OEN751

# GREEN BUILDINS DESIGN

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## Contents

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## 1. UNIT I ENVIRONMENTAL IMPLICATIONS OF BUILDINGS

Energy use, carbon emissions, water use, waste disposal; Building materials: sources, methods of production and environmental Implications. Embodied Energy in Building Materials: Transportation Energy for Building Materials; Maintenance Energy for Buildings.

### 1.1 Introduction

A ‘green’ building is a building that, in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts, on our climate and natural environment. Green buildings preserve precious natural resources and improve our quality of life.

There are a number of features which can make a building ‘green’. These include:

- Efficient use of energy, water and other resources
- Use of renewable energy, such as solar energy
- Pollution and waste reduction measures, and the enabling of re-use and recycling
- Good indoor environmental air quality
- Use of materials that are non-toxic, ethical and sustainable
- Consideration of the environment in design, construction and operation
- Consideration of the quality of life of occupants in design, construction and operation
- A design that enables adaptation to a changing environment

Any building can be a green building, whether it’s a home, an office, a school, a hospital, a community centre, or any other type of structure, provided it includes features listed above.

However, it is worth noting that not all green buildings are – and need to be - the same. Different countries and regions have a variety of characteristics such as distinctive climatic conditions, unique cultures and traditions, diverse building types and ages, or wide-ranging environmental, economic and social priorities – all of which shape their approach to green building.

## 1.2 Steps Involved in Creating Green Building

There are a number of ways to make a building green. These include:

***Taking an intelligent approach to energy***

 Minimising energy use in all stages of a building's life-cycle, making new and renovated buildings more comfortable and less expensive to run, and helping building users learn to be efficient too.

 Integrating renewable and low-carbon technologies to supply buildings' energy needs, once their design has maximised inbuilt and natural efficiencies.

***Safeguarding water resources***

 Exploring ways to improve drinking and waste water efficiency and management, harvesting water for safe indoor use in innovative ways, and generally minimising water use in buildings.

 Considering the impact of buildings and their surroundings on stormwater and drainage infrastructure, ensuring these are not put under undue stress or prevented from doing their job.

***Minimising waste and maximising reuse***

 Using fewer, more durable materials and generating less waste, as well as accounting for a building's end of life stage by designing for demolition waste recovery and reuse.

 Engaging building users in reuse and recycling.

***Promoting health and wellbeing***

 Bringing fresh air inside, delivering good indoor air quality through ventilation, and avoiding materials and chemicals that create harmful or toxic emissions.

 Incorporating natural light and views to ensure building users' comfort and enjoyment of their surroundings, and reducing lighting energy needs in the process.

 Designing for ears as well as eyes. Acoustics and proper sound insulation play important roles in helping concentration, recuperation, and peaceful enjoyment of a building in educational, health and residential buildings.

 Ensuring people are comfortable in their everyday environments, creating the right indoor temperature through passive design or building management and monitoring systems.

***Keeping our environment green***

 Recognising that our urban environment should preserve nature, and ensuring diverse wildlife and land quality are protected or enhanced, by, for example, remediating and building on polluted land or creating new green spaces.

 Looking for ways we can make our urban areas more productive, bringing agriculture into our cities.

***Creating resilient and flexible structures***

 Adapting to our changing climate, ensuring resilience to events such as flooding, earthquakes or fires so that our buildings stand the test of time and keep people and their belongings safe.

 Designing flexible and dynamic spaces, anticipating changes in their use over time, and avoiding the need to demolish, rebuild or significantly renovate buildings to prevent them becoming obsolete.

***Connecting communities and people***

 Creating diverse environments that connect and enhance communities, asking what a building will add to its context in terms of positive economic and social effects, and engaging local communities in planning.

 Ensuring transport and distance to amenities are considered in design, reducing the impact of personal transport on the environment, and encouraging environmentally friendly options such as walking or cycling.

 Exploring the potential of both 'smart' and information communications technologies to communicate better with the world around us, for example through smart electricity grids that understand how to transport energy where and when it is needed.

***Considering all stages of a building's life-cycle***

 Seeking to lower environmental impacts and maximise social and economic value over a building's whole life-cycle (from design, construction, operation and maintenance, through to renovation and eventual demolition).

 Ensuring that embodied resources, such as the energy or water used to produce and transport the materials in the building are minimised so that buildings are truly low impact.

### 1.3 Benefits of Green Building

They provide some of the most effective means to achieving a range of global goals, such as addressing climate change, creating sustainable and thriving communities, and driving economic growth. Highlighting these benefits, and facilitating a growing evidence base for proving them, is at the heart of what we do as an organisation. The benefits of green buildings can be grouped within three categories: environmental, economic and social. Here, we provide a range of facts and statistics from various third-party sources that present these benefits.

***Environmental***

One of the most important types of benefit green buildings offer is to our climate and the natural environment. Green buildings can not only reduce or eliminate negative impacts on the environment, by using less water, energy or natural resources, but they can - in many cases - have a positive impact on the environment (at the building or city scales) by generating their own energy or increasing biodiversity.

*At a global level:*

 The building sector has the largest potential for significantly reducing greenhouse gas emissions compared to other major emitting sectors – UNEP, 2009. This emissions savings potential is said to be as much as 84 gigatonnes of CO2 (GtCO2) by 2050, through direct measures in buildings such as energy efficiency, fuel switching and the use of renewable energy – UNEP, 2016.

 The building sector has the potential to make energy savings of 50% or more in 2050, in support of limiting global temperature rises to 2°C (above pre-industrial levels) – UNEP, 2016.

*At a building level:*

 Green buildings achieving the Green Star certification in Australia have been shown to produce 62% fewer greenhouse gas emissions than average Australian buildings, and 51% less potable water than if they had been built to meet minimum industry requirements.

 Green buildings certified by the Indian Green Building Council (IGBC) results in energy savings of 40 - 50% and water savings of 20 - 30% compared to conventional buildings in India.

 Green buildings achieving the Green Star certification in South Africa have been shown to save on average between 30 - 40% energy and carbon emissions every year, and between 20 - 30% potable water every year, when compared to the industry norm.

 Green buildings achieving the LEED certification in the US and othe The benefits of green buildings can be grouped within three categories: environmental, economic and social. Here, we provide a range of facts and statistics from various third-party sources that present these benefits.

***Economic***

Green buildings offer a number of economic or financial benefits, which are relevant to a range of different people or groups of people. These include cost savings on utility bills for tenants or households (through energy and water efficiency); lower construction costs and higher property value for building developers; increased occupancy rates or operating costs for building owners; and job creation.

At a global level:

 Global energy efficiency measures could save an estimated €280 to €410 billion in savings on energy spending (and the equivalent to almost double the annual electricity consumption of the United States) – European Commission, 2015.

At a country level:

 Canada's green building industry generated $23.45 billion in GDP and represented nearly 300,000 full-time jobs in 2014 – Canada Green Building Council / The Delphi Group, 2016.

 Green building is projected to account for more than 3.3 million U.S. jobs by 2018 – US Green Building Council / Booz Allen Hamilton, 2015.

At a building level:

 Building owners report that green buildings - whether new or renovated - command a 7 per cent increase in asset value over traditional buildings – Dodge Data & Analytics, 2016.

**Social**

Green building benefits go beyond economics and the environment, and have been shown to bring positive social impacts too. Many of these benefits are around the health and wellbeing of people who work in green offices or live in green homes.

 Workers in green, well-ventilated offices record a 101 per cent increase in cognitive scores (brain function) - Harvard T.H. Chan School of Public Health / Syracuse University Center of Excellence / SUNY Upstate Medical School, 2015.

 Employees in offices with windows slept an average of 46 minutes more per night - American Academy of Sleep Medicine, 2013.

 Research suggests that better indoor air quality (low concentrations of CO2 and pollutants, and high ventilation rates) can lead to improvements in performance of up to 8 per cent–Park and Yoon, 2011.

Our Better Places for People project focuses on creating buildings which are not only good for the environment, but also support healthier, happier and more productive lives.

World GBC and the Green Building Council of South Africa established a joint project to develop a framework to enable complex socio-economic issues to be integrated into any green building rating system in the world.

## 1.4 Ecological Footprint

Ecological Footprint is the impact of human activities measured in terms of the area of biologically productive land and water required to produce the goods consumed and to assimilate the wastes generated. More simply, it is the amount of the environment necessary to produce the goods and services necessary to support a particular lifestyle.

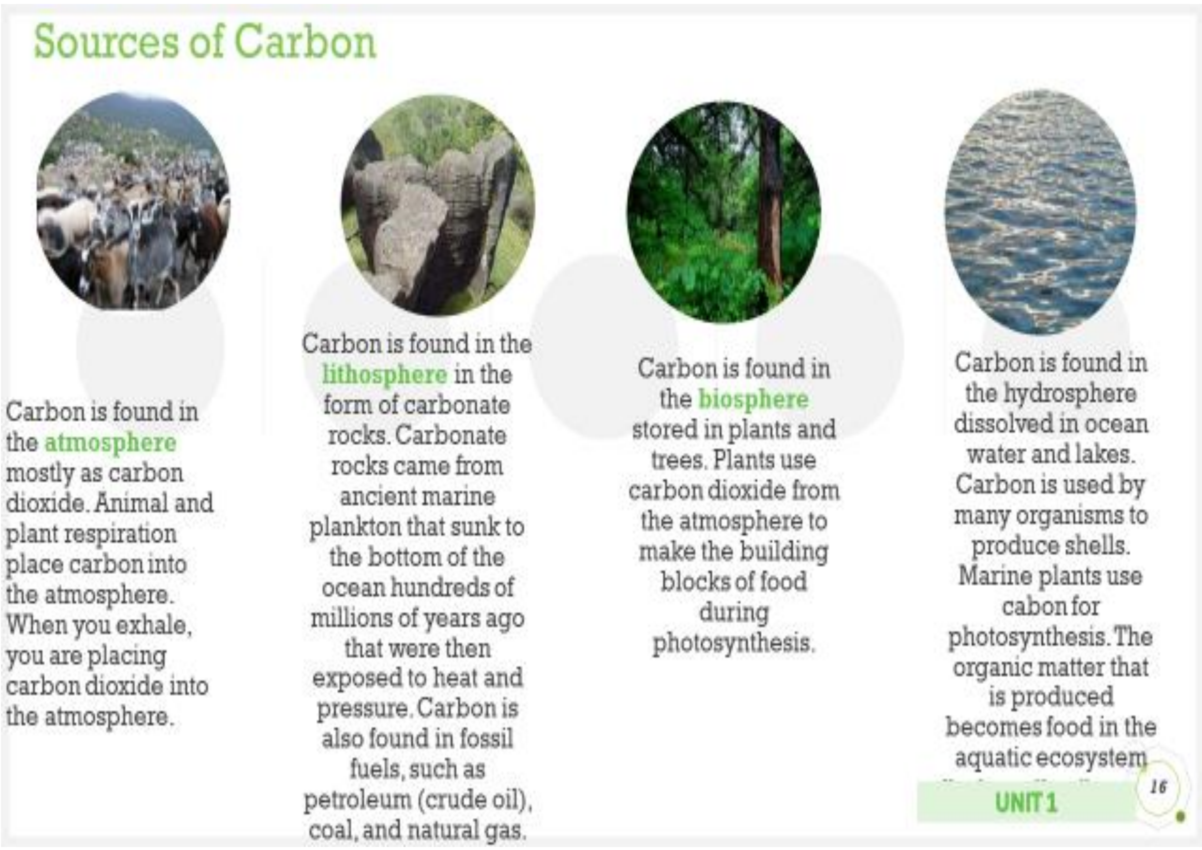
## 1.5 Energy Use

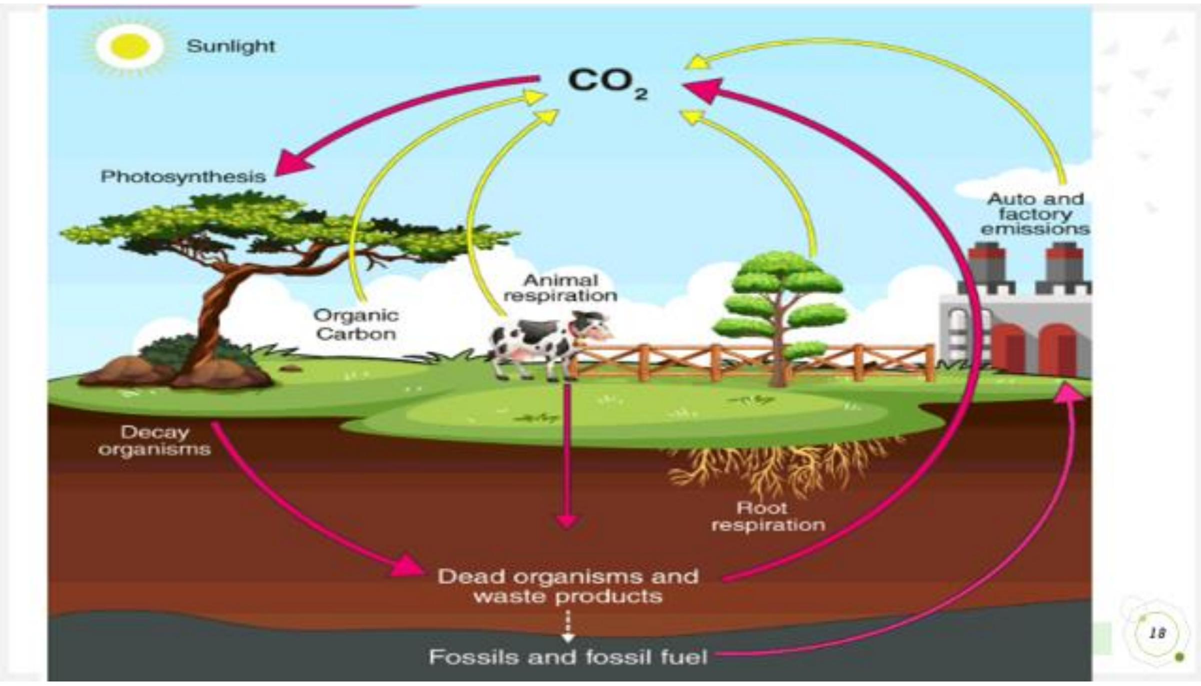
Energy is the foundation for green building. Energy codes define the minimum acceptable standards for a climate zone. This information has a direct impact on us as builders. Buildings comprise certain percent of direct energy use in India. Remaining percent goes into heating, ventilation, and air conditioning, heats hot water, lighting; and electrical appliances are beginning to cut a significant wedge into the pie. In terms of carbon dioxide production, in total, buildings are responsible for 48% of all greenhouse gases. Energy efficiency requires a systems-based approach to designing and building a home. All elements of the building shell; foundation, framing, roof structure and windows play key roles in defining the potential energy savings for a house. Energy use inside the home is the second tier of consideration. Mechanical equipment sized to the actual loads of the house, natural day lighting and ventilation greatly impact how much energy will be used to provide comfort and convenience. Appliances and lighting also impact net energy efficiency. All need to be considered in the early design stages to maintain cost effectiveness. The benefits of energy efficiency in building are summarised as following:

- Energy efficiency in buildings is compelling, cost effective and can help consumers to save money in the long term
- Energy efficiency in buildings help to meet energy targets and resource energy shortage

### 1.6 Carbon Cycle

The movement of carbon from one area to another is the basis for the carbon cycle. Carbon is important for all life on Earth. All living things are made up of carbon. Carbon is produced by both natural and human-made (anthropogenic) sources.



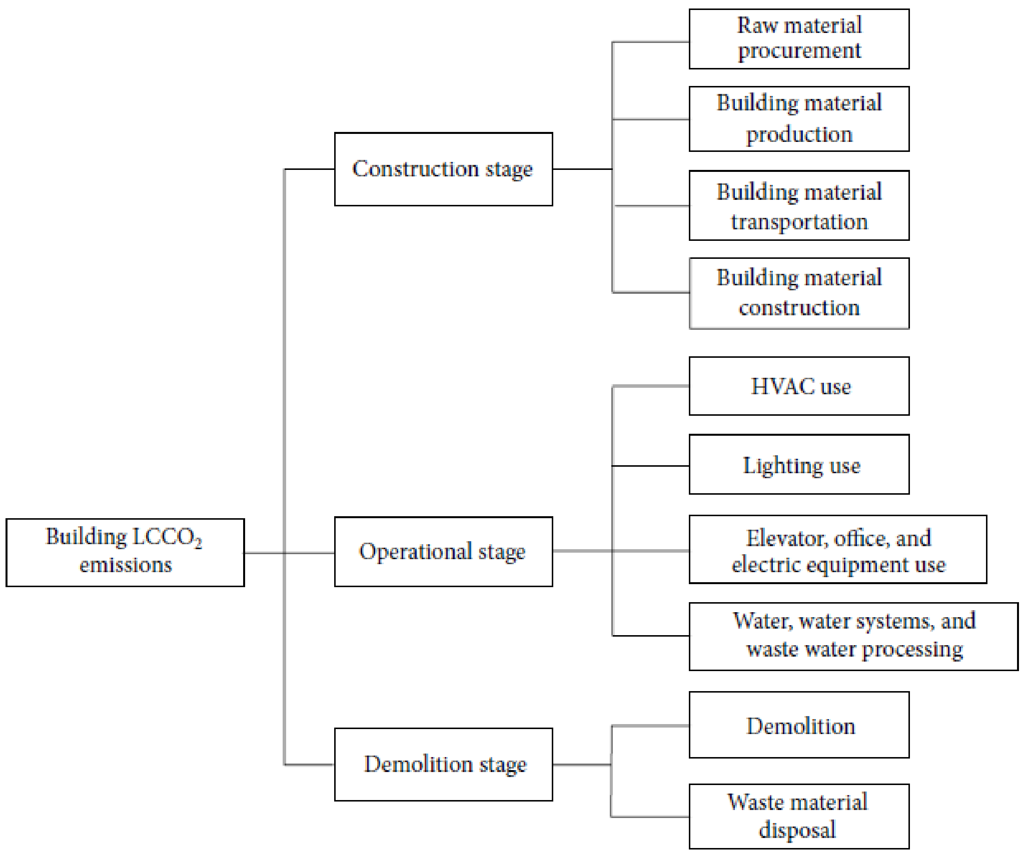




## 1.7 Carbon Emission

A building’s carbon footprint is defined as the amount of CO2 it produces during its operations and activities. It id found that residential and commercial buildings are responsible for almost 40 percent of U.S. carbon dioxide emissions. From houses and hotels to schools and skyscrapers, buildings in the United States use about 40 percent of the country's energy for lighting, heating, cooling, and appliance operation. It is estimated that the manufacture, transport, and assembly of building materials such as wood, concrete, and steel account for another eight percent of energy use. About 30 percent of the electricity buildings use is generated from coal-burning power plants, which release greenhouse gases, causing climate change. A building's LCCO2 emissions into three stages:

1. **The construction stage** (including processes such as procurement of raw materials, building material production, transportation, and construction),
2. **The operational stage**,
3. **The demolition stage** (including processes such as building demolition and waste material recycling and processing).

The maintenance stage was excluded due to its lower weight in importance, The carbon emissions of the operational stage primarily include those generated by heating, ventilation, and air conditioning (HVAC), lighting, office equipment, elevators, and water pumps. The sequestration from the surrounding greenery might also be considered. The below figure shows a flowchart of these phases.



## 1.8 Basic Measurement Method for Carbon Emissions

The "2006 IPCC national greenhouse gas inventory categories" states that the GHG emissions generated by energy activities can be calculated using the formula below:

$$C = \sum_{i,j,k} AD_{i,j,k} \cdot \mathrm{EF}_{i,j,k},$$

$$\mathrm{EF}_{i,j,k} = c_k \cdot \eta_{i,j,k} \cdot \frac{44}{12},$$

where $C$ is the amount of carbon emissions, $AD$ is the level of activity, and EF is the emission factor. $i$ is the industry and region, $j$ is the equipment and technology used, $k$ is the type of fuel used, $ck$ is the carbon content, and $\eta$ $i$,, is the oxidation rate.

$AD$ is based on the amount of fuel burned and is usually taken from national energy statistics. EF is the average emission factor (default value). For CO2, the emission factor is determined mainly by the fuel's carbon content. The burning conditions (burning efficiency and carbon residual in the objects such as slag and ashes) are relatively unimportant. Therefore, the amount of carbon emissions can be accurately estimated based on the total amount of fuel burned and the average carbon content in the fuel.

***Total Carbon Emission Computation for the Life Cycle of a Building***.

Based on Figure 1, the total amount of carbon emissions produced over the life cycle of a building was taken as the sum of the carbon emissions generated during the construction, operational, and demolition stages. The formula is

$$C = C\mathrm{b} + C\mathrm{u} + C\mathrm{d} - C\mathrm{t}$$

where $C$ is total amount of carbon emissions over the life cycle of the building; $C$b is the total amount of carbon emissions during the construction stage; $C$u is the total amount of carbon emissions during the operational stage; $C$d is the total amount of carbon emissions during the demolition stage; and $C$t is the total carbon sequestration by vegetation around the building.

***Total Carbon Emissions during the Construction Stage, $C$b***

The total amount of carbon emissions during the construction stage included processes such as material production, transportation, and construction; the formula is

$$Cb = Cbe + Cbt + Cbp$$

where

**$C$be** is the total carbon emissions generated by the building material production. It is obtained by multiplying the total quantity of materials used in a project with the carbon emission factor of the material during its production.

**$C$bt** is the total carbon emissions generated by the building material transportation. Transportation methods include trains, trucks, and ships. Commonlyused fuels for trucks include gasoline and diesel.

**$C$bp** is the total carbon emissions of building materials used during building construction. This equals the sum of the carbon emissions produced by the construction site electricity use by construction equipment and office devices. The carbon emissions produced by various construction crafts and the carbon emissions produced by the horizontal transportation occurring during the construction stage.

The electricity use at the construction site includes construction zone and living quarters electricity consumption; the former includes cranes, pile drivers, welding machines, and hoists, and the latter includes workers' living and office space. There are many pieces of fuel-consuming machinery at a construction site, and the main fuel-consuming processes include excavation, earth removal, earth work.

***Total Carbon Emissions during the Building Demolition Stage,*d**.

The computation of the carbon emissions generated during the demolition stage includes the carbon emissions generated during the demolition process and the construction waste material treatment process:

$$Cd = Cd1 + Cd2$$

where

$C$d1 is the carbon emissions generated during the demolition process.

$C$d2 is the carbon emissions produced during the waste material treatment process. Building materials that cannot be recycled are transported to waste disposal sites for open dumping or landfilling after demolition. Therefore, the CO2 emissions at this stage are mainly generated by the transportation process, when the waste materials are shipped to a waste disposal site.

***Total Carbon Sequestration by Vegetation around the Building, $C_t$.***

The carbon sequestration by vegetation around the building is calculated using formulas.

***Total Carbon Emissions during the Building Operational Stage, $C_u$.***

The buildings get hot in the summer and cold in the winter. The energy source during the building operational stage is electricity and water use. Therefore carbon emissions generated by air conditioning, lighting, elevators, equipments are considered here.

