2 Fixed Shading

Fixed shading devices are especially useful on the north side of a building, where they block the summer sun and, when deigned correctly, can let the winter sun enter the building.

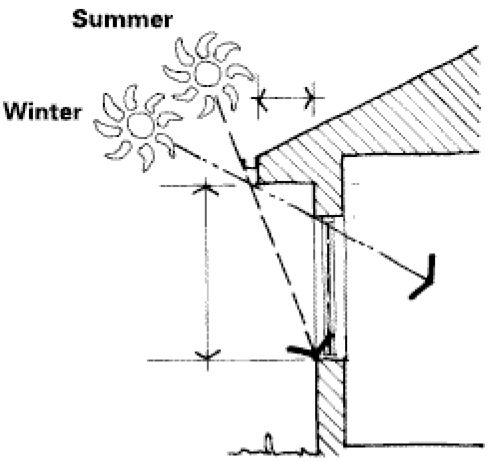


Fig. 29: Allowing sun penetration in winter

Allowing winter sun rays to enter a building should be carefully considered. Most buildings in Mauritius do not require heating in winter; therefore winter sun penetration may only be restricted to certain building types, such as houses located at higher altitudes on the central plateau (regions such as Curepipe and Floreal). However, depending on the amount of heat-generating equipment, occupancy, etc, winter solar heating may cause a house to overheat and occupants to use air conditioning. Therefore, designing fixed shading to allow for sun penetration should be carefully addressed, preferably through consultation with an environmental designer to ensure the fixed shading devices are located correctly.

Examples of fixed shading include eaves, pergolas and louvers.

Fig. 30: Examples of fixed shading

4.3 Moveable Shading

Movable shading devices allow the user to adjust the level of shading according to need.

Movable shading can be particularly useful for eastern and western elevations, since the low angle of the sun makes it difficult for fixed shading devices to provide sufficient protection.

Some systems allow choosing between excluding all sun, allowing all sun and manipulating the degree of sun levels. This is particularly useful for north-east and north-west elevations, which receive a combination of high and low angle sun throughout the day.

Examples of movable shading devices are: sliding screens, louver screens, shutters, retractable awnings and adjustable blinds.

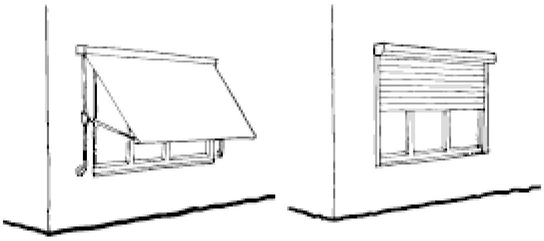


Fig. 31: Examples of moveable shading (adjustable awning, roller shutter blinds)

4.4 Shading using plants

Plants can not only be used as natural shading devices but can also provide other benefits, such as screening for privacy, noise filtering, and filtering of air before entering the building.

Trees with high canopies are useful for shading roofs and large portions of the building structure.

Fig. 32: Using trees for shading

Shrubs are appropriate for more localised shading of windows.

Wall vines and ground cover insulate against summer heat and reduce reflected radiation. Rather than having solid floors and tarmac, ground cover should be preferred, as solid dark coloured floors outside buildings absorb and re-radiate heat and cause this heated air to penetrate the building.

Apart from shading, plants also provide cooling by transpiration, filter pollutants and enhance the visual environment. Plants located in front of openings cool down the air as it passes through to enter the building.

4.5 Shading and daylight

Shading reduces unwanted heat gains in a building. However, care must be taken when choosing shading methods, in order not to restrict the adequate amounts of daylight from entering the building.

The difference between **daylight** and **sunlight** should be understood when designing for shading and daylighting. Daylight refers to the level of diffuse natural light coming from the surrounding sky dome or reflected off adjacent surfaces. Sunlight, however, refers to direct sunshine, which is a lot brighter than ambient daylight.

Direct sunlight's intensity can be a significant source of glare when falling on a work surface or reflected off a computer screen. It is therefore important, when designing a building for the introduction of daylight, to consider ways of reducing glare. Direct sunlight can cause significant heat gains if it is not properly blocked.

Fig. 33: The difference between a sunlit (left) and daylit (right) space.

Certain plants allow filtered light into the building, while still providing appropriate shading.
A useful strategy that can be used to allow daylight into a building without allowing direct sunlight is to use "clerestories".

Fig. 34: Use of clerestory for daylight

However, clerestories should be carefully located so that no light enters the building through them. In the example shown in Fig 34, the clerestory should ideally face south so that it is not prone to direct sunlight.

Note that clerestories are vertical windows. The use of horizontal roof windows or transparent materials should be avoided, as this will cause considerable amount of heat gains to enter the building from strong midday sun.

Other strategies to enhance daylight while providing shading is to use light coloured external surfaces or shading devices that reflect light into the building. The use of light shelves can act both as a shading device and light reflector.