## 1.9 Reduction in carbon emission by green Buildings

**Reduced Losses during Fabrication**

For many green buildings, the raw materials and components themselves are purchased from green suppliers. These suppliers adhere to strict standards and controls to ensure that their production methods conserve natural resources and reduce overall carbon dioxide emissions. Some of the ways that they do this include more efficient processes designed to reduce energy consumption during fabrication; transporting goods on more efficient means of transportation, and leveraging new and growing technologies like solar power to reduce dependence on fossil-fuel-based (and heavily carbon dioxide-emitting) power plants.

Furthermore, green buildings are erected in a way that minimizes inefficiencies and leverages modern materials science in a way to reduce overall emissions even during construction. Contemporary green building materials can dramatically reduce the overall carbon dioxide emissions, both in their construction and in their installation.

**Reduced Energy Consumption during Operation**

Some of the greatest benefits to the environment from green buildings come after the construction phase is concluded, and the building settles into a daily operation grind. Because most of the power grid around the world, and especially in India, relies heavily on fossil fuels–natural gas, coal, and oil–for the production of energy, every kilowatt hour used by a building is indirectly releasing carbon dioxide into the air. The advantage of a green building that uses less energy, then, is obvious: a reduced overall usage of energy, whether from energy-efficient appliances, passive heating and cooling, or sustainable architectures can dramatically shrink a building’s overall carbon footprint or even make it a net positive on the environment.

The great thing about building with a mind towards sustainability is that the same practices which protect the environment from excessive carbon dioxide production have the beneficial side effect of often reducing a building owner’s overall expenditures on building maintenance. Sustainable architecture, by definition, is designed to last without needing continual repair or refurbishment, but instead to work with, instead of against, the natural world. Using well-constructed, stable materials in concert with well-made equipment can save the building owner money while also leading towards environmental benefits.

## 1.10 Water Efficiency in Green Buildings

The excessive use of water drawn from both surface and underground sources has led to a deficit in this precious resource. Various water-efficiency measures (e.g. low-flow fixtures, sensors, use of non-potable water for irrigation applications) in commercial buildings and homes can greatly reduce water waste, yielding lower sewage volumes, reduced energy use, and financial benefits.

A Green building design largely emphasises on making effectual use of natural resources like water, energy, etc. while reducing several bad effects on the environment and the occupant’s health during its use. The 5 main gears of green buildings are:

1. *Site And Design Efficiency*
2. *Reduced Energy Usage*
3. ***Reduced Water Consumption***
4. *Environmentally Safe Construction Materials*
5. *Better Air Quality*

Considering water efficiency in Green Buildings, today several technologies are being used rainwater harvesting, recycling and reuse of grey water, low-flow fixtures, sensors etc.

## 1.11 Green Building Rating Systems for Water Efficiency

Several rating systems for Green Building have been developed by various countries across the globe to rate the green buildings based on its degree of the environmental goals which have been achieved by them. In India, the main certifying agencies who consider water efficiency are:

- **Green Rating for Integrated Habitat Assessment (GRIHA)**

- **Indian Green Building Council (IGBC)**
- **Leadership in Energy and Environmental Design (LEED, INDIA)**

## 1.12 Water Efficient Technologies

***Rain water harvesting***

In simple terms, it is the active collection and distribution of rainwater which rather than going to the sewage is put into use in daily life. Typically, rainwater is collected from the rooftops, deposited in a reservoir with filtration. Once the water is purified, it is can be used for cultivation, gardening, and other domestic uses.

One of the biggest uses of rainwater harvesting is in drier states where there is a lower rate of rainfall. They can store this water and can later purify it to make usable water or can use it for washing or watering plants.

***Landscaping Techniques***

The use of native, adapted, or drought- tolerant plants is the first step to reducing the amount of water used in landscaping. Native and adapted plants are suited for the climate of the project location, and do not usually require additional irrigation. Drought-tolerant plants are acclimated to long periods of time without water. Generally speaking, grass lawns are not conducive to lowering the amount of irrigation water needed. They require regular watering and lots of maintenance.

***Irrigation* Techniques**

There are a few options for reducing irrigation water use. One is to install a moisture sensor system, so the sprinklers only run when there is not enough moisture in the ground (this keeps them from running while it is raining or just after a rainstorm).

Drip irrigation systems ensure that water is delivered directly to the plants (not spraying on the building or sidewalks), and deliver it very efficiently, with less waste. Temporary drip irrigation systems are often used when landscaping is first planted, allowing the plants to get established. These systems are then removed as the native or adapted plants acclimate.

***Plumbing Fixtures:***

High efficiency toilets (HETs) use a gallon or less per flush. Dual-flush toilets use less water for liquid waste and more for solids. There are low-flow and waterless urinals, low-flow shower heads, and sensored faucets that limit the amount of water per use.

Aerator in the bathroom or kitchen faucet or a new efficient showerhead can work just as well.

***Pressure Reduction Valves***

These days, pressure reducing valves are being very commonly installed in high rise residential and commercial buildings to help to maintain a consistent water pressure at the water fixtures across the entire building from top to bottom.

With these higher pressures, water flows through the system with greater flow through the terminal fixtures beyond rated flow capacities, this additional water is wasted and it serves no extra benefit to the rated performance.

Most plumbing codes demand pressure reducing valves on the systems where water pressures exceed 80 psi and in most of the cases, pressures can be depressed through the implementation of supplementary pressure-reducing valves. In addition to that, higher pressures could break pipes and damage fixtures which could result in even greater water waste in domestic settings.

***Choice of Appliances***

High efficiency clothes washers and dishwashers greatly reduce the amount of water used per load by saving lot of energy and reducing the bills too.

***Water Reuse and Treatment***

There are two types of reuse systems, gray water and black water. Gray water is the water that comes out of bathroom sinks, showers, dishwashers, and washing machines. It is considered to be less contaminated than black water. With minimal filtration gray water can be used in irrigation or to flush toilets and urinals. With additional filtration, gray water can also be used for drinking and cleaning.

These systems require a separate piping system for the treated gray water. Black water comes from toilets and kitchen sinks. Extensive treatment is required before it can be reused for any purpose. These systems involve several filters and treatment with ultraviolet light. Black water treatment systems are available for both commercial and residential applications. The most cost effective option is usually to connect several large buildings together with a central treatment plant. But, it can be done on a smaller scale too.

## 1.13 Waste Disposal

Up to 40 per cent of the waste going to landfills is related to the construction and demolition of buildings. Even more waste is produced during the occupancy of buildings and the production of goods that we consume every day. Poor waste practices and treatment of the environment in the past have not only lead to a degradation of our water, air and land resources but also represent a big financial burden to current and future generations.

By reducing, recycling and reusing waste we can:

• Reduce the amount of waste going to landfill

• Reduce emissions, pollution and contamination

• Protect scarce resources

• Reduce overall construction costs

***Recycling & Reusing:***

Most construction and demolition materials can be recycled. Often, it is just a matter of separating waste, either on-, or off-site and sending it to the relevant waste stream. Many waste contractors are specialised in this area and will be able to provide you with detailed advice. Below is an overview of common materials and the relevant recycling/reuse opportunities.

- Steel can be melted and reused within new steel products. Using recycled steel reduces the embodied energy by 72%.
- Aluminium can be 100% recycled. Using recycled aluminium reduces the embodied energy by 95%.
- Gypsum plasterboard can and should be recycled as when it is disposed to landfill, it produces poisonous hydrogen sulphide.
- Timber can either be directly reused or turned into horticultural mulch. If not recycled, always specify sustainably sourced timber.
- Concrete can be crushed and recycled as aggregate for new concrete or road base and fill. Specify concrete with recycled aggregate in all viable applications.
- Glass can be reused as aggregate for concrete.
- Bricks and tiles can either be directly reused or crushed for backfill, aggregate or gravel.
- Plastics can often be granulated and reused to make new plastic products.

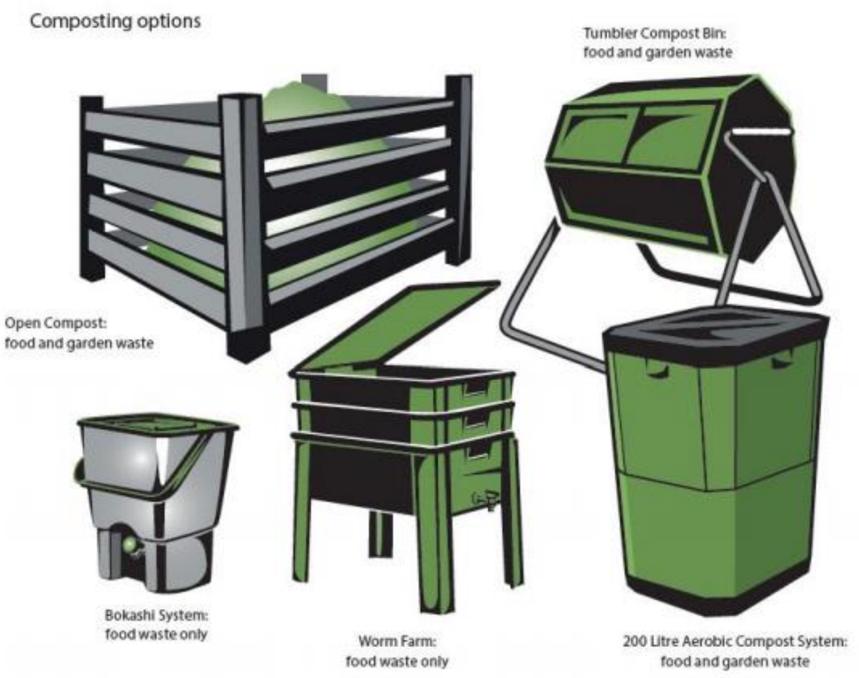
*Operational Wastes:*

Dedicated storage spaces should be allocated for the collection and sorting of waste. These spaces should be easily accessible to all building occupants and be in close proximity to waste collection points. Bins or storage containers should be allocated to accommodate different waste streams including recyclable waste, rubbish (non-recyclable waste), oversized household items, green waste, composting and small containers for hazardous waste, such as batteries and fluorescent light bulbs. Recycling bins should be sized and located to accommodate paper, cardboard, glass, plastics and metals. Rubbish bins should only accommodate common waste that cannot be recycled or composted and will go to landfill.


Best practice waste separation in multi-unit residential developments.

*Green waste and composting*

Green waste includes garden waste, such as branches, prunings and grass clippings. Composting includes largely food waste and should, like green waste be separated from common waste. Wherever possible, provisions should be made for onsite composting of food and green waste at a project's early design stage.




## 1.13 Environmental Implications of Building Materials

Natural resources are limited on earth but looking at the uncontrolled able consumption of construction material it is apparently unsustainable. Consumption of construction materials has compatibly increased along with production in the past century. Although there are few drops in the graph during 1940's and 1990's but no sustainability was employed for the economy of construction materials. With this trend of consumption of uncontrolled able construction materials will result in environmental degradation on a global scale.

**Each material is assessed at five stages of its life:**

- ✓ Mining/Extraction
- ✓ Manufacture
- ✓ Construction
- ✓ Use
- ✓ Demolition.

An Australian system, BMAS (Building Material Assessment System), based on life-cycle analysis, has been developed to compare the relative ecological impacts of various types of wall, floor and roof assemblies. High numbers indicate greater environmental impact; lower numbers indicate lesser impact.

**WALLS**

| | | |
|---|---|---|
| Timber Frame, Plasterboard | - | 7.2 |
| Steel Frame, Plasterboard | - | 7.4 |
| AAC Blocks - rendered | - | 20.6 |
| Clay Bricks - rendered | - | 49.1 |

**FLOORS**

| | | |
|---|---|---|
| Timber, Brick Piers, Footings | - | 41.9 |
| Concrete Raft Slab | - | 74.4 |

**ROOFS**

| | |
|---|---|
| Timber Frame, Corrugated Steel | 5.2 |
| Timber Frame, Terracotta Tile | 20.6 |

One thing suggested by these figures is that relatively small quantities of materials that have high impact (eg, steel), may be preferable to large quantities of materials that have lower impact (eg terracotta tile).

As always, designers, builders and building owners have to seek a balance between often conflicting considerations, appearance, comfort, ease of construction, maintenance costs, capital costs etc. Now, environmental impact is an added variable. However, it has been shown that if environmental considerations are included early in the design process, it is possible to incorporate them without incurring additional costs.

## 1.14 Embodied Energy in building materials

All human activities affect the environment. Some are less impactful. According to the United Nations Environment Program (UNEP), the construction sector is responsible for up to 30% of all greenhouse gas emissions. Activities such as mining, processing, transportation, industrial operations, and the combination of chemical products result in the release of gases such as CO2, CH4, N2O, O3, halocarbons, and water vapor. When these gases are released into the atmosphere, they absorb a portion of the sun'srays and redistribute them in the form of radiation in the atmosphere, warming our planet. With a rampant amount of gas released daily, this layer thickens, which causes solar radiation to enter and stay in the planet. This leads to desertification, ice melting, water scarcity, and the intensification of storms, hurricanes, and floods, which has modified ecosystems and reduced biodiversity.

The term **Embodied Energy** or **Embodied Carbon** refers to the sum impact of all greenhouse gas emissions attributed to a material during its life cycle. This cycle encompasses extraction, manufacturing, construction, maintenance, and disposal.

Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery. Embodied energy does not include the operation and disposal of the building material, which would be considered in a life cycle approach.

For example, reinforced concrete is a material with extremely high embodied energy. When manufacturing the cement, large amounts of CO2 are released in the Calcination stage, where limestone is transformed into calcium oxide (quicklime), as well as in the burning of fossil fuels in furnaces. If we add these issues to the exploitation of sand and stone, to the use of iron for the rebar, to its transport to the construction site to be added to the mix, we can understand the impact of each decision of a project on the environment. Other construction materials, such as ceramic, brick, and plastic, similarly require large amounts of energy to be manufactured since the minerals used in them must be extracted and treated in energy intensive processes.

It's important to keep in mind that there are two types of carbon emissions in relation to buildings: Embodied Carbon and Operational Carbon. The latter refers to all the carbon dioxide emitted during the life of an entire building, rather than just its materials, encompassing electricity consumption, heating, cooling, and more.

Understanding the amount of energy or carbon incorporated in building's materials is essential to creating more eco-conscious projects. A 'sustainable material' in one place may have a high energy load in another due to local availability and the type of transport involved. A standardized method of quantifying the environmental impact of buildings, from the extraction of materials and the manufacture of products to the end of their useful life and disposal, is the Life Cycle Assessment (LCA). Using a quantitative methodology, numerical results are obtained that reflect the impact categories and provide comparisons between similar products.

There are also other tools and technologies that promise to facilitate the process. Autodesk, together with the Carbon Leadership Forum and in collaboration with other construction and software companies, has developed the **Embedded Carbon in Construction Calculator (EC3)** tool, which is available to all beta users. The idea is to provide users with the information they need to make more informed decisions about the embodied carbon of each element of a building, promoting intelligent, conscious, and accessible solutions even for those who are not specialists. As always, awareness in making decisions and being conscious of the options available are always the best way to make processes more intelligent and sustainable.

**How is embodied energy measured?**

Embodied energy is measured as the quantity of non-renewable energy per unit of building material, component or system. It is expressed in megajoules (MJ) or gigajoules (GJ) per unit weight (kg or tonne) or area (m2) but the process of calculating embodied energy is complex and involves numerous sources of data.

## 1.15 Reducing embodied energy

Buildings should be designed and materials selected to balance embodied energy with factors such as climate, availability of materials and transport costs. Lightweight building materials often have lower embodied energy than heavyweight materials, but in some situations, lightweight construction may result in higher energy use. For example, where heating or cooling requirements are high, this may raise the overall energy use of the building. Conversely, for buildings with high heating or cooling requirements but where there is a large diurnal (day/night) temperature range, heavyweight construction (typically with high embodied energy) and the inclusion of high levels of insulation can offset the energy use required for the building. When selecting building materials, the embodied energy should be considered with respect to:

- The durability of building materials
- How easily materials can be separated
- Use of locally sourced materials
- Use of recycled materials
- Specifying standard sizes of materials
- Avoiding waste

 Selecting materials that are manufactured using renewable energy sources.

## 1.16 Embodied energy in transportation

Life cycle assessment accounts for the effects of transportation mode and not just distance. A product traveling a long distance using a highly efficient transportation method can actually have a smaller transportation footprint than a closer product travelling inefficiently. It is natural to expect that locally sourced products would be more environmentally responsible than those shipped a great distance. But this is usually based on the assumption that transportation energy contributes a lot to the overall energy equation – and life cycle assessment can prove that that this is usually not the case. While buying local may help the local economy, it is not necessarily the best environmental choice. In many cases, transportation energy is a very small component of overall energy consumption.

**Table 1: Embodied energy in production and transportation**

| Material | Energy in production (MJ) | Energy in Transportation (MJ) | | |
|---|---|---|---|---|
| | | 25 km | 50 km | 100 km |
| Cement (kg) | 5.85 | | 50 (tonnes) | 100 (tonnes) |
| Bricks ($m^3$) | 2550 | | 100 | 200 |
| Steel (kg) | 42 | | 50 (tonnes) | 100 (tones) |
| Sand ($m^3$) | -- | | 87.5 | 175 |
| aggregate($m^3$) | 20.5 | | 87.5 | 175 |
| Lime (kg) | 5.63 | | 87.5 | 175 |
| Concrete ($m^3$) 1:2:4 | 1664 | | | |
| Soil ($m^3$) | -- | | 87.5 | 175 |
| [illegible] | [illegible] | | | |

## 1.17 Maintenance energy in buildings

**Maintenance Energy for Buildings**

Every building's energy consumption can benefit from rigorous operations and maintenance (O&M) practices. Properly planned and executed O&M is one of the most cost-effective strategies for ensuring equipment longevity, reliability, safety, and energy efficiency in commercial buildings. By one estimate, O&M measures cost about 20 times less and achieve roughly the same energy savings as energy efficiency upgrades. There are various opportunities to improve efficiency through O&M that can be discovered through efforts such as engaging tenants, training building staff, and conducting continuous commissioning.

**Green Building Maintenance and Repairs:**

Listed below are several suggestions for building maintenance and repairs. In today's society, where many items are considered disposable, including things as significant as the building's roof and facade, any change in the maintenance practice that adds to the longevity of the building's components can be viewed as a "green" practice.

**Building Exterior and Roof:**

Before winter snows begin to accumulate, every roof area should be viewed or accessed. On flat roofs, drains need to be cleared of tree debris and trash. Standing water roofs may have a cooling effect in summer but it also accelerates deterioration on most flat roofing systems and leads to leaks. Wet insulation is completely ineffective in retaining the heat in the living space and wastes energy. Roofs that have mechanical units for heating and cooling also need to be inspected for leaks in duct work or missing insulation. If your building has a steep roof (shingles) with gutter systems, gutters should be cleaned after the leaves are down. Ice damming is not caused by blocked gutters but it certainly isn't aided by it. All loose and missing roof shingles should be replaced or sealed before winter. Replacing windows may not be in the budget but replacing, caulking, and sealing window openings and other penetrations that allow air infiltration is a way to reduce energy consumption and increase comfort. The use of low VOC (volatile organic compounds) sealants is also considered a green building practice. In northern Illinois climate, where freezing temperatures and high winds are common, it takes an opening in the siding of potential less than only an 1/8 inch around an exterior water faucet to freeze a pipe. By simply caulking these penetrations can prevent air infiltration. Residences with vinyl and aluminum siding may develop exterior discoloration from mildew and mold residues. Using non-toxic cleaning agents that may run off into storm water systems or contaminate the ground around the foundation is a green approach to maintaining the siding. Similarly, in high-rise buildings or those with large glass facades or windows that require periodic cleaning, non–toxic cleaning solutions should be employed.

**Mechanical Equipment:**

One of the largest areas of energy use in residential buildings, aside from lighting, is the energy needed for heating water for domestic use, such as showering and cooking. There are ways to improve the efficiency without replacing the existing water heating system for a more efficient one. Since domestic hot water is only used a few times during the day, insulating tanks with good quality and properly installed insulation, or installing timer controls on the heating mechanism, are both good ways to reduce energy consumption without affecting the end users.

Many central heating / cooling units operate below their optimum design efficiency or have shortened lives because of poor air circulation due to blocked or poorly maintained filters. Using filter media that is reusable or cleanable is a green alternative. Cleaning the cooling coils is also important in maintaining air flow. Be sure the MERV rating on the filter is compatible with the system. Air quality and the performance of the system go hand-in-hand with the maintenance of the filters.

**Lighting:**

The USGBC tells us that buildings use seventy-two percent (72%) of all electricity generated in the U.S. and contribute thirty-eight percent (38%) of all carbon dioxide emissions. Reducing electricity use by installing more efficient light bulbs is a simple way to save energy and the environment. CFL’s or compact fluorescent light bulbs are one type of bulb that achieves this by generating equal amounts of light while consuming kilowatts of energy.

Additionally, using timers or photocells to actuate the exterior building lights will reduce energy consumption. Be sure the maintenance staff adjusts the timers seasonally to maximize the safety and security of the residence and minimize the energy consumption.

# 2. UNIT II IMPLICATIONS OF BUILDING TECHNOLOGIES EMBODIED ENERGY OF BUILDINGS

**Framed Construction, Masonry Construction. Resources for Building Materials, Alternative concepts. Recycling of Industrial and Buildings Wastes. Biomass Resources for buildings.**

## 2.1 Embodied Energy Assessment for Buildings

The exploitation of natural resources is significantly reducing the reserves of natural materials around the world. It can be observed that the materials employed in construction have a great responsibility in the environmental impacts. There are several methods of environmental assessment. They are classified into three groups

- Embodied energy
- Life cycle analysis (LCA)
- Identification using more simplified procedures, such as **LEED** and **BREAM.**

All materials have some environmental impact and there are still no methods to accurately assess the total impact of a building. Even the analysis of individual materials is complex. The embodied energy is one of the most important measures for evaluating environmental impact, precisely because the use of non-renewable energy is the main reason for the general environmental degradation (through the release of CO2 ; and some emissions, such as acid rain).

Significant amount of energy is consumed in the production, transportation and application of building materials. Thus, the choice of materials and components can be made based on the analysis of the energy used for its production, and those considered best materials that consume less energy in their production processes and application in construction.

The incorporated energy can be defined as the amount of energy consumed for the production of a product, or a material or construction, and may be included the steps of extraction of raw material to the distribution of product on the market.

The four major building elements that should be considered in the embodied energy analysis of buildings are the structure, envelope, interior components and finishes, and building services system

## 2.2 Embodied Energy of various Buildings Materials

The embodied energy intensities of different building materials from various resources are listed as below.

| Materials | Energy intensities (MJ/kg) | Materials | Energy intensities (MJ/kg) |
|---|---|---|---|
| Aggregate (general) | 0.10 | Insulation | |
| Virgin rock | 0.04 | Cellulose | 3.30 |
| River | 0.02 | Fibreglass | 30.30 |
| Aluminium (virgin) | 191.00 | Polyester | 53.70 |
| Aluminium (recycled) | 8.10 | Glass wool | 14.00 |
| Asphalt (paving) | 3.40 | Paint | 90.40 |
| Cement | 7.80 | Solvent based | 98.10 |
| Cement mortar | 2.00 | Water based | 76.00 |
| Ceramic | | Plasterboard | 6.10 |
| Brick and tile | 2.50 | Plastics | |
| Brick (glazed) | 7.20 | PVC | 70.00 |
| Clay tile | 5.47 | Polyethylene | 87.00 |
| Concrete | | Polystyrene | 105.00 |
| Block | 0.94 | Sealants and adhesives | |
| Brick | 0.97 | Phenol formaldehyde | 87.00 |
| Paver | 1.20 | Urea formaldehyde | 78.20 |
| Pre-cast | 2.00 | Steel (recycled) | 10.10 |
| Ready mix, 17.5 MPa | 1.00 | Reinforcing, section | 8.90 |
| 30 MPa | 1.30 | Steel (virgin, general) | 32.00 |
| Roofing tile | 0.81 | Galvanised | 34.80 |
| Glass | | Stainless | 11.00 |
| Float | 15.90 | Timber (softwood) | |
| Laminated | 16.30 | Rough saw | 5.18 |
| Gypsum | 8.64 | Plywood | 18.90 |

## 2.3 Alternative Building Materials in Green Buildings

### 2.3.1 Materials

***Fly ash brick (FAB)***

Fly ash brick (FAB) is a building material, specifically masonry units, containing class C fly ash and water. Compressed at 28 MPa (272 atm) and cured for 24 hours in a 66 °C steam bath, then toughened with an air entrainment agent, the bricks last for more than 100 freeze-thaw cycles. Owing to the high concentration of calcium oxide in class C fly ash, the brick is described as "self-cementing". The manufacturing method saves energy, reduces pollution, and costs 20% less than traditional clay brick manufacturing.

PRICE = Rupees 12 to 50 depending upon the increase of the size

*Advantages*

Same number of bricks will cover more area than clay bricks. High Fire Insulation and Due to high strength, practically no breakage during transport and use. Due to uniform size of bricks mortar required for joints and plaster reduces almost by 50%. Due to lower water penetration seepage of water through bricks is considerably reduced. Gypsum plaster can be directly applied on these bricks without a backing coat of lime plaster. These bricks do not require soaking in water for 24 hours. Sprinkling of water before use is enough.

*Disadvantages*

Mechanical strength is low. But this can be rectified by adding marble waste, or Mortar between blocks. Limitation of size. Only modular size can be produced. Large size will have more breakages.

***Jaali Walls***

Allow controlled passage of air and light into the interior space. Throw patterns of light and shadow on the floor enhancing aesthetics. Ensure constant flow of breeze into the interior – occupant comfort cools the interiors. An alternative to costly window construction. Diffuse the glare of direct sunlight.

PRICE = 4.5” BRICK WALL rupees 5 to 7 per brick

***Low-e glass***

Low-e is standard clear glass which has a special coating on one surface of the glass. Low-e refers to low emissivity and this describes the capacity of a surface to radiate heat. Emissivity is measured across a scale from 0 to 1 with 1 representing the highest emissivity. Long wave infrared is the heat produced by our bodies, heaters and the furnishings in a warm room. The transmission of long wave infrared is significantly reduced by the low-e coating. It reflects the amount of energy escaping through the glass keeping the room warmer and reducing the amount of heat required to be generated by the artificial heaters.

PRICE = Rs 550/4mm

*Advantages*

1. Improves solar and thermal control and Reduces summer heat gain and winter heat loss. Decreases UV transmission such as furniture fading Reduces condensation in double glazing

2. Low-e glass can reduce the amount of heat that is conducted through the glass by around 30% compared to ordinary glass. Low-e glass further improves thermal efficiency by cutting glare and preventing damage interior furnishing caused by ultra-violet rays.

3. Newer generation low-e often uses laminated and toned glass combinations to provide superior performance over non coated glass. The most comprehensive solution is found by combining a low-e coating with double glazing. Using low-e coating and a suitable frame can stop up to 70% of heat loss and 77% of heat gain when compared to standard 3mm glass.

*Disadvantages*

Can reduce valuable solar heat gain in colder climates

***Earth sheltering***

It is a an ancient architectural practice of using earth against building walls/ roofs for external thermal mass, to reduce heat loss, and to easily maintain a steady indoor air temperature. Roof

Gardens cover 55 % of the exposed roof area of the building – high reduction of heat gain

**2.3.2 Interiors**

***Bagasse Board***

By product of sugarcane industry-a good substitute for plywood or Particle Board .It has wide usage for making partitions, furniture etc. Eco-friendly method - does not involve any harm to the timbers, unlike plywood. Used for furniture in interiors of the building (PRICE = 33 PER PIECE)

***VOC*s**

They are coatings, especially paints and protective coatings. Solvents are required to spread a protective or decorative film. Typical solvents are aliphatic hydrocarbons, ethyl acetate, glycol ethers, and acetone. Motivated by cost, environmental concerns, and regulation, the paint and coating industries are increasingly shifting toward aqueous solvents. (PRICE = 275 PER PIECE)

**Straw Bale**

Unlike other recycled materials, straw bale can be used in its raw state -requiring no further processing and is quite affordable. By utilizing straw bale, the building will naturally provide very high levels of insulation for climate change Straw bale is a low impact, low carbon building material that has gained more mainstream acceptance by the public. However, areas with extreme humidity and high rainfall may not be the appropriate choice for straw bale construction.

**HempCrete**

Made using the woody, balsa-like interior of the Cannabis sativa plant combined with lime and water, HempCrete material provides a natural airtight yet breathable and flexible insulation. HempCrete is also mold free and pest resistant as well as nearly fireproof. Considered as a sustainable building material, hemp can be grown and replenished relatively quick.

**Bamboo**

Underutilized for many years, bamboo has long been used as a traditional building material and is gaining more spotlight due to its potential for eco-friendly purposes in green construction.

Bamboo produces more oxygen and absorbs more carbon dioxide, which is very ideal in combating global climate change. Apart from that, Bamboo is easily grown and harvested, making it one of the most cost-effective construction materials to date. Bamboo is also highly sustainable and give san aesthetic appeal in construction for housing.

**Recycled Plastic**

Plastics are one of the most energy-efficient materials over their entire life-cycle. The fact being that the typical lifespan of plastic applications in building and construction is up to 30 to 50 years.

**Wood**

Wood is a historic, classic and durable green building material that has a longevity, aesthetics and flair to buildings for thousands of years.

Using wood as a material in building construction can have significant environmental benefits. Manufacturing wood for construction is less energy intensive than other materials, including concrete, steel, cement or glass production with some percentage of recycled material. The finished product also has lower embodied energy.

**Rammed Earth**

Because of the potentially low manufacturing impacts, rammed earth has recently become a highlight amongst eco-friendly and sustainable architect for a vernacular green building material for its “Eco Houses”.

Rammed earth provides several advantages such as superior thermal mass, temperature and noise control, strength and durability, low maintenance, fire proofing, load bearing and pest deterrence. In terms of aesthetics, Rammed earth offers a natural and eco-friendly environmental ambience because of its natural color made by aggregated earth substances.

**Mycelium**

Mycelium, a concrete which is capable of organic self-healing, reduces the need for high price repairs. It’s an eco-friendly insulation material that outperforms traditional fiberglass. Mycelium will be a major step for biomass green building materials.

**Ferrock**

Ferrock, a carbon-negative cement alternative which offers a stronger and greener alternative to standard cement manufacturing methods helps reduce a significant amount of carbon emission between fuel burning to running cement mixers and chemical processes.

Any structure that is made with Ferrock cement will inevitably be longer-lasting and does not need repairs and replacement. The eco-friendly benefits to this green cement list goes on.

**Timbercrete**

A combination between timber waste from various sources and concrete results in what you would call a Timbercrate – a green material that is lighter that solid concrete with greater strength and insulating capabilities.

This green material provides unique thermal qualities that combine thermal mass and insulation usually turned constructed for eco-housing. Timbercrete is also bushfire proof, which allows minimal heat transfer and radiation. The other benefit is that this material is very user-friendly, which can be nailed, screwed and sawn easily by anyone.

***Other Green Building Materials***

**1. Earthen Materials**

- Earthen materials like adobe, cob, and rammed earth are being used for construction purposes since yore.
- For good strength and durability- chopped straw, grass and other fibrous materials etc. are added to earth.
- Even today, structures built with adobe or cob can be seen in some remote areas.

Fig 1: Adobe made Structure

**2. Engineered Wood**

- Wood is one of the most famous building materials used around the world.
- But in the process of conversion of raw timber to wood boards and planks, most percentage of wood may get wasted.
- This wastage can also be used to make structural parts like walls, boards, doors etc. in the form of engineered wood.
- Unlike solid wood, engineered wood contains different layers of wood, usually the middle layers are made of wood scraps, softwoods, wood fibers etc.

Fig 2: Engineered Wood Board over Solid Wood Board

**3. Bamboo**

- Bamboo is one of the most used multipurpose and durable materials used in construction.
- These trees grow faster irrespective of climatic conditions. So, it makes it economical as well.
- They can be used to construct frames or supports, walls, floors etc.
- They provide a good appearance to the structures.

Fig 3: Bamboo Structure

**4. SIPs**

- Structural insulated panels (SIPs) consist of two sheets of oriented strand boards or flake board with a foam layer between them.
- They are generally available in larger sizes and are used as walls for the structure.
- Because of their large size, they need heavy equipment to install however, they provide good insulation.

Fig 4: Structural Insulated Panel (SIP)

**5. Insulated Concrete Forms**

- Insulated concrete forms contain two insulation layers with some space in between them. This space contains some arrangement for holding reinforcement bars, after placing reinforcement, concrete is poured into this space.
- They are light in weight, fire resistant, low dense and have good thermal and sound insulation properties.

Fig 5: Insulated Concrete Forms

**6. Cordwood**

- If wood is abundantly available and easily accessible to the site of construction, cordwood construction is recommended.
- It requires short and round pieces of wood which are laid one above the other, width wise, and are bonded together by special mortar mix.
- They are strong, environmental friendly and also give good appearance to the structure.

Fig 6: Cordwood Wall

**7. Straw Bale**

- Straw bale is another green building material which can be used as framing material for building because of good insulating properties. They can also act as soundproof materials.
- Non-load bearing walls of straw bale can be used as fill material in between columns and, in beams framework is recommended.
- Since air cannot pass through them, straw bales also have some resistance to fire.

Fig 7: Straw Bale Wall

**8. Earth Bags**

- Earth bags or sand bags are also used to construct walls of a structure.
- These types of structures can be seen in military bases, near banks of water resources etc.
- Generally, bags made of burlap are recommended but they may rot very easily and hence, polypropylene bags are used nowadays.

Fig 8: Earth Bag Walls

**9. Slate Roofing**

- Slate is naturally formed rock which is used to make tiles.
- Slate tiles have high durability and they are used as roofing materials.
- Slate roofing is preferred when it is locally or cheaply available.

Fig 9: Slate Roofing

**10. Steel**

- Steel roof panels and shingles are highly durable and they can be recycled again and again. So, these are the best choices for green roofing materials.

Fig 10: Steel Roofing

**11. Thatch**

- Thatch is nothing but dry straw, dry water reed, dried rushes etc. These are the oldest roofing materials which are still in use in some remote locations of the world and even in cities for aesthetic attractions.
- It is cheaply available for roofing and a good insulator too.

Fig 11: Thatch Roofing

**12. Composites**

- Roof panels made of composite materials such as foam or cellulose layer sandwiched between two metal sheets or two plastic sheets also come under green building materials.
- They are light in weight, inexpensive and provide good insulation for the structure and save energy.

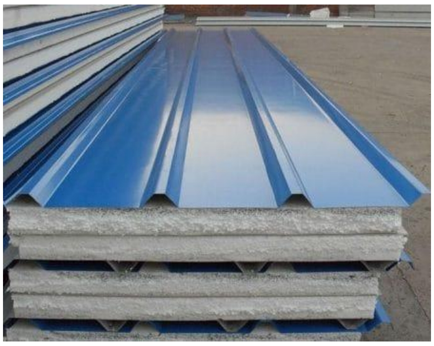


Fig 12: Composite Roof Panels

**13. Natural Fiber**

- Natural fibers like cotton, wool can also be used as insulation materials.
- Recycled cotton fibers or wool fibers are converted into a batt and installed in preformed wooden frame sections.

Fig 13: Cotton Insulation

**14. Polyurethane**

- Polyurethane foam is available in the form of spray bottles. They are directly sprayed onto the surface or wall or to which part insulation is required.
- After spraying it expands and forms a thick layer which hardens later on.
- They offer excellent insulation and prevent leakage of air.

Fig 14: Polyurethane Foam Spray

**15. Fiberglass**

- Fiberglass is also used for insulation purposes in the form of fiberglass batts.
- Even though it contains some toxic binding agents, because of its super insulation property at low cost it can be considered as a green building material.

Fig 15: Fibreglass batt

**16. Cellulose**

- Cellulose is a recycled product of paper waste and it is widely used around the world for insulation purposes in structure.
- It acts as good sound insulator and available for cheap prices in the market.

Fig 16: Installing Cellulose Insulation

**17. Cork**

- Cork is also a good insulator. Boards or panels made of cork are available in markets.

- A great amount of electrical energy can be saved by corkboard insulation in winter.
- These cork boards are also good for sound insulation.

Fig 17: Installing Cork Boards

**18. Polystyrene and isocyanurate**

- Polystyrene and isocyanurate foam sheets are another type of insulation materials which are available in the form of boards or sheets.
- These are generally provided as insulators on exterior sides of a structure, below the grade etc.

Fig 18: Installation of Polystyrene Foam Sheets

**19. Natural Clay**

- Plastering of walls can be done using natural clay rather than other gypsum-based plasters.
- Natural clay plaster with proper workmanship gives a beautiful appearance to the interior.

Fig 19: Natural Clay Plastered Wall

**20. Non-VOC paints**

- Non-VOC paint or green paint is recommended over VOC containing paints.
- Presence of Volatile Organic Compounds (VOC) in paint reacts with sunlight and nitrogen oxide resulting in the formation of ozone which can cause severe health problems for the occupants.
- If non-VOC paint is not available then try the paint with very low-VOC content in it.


Fig 20: Non-VOC Paint

**21. Natural Fiber Floor**

- Naturally occurring materials like bamboo, wool and cotton fiber carpets, cork etc. can be used for flooring purposes.

Fig 21: Natural Fiber Flooring Rugs

**22. Fiber Cement**

- Fiber cement boards are made of cement, sand and wood fibers.
- For exterior siding, fiber cement boards are good choice because of their cheap price, good durability and good resistance against fire.

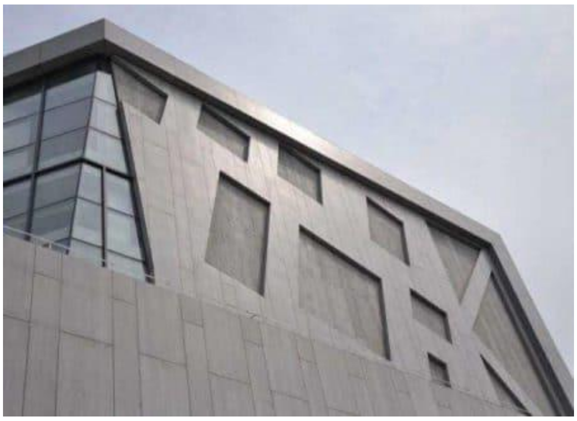


Fig 22: Exterior Siding with Fiber Cement Boards

**.23. Stone**

- Stone is a naturally occurring and a long-lasting building material. Some Stone structures built hundreds of years ago are still in existence without much abrasion.
- Stones are good against weathering hence they can be used to construct exterior walls, steps, exterior flooring etc.

### 2.3.3 Lighting

***Solar Street light***

Solar street lights are raised light sources which are powered by photovoltaic panels generally mounted on the lighting structure or integrated in the pole itself. The photovoltaic panels charge a rechargeable battery, which powers a fluorescent or LED lamp during the night. Most solar panels turn on and turn off automatically by sensing outdoor light using a light source. Solar streetlights are designed to work throughout the night. Many can stay lit for more than one night if the sun is not available for a couple of days. Latest designs use wireless technology and fuzzy control theory for battery management.

PRICE = Rs 3500 - 9,250 per Piece

*Advantages*

Solar street lights are independent of the utility grid. Hence, the operation costs are minimized. Solar street lights require much less maintenance compared to conventional street lights. Since external wires are eliminated, risk of accidents are minimized. This is a non-polluting source of electricity. Separate parts of solar system can be easily carried to the remote areas, It allows the saving of energy and also cost.

*Disadvantages*

1. Initial investment is higher compared to conventional street lights. Risk of theft is higher as equipment costs are comparatively higher.

2. Snow or dust, combined with moisture can accumulate on horizontal PV-panels and reduce or even stop energy production. Rechargeable batteries will need to be replaced several times

over the lifetime of the fixtures adding to the total lifetime cost of the light.

3. The charge and discharge cycles of the battery is also very important considering the overall cost of the project.

***Solar panel***

Solar panel refers to a panel designed to absorb the sun's rays as a source of energy for generating electricity or heating. A photovoltaic (PV) module is a packaged, connect assembly of typically 6×10 solar cells. Solar Photovoltaic panels constitute the solar array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions, and typically ranges from 100 to 365 watts. A single solar module can produce only a limited amount of power; most installations contain multiple modules. A photovoltaic system typically includes a panel or an array of solar modules, a solar inverter, and sometimes a battery and/or solar tracker and interconnection wiring. PRICE = Rs 40 -75Watt

### 2.2.4 Renewable Energy

Source Solar energy is a truly renewable energy source. It can be harnessed in all areas of the world and is available every day. We cannot run out of solar energy, unlike some of the other sources of energy. Solar energy will be accessible as long as we have the sun, therefore sunlight will be available to us for at least 5 billion years, when according to scientists the sun is going to die. Reduces Electricity Bills

Diverse Applications

Solar energy can be used for diverse purposes. You can generate electricity (photovoltaics) or heat (solar thermal). Solar energy can be used to produce electricity in areas without access to the energy grid, to distill water in regions with limited clean water supplies and to power satellites in space.

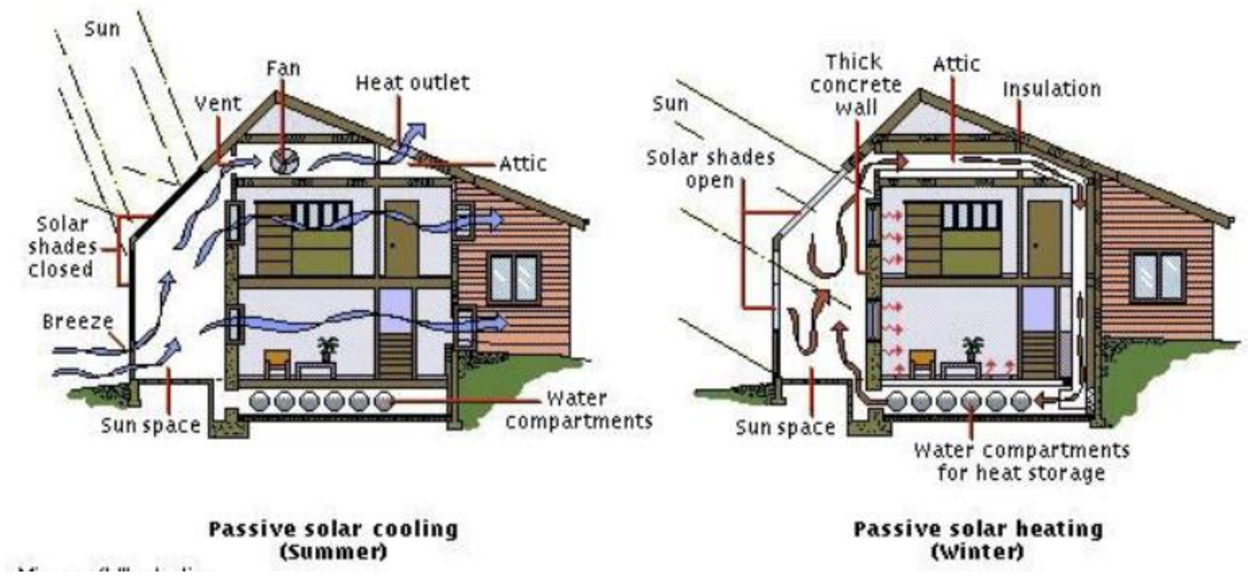
*Disadvantages of Solar Energy*

1. Cost

2. Weather Dependent

3. Solar Energy Storage Is Expensive

4. Uses a Lot of Space




***Compact fluorescent lamp***

A compact fluorescent lamp (CFL), also called compact fluorescent light, energy-saving light, and compact fluorescent tube, is a fluorescent lamp designed to replace an incandescent lamp; some types fit into light fixtures normally used for incandescent lamps. Compared to general-service incandescent lamps giving the same amount of visible light, CFLs use one-fifth to one-third the electric power, and last eight to fifteen times longer (PRICE = Rs 180 PER PIECE)

*Advantages:*

1. CFLs are up to four times more efficient than incandescent bulbs. You can replace a 100-watt incandescent bulb with a 22-watt CFL and get the same amount of light. CFLs use 50 to 80 percent less energy than incandescent lights.

2. While initially they cost more, CFLs are less expensive in the long run because they last much longer than incandescent bulbs. And since CFLs use a third of the electricity and last up to 10 times as long as incandescent bulbs, they are much less expensive overall.

3. Reduces carbon emissions. Just one bulb can reduce a half-ton of CO2 from the atmosphere over the life of the bulb.

4. CFLs are highly versatile. They come in enough shapes and sizes that you can use them for recessed fixtures, table lamps, track lighting or ceiling lighting. Three-way CFLs and CFLs that work with dimmers are also available.

*Disadvantages of CFLs*

CFLs also have their share of disadvantages and limitations. Most of them stem from the fact that not every bulb is suitable for every job, so it is more a matter of finding the right match. The only serious disadvantage is the mercury content in CFLs.

1. While CFLs are supposed to last about 10,000 hours, turning them on and off too frequently can reduce that lifetime substantially.

2. When CFLs are used outdoors they must be covered and protected from the elements. They are also sensitive to temperature, and low temperatures can cause lower light levels.

3. CFLs are not suitable for focused or spotlights or where narrow beams of light are required. They are meant only for ambient light.

***Energy Star***

Energy Star (trademarked ENERGY STAR) is an international standard for energy efficient consumer products originated in the United States

**Lighting**

The Energy Star is awarded to only certain bulbs that meet strict efficiency, quality, and lifetime criteria. Energy Star qualified fluorescent lighting uses 75% less energy and lasts up to ten times longer than normal incandescent lights. Energy Star Qualified light emitting diode

(LED) Lighting: Reduces energy costs — uses at least 75% less energy than incandescent lighting, saving on operating expenses. Reduces maintenance costs — lasts 35 to 50 times longer than incandescent lighting and about 2 to 5 times longer than fluorescent lighting.. Reduces cooling costs — LEDs produce very little heat.

### 2.2.5 Home electronics

Energy Star qualified televisions use 30% less energy than average. A wider range of Energy Star qualified televisions will be available. Other qualified home electronics include cordless phones, battery chargers, VCRs and external power adapters, most of which use 90% less energy.