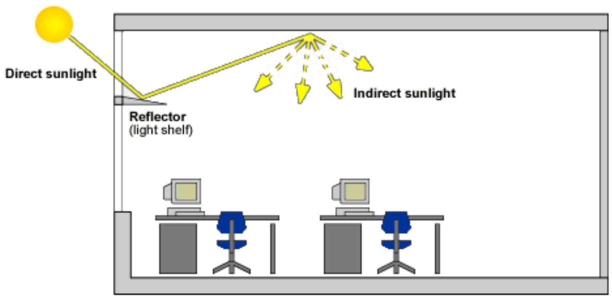


Fig. 35: Use of light shelf as reflector

5 Thermal Mass

Thermal mass is a concept which is used in building design and describes how the “mass” of the building can be used beneficially to reduce moderating internal temperatures and delaying the penetration of heat into a building.

Ancient architecture often showed the use of thermal mass. From the century-old adobe pueblo buildings of the Southwest Indians, to the rock walls in the ancient stone city of Great Zimbabwe, many indigenous forms of architecture used and took advantage of the thermal storage capacity of the building mass. The mass can store heat and even out the temperature fluctuations in a hostile living environment.

Appropriate use of thermal mass can improve the level of comfort in a building and also its cooling bills.

5.1 *General Principles*

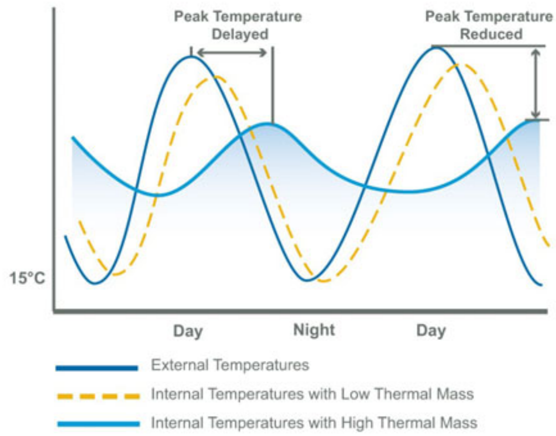


Fig. 36: How thermal mass can moderate temperature fluctuations

The correct use of thermal mass can moderate internal temperatures by averaging day/night (diurnal) extremes. This increases comfort and reduces energy costs.

In order to be effective, thermal mass must be integrated with sound passive design strategies, i.e. orientation for easier shading, appropriate areas of glazing, appropriate levels of shading, insulation (where effective) and night cooling.

5.2 *Thermal properties of common materials*

Examples of materials with high thermal mass (high-density materials) are concrete, bricks, and tiles. These materials require more heat energy to change their temperature.

Lightweight materials, such as timber, have low thermal mass.

In order to be effective as thermal mass, materials need to have the following properties:

High density: The denser the material (i.e. the higher the mass per unit volume), the higher is its thermal mass. For example, concrete has high thermal mass, whereas aerated concrete blocks have low thermal mass, while insulation (usually lightweight and containing trapped air) has almost no thermal mass.

Good thermal conductivity: The material must allow heat to flow through it. For example, rubber is a poor conductor of heat, while reinforced concrete is a good conductor. However, the conductivity should not be too high. For example, steel has very high conductivity, and it absorbs and gives off energy too quickly to create the delayed (lag) effect required in thermal mass for diurnal moderation.

Low reflectivity: It is well known that dark, matt and rough surfaces absorb and re-radiate more heat energy than smooth, reflective surfaces. If the walls of a building contain a considerable amount of thermal mass, a more reflective floor reflect heat and distribute it to the walls, which can be more easily cooled down at night since they are exposed to cooler night-time temperatures.

5.3 Typical thermal mass applications

In cold temperate climates, thermal mass is often used as a heat store to absorb solar heat gains which is used to heat the interior of buildings. In Mauritius however, thermal mass should mainly be used to aid in passive cooling.

As mentioned in the above sections, thermal mass can moderate internal temperatures by averaging the day/night extremes, and by creating a delay in the occurrence of peak internal temperature as compared to the external temperature (See Fig. 36).

In order to be used for passive cooling, thermal mass can be provided through the use of exposed concrete/tiles on the internal facades of the building and thermal mass in walls. Exposed concrete floors/tiles and walls, which are not in direct exposure to the sun, can be very effective in absorbing excess heat from the interior of the building.

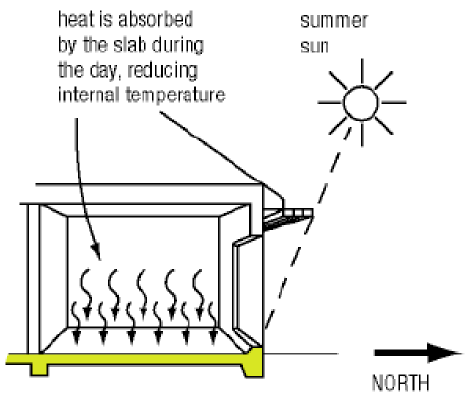


Fig. 37: Thermal mass protected from direct sunlight

A large amount of the heat gains in heavyweight (thermally massive) buildings can be absorbed by the thermal mass in the floors and walls, helping prevent an excessive temperature rise and reducing the risk of overheating. This makes naturally ventilated buildings more comfortable and, in air-conditioned buildings with thermal mass, the peak cooling load can be reduced and delayed.

The thermal capacity of the building fabric allows a significant amount of heat to be absorbed with only a small increase in the surface temperature. This is an important quality of heavyweight construction as the relatively low surface temperature results in a beneficial radiant cooling effect for the occupants, allowing a slightly higher air temperature to be tolerated than would otherwise be possible.

Night-time cooling is especially effective in thermally massive buildings, whereby cool air ventilates the building at night, and removes heat that has built up in the building envelope (walls, floors, roofs). The combines used of night cooling and thermal mass is discussed in section 5.4 below.

5.4 Thermal mass and night-cooling

Night cooling is usually very effective when used in combination with thermal mass (refer to section 3.5).

The use of high thermal mass in the walls and floor is particularly useful in office buildings or buildings, where the building is unoccupied at night when the delayed heat transfer occurs from the thermal mass into the building. Coupled with night cooling, the thermal mass can be very effective in reducing the amount of solar heat gains entering the building through the walls during daytime. If the walls are properly shaded, the thermal mass can absorb internal heat gains (from people, equipment and lighting) and re-radiate the stored heat at night.

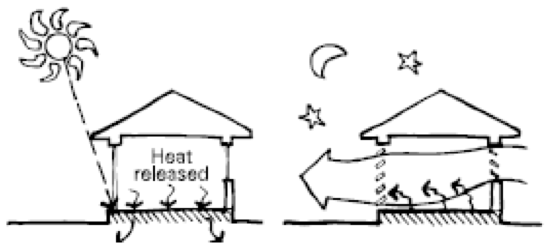


Fig. 38: Thermal mass and night cooling

5.5 Location of thermal mass in insulated buildings

Thermal mass needs to be strategically located to prevent overheating. In uninsulated buildings, it should not be directly exposed to solar heat gains by using adequate shading (refer to Chapter 4) and adequate night ventilation should be allowed to remove stored heat energy, without increasing internal temperatures.

In insulated buildings, it is important **not** to locate the thermal mass outside of the insulation, in which case the thermal mass will only be storing heat from the sun and releasing it back to the outside. In order to use thermal mass for cooling, it should ideally be located inside the insultation.

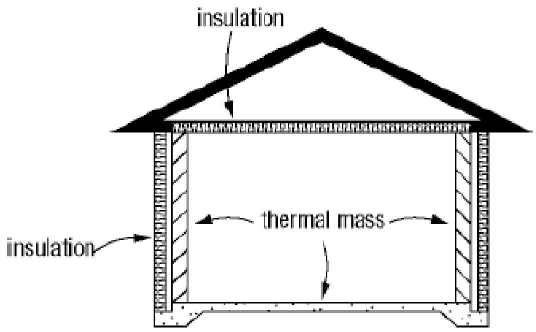


Fig. 39: Thermal mass in insulated envelope

Locating the thermal mass inside the insulated framework will allow the mass to be used to absorb the internal heat gains, while the insulation prevents solar heat gains from entering the building.

6 Insulation

Adding insulation to walls, floors, ceilings, roof and foundations improves their thermal resistance (R-value). The insulation should be properly installed as it contributes to the building's overall energy performance. The building should be properly sealed to reduce air infiltration.

6.1 Types of insulation

The common types of insulation are as follows:

- Loose fill
- Batts and blankets
- Rigid board
- Spray foam

The different types of insulation are shown in Table 1. The most appropriate type of insulation to use will vary based on the type of construction, the extent of the rehabilitation planned and applicable code requirements.

Table 1: Different types of insulation

Types	Advantages	Disadvantages
Loose fill-in/blown-in/cellulose	• Not harmful and fire resistant • Noise reduction • Inexpensive • Thermal and acoustic insulation	• Absorbs moisture and thus lead to mold formation
Batts and blankets	• Constitutes of more green and recycled products • Flexibility of blanket insulation	• Decrease in insulation efficiency due to the formation of gaps
Rigid board	• Strengthen the wall • Effective sound barrier • Can withstand high temperature • Fire resistant	• Installed in open, exposed wall only • Air and moisture leaks • Extra costs involved in the long term • Not flexible
Spray foam	• Better insulation • Prevents mold formation • Long-lasting	• Expensive • Messy

	• Does not cause irritation • Ease of installation	
Refective system	• Prevents downward heat flow	

6.2 Properties of common insulation types

6.2.1 Loose fill-in/blown-in/cellulose

Loose fill insulation makes use of loose and fibrous materials from fiberglass, rock wool and cellulose. All three primary types of loose-fill insulation are environment friendly because recycled waste materials are used in their production.

Cellulose insulation is made from recycled newsprint fibers that are treated with non-toxic borate. Fiberglass loose-fill insulation is spun from molten glass into fibers. The glass is typically melted in high-temperature gas furnaces. Most major manufacturers use 20-30% recycled glass content. Rock wool (or slag wool) loose-fill insulation is similar to fiberglass except that it is spun from blast furnace slag and other rock-like materials instead of molten glass. The production of rock wool uses by-products that would otherwise be wasted.

Loose fill-in insulations are either produced as or broken down into shreds, granules or nodules. These small particles form fluffy materials that conform to the spaces in which they are installed. Loose fills are most commonly sold in bags and are blown into building cavities using special equipment.