### 2.2.6 Plumbing

***Automatic Urinal Sensor***

Automatic urinal sensors are designed to provide automatic flushing in Urinals Pots. They stop the wastage of precious water, eliminate the stinking smells and maintain proper hygiene in your washroom automatically. BPE stylish and sleek battery operated Auto flushers are especially designed and manufactured in India to withstand tougher conditions and provide excellent robust performance at site with power problems. BPE battery models provide install once and forget for life solution with highly optimized battery life of minimum one year or one lac operations on 4 X AA size alkaline batteries. Urinal Flusher range and flushing duration are both adjustable.

PRICE = RS 4250 TO 6500

***Sensor Tap/ Automatic Sensor Faucet***

Automatic sensor tap provides magic like NO TOUCH type operation in wash basins or sinks and are hygienic in use. They add style and more prestigious look to your offices, organization. These Automatic Tap Systems are designed on latest solid state electronic techniques to provide exclusive performance, durability and dependability in continuous use even in the highest humidity levels of toilets. This automatic operation is totally hygienic and protects you from all infections and diseases which spread from one person to another through ordinary taps. Sensing range is adjustable. Operation status is displayed by green/red indicators.

PRICE = RS 4000 TO 7600

***Dual flush toilet***

A low-flush toilet (or low-flow toilet or high-efficiency toilet), is a flush toilet that uses significantly less water than a full-flush toilet. Low-flush toilets use 4.8 liters (1.3 US gal; 1.1 imp gal) or less per flush as opposed to 6 liters (1.6 US gal; 1.3 imp gal) or more. PRICE = TANK RS 600 – 900 / CISTER RS 500

### 2.2. 7 Landscaping

**Grasscrete**

Also known as "Sustainable Urban Drainage", Grasscrete is a green alternative to standard concrete surfaces for parking lots, driveway and other access roads giving drainage benefits and improving stormwater absorption. Grasscrete is beneficial for businesses and developers because it drains at about the same rate (90%) as would an ordinary lawn in the same location. With 47% concrete and 53% holes filled with grass, it will help to form a natural bio-filter to significantly remove pollutants.

***Canopy Trees***

1. Create mass from the outside, for a canopied space from the inside

2. Tree trunks act as landscape columns and give architectural character to the site

3.. Modify the natural light quality Penetrating sunlight adds to the dynamism of the space

***Understorey Trees***

1. Suitable for small, intimate courtyards

2. Provide color, shade without overpowering the space

3. Used as accent plants or focal plants

4. Are effective in screening mid or low angle sun

***Shrubs***

1. Define and separate spaces without blocking vision

2. Shrubs can effectively unify a composition

***Ground Cover***

1. Unify groups of plants into a composition

2. Creates edges AND Lead the eye to focal points, building entries

3. Can create lines of visual character overlapping with paving

4. Beneficial in stabilizing slopes, preventing erosion

5. Bio degradable plastic grass crates can be used to hold grass– easy removal and maintenance.

6. Stone grid pavers can be used on roads for easy drainage of water.

7. Waste stone can be used for paving the gardens.

## 2.4 Recycling Industrial Waste into Building Material

Industrial waste is one of the most important sources of environmental pollution in the world. Providing economic opportunities for recycling these wastes represent an essential solution to this problem to encourage waste producers to dispose it safely and to provide an added value for these wastes.

The use of different waste in the concrete mix or for obtaining new types of concretes had as result the development of a new type of construction materials: green materials. In this category is included inorganic polymer concrete which is obtained predominantly from industrial waste materials. Concrete of any type had been used as it is or in combination with other materials, the most known being the steel with which had resulted reinforced concrete and prestressed concrete, that are still today very common and useful in construction industry. Polymer concrete is a new type of concrete in which the cement is replaced by a polymer. A high variety of waste are used for obtaining concretes of different requirements related to strength, to chemical resistance, with high durability, rapid hardening, etc.

An important way to use the wastes is to introduce them as a powder or filler in the composition of construction materials (cement, concrete, asphalt, etc.) or to use as aggregates (concrete or bricks from demolition can be used as an aggregate, steel slag can be transformed into aggregates, etc.). Concrete is one type of building material that can incorporate many types of waste such as silica fume, fly ash, cinder, husk, tires, glass, etc.

***Silica fume***

It is specially used as mineral admixture in concrete because of the fineness of the particles which can fill better the spaces between the components of concrete mix. The new types of concretes (the high strength and high performance concrete, ultra-high performance concrete, with compressive strengths going to 150-180 MPa), high strength polymer concrete, etc. that are used in the new modern structures are obtained by adding in the mix silica fume in dosages between 8-12% . Experimental studies shown that the compressive strength of concrete can increase with about 20% in the case of a dosage of 10% silica fume.

In the ordinary cement concrete or polymer concrete, silica fume is added in different percentages, as replacement or not of cement, for improving the properties, in particular the compressive strength, durability characteristics, bond strength. These good effects of silica fume on the concrete are resulting from the fact that the particles of silica fume are very small and also from the pozzolana reaction of silica fume with cement paste components. In the behavior of structural elements it was observed according to experimental studies, that the failure of beams was improved, the concrete with silica fume had a better behavior to shear force, the number of cracks in tension zone at failure was reduced, which indicate that elements are less destroyed at failure.

In the hydraulic constructions, concrete with silica fume responds better to requirements of hydraulic construction because this concrete has a better behavior to frost-thaw cycles, to abrasion, cavitation, is resistant to chemical attack and it is less permeable, facts which result in a smaller dosage of cement.

Silica fume is also used for obtaining other types of concrete, such as self-compacting concrete, fiber reinforced concrete, polymer concrete. In the case of polymer concrete from experimental studies it was concluded that the increase in compressive strength is not too much as in the case of tensile strength.

***Slag***

It can be used in preparing composite cements or as aggregates in preparing concrete.

Slag cements are used in concrete structures because it gives some advantages, such as: less carbon dioxide emission, during the production, lower hydration heat during hardening, low permeability and good resistance to sulphate attack .

***Ground granulated Blast Furnace Slag (GGBFS)*** improves the flexural strength and compressive strength of concrete and asphalt mixes, which recommend its use in roads, highways, pavements, hydraulic constructions, etc. Ground granulated slag is used in producing cement concrete as mix compound of the concrete or as component of cement. The use of ground granulated slag as component of concrete has the advantage of using it in different dosages, which is important in obtaining desired properties. Ground granulated slag can be used in obtaining Portland blastfurnace cement, which contains up to 5% until 95% of filler. Also, this type of waste can be used in preparing concrete as cementitious material due to its hydraulic property.

In this case the fineness of ground granulated slag must appropriate to that of cement or even greater. The use of ground granulated slag used in obtaining concrete is benefic for the environment, but also it improves some properties of concrete such as: fresh concrete has a better workability, structure of hardened concrete is more compact, that resulting in increasing the long term strengths and durability. The content of ground granulated slag in the mix and its fineness depend on the purpose for which it is used in obtaining specific properties of concrete. Research studies reported a replacement of cement with dosages between 10 and 80% from the cement mass. The smaller quantities of waste are for increasing mechanical properties and high dosages are for improvement the resistance to chemical attack.

The ground granulated blast furnace slag is also used in asphalt concrete for roads, highways, pavements, etc. An important utilization in the last time is to obtain high performance concretes, with improved durability, which is required in bridges, marine constructions, hydraulic dams, etc.

Another possibility of consuming ground granulated slag waste is to manufacture fibers which can be used in production of insulation material as slag wool. Experimental studies on concrete with aggregates obtained of steel slag had shown that this type of waste can be used in road construction or in infrastructure works because the presence of steel increased the density of hardened concrete. Good mechanical properties were obtained in the case of cement concrete and polymer concrete with slag aggregates and addition of silica fume.

### *Sludge*

Sludge is used in the production of concrete as filling material because its benefits such as improving the compressive strength, freeze-thaw resistance and waterproofness. Also it can be used as replacement of fine aggregates in asphalt paving.

The paper sludge is used for obtaining blended cements which contain 90% Portland cement and 10% waste. Also, the paper making waste can be processed to obtain a composition of cellulose fibers and clay which is suitable to use as insulating material or as filler in building materials.

The utilization of paper waste sludge obtained from a paper industry, as a replacement to the mineral filler in various concrete mixes was experimentally analyzed. Concrete mixes containing various contents of the waste (3, 5, 8 and 10%) were studied and the results shown a recommended replacement of sand of about 5% for obtaining concrete for masonry construction.

### *Fly ash*

The fly ash utilization is diversified in time and referring to construction industry this waste is used in: cement and concrete manufacturing, production of bricks, tiles and pavements, lightweight aggregates, etc. The new researches used fly ash in obtaining eco-concrete, which eliminated from the mix the cement, the geopolymer obtained being a material more friendlily with the environment. Although a large proportion of global FA is used by the building industry, there is a still proportion which is disposed of in ponds or landfills.

In the cement production the fly ash is used in the composition, in different quantities and the cement obtained are named composite cements. In the cement-concrete production, a part of cement is replaced with different dosages of fly ash, normal dosages being between 10-40% and up to 75%. The advantages of using fly ash in concrete are given by the reduction of cement dosage, and also by the beneficial effects which improve concrete properties (mechanical strength and durability resistance), reduce bleeding, reduce cracking, decrease the heat during hardening of concrete.

Experimental studies on cement concrete with fly ash shown that the addition of fiber, near fly ash is beneficial in improving the properties. Statistical optimization of mechanical properties for a concrete with 10% replacement of cement recommended for example for glass fiber type, a percentage of 1% from the concrete mass and a length of fiber of 35 mm in the case of compressive strength and higher percentages and smaller length, in the case of tensile strengths.

In obtaining the inorganic polymer concrete, which is a “green” material, fly ash that is considered alkali activated cement, replaces totally the cement from the mix. In fly ash-based geopolymer binder, fly ash reacts with an alkaline solution and the geopolymer paste acts as only binder for aggregates. The basic ingredients of fly ash-based geopolymer concrete are fly ash, sodium hydroxide, sodium silicate, fine aggregates and coarse aggregate.

The formulation of high-performance materials that are stronger and more durable than conventional cement-based materials has emerged as an issue of considerable importance in the construction industry. It is possible to utilize fly ash to produce a high-performance material at a potentially lower cost and without compromising its structural integrity.

The high-performance polymer concrete made with fly-ash fillers presents the compressive strength, flexural strength, creep deformation and bond strength with values bigger than that of Portland cement concrete. Even in the case of fly ash the polymer dosage can be higher than in the case of other additions, the mechanical properties are increased in comparison with polymer concrete without addition. The use of fly ash as an aggregate in polymer concrete is very promising because it could be used as an overlay in pavement, bridges, and runways or in precast applications such as utility, transportation, and hydraulic components.

Industrial fly ash is also used for the production of low-strength material, also known as ‘flowable fill’. It is used as a replacement of compacted soil in cases where the application of the latter is difficult or impossible. Also other wastes such as the cement kiln dust, asphalt dust, coal fly ash, coal bottom ash and quarry waste are used for preparing low-strength building materials. The content of these wastes in the mix is between 25-50%.

## 2.5 Recycling Constructional Waste into Building Material

Various building materials generated in the site during construction operation or during the demolition of building can be successfully reused as a new material upon processing. Over the last five years, India’s first and only recycling plant for construction and demolition (C&D) waste has saved the overflowing landfills of Delhi from 15.4 lakh tonnes of debris by 2019.

The plant uses manual segregation for bigger plastic pieces as well as a magnetic separator for metallic objects.

The waste is crushed, washed and used to make ready-mix concrete, kerb stones, cement bricks, pavement blocks, hollow bricks and manufactured sand.

The construction and demolition waste recycling plant in Burari, where tiles are made from crushed debris. Photo: Special Arrangement

The other building materials which are recycled are as follows

**1. Brick**

Brick wastes are generated as a result of demolition, and may be contaminated with mortar and plaster. Brick wastes are sometimes blended with other materials like timber and concrete. Currently, bricks are recycled by crushing and using as filling materials.

**2. Concrete**

Concrete wastes can be generated due to demolition of existing structures and testing of concrete samples etc. commonly recycling measures of concrete wastes are used crushed concrete as aggregate. The crushed concrete aggregate has been used as a replacement to natural aggregate in new concrete, and it also has been employed in the construction of road base and trenches.

**3. Ferrous Metal**

Ferrous metal is another type of wastes which not only highly profitable but also can be recycled nearly completely. In addition, ferrous metal can be recycled multiple times.

**4. Masonry**

Masonry waste is produced as a result of demolition of masonry buildings. It can be recycled by crushing the masonry waste and used as recycled masonry aggregate. A special application of recycled masonry aggregate is to use it as thermal insulating concrete. Another potential application for recycled masonry aggregate is to use it as aggregate in traditional clay bricks.

**5. Non-ferrous Metal**

Aluminum, copper, lead, and zinc are examples of nonferrous materials wastes produced at construction sites. The majority of these materials can be recycled.

**6. Paper and Cardboard**

Paper and paper board is another type of waste materials which is estimated to comprise one-third construction and demolition wastes by volume. These waste materials are recycled and reprocessed to produce new paper products.

**7. Plastic**

The plastic wastes are best possible for recycling if these materials are collected separately and cleaned. Recycling is difficult if plastic wastes are mixed with other plastics or contaminants. Plastic may be recycled and used in products specifically designed for the utilization of recycled plastic, such as street furniture, roof and floor, PVC window noise barrier, cable ducting, panel.

**8. Timber**

Timber waste from construction and demolition works is produced in large quantity all over the world. Whole timber arising from construction and demolition works can be utilized easily and directly for reused in other construction projects after cleaning, de-nailing and sizing.

## 2.6 Biomass as Construction Material

***Biomass***

Biomass is organic material that comes from plants and animals, and it is a renewable source of energy. Biomass contains stored energy from the sun. Plants absorb the sun's energy in a process called photosynthesis. When biomass is burned, the chemical energy in biomass is released as heat. Biomass can be burned directly or converted to liquid biofuels or biogas that can be burned as fuels.

**Examples of biomass and their uses for energy**

- Wood and wood processing wastes—burned to heat buildings, to produce process heat in industry, and to generate electricity
- Agricultural crops and waste materials—burned as a fuel or converted to liquid biofuels
- Food, yard, and wood waste in garbage—burned to generate electricity in power plants or converted to biogas in landfills
- Animal manure and human sewage—converted to biogas, which can be burned as a fuel.

The experimental use of new building materials by the use of certain raw energy from biomass such as firewood, agricultural residues and forestry waste from the food industry, is rapidly growing. The pruning of olive groves, vineyards and orchards produce a large amount of wood waste is not always valued properly. Similarly, the problem of the management of by-products resulting from the extraction of olive oil and the reduction of their impact on the environment has been the subject of many scientific studies aimed at identifying possible solutions aimed at disposal painless or better yet their recycling, finalized to the realization of building materials.

In such sense, the agriculture and forestry industry can become a major player in the energy sector, as every- thing it's get, and as waste (prunings, non-marketable products, waste from forest harvesting, etc.) and as a finished product (sorghum, corn etc.), is com- posed of carbon and is therefore potentially be used to produce energy. Scientific studies and experimentations in the research lab, in this context, is focused on innovation in the composition of matter of concrete, plaster, insulation materials, etc. In particular, in addition to recycling of waste material, the significant amount of ash is used in in cement and in brick industry. In addition to these, use of natural fibers in construction industry is widely growing.

### 2.6.1 Natural Fibres as Construction material

Natural fibers reinforced with polymer concrete base composites have gained more interest because of they are less expensive, light weight, easy processing, high specific modulus and also sustainable.

The interest in long term sustainability of material resources has make advancements in bio-composites or polymer concrete materials made up with natural fibers and resin. Polymeric composites may be understood as the combination of two or more materials, for example, reinforcement elements or filler involved by a polymeric matrix.

Natural fibers such as jute, sisal, pineapple, abaca and coir have been studied as reinforcement and filler in cement based composites. Besides, Plant fibers from agricultural crops are renewable materials which have potential for creating green products and replacing synthetic materials. Amongst the all the natural fibers listed, Bagasse is biomass remaining after sugarcane stalks are crushed to extract their juice.

A sugar factory produces nearly 30% of Bagasse out of total crushing. Many research efforts till date were attempted to use Bagasse as a renewable feedstock as domestic fuel for power generation and for the production of bio-based material. The use of Bagasse as fuel will produce significant amount of carbon during its use, which is not desirable. However, the consumption of the Bagasse is very low, especially in Asian country. Transforming Bagasse into high-quality panel products provides a prospective solution the Bagasse-fiber-based cementinious composite has a potential as the core material replacing high density and expensive wood-based fiberboard. Bagasse is also commonly used for various building boards whose acoustical properties make them very desirable for homes, offices, and other buildings. The advantages of these materials are

- Capability, improved capacity against delamination, spalling and fatigue.
- High volume fraction (<2%): The fibers used at this level lead to strain hardening of the composites. Because of this improved behavior, these composites are often referred as High-performance fiber-reinforced composites (HPFRC).In the last decade; even better Composites were developed and are referred as ultra-high-performance fiber-reinforced concretes (UHPFRC).

Hemp is a plant that produces more biomass in the world, growing in 4 months up to 4 m/h, for this reason is called "carbon negative material". Until a few decades ago, Italy was the second largest producer of hemp and it was firmly rooted in the tradition of production. Because of the inability to compete with the Asian markets, the use of hemp has been increasingly reduced.

In Europe, the use hemp is quite generalized and ex- tended to other areas, such as Germany, which uses the hemp fibers for the automotive industry, through fi- broresine, plastic and padding, now used by all the major manufacturers, France, which using fiber-reinforced mortar,) plaster with untreated hemp and lime, made of hemp-lime and water with a grainy texture similar to cork and Italy, where hemp is widespread in the textile and construction sectors through the use of the flower and drum for wax, paint, insulation boards, plaster and precast blocks. Composite obtained with the use of hemp fiber, is currently commercially in the form of blocks, or for en- tire construction systems in blocks of hemp (and lime) and wood structure. The bio composite used is usually formed from the woody part of the stem of hemp with a binder based on lime.

Once cured, the bio composite becomes rigid and lightweight with wide range of applications. Combining blocks of hemp and lime to lime mortar fiber-reinforced, developed in France, it would get the first technology completely based on hemp (technical lime-shives). The advantages of this technology are:

- Construction of energy efficient buildings, bio compatible, with zero emissions.

- $CO_2$ absorption during the production and use of material (combating climate change).
- Thermal and acoustic insulation and vapor permeability.
- Finding materials on site, local supply chain, lower costs of construction.

### 2.6.2 Advantages of recycled and biomass fibers in reinforced concrete

- Natural and recycled fibers offer many benefits for reinforcement
- Low cost and abundant
- Renewable
- Non-hazardous-replacement of asbestos
- Concrete with recycled short fibers shows positive effect to utilize the waste resources and helps to maintain the environment clean. Also it is a provision as an alternative material for the construction industry.
- Polymeric and synthetic fibers alter the energy absorption properties of the composites significantly.
- Uniform fiber distribution at various size scales improves mechanical properties of composite. A small microfiber stabilize the micro cracks and increase the strength by reducing the porosity of the cement paste and helps to increases the strength.
- Other benefits of FRC include improved fatigue strength, wear resistance, and durability of concrete material.
- Utilizing natural and recycled fibers will reduces the load on the land fields
- It is the way to create wealth from waste.

The use of biomass and recycled fibers from industrial or postconsumer waste could offer additional advantages of waste reduction and resources conservation. Concrete with natural, and recycled material combine very good mechanical properties with ecological characteristics have opened up the possibility of using them in sustainable civil and architectural applications. Fibrous materials can contribute for creating sustainable buildings that save the energy, reduce environmental impact and provide a quality indoor environment for their occupants. The utility of such green material will bring more technological strategies and alternative visions of how to include fibers for constructing sustainable places and it provides the path towards sustainability in the construction engineering area.

# 3. UNIT III COMFORTS IN BUILDING

*Thermal Comfort in Buildings- Issues; Heat Transfer Characteristic of Building Materials and Building Techniques. Incidence of Solar Heat on Buildings-Implications of Geographical Locations.*

## 3.1 Thermal Comfort

According to the international standard EN ISO 7730, thermal comfort is: "**that condition of mind which expresses satisfaction with the thermal environment**". In simple words, it is the comfortable condition where a person is not feeling too hot or too cold.

Human thermal comfort cannot be expressed in degrees and can't be defined by an average range of temperatures. It is a very personal experience and a function of many criteria, which differs from person to person in the same environmental space. The Health and Safety Executive estimates that reasonable comfort can be established when a minimum of 80% indoor occupants are feeling comfortable with the thermal environment.

### 3.1.1 Issues related to thermal comfort in buildings

Constant thermal discomfort is likely to lead either to "**Sick Building Syndrome**" **(SBS)** or "**Building Related Illness" (BRI)**. The term SBS is used to describe acute health and comfort effects of occupants related to the time spent in a building, without specific illness or cause. The ailment may be localized in a certain room or may be widespread all over the building.

On the other hand, the term BRI is used when symptoms of diagnosable illness are identified and can be attributed directly to airborne building contaminants. Problems appear when a building is operated or maintained inconsistently to its original design or prescribed operating procedures. For example, high temperature and high relative humidity jointly serve to reduce thermal comfort and indoor air quality. Poor building design or occupant inconsiderate activities could also lead to indoor air problems.

Some of the indicators of SBS include symptoms associated with acute discomfort, (eye, nose, or throat irritation; a headache; dry or itchy skin; a dry cough; difficulty in concentrating; dizziness and nausea; fatigue) and sensitivity to scents. Generally, the cause of the symptoms is unknown. However, most of the people who express these symptoms, report relief soon after leaving the building.

On the other hand, indicators of BRI may include symptoms such as chest tightness; a cough; chills; fever, and muscle aches. These symptoms can be clinically determined and have clear causes. It usually takes some time after leaving the building to recover. There are several causes of SBS that are the most common.

Inadequate ventilation may occur if heating, ventilating, and air conditioning (HVAC) systems do not adequately spread air to occupants in the building. It can cause issues such as condensation, mold, emission of volatile organic compounds (VOCs), mites, fabric deterioration, draughts, heat loss, carbon emissions which, not only affect the fabric of the building but can cause illness to the occupants.

Furthermore, sources of air pollution can be inside the building. For example, adhesives, upholstery, carpeting, copy machines, manufactured wood products, pesticides, and cleaning agents may emit VOCs, including formaldehyde. Environmental tobacco smoke contributes high levels of VOCs and other toxic compounds. Additionally, sources of air pollution can also be outside the building.

For example, contaminants from motor vehicle exhaust; plumbing vents, other buildings exhausts or building exhausts itself can enter the building through windows, poorly located air intake vents, or other openings and become a threat to air quality in a building.

Another health menace is **electromagnetic radiation** coming from a computer, cell phone emitting or wiring without proper grounding. Moreover, excessive work stress or dissatisfaction, long working hours along with poor interpersonal relationships and communication can be linked to psychological factors associated with SBS.

These elements often act together and make a contribution to other complaints such as humidity, inadequate temperature, or lighting. When building management, occupants, and maintenance personnel fully communicate and understand the causes and consequences of SBS, they can work on how to prevent problems from occurring or to solve them if they do.

So far, findings have proved that intellectual, working and observing abilities are showing the most in a pleasant environment. Based on researches it is suggested that potential yearly gain due to increased productivity achieved by reduction of respiratory infections could be about 6 to 14 billions of dollars. Furthermore, SBS diseases reduction could increase income from 15 to 38 billions of dollars, while increased working productivity could raise

## 3.2 Factors affecting thermal comfort in buildings

There are several factors which influence the thermal comfort in buildings. Thermal comfort is a cumulative effect resulting from a series of environmental and personal factors. Environmental factors.

### 3.2.1 Personal factors

Personal Factors affecting Thermal Comfort

- Clothing — Clothes insulate a person from exchanging heat with the surrounding air and surfaces.
- Metabolic heat — The heat produced by physical activity. Usually, a person who stays still feels cooler than those who are moving.

There are other contributing factors that could be considered such as the availability of drinks and food, acclimatization device, or health status of the individual.

### 3.2.2 Environmental factors

The various environmental factors which are influencing the thermal comfort of the buildings are as follows

***1. Air tightness and ventilation***

An airtight envelope, together with natural or mechanical ventilation, can control the indoor thermal environment by managing the air exchanges with the outside.

***2. Thermal inertia***

The materials used to construct the building (the choice of brick, stone or wood, for example) have an impact on how quickly changes in weather conditions are felt.

***3. Solar gain***

Through its overall shape, orientation, number and size of windows and the ability of surfaces to reflect heat, the building envelope can control how much heat from the sun (solar gain) is allowed to enter into the building.

*4. Insulation*

Insulating the building envelope and using thermally efficient windows reduces heat loss in winter and conduction heat gains in summer.


## 3.3 Methods to improve Thermal comfort in Buildings

*1. Use a HVAC system*

Using an HVAC system that actually measures and regulates the radiant component of operative temperature goes a long way to achieving thermal comfort. The best way to achieve this is to install a radiant cooling / heating system with a means to measure and monitor the (mean radiant temperature) MRT. In addition to the best regulation of the thermal environment, these systems are energetically more efficient than all-air alternatives, as well as quieter and more spatially efficient.

Radiant cooling / heating systems do not directly affect air temperature, and do not control ventilation or indoor air quality (IAQ). Therefore, they have to be used in conjunction with a system that fulfils these purposes, such as a dedicated outdoor air system (DOAS).

*2. Minimise leakage*

Depending on the outdoor conditions, your HVAC system may be heating up and humidifying cold, dry air, or it could be cooling down and dehumidifying hot, humid air. Either way, the air needs to pass through the HVAC equipment for this to happen efficiently and effectively. If there is leakage in the building envelope and air is transferring in and out of the building other than through the HVAC system, Indoor Environmental Quality will be lowered.

Essentially, air could be coming in that is below or above the desired temperature and relative humidity. This will substantially lower thermal comfort. Moreover, at the site of a leak, the pressure or temperature differential between indoor and outdoor conditions can create drafts, which can further lower thermal comfort.

As a side note, leakage causes other reasons for concern. Perhaps most importantly, leakage significantly lowers the energetic efficiency of an HVAC system. This is because air transfer in and out of the building happens without passing through the air handling unit (AHU) and the energy recovery wheel (if one is installed). This will cause the HVAC system to have to work harder to regulate indoor conditions.

***3. Design and build for some occupant control***

Allowing access to the thermostat, or operable windows and blinds, might boost perceived thermal comfort. Part of this is designing the building to maximise the potential use of natural ventilation and radiation from the sun. These will not only lower the energy load of the HVAC system, but also allow occupants to more precisely control their environment as they desire.

## 3.4 Design Strategies to Achieve thermal comfort in buildings

External heat gains are caused primarily by sunlight and high external temperatures, and these factors are controlled through the consideration of passive design measures (including optimising orientation and site layout, geometry, room layout and shading devices), construction measures (targeting glazing solar energy transmittance, thermal mass and air leakage) and active design measures (such as heating and cooling capacities, efficiencies and set points, ventilation rates and heat recovery efficiency). It is worth noting that there are very different ‘internal gains’ heat profiles in hours across the day for residential and office settings.

The strategies can be classified into two types

- Natural design strategy
- Mechanical design strategy

### 3.4.1 Natural Design Strategy

In tropical climate, thermal comfort is obtained by reducing temperatures to adequate levels and by increasing natural ventilation within the building. Green designs will favor a non energy demanding approach in order to take advantage of the natural surroundings opportunities such as wind. But using wind for sufficient natural ventilation in hot and humid climates is not only about opening a window. Green design aims to use passive strategies to facilitate natural ventilation by orienting buildings correctly, thinking of space layout from the start and sizing calculating the openings in order favor wind circulation, natural ventilation will be facilitated and its effectiveness increased.

Relying on natural ventilation is profitable as it uses natural wind resources, no energy required, to make our daily lives at home or at work more comfortable but it will also ensures that renewed fresh air will be provided within spaces. "60% less energy is used by naturally ventilated buildings". The methods to achieve it are as follows

**1. Orientation:**

Orientation is an important factor in providing a building with passive thermal comfort; to take advantage of solar gains to reduce heat loads or to protect against unwanted solar gains. For example, a south-west facing elevation will receive direct sunlight in the late afternoon when the ambient external temperature is at its highest. A west facing building (living room) is receives a relatively higher amount of solar gain per m2, primarily as a result of the solar incidence. Angles of incidence closer to perpendicular to the window will result in higher transmission of the solar energy, until the angle exceeds 55°, when the transmission reduces sharply.

**2. Solar incidence: lower angles may result in greater overheating from solar gains**

Thermal mass refers to the ability of building materials to store and emit heat, so careful consideration should be given to integrating thermal mass and ventilation strategies. When the air within a space is warmed due to direct sunlight or heat gains from people and appliances, some building materials absorb heat. As the air in the space cools overnight, this heat is re-emitted into the space, thus oscillations in temperatures are attenuated somewhat, relative to a building with low mass which is more 'reactive' to heat input. Dense building materials which are exposed to the internal environment can absorb and release heat due to their thermal mass (heat capacity), although this is significantly reduced by for example, levels of internal insulation and service voids, which have very low thermal mass. However, it should be noted that our analysis shows that there is limited benefit between a light-weight (glass and steel) and medium-weight building (traditional cavity construction), although there is an evident benefit in medium-weight to heavy-weight (concrete structure and masonry internal elements).

Moreover, achieving benefits from thermal mass requires that it is used optimally, for example the temperature attenuation from thermal mass requires that the mass be effectively ‘reset’ i.e. purged of heat, so that it has the capacity to absorb unwanted heat when most convenient. This is the theory behind night ventilation strategies, which are effective in some circumstances; increased ventilation rates are required to purge the heat from the building via the air, but consider that increased mechanical ventilation volumes significantly increases fan power consumption.

**3. The importance of fenestration design and glazing choices**

The fenestration design and glazing choices have a large impact on thermal comfort as radiation from the sun passes through glazing to heat the internal fabric of the building, accumulating inside. In a domestic setting, windows have massive implications on the heating and cooling loads of a building, as up to 40% of a home’s heating energy can be lost via windows and the required cooling capacity can be increased by up to 50%. As a rule of thumb in commercial settings, a façade with greater than 25% (glazing to floor area) should be given increased attention, particularly the glazing solar factor, which has a significant impact on overheating compliance.

**4. Shading and daylight**

The choice of the shading device that is used is determined by the orientation, and common ‘shading’ strategies include overhangs, external louvers, external shading and internal blinds, however, limitations may exist in the external context (for example, restrictions in a conservation area), and there are pros and cons for each shading device type such as level of occupant control, glare, and implications for views and daylight. South-facing windows need to be protected from high-level sun and this can be done by overhangs/balconies or horizontal awnings. Windows facing east or west experience the sun much lower in the sky, so the most effective shading devices such as external louvers may result in daylight implications, so careful consideration is required to ensure shading without completely blocking views.

**Blinds and shutters**

They block solar radiation and thus reduce the amount of heat entering a room. Overheating during summer can be efficiently reduced, and even eliminated, by the use of proper solar shading. It can also improve the thermal insulation of windows in winter. This can reduce thermal discomfort from cold radiation and temperature asymmetry. Even better, when applied at night, this extra insulation can decrease the demand for heating. In terms of energy, shading should only be used at night during winter, because the solar gains are often of greater importance than the heat loss.

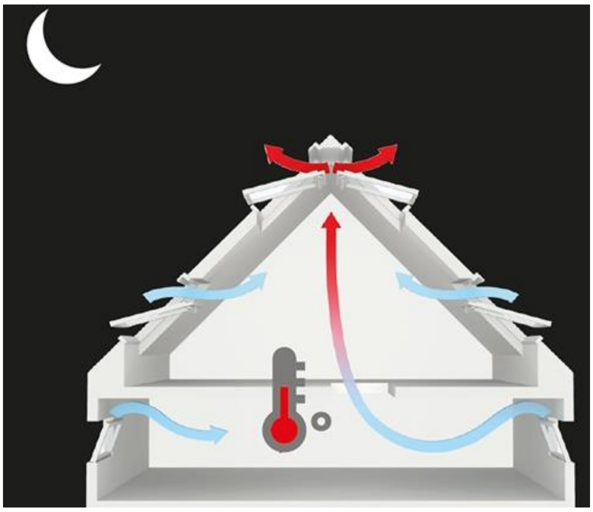
**4. Ventilative cooling**

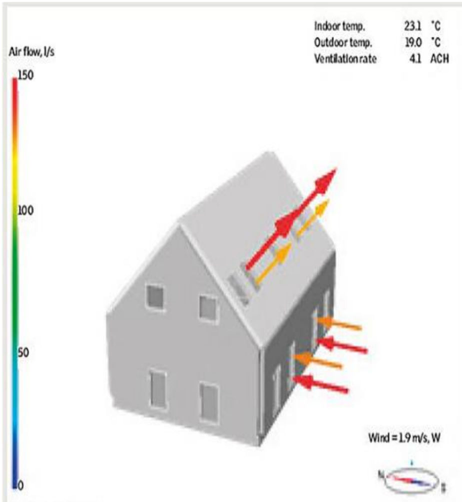
Ventilative cooling refers to the use of natural or mechanical ventilation strategies to cool indoor spaces. The use of outside air reduces the energy consumption of cooling systems while maintaining thermal comfort. The most common technique is to use increased ventilation airflow rates and night ventilation. Ventilative cooling is applicable in a wide range of buildings and may be critical to realising low energy targets for renovated or new Nearly Zero-Energy Buildings (NZEBs) .

Natural ventilative cooling by opening windows is a very direct and fast method of influencing the thermal environment. An open window will cause increased air motion, and if the outdoor temperature is lower than indoors the temperature will fall. Even when the outdoor air temperature is slightly higher than the indoor, the elevated air speed due to increased airflow will increase the cooling of the body and reduce the thermal sensation. For ventilative cooling, a division could be made between two strategies in terms of natural ventilation – day ventilation and night ventilation.

• Ventilation during the day removes excess heat from the building by creating high air movements by natural ventilation.

• Night ventilation (also referred to as night cooling) will cool down a building's thermal mass at night by using cool outdoor air. The following day, less cooling energy (or none at all) is needed in the building, as the thermal mass has already been cooled down. Buildings with high thermal mass soak up more heat during the day, that needs to be removed – an ideal situation for night cooling strategy






### 3.4.2 Mechanical Design Strategy

Mechanical design strategies include eating or colling using HVAC systems. This also includes the drying or dampening of air by mechanical methods.

## 3.5 Heat Transfer Characteristics of Building Materials

Heat always moves from warmer areas to colder areas. In winter, we heat the interior of a home, so the direction of heat flow is from inside to outside. In summer when it’s hotter outdoors, the direction is reversed.

The greater the temperature difference, the faster heat flows. If it’s 70°F inside and 75°F outside, there’s not much energy moving through the enclosure, and the difference is not very noticeable. But, if it’s 70°F inside and 0°F outside, there is a lot of heat flow, and the difference is immediately noticeable. (Note: Heat flow has a big impact on comfort; that is, how we feel about the heat or the lack of it.)

Air contains moisture vapor. The warmer the air is, the more moisture it can hold. If the air cools sufficiently to cause the moisture in the air to condense on a surface in the home, it can have a huge impact on building durability

Heat moves through building assemblies primarily in three ways.

- By conduction
- By convection
- By radiation.

### 3.5.1 Conduction

Conduction is the movement of heat energy directly through solid materials from molecule to molecule. The movement of the material plays no role in the transfer of heat. Building materials conduct energy at different rates.

Metals, such as copper and steel, for example, have high conductivity, meaning heat energy moves through them at a very efficient rate. Fiberglass batts and rigid foam, on the other hand, have low conductivity. Materials that are poor conductors serve as insulators when they are placed between more-conductive materials in an assembly such as a wall or a roof.

The flow of heat through an assembly of materials is slowed down appreciably by insulating materials. Wood is somewhere in the middle for conductivity. It's not a good insulator unless it is shredded and has lots of air pockets between the wood fibers. (The secret behind most insulation is air pockets that disrupt the conductive heat flow through a material.)

The rate of conductive heat flow is measured as U-value, and resistance to heat flow is measured by its reciprocal, R-value.

U-value = rate of heat transfer

R-value = resistance to heat transfer

The lower a given material's U-value, the less conductive it is. The higher the U-value of a material, the more conductive it is.

### 3.5.2 Convection

When heat is transported by a fluid, like air or water, this is called convection. The extent of convective heat transfer depends on a number of things, like the position of the surface (horizontal or vertical), but mainly on the speed of the passing air. The speed in outdoors is determined by wind speed and direction.

When the air is driven by an outside wind force, this is called "forced convection". When there is no wind, convection will occur by temperature or density differences. This is called "free convection". The example of the hot air ascending above a radiator is an example of free convection. Room air is heated by the radiator and ascends because the density of the hot air next to the radiator is lower than the density of the cooler air in the rest of the room.

This results in the warmer air rising, and being displaced by the cooler air. The heat transfer through forced convection is higher than that due to free convection, because of higher air speed.

### 3.5.3 Radiation

Radiation is the movement of heat through space (not air) as electromagnetic waves. The sun's energy reaches earth by radiation. Radiation is not affected by the air. The sun and a campfire both emit radiant heat, even when the wind is blowing. Radiant heat moves at the speed of light without heating the space between the radiant source (often called a "radiant body," be it the sun, or a heated slab, or a mass of asphalt roofing, underlayment and wood sheathing) and the surface of another object.

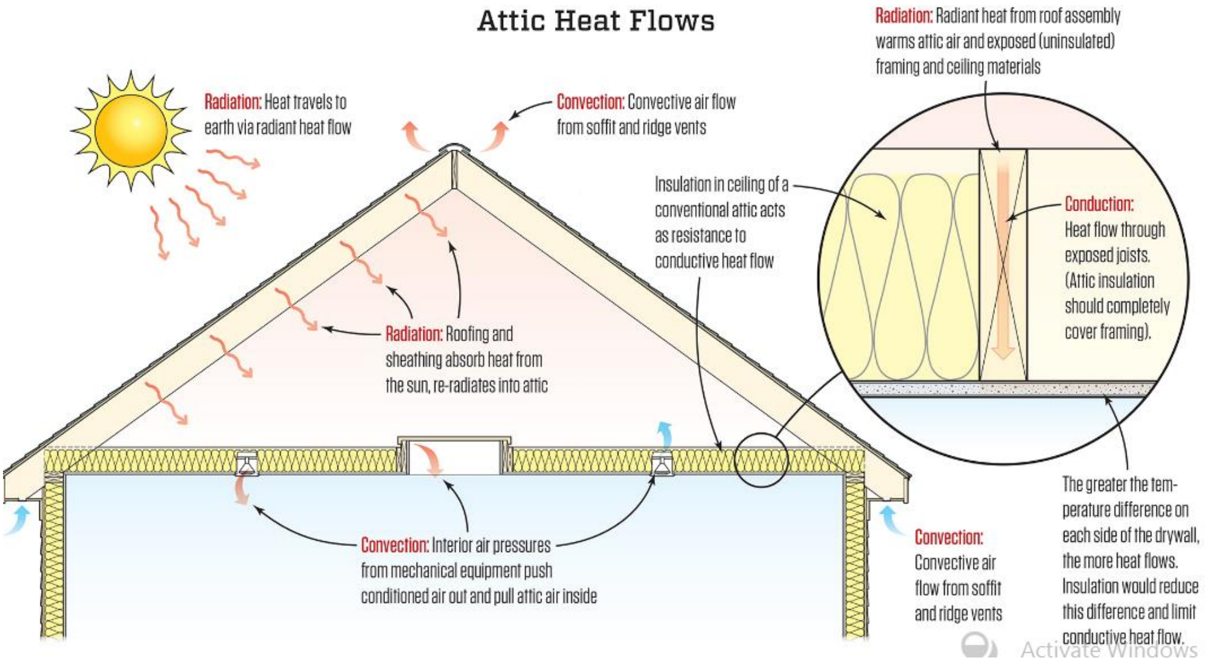
When an object, or an assembly is warmed by radiant energy, the energy is absorbed into the material. To be warmed by a radiant heat source, the surface needs to be in the line of sight of the heat source. This is why shading works. We can put an overhang or an awning between the sun and a window to reduce radiant heat flow. In that case, the sun warms the overhang or the awning when the energy is absorbed into those materials.

Several other variables affect the rate of radiant heat transfer. In addition to the difference in temperature, which affects the rate of all methods of heat flow, the rate of radiant heat flow depends on

The distance between the two surfaces. The sun is far enough away that we aren't vaporized by it's immense energy output, as we might be if the earth were closer to the sun. Similarly, the further we are from a campfire or a heat slab, the less we feel its warmth.

The optical properties of the surfaces determines whether radiant energy is absorbed or reflected. Dark surfaces, for example absorb radiant energy, while light or shiny surfaces reflect radiant energy. For example, during the summer, heat absorbed through roofs and through windows are the two main sources of heat gain in homes. To control this heat gain, many windows include a very thin metal coating on one surface to reflect radiant heat. And on roofs, we can use light-colored roofing to reflect heat, or we can install a radiant barrier—a layer of foil on the sheathing facing into the attic.

The angle of the surfaces to each other is related to the optical properties. If one surface is obliquely angled away from another surface, more energy will bounce off or reflect than if the two surfaces are closer to parallel to each other. Radiant energy moves in straight lines and when a surface is directly facing another, more of the warm surface's energy will "see" the facing surface.




### 3.5.4 Phase Change

When substances change phase, for example changing from liquid to gas, they absorb or release heat energy. For example, when water evaporates, it absorbs heat, producing a cooling effect, and when it condenses it releases heat. So when water evaporates from the surface of a building, or when sweat evaporates from the skin, it has a cooling effect. This is also important in refrigeration, where refrigerant gases absorb heat from the cooling medium (typically water) as they evaporate, and when they condense, they release heat which is rejected to the outside (or recovered). Phase change materials can also be used in construction to reduce internal temperature changes by storing latent heat in the solid-liquid or liquid-gas phase change of a material.

## 3.6 Incidence of Solar heat on buildings

The principal function of a house is to provide shelter but in the long term the house must be comfortable. One of the most important physiological criteria for comfort in a house is Thermal

Comfort. Thermal Comfort is a function of solar irradiance as the main generator of ambient thermal energy. The solar energy induces a number of effects in the environment thus creating different climates as modified by local geographical features. This climate, in turn, influences human thermal comfort in the environment.

The earth's thermal balance is maintained due to its axial rotation and its inclination at 66' to the plane of its solar orbit. The solar radiation has three components namely direct beam, diffuse and the reflected components. These are related to each other as follows.

**It = Id + If + Ir**

It is relatively easy to measure the global solar radiation using a number of instruments like pyranometer and the Campbell Stokes Sunshine Recorders. However, in practice the direct beam can also be determined by subtraction using the relationship in equation and the reflected component is less than 10% and in most instances this component is so small that it can be ignored. In lowland areas in Malawi and in the dry season,

the reflected component can be high.

Solar gain is the heat gain of a building as a result of solar irradiation onto the building and through its transparent surfaces . In zero energy buildings the irradiation through windows can be controlled by active shading to reduce energy consumption. In winter, solar gain can be admitted to decrease heating costs. In summer, solar gain can be deflected to prevent expending energy for cooling.

During the day the angle of incidence of the sunlight varies. This changes the fraction of transmitted light. At some angles, for some wavelengths, all light is reflected, while for other wavelengths and angles light is partially transmitted.

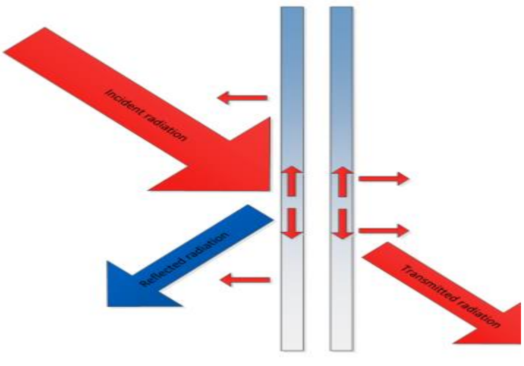



**Figure 1** *transmission, and reflection by a façade element, smaller arrows indicate absorption and conduction.*

In Europe, the coefficient G represents the average fraction of total transmitted light for a given window, while in the US the Solar Heat Gain Coefficient is used (SHGC).

For a typical window this fraction can be as high as 55 % . This means that over half of irradiated energy is transmitted into the building. For a room facing south at winter noon in a northern European country, this translates into roughly 0.5 kilowatt of heat entering through each square meter of window.

## 3.7 Implications of Geographical Locations

Solar radiation, often called the solar resource, is a general term for the electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies. However, the technical feasibility and economical operation of these technologies at a specific location depends on the available solar resource.

Every location on Earth receives sunlight at least part of the year. The amount of solar radiation that reaches any one spot on the Earth's surface varies according to:

- Geographic location
- Time of day
- Season
- Local landscape
- Local weather.

Because the Earth is round, the sun strikes the surface at different angles, ranging from 0° (just above the horizon) to 90° (directly overhead). When the sun's rays are vertical, the Earth's surface gets all the energy possible. The more slanted the sun's rays are, the longer they travel through the atmosphere, becoming more scattered and diffuse.

Because the Earth is round, the frigid polar regions never get a high sun, and because of the tilted axis of rotation, these areas receive no sun at all during part of the year.The Earth revolves around the sun in an elliptical orbit and is closer to the sun during part of the year.

When the sun is nearer the Earth, the Earth's surface receives a little more solar energy. The Earth is nearer the sun when it is summer in the southern hemisphere and winter in the northern hemisphere. However, the presence of vast oceans moderates the hotter summers and colder winters one would expect to see in the southern hemisphere as a result of this difference.

The 23.5° tilt in the Earth's axis of rotation is a more significant factor in determining the amount of sunlight striking the Earth at a particular location. Tilting results in longer days in the northern hemisphere from the spring (vernal) equinox to the fall (autumnal) equinox and longer days in the southern hemisphere during the other 6 months. Days and nights are both exactly 12 hours long on the equinoxes, which occur each year on or around March 23 and September 22.