6.2.2 Batts and blankets

Blanket insulation makes use of mineral fibers such as those processed from rock wool and fiberglass. Batts and blankets come in widths to fit securely between the wood-framing members. Some come with a radiant barrier backing. Batts generally come in lengths of 1.2 or 2.4 meters. Blankets come in long rolls that are cut to the desired length for installation. Both batts and blankets typically have an R-value of approximately R-3 per 2.5 centimeter of thickness.

6.2.3 Rigid board

Rigid board insulation is commonly made from fiberglass, polystyrene or polyurethane and comes in a variety of thicknesses with a high insulating value (approximately R-4 to R-8 per 2.5 centimeter).

Foam insulation board, also known as polyisocyanurate insulation, is made by mixing together polyether and isocyanate that then close together to form closed cells. These closed cells have much in common with polyurethane in terms of chemical makeup and physical appearance, but with the added benefit of improved insulating properties.

6.2.4 Spray foam

Spray foam insulation is a two-part liquid containing a polymer (such as polyurethane or modified urethane) and a foaming agent. The liquid is sprayed through a nozzle into wall, ceiling and floor cavities. As it is applied it expands into a solid cellular plastic. Spray foam insulation should be applied by a professional using special equipment to meter, mix, and spray into place.

6.3 Typical applications

General applications for the four basic types of insulations are shown in Table 2.

Table 2: Typical applications

Form	Insulation Materials	Where Applicable	Installation Method(s)
Batts and blankets	Fiberglass Mineral (rock or slag) wool Plastic fibers Natural fibers	Unfinished walls, including foundation walls, and floors and ceilings.	Fitted between studs, joists, and beams.
Rigid foam	Polystyrene Polyisocyanurate Polyurethane	Unfinished walls, including foundation walls, floors and ceilings, unvented low-slope roofs.	Interior applications: must be covered with 1.3cm gypsum board or other building-code approved material for fire safety. Exterior applications: must be covered with weatherproof facing.
Loose-fill	Cellulose Fiberglass Mineral (rock or slag) wool	Enclosed existing wall or open new wall cavities, unfinished attic floors, hard-to-reach places such as irregularly shaped areas, obstructions, new construction and reftrofit situations .	Blown into place using special equipment, sometimes poured in.
Spray foam	Cementitious Phenolic Polyisocyanurate Polyurethane	Enclosed existing wall or open new wall cavities, unfinished attic floors , sealants, adhesives for roofs	Applied using small spray containers or in larger quantities as a pressure sprayed (foamed-in-place) product

Spray polyurethane foam (SPF)		Tanks, cold vessel insulation for products such as wine, chemicals and soft drinks and also hot/warm vessel insulation	

6.4 Where to locate insulation

A concrete block house provides a sturdy shell that offers an insulation factor. In order to provide a suitable cavity for insulation, a sub wall is framed just inside the surface of the concrete block. Once you've created the stud space, you can begin the insulation process. Insulation with an R-value of 13, will provide a finished wall value of approximately R-23, when combined with the existing insulation factor of the concrete blocks.

Insulated concrete blocks can accommodate many walls in a home. The better concrete masonry units reduce the area of connecting webs as much as possible.

6.4.1 Types of Concrete Block Insulation

There are several ways to incorporate foam insulation—such as polystyrene, polyisocyanurate or polyiso, and polyurethane—into concrete blocks. The hollow cores of concrete blocks can be filled by pouring and/or injecting loose foam beads or liquid foam. Some manufacturers make concrete blocks that accommodate rigid foam inserts.

Some block makers coat polystyrene beads with a thin film of concrete. The concrete serves to bond the polystyrene while providing limited structural integrity. The most common group of ingredients are expanded polystyrene mixed with Portland cement, sand, and chemical additives. These make surface-bonded wall assemblies with a wall R-value of R-1 per 25mm thickness. Polystyrene inserts placed in the block cores increase the unit thermal resistance to about R-2 per 25mm.

Hollow-core units made with a mix of concrete and wood chips can be used. They are installed by stacking the units without using mortar (dry-stacking). Structural stability comes from the concrete fill and appropriate rebar throughout for structural walls. One potential problem with this type of unit is that the wood is subject to the effects of moisture and insects.

Concrete blocks are also sometimes filled with vermiculite or perlite pellets.

6.4.2 Installation

Concrete block insulation is typically installed for new home construction or in homes undergoing major renovation. Since installation involves masonry skills, it's best to have a certified cement mason do it.

When using masonry blocks for a foundation wall, filling the block cores with high-pressure foam works better than most poured-in insulations, like polystyrene beads or vermiculite or perlite pellets.

Note that even though filling the block cavities and special block designs improve a block wall's thermal characteristics, it doesn't reduce heat movement very much when compared to insulation installed over the surface of the blocks either on the exterior or interior of the foundation walls. Field studies and computer simulations have shown that core-filling of any type offers little fuel savings since the majority of heat is conducted through the solid parts of the walls such as block webs and mortar joints.

Insulating concrete forms result in cast-in-place concrete walls that are sandwiched between two layers of insulation material. These systems are strong and energy efficient. Common applications for this method of construction are low-rise buildings, with property uses ranging from residential to commercial to industrial. Traditional finishes are applied to interior and exterior faces, so the buildings look similar to typical construction, although the walls are usually thicker.