Countries such as the United States, which lie in the middle latitudes, receive more solar energy in the summer not only because days are longer, but also because the sun is nearly overhead. The sun's rays are far more slanted during the shorter days of the winter months. Cities such as Denver, Colorado, (near 40° latitude) receive nearly three times more solar energy in June than they do in December.

The rotation of the Earth is also responsible for hourly variations in sunlight. In the early morning and late afternoon, the sun is low in the sky. Its rays travel further through the atmosphere than at noon, when the sun is at its highest point. On a clear day, the greatest amount of solar energy reaches a solar collector around solar noon.

*Diffuse And Direct Solar Radiation*

As sunlight passes through the atmosphere, some of it is absorbed, scattered, and reflected by:

- Air molecules
- Water vapor
- Clouds
- Dust
- Pollutants
- Forest fires
- Volcanoes.

This is called diffuse solar radiation. The solar radiation that reaches the Earth's surface without being diffused is called direct beam solar radiation. The sum of the diffuse and direct solar radiation is called global solar radiation. Atmospheric conditions can reduce direct beam radiation by 10% on clear, dry days and by 100% during thick, cloudy days.

*Measurement*

Scientists measure the amount of sunlight falling on specific locations at different times of the year. They then estimate the amount of sunlight falling on regions at the same latitude with similar climates. Measurements of solar energy are typically expressed as total radiation on a horizontal surface,or as total radiation on a surface tracking the sun. Radiation data for solar electric (photovoltaic) systems are often represented as kilowatt-hours per square meter (kWh/m2). Direct estimates of solar energy may also be expressed as watts per square meter (W/m2).

*Distribution*

The solar resource across the United States is ample for photovoltaic (PV) systems because they use both direct and scattered sunlight. Other technologies may be more limited. However, the amount of power generated by any solar technology at a particular site depends on how much of the sun's energy reaches it. Thus, solar technologies function most efficiently in the southwestern United States, which receives the greatest amount of solar energy.

# 4. UNIT IV UTILITY OF SOLAR ENERGY IN BUILDINGS

*Utility of Solar energy in buildings concepts of Solar Passive Cooling and Heating of Buildings. Low Energy Cooling. Case studies of Solar Passive Cooled and Heated Buildings*

## 4.1 History of Solar Energy

The idea of passive solar building design first appeared in Greece around the fifth century BC. Up until that time, the Greeks' main source of fuel had been charcoal, but due to a major shortage of wood to burn they were forced to find a new way of heating their dwellings. With necessity as their motivation, the Greeks revolutionized the design of their cities. They began using building materials that absorbed solar energy, mostly stone, and started orienting the buildings so that they faced south. These revolutions, coupled with overhangs that kept out the hot summer sun, created structures which required very little heating and cooling.

Socrates wrote, "In houses that look toward the south, the sun penetrates the portico in winter, while in summer the path of the sun is right over our heads and above the roof so that there is shade."

From this point on, most civilizations have oriented their structures to provide shade in the summer and heating in the winter. The Romans improved on the Greeks' design by covering the southern-facing windows with different types of transparent materials.

Another simpler example of early solar architecture is the cave dwellings in the south western regions of North America. Much like the Greek and Roman buildings, the cliffs in which the indigenous people of this region built their homes were oriented towards the south with an overhang to shade them from the midday sun during the summer months and capture as much of the solar energy during the winter as possible.

Active solar architecture involves the moving of heat and/or coolness between a temporary heat storage medium and a building, typically in response to a thermostat's call for heat or coolness within the building. While this principle sounds useful in theory, significant engineering problems have thwarted almost all active solar architecture in practice.

A more complex and modern incarnation of solar architecture was introduced in 1954 with the invention of the photovoltaic cell by Bell Labs. Early cells were extremely inefficient and therefore not widely used, but throughout the years government and private research has improved the efficiency to a point where it is now a viable source of energy.

## 4.2 Advantages of Using Solar Power in Buildings

- **Limitless Resource**: Solar energy is renewable energy that never ends its supply.
- **Low environmental impact**: Depending on the scale of the system installed – from distributed rooftop PV arrays to large utilities – solar technologies can produce lower environmental pollution.
- **Energy Independence**: It makes Buildings energy independent and puts less pressure on natural sources of energy.
- **Multipurpose:** It can be used in various ways and for multiple applications.
- **Ability for Additions**: You can expand your PV systems effortlessly as they are modular.
- **Portable**: Can be transported easily.
- **Post-Installation is Zero:** Once the infrastructure has been installed no cost will be there after that (except changing inverter and batteries).

## 4.3 Methods to Empower Solar Powered Buildings

Solar Powered Buildings improve the Heating & Cooling System's efficiency by 30 percent by proper installation of a new HVAC system. Operating cost of a highly-efficient solar water heater can be reduced by 90% in Solar Powered Energy Efficient Buildings.

When you use Low-Emissivity (Low-e) Window Glazing, it helps in reduces the space cooling need by approximately 40 percent. A light-colour roof reduces a roof's temperature as it absorbs less than 50 percent of the solar energy.

When Energy Efficient Lights and Energy Efficient Appliances are used, a Solar Building can reduce the energy use by 20-30%. With the continued emergence of construction technology innovations, it is becoming easier to achieve greater energy efficiency in buildings. Solar Powered Buildings with proper use of technology are more efficient in energy consumption.

## 4.4 Active Solar Energy

Active Solar Space Heating: In an active solar space heating system, a collector holding a heat-transfer medium such as air or liquid captures the sun's thermal energy, which is then distributed through the building via electric fans or pumps. Currently, there are no prefabricated residential solar heating systems, so interested customers must hire a specialized engineering firm to design an adequate system. The costs for such custom systems range from $3,000 to $10,000 depending on the size of the space. With savings in electricity or natural gas, active solar heating systems can pay for themselves in 7 to 10 years.

### 4.4.1 Active Solar Building Techniques

- **Solar water heaters**

This produce thermal energy to heat water for households, commercial entities, and swimming pools. These heaters are one of the most commonly implemented renewable energy technologies because of their cost effectiveness and relatively simple installation. With the proper model installed, they heat efficiently regardless of outside temperature. Solar water heaters typically need a backup conventional gas or electric water heater to account for cloudy days or unusually high water demand.

Solar water heaters consist of two parts: ***a solar collector and a storage tank***. In warm climates, collectors heat water directly, but in cold climates, a denser fluid is heated and then transported to a water tank where it heats the water indirectly. The heater can be built to use an active or passive system for circulating warmed fluid depending on climate and the time of day when water demand is highest. The maximum heating temperature varies with collector model, but water temperature can exceed 200 degrees Fahrenheit, suitable for commercial purposes.

Solar water heaters can reduce conventional energy consumption for heating water by 60 percent in commercial applications and up to 75 percent in homes. Although initial home installation costs range from $1,500 to $3,000—at least double that of conventional heaters—the reduction in gas or electric bills realized over their 15-20 year lifespan allow solar water heaters to equal or better the long term cost of other water heaters.

- **Photovoltaic (PV) cells**

They are also known as solar cells, are an active system in which small panels faced with semiconducting material turn sunlight into electricity. This material, usually made of silicon but potentially other polycrystalline thin films, generates a direct current when sunlight hits the panel. Commercially available PV panels are up to 22.5 percent efficient at converting sunlight into electricity in optimal conditions, but even in partly cloudy weather, they can operate at 80 percent of their maximum output. The United States is the leader in thin-film technology, which enables PV cells to be installed on windows and roof tiles. PV systems can be tailored to meet a building's energy needs by adding concentrating or sun-tracking devices, DC-AC converters, and/or battery storage.

PV systems may or may not be connected to the electric transmission grid. PV systems linked to the transmission grid can supplement utilities' energy supply during daylight hours, which normally include the peak energy demand periods. Independent PV cells can power a variety of individual items, from personal calculators and streetlights to water pumps on ranches and remote settlements far from power lines. A few utility-scale PV installations have been constructed although energy production is limited to daylight hours and they generally have higher upfront costs than fossil fuel plants.

- **Concentrated solar power (CSP)**

It is an active system distinguished from other solar energy systems by its ability to function as a utility-scale power plant. CSP uses fields of mirrors to concentrate solar energy into channels holding heat-responsive fluid. The high temperatures excite the fluid to a point where it powers a turbine or engine, which in turn runs an electric generator. Without storage facilities, CSP systems can generate electricity for about eleven hours on a sunny summer day in the Southwest. However, CSP systems do have the potential to provide baseload power for utilities. A CSP system that uses oil or molten salt as a medium in the heat-transfer process can retain the thermal energy in thermos-like tanks for use when sunlight is not available. Another option hybridizes CSP with natural gas boilers, which heat the fluid when the sunlight cannot. Existing natural gas and coal power plants can be retrofitted with CSP technology.

Different models of CSP systems include: Linear Concentrating Systems, Parabolic Trough Systems (the cheapest and most common system in the United States), Linear Fresnal Systems, Dish/Engine Systems (which produce energy on a smaller scale, generally between 3 and 25 kilowatts), and Power Tower Systems (the most efficient CSP systems but also the most expensive and demanding on water and land resources).

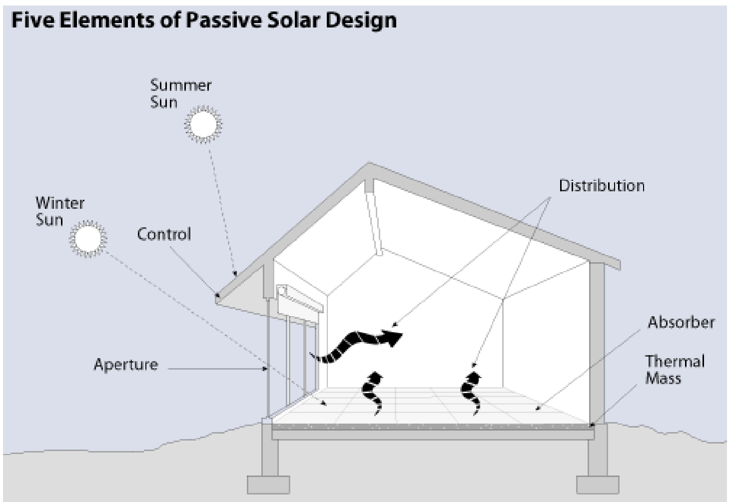
CSP requires a substantial initial investment, and it typically uses more land and water than other solar technologies. The Southwest has excellent sunlight conditions for CSP, but the water supply needed—which can be as much as coal plants—places a heavy demand on the arid climate. Desalination and dry cooling systems can reduce the water demand by 97 percent but add to the cost of the plant.

## 4.5 Passive Solar Design

Passive solar design takes advantage of a building's site, climate, and materials to minimize energy use. A well-designed passive solar home first reduces heating and cooling loads through energy-efficiency strategies and then meets those reduced loads in whole or part with solar energy. Because of the small heating loads of modern homes it is very important to avoid oversizing south-facing glass and ensure that south-facing glass is properly shaded to prevent overheating and increased cooling loads in the spring and fall. For passive solar homes, a portion of the south side of the house must have an unobstructed "view" of the sun. Hence consider possible future uses of the land to the south of site—small trees become tall trees, and a future multi-story building can block home's access to the sun. In some areas, zoning or other land use regulations protect landowners' solar access.

### 4.5.1 Design basics of Passive Solar Building

**Aperture/Collector**: The large glass area through which sunlight enters the building. The aperture(s) should face within 30 degrees of true south and should not be shaded by other buildings or trees from 9a.m. to 3p.m. daily during the heating season.



**Absorber**: The hard, darkened surface of the storage element. The surface, which could be a masonry wall, floor, or water container, sits in the direct path of sunlight. Sunlight hitting the surface is absorbed as heat.

**Thermal mass**: Materials that retain or store the heat produced by sunlight. While the absorber is an exposed surface, the thermal mass is the material below and behind this surface.

**Distribution**: Method by which solar heat circulates from the collection and storage points to different areas of the house. A strictly passive design will use the three natural heat transfer modes- conduction, convection and radiation- exclusively. In some applications, fans, ducts and blowers may be used to distribute the heat through the house.

**Control**: Roof overhangs can be used to shade the aperture area during summer months. Other elements that control under and/or overheating include electronic sensing devices, such as a differential thermostat that signals a fan to turn on; operable vents and dampers that allow or restrict heat flow; low-emissivity blinds; and awnings.

### 4.5.2 Methods to implement Solar Gain

- **Direct Gain**

In a direct gain design, sunlight enters the house through south-facing windows and strikes masonry floors and/or walls, which absorb and store the solar heat. As the room cools during the night, the thermal mass releases heat into the house.Some builders and homeowners use water-filled containers located inside the living space to absorb and store solar heat. Although water stores twice as much heat as masonry materials per cubic foot of volume, water thermal storage requires carefully designed structural support. An advantage of water thermal storage is that it can be installed in an existing home if the structure can support the weight.

- **Indirect Gain (Trombe Wall)**

An indirect-gain passive solar home has its thermal storage between the south-facing windows and the living spaces. The most common indirect-gain approach is a Trombe wall. The wall consists of an 8-inch to 16-inch thick masonry wall on the south side of a house.

A single or double layer of glass mounted about one inch or less in front of the dark-colored wall absorbs solar heat, which is stored in the wall's mass. The heat migrates through the wall and radiates into the living space. Heat travels through a masonry wall at an average rate of one inch per hour, so the heat absorbed on the outside of an 8-inch thick concrete wall at noon will enter the interior living space around 8 p.m.

- **Isolated Gain (Sunspaces)**

The most common isolated-gain passive solar home design is a sunspace that can be closed off from the house with doors, windows, and other operable openings. Also known as a sunroom, solar room, or solarium, a sunspace can be included in a new home design or added to an existing home. Sunspaces should not be confused with greenhouses, which are designed to grow plants. Sunspaces serve three main functions -- they provide auxiliary heat, a sunny space to grow plants, and a pleasant living area. The design considerations for these three functions are very different, and accommodating all three functions requires compromises.

### 4.5.3 Basic Elements of Passive Solar heating

In simple terms, a passive solar home collects heat as the sun shines through south-facing windows and retains it in materials that store heat, known as thermal mass. The share of the home’s heating load that the passive solar design can meet is called the passive solar fraction, and depends on the area of glazing and the amount of thermal mass. The ideal ratio of thermal mass to glazing varies by climate. Well-designed passive solar homes also provide daylight all year and comfort during the cooling season through the use of night time ventilation. To be successful, a passive solar home design must include some basic elements that work together:

**Properly oriented windows**

Typically, windows or other devices that collect solar energy should face within 30 degrees of true south and should not be shaded during the heating season by other buildings or trees from 9 a.m. to 3 p.m. each day. During the spring, fall, and cooling season, the windows should be shaded to avoid overheating. Be sure to keep window glass clean.

**Thermal mass**

Thermal mass in a passive solar home -- commonly concrete, brick, stone, and tile -- absorbs heat from sunlight during the heating season and absorbs heat from warm air in the house during the cooling season. Other thermal mass materials such as water and phase change products are more efficient at storing heat, but masonry has the advantage of doing double duty as a structural and/or finish material. In well-insulated homes in moderate climates, the thermal mass inherent in home furnishings and drywall may be sufficient, eliminating the need for additional thermal storage materials. Make sure that objects do not block sunlight on thermal mass materials.

**Distribution mechanisms**

Solar heat is transferred from where it is collected and stored to different areas of the house by conduction, convection, and radiation. In some homes, small fans and blowers help distribute heat. Conduction occurs when heat moves between two objects that are in direct contact with each other, such as when a sun-heated floor warms your bare feet. Convection is heat transfer through a fluid such as air or water, and passive solar homes often use convection to move air from warmer areas -- a sunspace, for example -- into the rest of the house. Radiation is what you feel when you stand next to a wood stove or a sunny window and feel its warmth on your skin. Darker colors absorb more heat than lighter colors, and are a better choice for thermal mass in passive solar homes.

**Control strategies**

Properly sized roof overhangs can provide shade to vertical south windows during summer months. Other control approaches include electronic sensing devices, such as a differential thermostat that signals a fan to turn on; operable vents and dampers that allow or restrict heat flow; low-emissivity blinds; operable insulating shutters; and awnings.

**Refining the Design**

Although conceptually simple, a successful passive solar home requires that a number of details and variables come into balance. An experienced designer can use a computer model to simulate the details of a passive solar home in different configurations until the design fits the site as well as the owner's budget, aesthetic preferences, and performance requirements. Some of the elements the designer will consider include:

- Insulation and air sealing
- Window location, glazing type, and window shading

- Thermal mass location and type.
- Auxiliary heating and cooling systems.

## 4.6 Passive Solar Cooling

Passive cooling is the least expensive means of cooling a home in both financial and environmental terms. Some level of passive cooling is required in every climate at some time of the year. As cooling requirements are dictated by climate, distinctly different approaches to passive cooling are required for:

- Hot humid climates (Zone 1) where no heating is required
- Temperate and warm climates (Zones 2−6) where both heating and cooling are required
- Cool and cold climates (Zones 7−8) where heating needs are more important.

### 4.6.1 Techniques to Cool buildings

The efficiency of the building envelope can be maximised in a number of ways to minimise heat gain:

- Shading windows, walls and roofs from direct solar radiation
- Using lighter coloured roofs to reflect heat
- Using insulation and buffer zones to minimise conducted and radiated heat gains
- Making selective or limited use of thermal mass to avoid storing daytime heat gains.

To maximise heat loss, use the following natural sources of cooling:

- Air movement
- Cooling breezes
- Evaporation
- Earth coupling
- Reflection of radiation.

### 4.6.2 Cooling sources

Sources of passive cooling are more varied and complex than passive heating, which comes from a single, predictable source — solar radiation.

Varying combinations of innovative envelope design, air movement, evaporative cooling, earth-coupled thermal mass, lifestyle choices and acclimatisation are required to provide adequate cooling comfort in climate zones. Additional mechanical cooling may be required in hot humid climates and in extreme conditions in many climates, especially as climate change leads to higher temperatures during the daytime and overnight.

**Air movement**

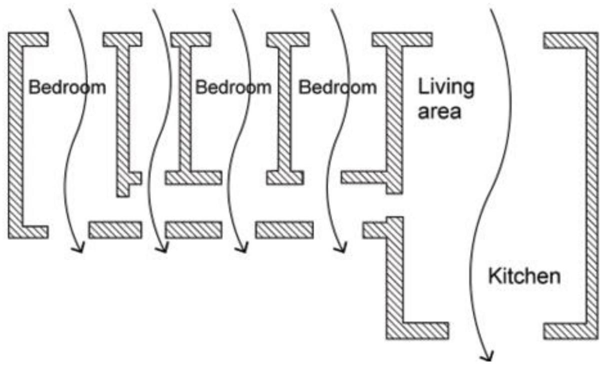
Air movement is the most important element of passive cooling. It cools people by increasing evaporation and requires both breeze capture and fans for back-up in still conditions.

It also cools buildings by carrying heat out of the building as warmed air and replacing it with cooler external air. Moving air also carries heat to mechanical cooling systems where it is removed by heat pumps and recirculated. This requires well-designed openings (windows, doors and vents) and unrestricted breeze paths.

In all climates, air movement is useful for cooling people, but it may be less effective during periods of high humidity. An air speed of 0.5m/s equates to a 3°C drop in temperature at a relative humidity of 50%. This is a one-off physiological cooling effect resulting from heat being drawn from the body to evaporate perspiration. Air movement exposes the skin to dryer air. Increased air speeds do not increase cooling at lower relative humidity but air speeds up to 1.0m/s can increase evaporative cooling in higher humidity. Air speeds above 1.0m/s usually cause discomfort.

**Cool breezes**

Where the climate provides cooling breezes, maximising their flow through a home when cooling is required is an essential component of passive design. Unlike cool night air, these breezes tend to occur in the late afternoon or early evening when cooling requirements usually peak.



A floor plan of a long narrow house shows windows and doors in bedrooms and living areas that are laid out in a way that maximises cool breezes. Cool breezes work best in narrow or open plan layouts. Cool breezes work best in narrow or open plan layouts and rely on air-pressure differentials caused by wind or breezes. They are less effective in:

- Buildings with deep floor plans or individual small rooms
- Long periods of high external temperature (ambient or conducted heat gains above 35–40 watts per square metre (W/m2)
- Locations with high noise, security risk or poor external air quality, where windows may need to be closed.

Coastal breezes are usually from an onshore direction (south-east and east to north-east in most east coast areas, and south-west in most west coast areas, e.g. the ‘Fremantle Doctor’).

In mountainous or hilly areas, cool breezes often flow down slopes and valleys in late evening and early morning, as heat radiating to clear night skies cools the land mass and creates cool air currents.

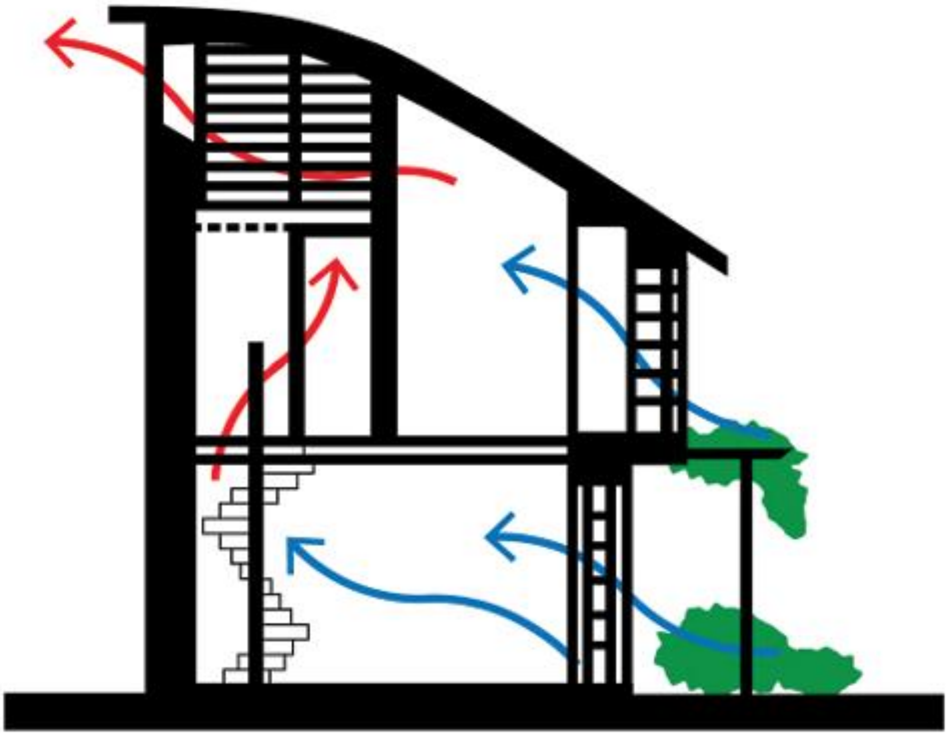
Thermal currents are common in flatter, inland areas, created by daily heating and cooling. They are often of short duration in early morning and evening but with good design can yield worthwhile cooling benefits.