7 Glazing

7.1 Types of glazing

The window glazing technologies include:
(i) Gas fills

The space between the glass panes is filled with inert gases to improve the thermal performance of windows. These inert gases (argon and krypton) have a higher resistance to heat flow than air and they are sealed between the window panes to decrease the window's U-factor.

(ii) Heat absorbing tints

Heat-absorbing window glazing contains special tints that change the color of the glass. Tinted glass absorbs a large fraction of the incoming solar radiation through a window. This reduces the solar heat gain coefficient, visible transmittance and glare. Since some heat continues to pass through tinted windows by conduction and re-radiation, the window's U-factor is not lowered. Grey- and bronze-tinted windows reduce the penetration of both light and heat into buildings in equal amounts. Blue- and green-tinted windows offer greater penetration of visible light and slightly reduced heat transfer compared with other colors of tinted glass. In hot climates, black-tinted glass should be avoided because it absorbs more light than heat. Electrochromic glass is another type of tinted glass. It is an optical switching technology that can vary its transmittance. When voltage is applied to the window, it changes from clear to a dark tint in 3 to 5 minutes. Reversing the voltage restores the window to a clear state. Electrochromic windows are used both for fenestration and solar control.

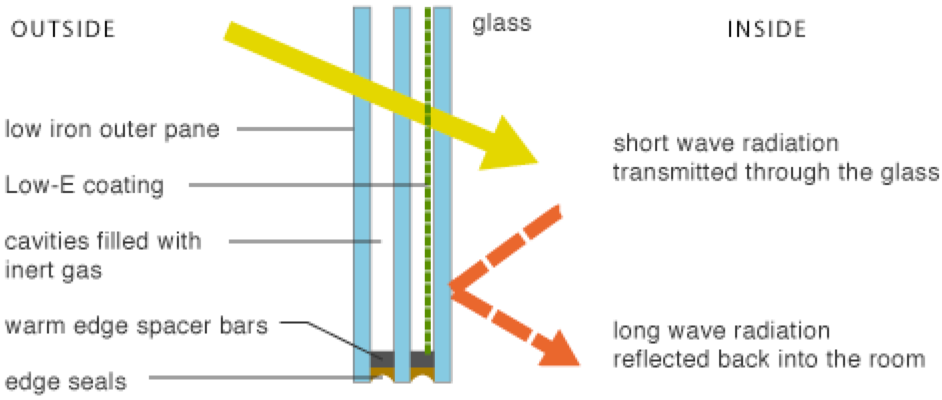
(iii) Insulated (double-glazed, triple-glazed)

Insulated window glazing refers to windows with two or more panes of glass. They are also called double-glazed, triple-glazed, or storm windows. To insulate the window, the glass panes are spaced apart and hermetically sealed to form a single-glazed unit with an air space between each pane of glass. The glass layers and the air spaces resist heat flow. As a result, insulated window glazing primarily lowers the U-factor, but it also lowers the solar heat gain coefficient.

(iv) Low-emissivity (Low-E) coatings

Low-emissivity (Low-E) coatings on glazing or glass control heat transfer through windows with insulated glazing. Windows manufactured with Low-E coatings typically cost about 10%–15% more than regular windows, but they reduce energy loss by as much as 30%–50%.

A Low-E coating is a microscopically thin, virtually invisible, metal or metallic oxide layer deposited directly on the surface of one or more of the panes of glass. By coating the face of the inner pane of glass with metal or metal oxide, short wave radiation from the sun is permitted to enter the building, whilst long wave radiation in the form of heat from the inside is reflected back into the room.



The Low-E coating reduces the infrared radiation from a warm pane of glass to a cooler pane, thereby lowering the U-factor of the window. Different types of Low-E coatings have been designed to allow for high, moderate or low solar gain. A Low-E coating can also reduce a window's visible transmittance. For hot climates, the Low-E coating should be applied to the outside pane of glass whereas for cold climates, the coating should be applied to the inside pane of glass. Low-E coatings are applied in either soft or hard coats. Soft Low-E coatings degrade when exposed to air and moisture, are easily damaged and have a limited shelf life. Hard Low-E coatings are more durable and can be used in add-on (retrofit) applications. However, the energy performance of hard-coat, Low-E films is slightly poorer than that of soft-coat films.

(v) Spectrally selective coatings

Spectrally selective coatings filter out 40%–70% of the heat normally transmitted through insulated window glass or glazing while allowing the full amount of light to be transmitted.

Spectrally selective coatings are optically designed to reflect particular wavelengths but remain transparent to others. Such coatings are commonly used to reflect the infrared portion of the solar spectrum while admitting a higher portion of visible light. They help create a window with a low U-factor and solar heat gain coefficient but a high visible transmittance. Spectrally selective coatings can be applied on various types of tinted glass to produce "customized" glazing systems capable of either increasing or decreasing solar gains according to the aesthetic and climatic effects desired.

(vi) Reflective coatings

Reflective coatings usually consist of thin, metallic layers. They come in a variety of metallic colors, including silver, gold and bronze. Reflective coatings on window glazing or glass reduce the transmission of solar radiation, blocking more light than heat. Therefore, they greatly reduce a window's visible transmittance (VT) and glare but they also reduce a window's solar heat gain coefficient (SHGC).

Reflective window glazing is commonly used in hot climates where solar heat gain control is critical. However, the reduced cooling energy demands they achieve can be offset by the resulting need for additional electrical lighting, so reflective glass is mostly used just for special applications. Reflective coatings are available both for single-pane applications and in some coatings that must be sealed inside double-glass units.

7.2 Thermal performance of different glazing types

7.2.1 Gas fills

The combination of inert gases with multiple panes, low-conductivity frames and Low-e coatings has resulted to U-factors as low as 0.14.

The optimal spacing for an argon-filled unit is about 11-13 mm whereas the optimum gap width for krypton is 9 mm.

7.2.2 Heat absorbing tints

Tinted windows yield only a modest reduction in the SHGC and reduce visible transmittance by a slightly larger amount. Black-tinted glass is the worst choice for cooling load reduction, because it absorbs much more visible energy than near-infrared. Green or blue-tinted glass is more selective than other colours for letting light in while keeping heat out.

7.2.3 Insulated (double-glazed, triple-glazed)

Glass has high heat conductivity. By trapping air between two clear panes, manufacturers can produce glazing with half the heat flow of standard glazing – a U-factor of about 0.6. With insulated windows, the thermal weak point becomes the edge of the unit where the glass meets the window frame. Manufacturers use thermal breaks in metal frames, increase the use of wood and clad-wood sash and frames and frame materials with lower thermal conductivity, such as vinyl, to improve performance.

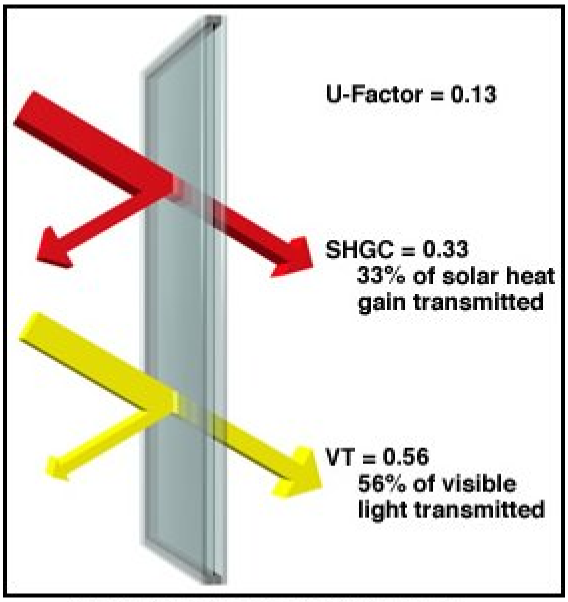
7.2.4 Low-emissivity coatings

Low-E coating is used with insulated glazing and can reduce energy loss by up to 50%.

The emissivity for Hard Low-E coating (e.g. Pilkington K glass) applied during the manufacturing process is between 0.15 and 2.0 whereas that for Soft (e.g. St Gobain Planitherm Total) applied after manufacture is between 0.05 and 0.10. They produce a lower u value.

7.2.5 Spectrally selective coatings

A common measure of the performance of spectrally-selective glazing units is the light-to-solar ratio (LSR). This is the ratio of visible light transmission divided by the solar heat gain coefficient for the glazing system. The highest possible ratio is approximately 2.0. Clear glazing units have a value close to 1.0, while a good spectrally-selective glazing system would have a value greater than 1.7.



Credit: Efficient Windows Collaborative

7.2.6 Reflective coatings

Most reflective glazings block daylight more than solar heat. Reflective glass has achieved its greatest market penetration in hot-climate applications. However, reflective glass reduces cooling loads at the expense of daylight transmittance so the reduction is offset by the heat created by the additional electric lighting required.

Table 1: Thermal performance of some glazing combinations

Glass Type (Product)	Visible Transmittance (% Daylight)	U-factor	Solar Heat Gain Coefficient (SHGC)
Single Pane glass (standard clear)	89	1.09	0.81
Single White Laminated w/Heat Rejecting Coating (*Southwall California Series*®)	73	1.06	0.46
Double Pane Insulated Glass (standard clear)	79	0.48	0.70
Double Bronze Reflective Glass (*LOF Eclipse*®)	21	0.48	0.35
Triple Pane Insulated Glass (standard clear)	74	0.36	0.67
Pyrolitic Low-e Double Glass (*LOF Clear Low-e*®)	75	0.33	0.71
Soft-coat Low-e Double Glass w/Argon gas fill (*PPG Sungate*® *100 Clear*)	73	0.26	0.57
High Efficiency Low-e	70	0.29	0.37

(*Solarscreen 2000 VEI-2M™*)			
Suspended Coated Film (*Heat Mirror™ 66 Clear*)	55	0.25	0.35
Suspended Coated Film w/ Argon gas fill (*Azurlite® Heat Mirror SC75*)	53	0.19	0.27
Double Suspended Coated Films w/ Krypton (*Heat Mirror™ 77 Superglass*)	55	0.10	0.34

7.3 Skylights - their effect on light and heat gains

Skylights provide daylighting and warmth. An energy-efficient skylight can help minimize the heating, cooling and lighting costs. Research conducted by the Institute of Energy & Sustainable Development has confirmed that installation of an appropriate level of skylighting can reduce overall energy consumption.