**Cool night air**

Cool night air is a reliable source of cooling in inland areas where cool breezes are limited and diurnal temperature ranges usually exceed 6−8°C. Hot air radiating from a building fabric’s thermal mass is replaced with cooler night air drawn by internal−external temperature differentials rather than breezes. Full height, double hung windows are ideal for this purpose. Further cooling can be gained by including whole of house fans.

**Convective air movement**

The rule of convection: warm air rises and cool air falls. Stack ventilation, or convective air movement, relies on the increased buoyancy of warm air which rises to escape the building through high level outlets, drawing in lower level cool night air or cooler daytime air from shaded external areas (south) or evaporative cooling ponds and fountains.



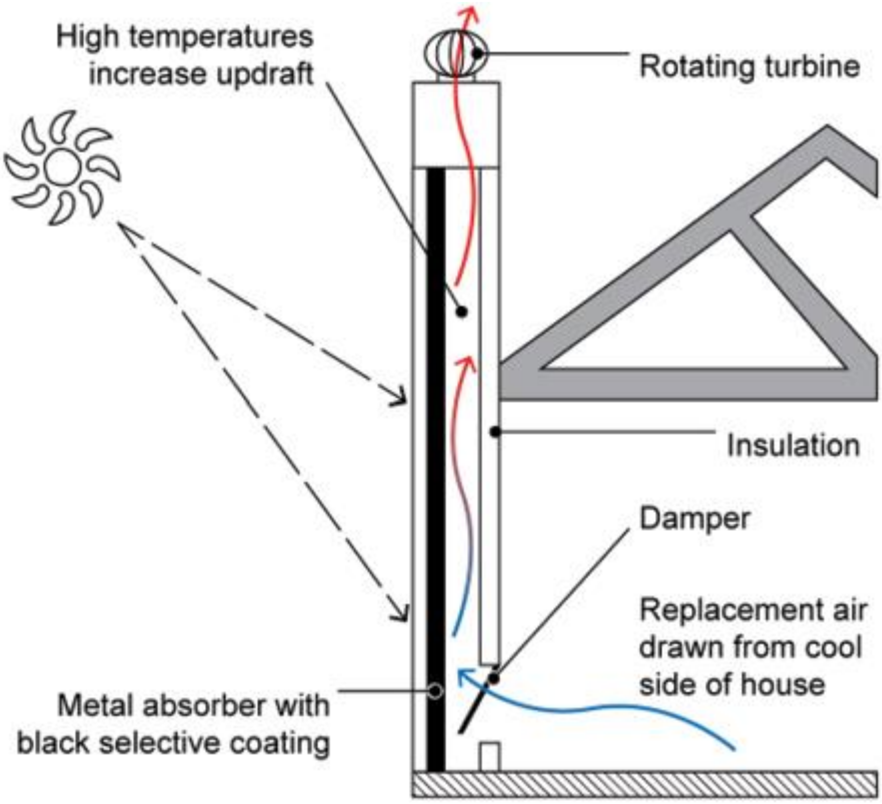
A cross-section of a home, where cool air is drawn in from a shaded garden area. Warm air rises to the second storey of the home, where it is drawn out high windows or vents. Convection causes warm air to rise, drawing in cool air.

Convective air movement improves cross-ventilation and overcomes many of the limitations of unreliable cooling breezes. Even when there is no breeze, convection allows heat to leave a building via clerestory windows, roof ventilators and vented ridges, eaves, gables and ceilings.

Convection produces air movement capable of cooling a building but usually has insufficient air speed to cool people.

**Solar chimneys**

Solar chimneys enhance stack ventilation by providing additional height and well-designed air passages that increase the air pressure differential. Warmed by solar radiation, chimneys heat the rising air and increase the difference in temperature between incoming and out-flowing air.




The increase in natural convection from these measures enhances the draw of air through the building.

A cross-section of a home with a solar chimney is shown. The solar chimney draws replacement air from the cool side of the house. Solar radiation absorbed by a metal absorber with a black selective coating causes high temperatures in the chimney, increasing updraft. Hot air exits the chimney through a rotating turbine at the top. The house-facing side of the chimney is insulated.

Solar chimneys enhance ventilation.

**Evaporative cooling**

As water evaporates it draws large amounts of heat from surrounding air. Evaporation is therefore an effective passive cooling method, although it works best when relative humidity is lower (70% or less during hottest periods) as the air has a greater capacity to take up water vapour.

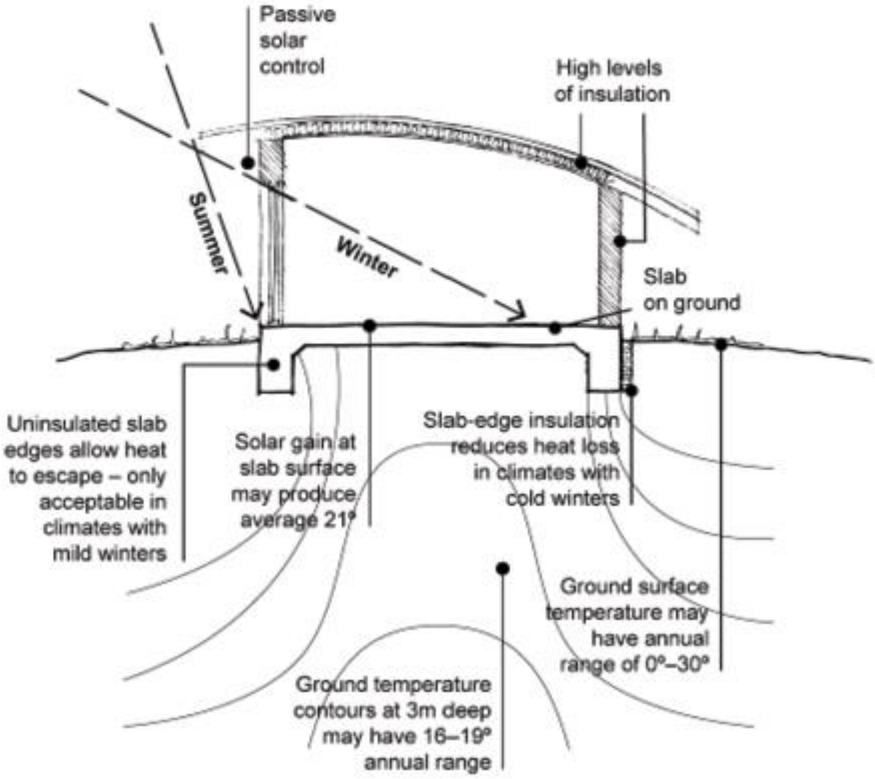
Rates of evaporation are increased by air movement. Pools, ponds and water features immediately outside windows or in courtyards can pre-cool air entering the house. Carefully located water features can create convective breezes. The surface area of water exposed to moving air is also important. Fountains, mist sprays and waterfalls can increase evaporation rates. The outside of a home has extensive vines on a patio. Adjacent to the patio area is a pond.

Ponds pre-cool air before it enters a house. Mechanical evaporative coolers are common in drier climates and inland areas where relative humidity is low. They use less energy than refrigerated air conditioners and work better with doors and windows left open. Their water consumption can be considerable.

**Earth coupling**

Earth coupling of thermal mass protected from external temperature extremes (e.g. floor slabs) can substantially lower temperatures by absorbing heat as it enters the building or as it is generated by household activities.

The cross-section of a home shows a slab set on the ground. The angle of the eaves prevents summer sun directly reaching the windows. But winter sun enters the windows, warming the slab on the ground. **This is known as passive solar control.**




Passively shaded areas around earth-coupled slabs keep surface ground temperatures lower during the day and allow night-time cooling. Poorly shaded surrounds can lead to earth temperatures exceeding internal comfort levels in many areas. In this event, an earth-coupled slab can become an energy liability.

Ground and soil temperatures vary throughout. Earth-coupled construction (including slab-on-ground and earth covered or bermed) utilises stable ground temperatures at lower depths to absorb household heat gains.

## 4.7 Passive cooling design principles

To achieve thermal comfort in cooling applications, building envelopes are designed to minimise daytime heat gain, maximise night-time heat loss, and encourage cool breeze access when available. Considerations include:

- Designing the floor plan and building form to respond to local climate and site
- Using and positioning thermal mass carefully to store coolness, not unwanted heat
- Choosing climate appropriate windows and glazing
- Positioning windows and openings to enhance air movement and cross ventilation

- Shading windows, solar exposed walls and roofs where possible
- Installing and correctly positioning appropriate combinations of both reflective and bulk insulation
- Using roof spaces and outdoor living areas as buffer zones to limit heat gain.

Integration of these variables in climate appropriate proportions is a complex task. Energy rating software, such as that accredited under the Nationwide House Energy Rating Scheme (NatHERS). While the NatHERS software tools are most commonly used to rate energy efficiency (thermal performance) when assessing a house design for council approval, their capacity, in ‘non-rating mode’, as a design tool is currently under-used.

**Envelope design — floor plan and building form**

Envelope design is the integrated design of building form and materials as a total system to achieve optimum comfort and energy savings.

Heat enters and leaves a home through the roof, walls, windows and floor, collectively referred to as the building envelope. The internal layout — walls, doors and room arrangements — also affects heat distribution within a home.

Good design of the envelope and internal layout responds to climate and site conditions to optimise the thermal performance. It can lower operating costs, improve comfort and lifestyle

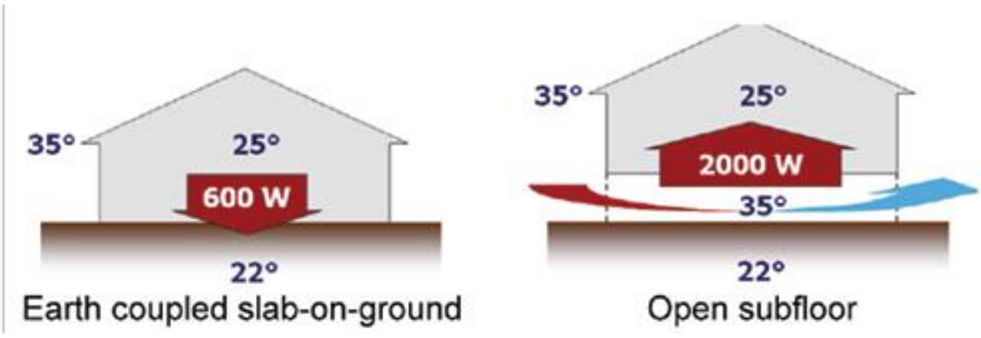
Varied responses are required for each climate zone and even within each zone depending on local conditions and the microclimate of a given site.

- Maximise the indoor‒outdoor relationship and provide outdoor living spaces that are screened, shaded and rain protected.
- Maximise convective ventilation with high level windows and ceiling or roof space vents.
- Zone living and sleeping areas appropriately for climate — vertically and horizontally.
- Locate bedrooms for sleeping comfort.
- Design ceilings and position furniture for optimum efficiency of fans, cool breezes and convective ventilation.
- Locate mechanically cooled rooms in thermally protected areas (i.e. highly insulated, shaded and well sealed).

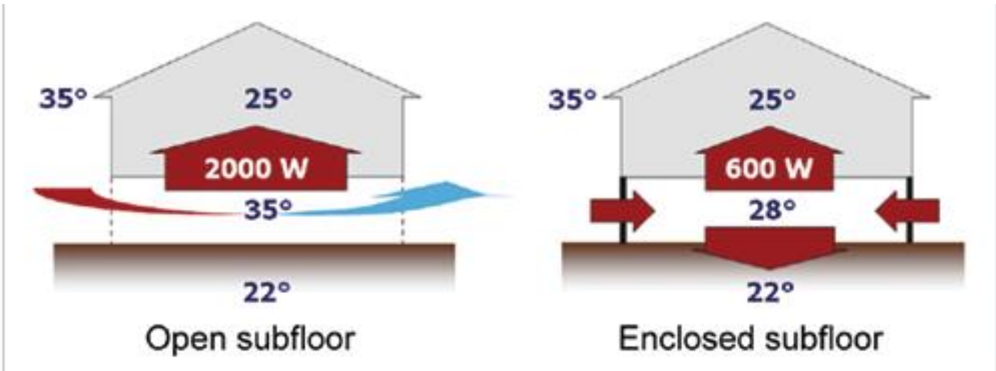
**Thermal mass**

Thermal mass is the storage system for warmth and 'coolth' (the absence of warmth) in passive design.

Climate responsive design means positioning thermal mass where it is exposed to appropriate levels of passive summer cooling (and solar heating in winter). Badly positioned mass heats up and radiates heat well into the night when external temperatures have dropped. As a rule of thumb, avoid or limit thermal mass in upstairs sleeping areas. In climates with little or no heating requirement, low mass is generally the preferred option.



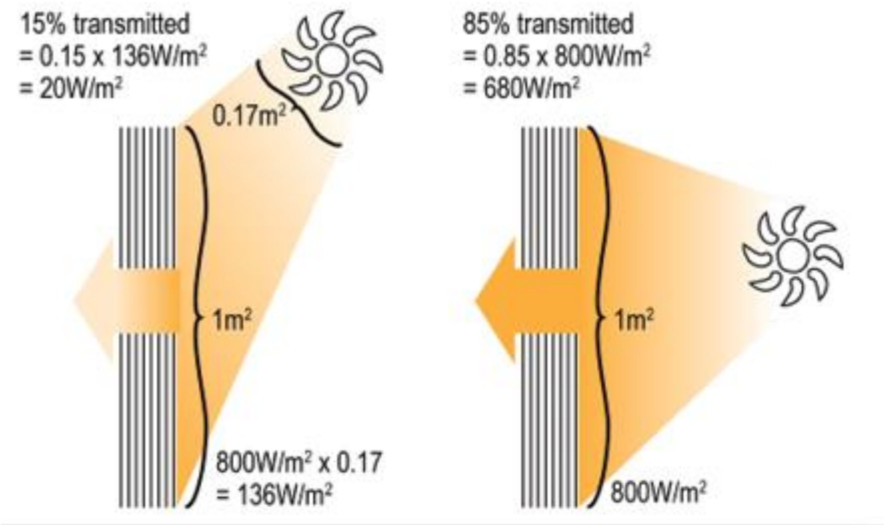

Earth-coupled concrete slabs-on-ground provide a heat sink where deep earth temperatures (at 3m depth or more) are favourable, but should be avoided in climates where deep earth temperatures contribute to heat gain. In these regions, use open vented floors with high levels of insulation to avoid heat gain.




A diagram shows two houses; one on a concrete slab on the ground, the other on stilts. If the outside temperature is 35 degrees Celsius, and the ground temperature is 22 degrees Celsius, and the inside temperature is 25 degrees Celsius, 600 watts of energy will be transferred from inside the home to the thermal mass of the house. For the house on stilts, these same temperatures outside, beneath and inside the home would mean that 2000 watts of energy will be transferred from beneath the home into the house, In regions where deep earth temperatures are lower, consider enclosing subfloor areas to allow earth coupling to reduce temperatures and therefore heat gains.

**Windows and shading**

Windows and shading are the most critical elements in passive cooling. They are the main source of heat gain, via direct radiation and conduction, and of cooling, via cross, stack and fan-drawn ventilation, cool breeze access and night purging (see Glazing; Shading).



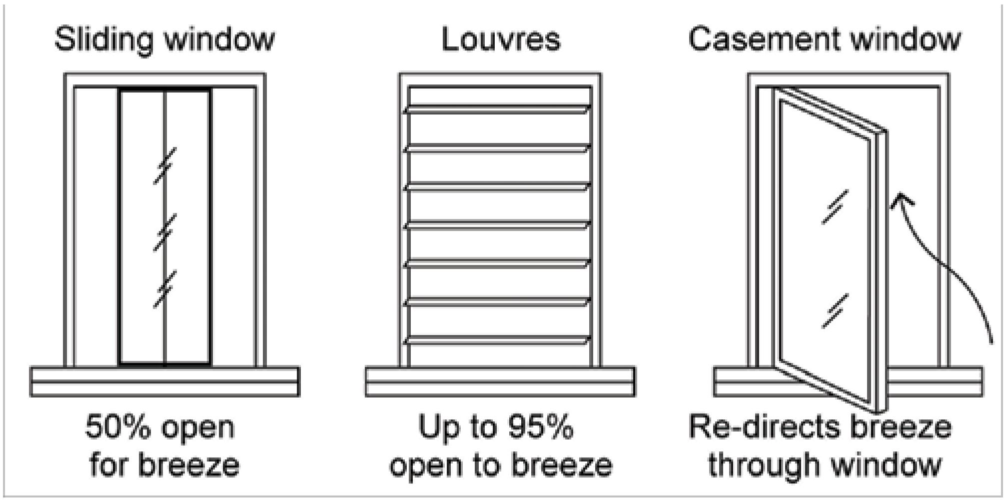

Low sun angles through east and west-facing windows increase heat gain, while north-facing windows (south in tropics) transmit less heat in summer because the higher angles of incidence reflect more radiation.

A diagram shows the sun’s radiation hitting a window. If the solar radiation is 800 watts per square metre, and the surface area of a window is one square metre, and the angle of the sun means that 85% of the sun’s energy is transmitted, this means that 680 watts per square metre of energy will enter the window. A diagram shows the sun’s radiation where the sun is at a high point above the window. In this case, only 17% of the sun’s radiation enters the window, meaning 136 watts per square metre .

**Air movement and ventilation**

Design to maximise beneficial cooling breezes by providing multiple flow paths and minimising potential barriers; single depth rooms are ideal in warmer climates.

Because breezes come from many directions and can be deflected or diverted, orientation to breeze direction is less important than the actual design of windows and openings to collect and direct breezes within and through the home.

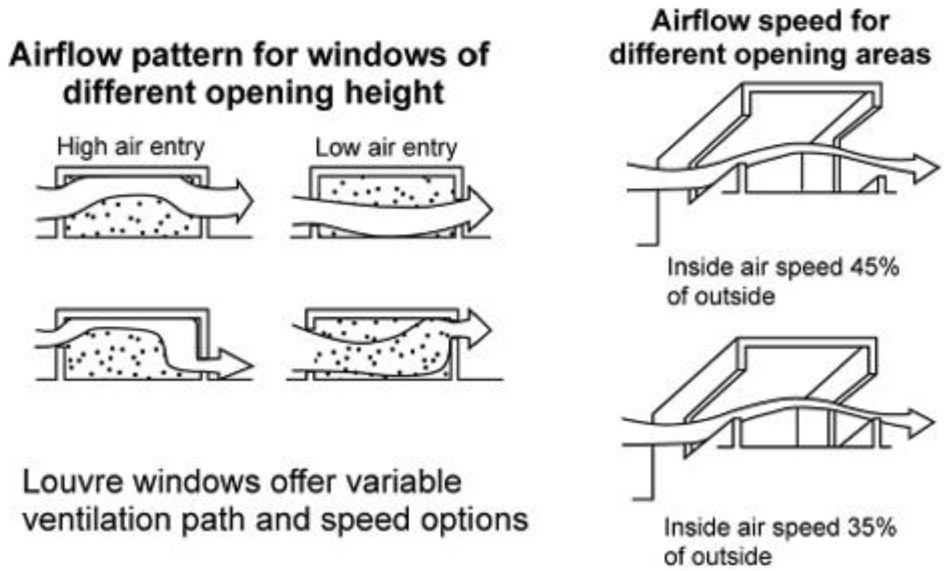



Source: Dept of Environment and Resource Management, Qld

Use casement windows to catch and deflect breezes from varying angles. A diagram shows three different types of windows: a sliding window, louvres, and a casement window. A sliding window allows 50% of the window space to be open for breeze; louvre windows can be opened up to 95% to allow a breeze; and a casement window re-directs the breeze through it. For breeze collection, window design is more important than orientation.

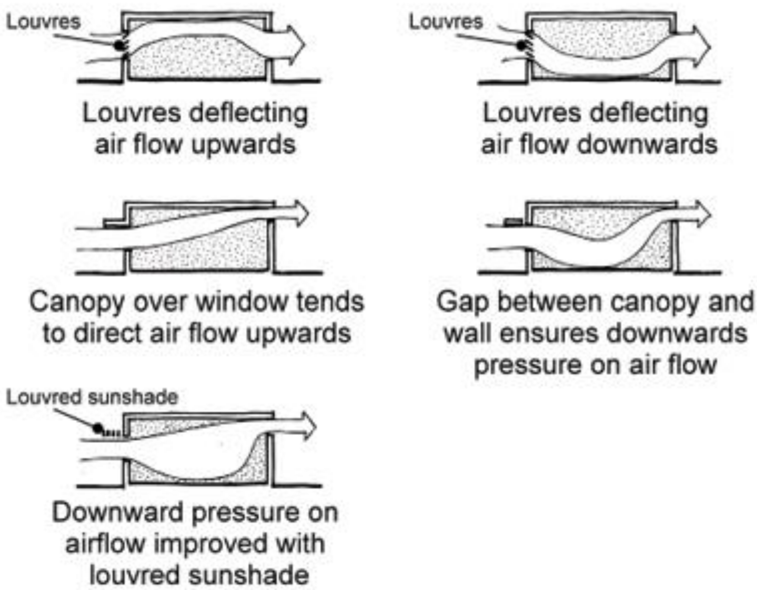
Wind doesn't blow through a building — it is sucked towards areas of lower air pressure. To draw the breeze through, use larger openings on the leeward (low pressure or downwind) side of the house and smaller openings on the breeze or windward (high pressure or upwind) side. Openings near the centre of the high pressure zone are more effective because pressure is highest near the centre of the windward wall and diminishes toward the edges as the wind finds other ways to move around the building.

A diagram notes louvre windows offer variable ventilation path and speed options. The airflow patterns for windows of different opening height are different; when windows are high on both sides of a room, airflow is across the ceiling of the room; when both windows are low, airflow is across the floor of the room. When the entry window is high and the exit window is low, the air flows across the ceiling and then down the exit wall to the window. Airflow pattern and speed for different opening areas.




In climates requiring winter heating the need for passive solar north sun influences these considerations; designers should strive for a balanced approach.

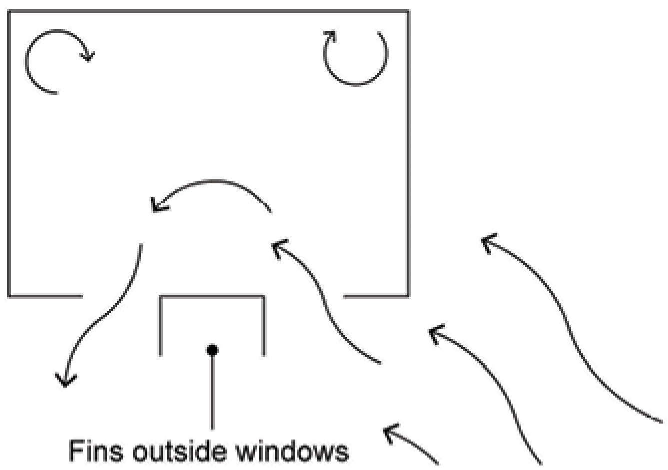
The design of openings to direct airflow inside the home is a critical but much overlooked design component of passive cooling. Size, type, external shading and horizontal/vertical position of any openings (doors and windows) is critical — as shown in the diagrams below.