Skylights can also provide ventilation. Ventilating a building through a skylight opening releases the hot air that naturally accumulates near the ceiling.

A skylight in the roof of a house will typically lose 35%-45% more heat during cold weather than the exact same window installed on the side of the house. Skylights provide some of the best ways

to admit daylight and distribute it evenly, saving energy and improving visual comfort levels.

Skylights lose heat through convection and radiation. Most skylights have a curb (a supporting frame) which fits on between roof rafters. The curb increases the total surface area and also increases the potential for heat loss.

7.3.1 Increasing skylight energy efficiency

7.3.1.1 Design

The skylight's position should be considered to maximize daylighting and/or passive solar heating potential. Skylights on roofs that face south provide fairly constant but cool illumination. Those on east-facing roofs provide maximum light and solar heat gain in the morning. West-facing skylights provide afternoon sunlight and heat gain. South-facing skylights provide the greatest potential for desirable winter passive solar heat gain than any other location, but often allow unwanted heat gain in the summer.

7.3.1.1.1 Glazing

Skylight glazing usually consists of either plastic or glass. Other glazing technologies may also be used for solar heat control.

7.3.1.2 Daylighting

Recent technologies maximize skylights for daylighting. An "element" on the roof becomes an aperture for collecting sunlight. It may be a sun-tracking, open-sided cylinder, a large lens-like element or or a conventional skylight with a mirrored reflector mounted adjacent to it. This aperture may then connect to a mirrored pipe which has a diffusing lens that mounts on or is recessed into the ceiling of the room below. Most tubular skylights have this feature. These skylight designs effectively reduce daytime overheating and night time heat loss.

7.3.1.3 Moisture Control

In very cold weather, skylights are often prone to water vapor condensing on the glazing. Better skylights usually have an interior channel to collect the condensate so it can evaporate later. The most thermally efficient skylights are less prone to condensation problems.

7.3.1.3.1 Shape

Skylights are available in a variety of shapes and sizes. The most common shapes include rectangular, circular, oval, diamond, triangular, multi-sided, and tubular.

7.3.1.3.2 Installation

Skylights must be properly installed to ensure that its energy performance is achieved. Thus, it's important to consider slope and moisture control.

7.4 Reducing heat gains through glazing

Some Low-E coatings and solar control films reduce solar heat gain without impairing visible light transmission excessively. These include tinted glass and spectrally selective coatings, which transmit visible light while reflecting the long-wave infrared portion of sunlight. Many spectrally selective coatings also have some Low-E properties as well.

Modern window glazing falls into three categories:

- chemically or physically altered glass,
- coated glass or films
- multiple-layered assemblies

7.4.1 Chemically or physically altered glass

Tinting can reduce solar heat gain during the cooling season by 25%-55%. Tinted glass is made by alteration of the chemical properties of the glass. The tints absorb a portion of the sunlight and solar heat before it can pass all the way through the window to the room. Spectrally selective tints reduce infrared light transmission while allowing relatively more visible light to pass through. Spectrally selective glass also absorbs much of the ultraviolet (UV) portion of the solar spectrum. In a multi-paned window, they function best as the outermost sheet of glazing. Thermal performance is increased when combined with a Low-E coating.

7.4.2 Coatings and Films

The thickness and reflectivity of the metal layer (Low-E coating) and the location of the glass it is attached to directly affects the amount of solar heat gain in the room. Most window manufacturers now use one or more layers of low-E coatings in their product lines. Low-E coatings reduce long-wave radiation heat transfer by 5 to 10 times. The lower the emissivity value the better the material reduces the heat transfer from the inside to the outside. Most Low-E coatings also slightly reduce the amount of visible light transmitted through the glazing relative to clear glass. Representative emissivity values for different types of glass are as follows:

- Clear glass, uncoated: 0.84
- Glass with single hard coat Low-E: 0.15

- Glass with single soft coat Low-E: 0.10

Plastic films are available for application on existing windows. Use appropriate film for your needs, and understand all directions before beginning. Plastic films generally last about 8 to 10 years.

7.5 Light transmission and daylight

7.5.1 Daylighting

Daylighting is the use of windows and skylights to bring sunlight into the building. Nowadays, highly energy-efficient windows, as well as advances in lighting design, allow efficient use of windows to reduce the need for artificial lighting during daylight hours without causing heating or cooling problems. The best way to incorporate daylighting in a building depends on the climate and building design. The sizes and locations of windows should be based on the cardinal directions rather than their effect on the street-side appearance of the house.

North-facing windows are most advantageous for daylighting and for moderating seasonal temperatures. They allow most winter sunlight into the building but little direct sun during the summer, especially when properly shaded. North-facing windows are also advantageous for daylighting. They admit relatively even, natural light, producing little glare and almost no unwanted summer heat gain.

Although east- and west-facing windows provide good daylight penetration in the morning and evening, respectively, they should be limited. They may cause glare, admit a lot of heat during the summer when it is usually not wanted, and contribute little to solar heating during the winter.

7.5.1.1 Benefits of Daylighting

Daylighting has the potential to significantly improve life-cycle cost, increase user productivity, reduce emissions, and reduce operating costs:

- **Improved Life-Cycle Cost**: With dimmable ballasts, fixtures and controls, daylighting has been shown to save from 10% to 50% of the incremental first cost annually.
- **Increased User Productivity:** Daylight enlivens spaces and has been shown to increase user satisfaction and visual comfort leading to improved performance.
- **Reduced Emissions:** By reducing the need for electric consumption for lighting and cooling, the use of daylight reduces greenhouse gases and slows fossil fuel depletion.
- **Reduced Operating Costs:** Electric lighting accounts for 35 to 50 percent of the total electrical energy consumption in commercial buildings. By generating waste heat, lighting also adds to the loads imposed on a building's mechanical cooling equipment. The energy savings from reduced electric lighting through the use of daylighting strategies can directly reduce building cooling energy usage an additional 10 to 20 percent. Consequently, for many institutional and commercial buildings, total energy costs can be reduced by as much as one third through the optimal integration of daylighting strategies.

7.5.1.2 Daylighting Concepts

An awareness of basic visual acuity and performance issues is essential to an effective daylighting design.

- **Veiling Reflections:** Veiling reflections of high brightness light sources off specular (shiny) surfaces obscure details by reducing contract. They should be avoided, particularly where critical visual tasks occur.
- **Distribution:** Introduce as much controlled daylight as deep as possible into a building interior. The human eye can adjust to high levels of luminance as long as it is evenly distributed. In general, light which reaches a task indirectly (such as having bounced from a white wall) will provide better lighting quality than light which arrives directly from a natural or artificial source.
- **Glare:** The aim of an efficient daylighting design is not only to provide illuminance levels sufficient for good visual performance, but also to maintain a comfortable and pleasing atmosphere. Glare, or excessive brightness contrast within the field of view, is an aspect of lighting that can cause discomfort to occupants. The human eye can function quite well over a wide range of luminous environments, but does not function well if extreme levels of brightness are present in the same field of view.
- **Variety:** Some contrast in brightness levels may be desirable in a space for visual effectiveness. Dull uniformity in lighting can lead to tiredness and lack of attention—neither of which is compatible with a productive environment. Often times a good daylighting solution will integrate a "blast" of beam daylight in a circulation area for visual interest and to help lead occupants through a building. The human eye is naturally attracted to this bright area and can be useful in guiding people down an otherwise banal corridor.

Good daylighting requires attention to both qualitative and quantitative aspects of design. Make sure the combination of natural and artificial sources provides adequate light levels for the required task.

- The Illuminating Engineering Society of North America publishes an industry-standard method for determining recommended illuminance levels (expressed in units of footcandles, or fc) for various tasks.
- For office spaces, the U.S. General Services Administration has interpreted the IES method to recommend a minimum of 540 lumens per square meters on an imaginary desk-height horizontal "work surface." Nevertheless, when used in conjunction with indirect an ambient lighting system and direct task lighting, a high-quality daylighting design can be achieved with ambient lighting levels of 320 lumens per square meters or less.

To be effective, daylighting must be integrated with electric lighting design. In particular, daylighting must be coupled with efficient electric lighting controls if net energy savings are to be realized.

- As part of a daylighting design, consider the use of continuously dimming fixtures controlled by luminous sensors.

7.5.2 Light transmission

Transparent objects transmit light i.e some of the light that is incident to the surface of the object passes through the object. Not all light passes through. However, not all the light passes through, e.g. window glass with a thickness of 2 mm allows most of the light to go through, but if the glass is very much thicker or tinted, the transmitted light is appreciably altered.

The light that does not get through is said to be absorbed by the medium through which it passes. When a beam monochromatic light passes through a transparent medium, part of the light is absorbed and the transmitted beam has a lower intensity than the intensity of the incident beam.

The transmittance, **T** of the solution is defined as the ratio of the intensities of the transmitted beam, **I** to the intensity, $\mathbf{I_o}$ of the incident beam:

$$\mathbf{T = I/I_o}$$

7.6 Compromise between daylighting and heat gain control

Although daylight can decrease the amount of electric light used, heat gain can offset any savings from reduced lighting loads. When buildings are internally load-dominated, meaning the building must be cooled for most of the year, it’s important to fine-tune the glazing system to harvest daylight without too much heat gain. With careful design, heat gain related to daylighting can be minimised.

Spectrally selective coatings can be used to block most of the infrared and ultraviolet radiation while allowing the majority of the visible light spectrum through the glass. Even with high-performance glass, however, light energy still enters the building. This light energy then hits solid surfaces and is absorbed and reradiated in the space as heat.

Tubular skylights are smaller than most other skylights. They consist of roof-mounted light or solar collectors, which increase their daylighting potential without the need to increase their size. Because the rooftop solar collector has a small surface area, tubular skylights minimize heat loss in the winter and heat gain in summer. Their small size also minimizes their impact on a home's architecture.

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