Source: Steve Szokolay

In the humid tropics it is important to ensure that air flows into a room at a level that suits its function. Louvres can be used to deflect air flow upwards or downwards. A canopy over a window tends to direct air flow upwards whereas a gap between the canopy and the wall ensures a downwards pressure, which is further improved in the case of a louvred sunshade.

Airflow pattern for windows of different opening height. Louvre windows help to vary ventilation paths and control air speed.




Consider installing a louvre window above doors to let breezes pass through the building while maintaining privacy and security. In climates requiring cooling only, consider placing similar panels above head height in internal walls to allow cross-ventilation to move the hottest air.

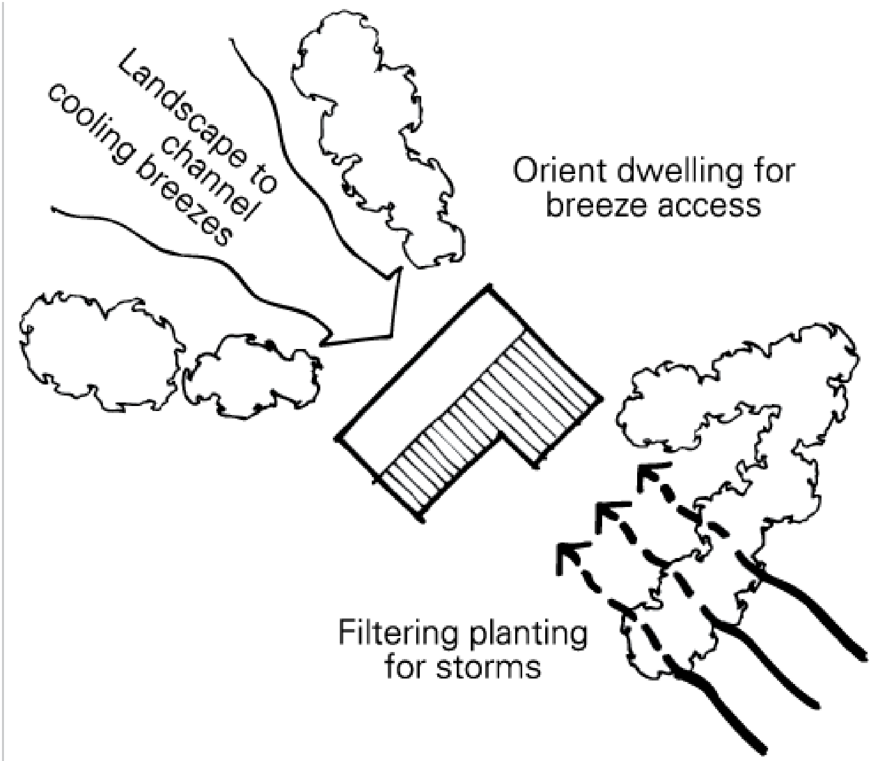
Position windows (vertically and horizonally) to direct airflow to the area where occupants spend most time (e.g. dining table, lounge or bed).

In rooms where it is not possible to place windows in opposite or adjacent walls for cross-ventilation, place projecting fins on the windward side to create positive and negative pressure to draw breezes through the room, as shown in the diagram below.A room is shown that has three enclosed walls, with two windows on the other wall. Fins outside these two windows direct the airflow so that it enters one window and exits the other.

Use fins to direct airflow.

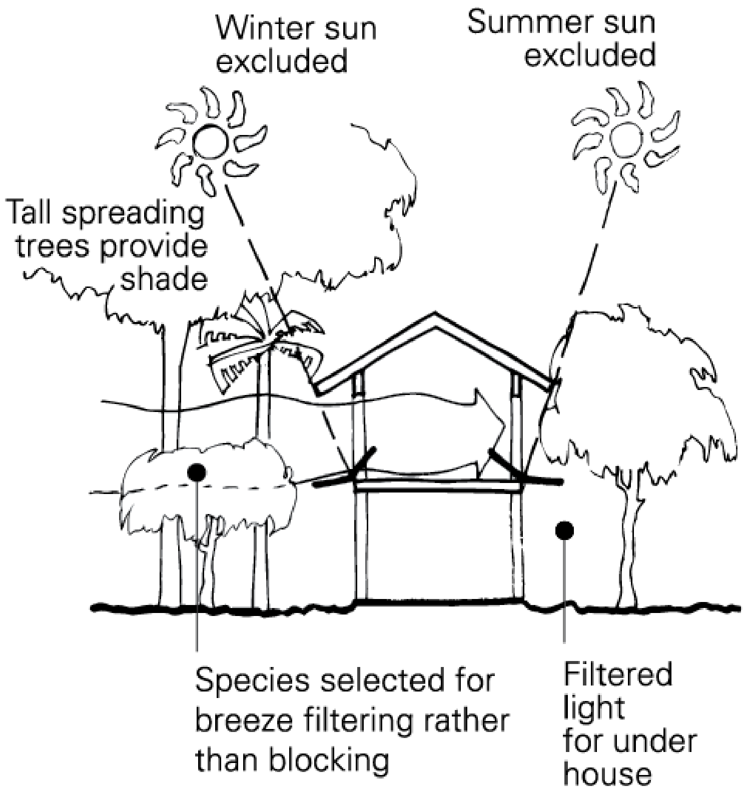
Design and locate planting, fences and outbuildings to funnel breezes into and through the building, filter stronger winds and exclude adverse hot or cold winds.

A diagram shows a house surrounded by two main sections of garden. The house is oriented so that breeze access is not blocked by plantings. Plantings funnel the cool breezes received by the house from one direction.




A wall of plantings blocks the airflow and wind from the opposite direction that is received during storms.

Plant trees and shrubs to funnel breezes.



A diagram shows a house on stilts, with an enclosed sub-floor area. Adjacent tall spreading trees provide shade and exclude both the winter and summer sun. Smaller trees and shrubs adjoining the house are selected for breeze filtering rather than blocking. Light for under the house is filtered.

Plant trees and shrubs to funnel breezes.

**Insulation**

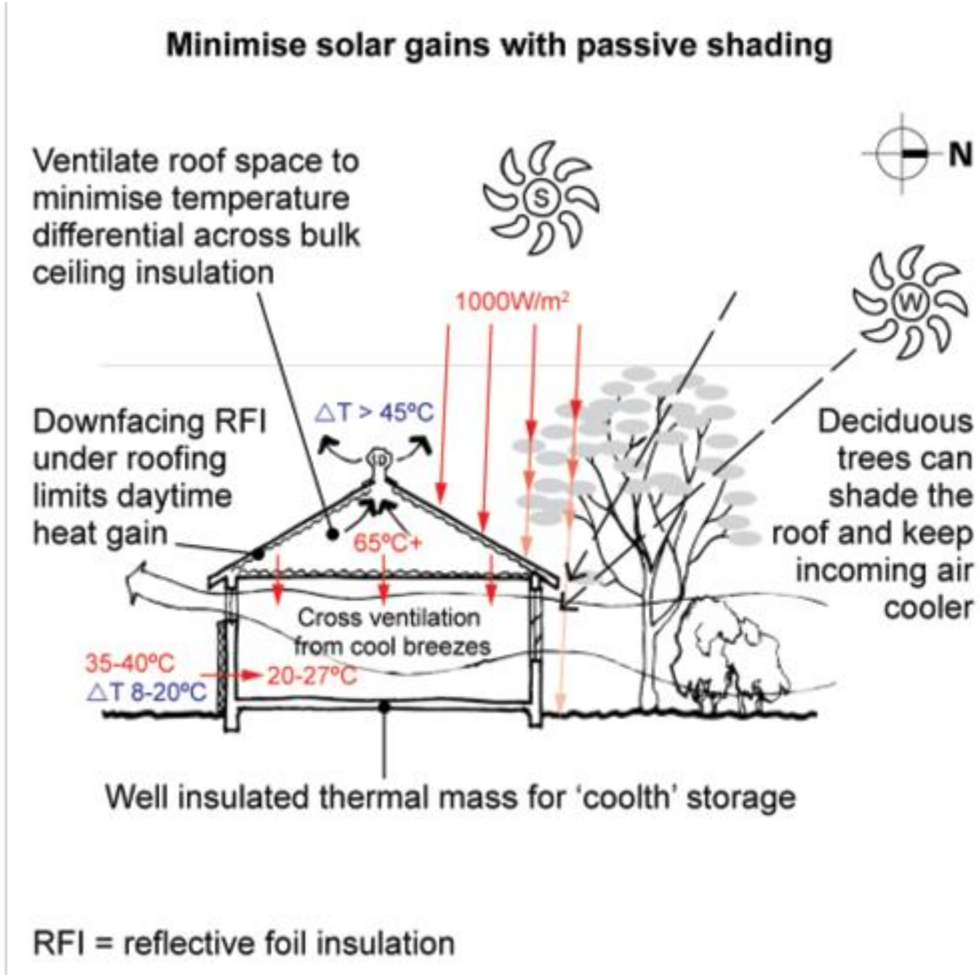
Insulation is critical to passive cooling — particularly to the roof and floor. Windows are often left open to take advantage of natural cooling and walls are easily shaded; roofs, however, are difficult to shade, and floors are a source of constant heat gain through conduction and convection, with only limited cooling contribution to offset it.

Insulation levels and installation details for each climate zone are provided in Insulation and Insulation installation. Pay careful attention to up and down insulation values and choose appropriately for purpose and location.

In climates that require only cooling or those with limited cooling needs, use multiple layers of reflective foil insulation in the roof instead of bulk insulation to reduce radiant daytime heat gains while maximising night-time heat loss through conduction and convection. This is known as the one-way insulation valve. Reflective foil insulation is less affected by condensation and is highly suited to cooling climate applications as it reflects unwanted heat out while not re-radiating it in.

**Roof space**

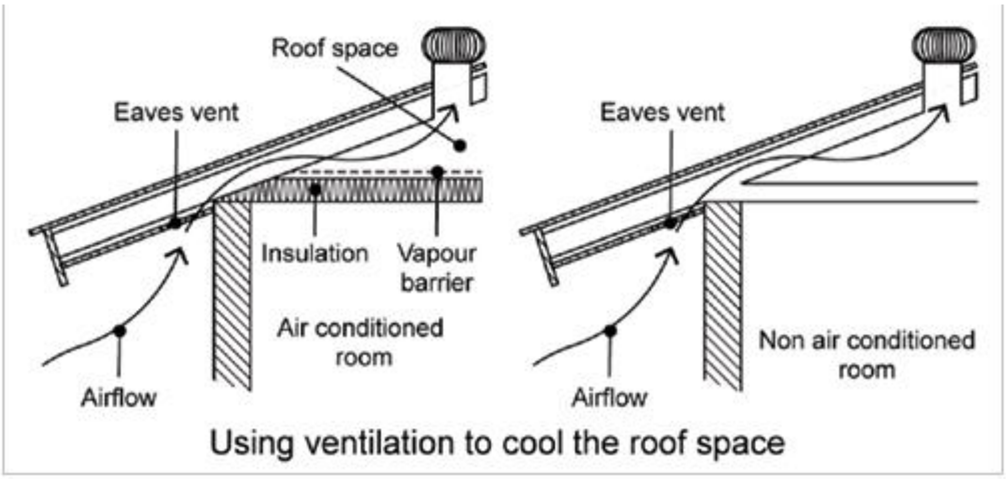
Well-ventilated roof spaces (and other non-habitable spaces) play a critical role in passive cooling by providing a buffer zone between internal and external spaces in the most difficult area to shade, the roof.




A diagram shows the cross-section of a north-facing home. Eaves provide passive shading and summer sun exclusion on the north walls, but allow maximum summer sun to penetrate. Planting filters and directs breezes towards openings in the home, which receives cross ventilation from cool breezes. The roof space is ventilated, and good roof and ceiling insulation is used. Heavy weight walls internally with external insulation. The south-facing walls have limited windows and better insulation to avoid hot summer. Well-ventilated roof spaces form a buffer between internal and external areas.

Ventilators can reduce the temperature differential (see Passive heating) across ceiling insulation, increasing its effectiveness by as much as 100%. The use of foil insulation and light coloured roofing limits radiant heat flow into the roof space.

Use careful detailing to prevent condensation from saturating the ceiling and insulation. Dew-points form where humid air comes into contact with a cooler surface, e.g. the underside of roof sarking or reflective foil insulation cooled by radiation to a clear night sky.




Source: COOLmob

A cross-section diagram shows the eaves and the roof space. For an air conditioned room, air flow is drawn through the eaves vent inside the roof space, where insulation provides a vapour barrier. The air is then drawn out of the roof through a roof turbine ventilator. For a non-air conditioned room, air flow is drawn through the eaves vent inside the rooft space, where it is then drawn out of the roof through a roof turbine ventilator. Using ventilation to cool the roof space.

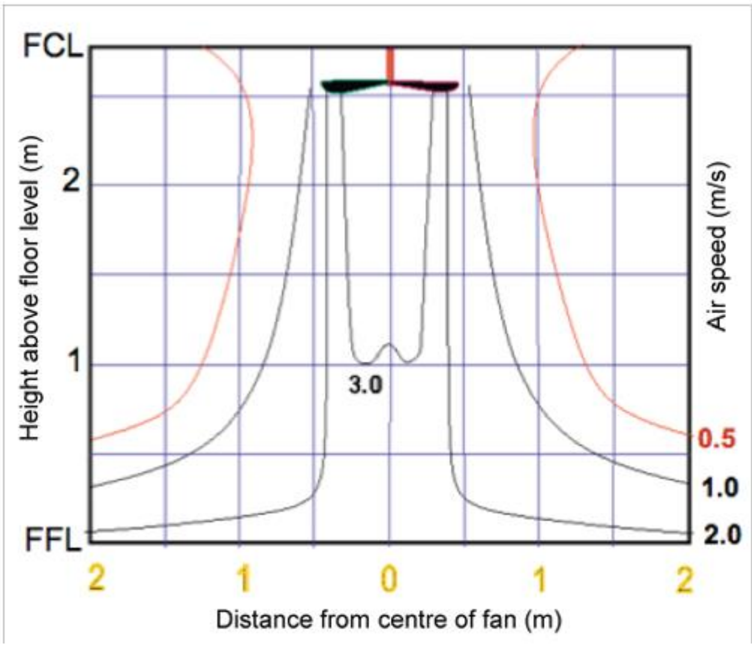
### 4.8. Hybrid cooling systems

Hybrid cooling systems are whole house cooling solutions that employ a variety of cooling options (including air conditioning) in the most efficient and effective way. They take maximum advantage of passive cooling when available and make efficient use of mechanical cooling systems during extreme periods.

- **Fans**

Fans provide reliable air movement for cooling people and supplementing breezes during still periods. At 50% relative humidity, air movement of 0.5m/s creates maximum cooling effect; faster speeds can be unsettling. As noted above, air speeds up to 1.0m/s can be useful in higher relative humidity, but prolonged air speeds above 1.0m/s cause discomfort.

Standard ceiling fans can create a comfortable environment when temperature and relative humidity levels are within acceptable ranges. In a lightweight building in a warm temperate climate, the installation of fans in bedrooms and all living areas (including kitchens and undercover outdoor areas) significantly reduces cooling energy use.




Source: Adapted from Ballinger 1992

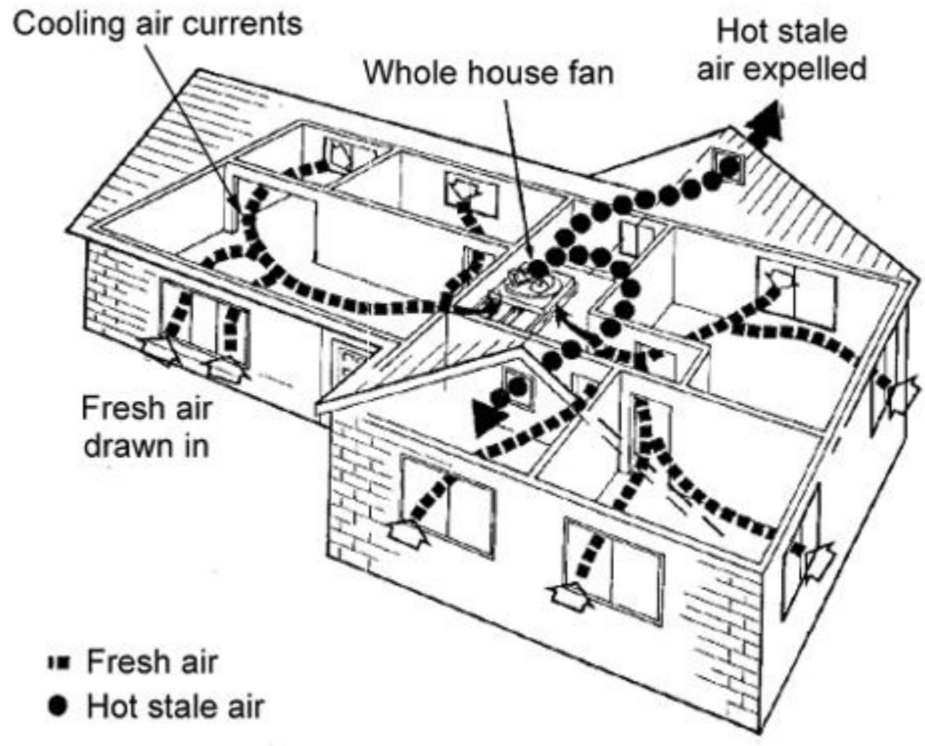
A graphical diagram shows air movement relative to fan position, for a fan that is in the centre of a four metre-wide room. Air speed is highest 1.5 metres directly below the fan, at 3 metres per second. Air speed is also relatively high along the floor. For about one metre adjoining the walls, from the ceiling to around 1 metre off the ground, air flow is minimally affected, at around 0.5 metres per second.

*Air movement relative to fan position:*

Fans should be located centrally in each space, one for each grouping of furniture. An extended lounge/dining area needs two fans. In bedrooms, locate the fan close to the centre of the bed. Because air speed decreases with distance from the fan, position fans over the places where people spend the most time.

Whole of house fans

Whole of house or roof fans are ideal for cooling buildings, particularly where cross-ventilation design is inadequate. However, they do not create sufficient air speed to cool occupants.




Source: Breezepower

A cut-through diagram of a house shows air flow within the house. Fresh air is drawn in through windows and travels through the house by air currents. Hot stale air is expelled via eave or gable vents.

Whole of house fans should be positioned centrally, e.g. in the roof, stairwell or hallways. Typically, a single fan unit is installed in a circulation space in the centre of the house (hallway or stairwell) to draw cooler outside air into the building through open windows in selected rooms, when conditions are suitable. It then exhausts the warm air through eaves, ceiling or gable vents via the roof space. This also cools the roof space and reduces any temperature differential across ceiling insulation. Control systems should prevent the fan operating when external air temperatures are higher than internal.

- **Air conditioning**

Refrigerated air conditioning lowers both air temperature and humidity and provides thermal comfort during periods of high temperature and humidity. However, it is expensive to install, operate and maintain, and has a high economic and environmental cost because it consumes significant amounts of electricity unless high efficiency equipment is used in a very high performance building envelope. As it also requires the home to be sealed off from the outside environment, occupants are often unaware of improvements in the weather.

Air conditioning is commonly used to create comfortable sleeping conditions. The number of operating hours required to achieve thermal comfort can be substantially reduced or eliminated by careful design of new homes, as well as alterations and additions to existing homes.

Running a refrigerated air conditioner in a closed room for about an hour at bedtime often lowers humidity levels to the point where air movement from ceiling fans can provide sufficient evaporative cooling to achieve and maintain sleeping comfort. Some air conditioning units simply operate as fans when outdoor ambient temperature drops below the thermostat setting, so they can replace a ceiling fan.

Efficient air conditioning requires more than simply installing an efficient air conditioner. Hybrid cooling solutions require a decision early in the design stages about whether air conditioning is to be used and how many rooms require it. Many inefficient air conditioning installations occur when they are added to a home designed for natural cooling as an ***afterthought to improve comfort.***

***Design of air conditioned spaces***

There is usually no need to air condition all rooms. Decide which rooms will receive most benefit, depending on their use, and try to reduce the total volume of air conditioned air space (room size, ceiling height). Often one or two rooms are sufficient to provide comfort during periods of high humidity and high temperatures.

Design for night-time sleeping comfort by conditioning rooms commonly used in the early evening with bedrooms adjoining. A conditioned, masonry-wall television room in the centre of a free running (passively cooled) home with sleeping spaces adjoining it provides both direct and indirect cooling benefits. Efficient (low heat output) lighting and appliances are important in such an application. A cool masonry wall in a bedroom gives both psychological and physiological comfort through combined radiant heat loss and reliable air movement from fans.

A photo of a tropical house shows that it is raised well off the ground on stilts, has numerous windows and a substantial shaded veranda.

Design conditioned rooms with high levels of insulation and lowest exposure to external temperature influences, usually found in the centre of the house. Adjoining living spaces should be well ventilated, free running (passively cooled), with fans to encourage acclimatisation, and provide a thermal buffer to conditioned spaces. Address condensation in externally ventilated rooms surrounding conditioned rooms. Walls with high thermal mass have fewer dew-point problems than lightweight insulated walls and can store ‘coolth’.

When insulated walls surround an air conditioned space, a vapour barrier should be installed between the warm humid air and the insulation material to prevent the insulation being saturated by condensation. Choose materials and finishes that are resistant to damage from condensation for any linings placed over the vapour barrier: placing reflective foil insulation under a plasterboard wall lining, for example, causes the dew-point to form under the plasterboard.

Avoid conditioning rooms that have high level indoor–outdoor traffic. Alternatively, use airlocks to minimise hot air infiltration or install an automatic switching device (such as a reed switch or other micro switch) to the doors leading to the air conditioned room that allows operation only when the door is closed.

***Operation***

- Identify the months and times of day when mechanical cooling will be required and use control systems, sensors and timers to reduce total operating hours. Turn air conditioners off when you go out.
- Set thermostats to the warmest setting that still achieves comfort. Experiment — you may find 26°C quite comfortable when you thought you needed 21°C.
- Adapt your lifestyle where possible to take advantage of comfortable external conditions when they exist, to minimise operating periods for mechanical cooling systems.

## 4. 9. Climate specific design principles

Climate specific design responses and passive cooling methods are different for:

- Hot humid climates (Zone 1) where cooling only is required
- Temperate and warm climates (Zones 2–6) where both heating and cooling are required
- Cool and cold climates (Zones 7–8) where heating needs are predominant.

### 4.9.1 Hot humid climates requiring cooling only (Zone 1)

Hot humid climates require a fundamentally different design approach to those commonly recommended throughout Your Home, which focuses predominantly on climates requiring both summer cooling and winter heating. The most significant difference is in the size and orientation of windows or openable panels and doors. In these climates, modest amounts of well-shaded glazing can and should be positioned on every façade to encourage air movement.

Windows or other openings should be located, sized and designed to optimise air movement, not solar access. As stated earlier, wind doesn't blow through a building — it is sucked towards areas of lower air pressure.

Locate larger openings on the downwind, or leeward, side of the house and smaller openings on the breeze, or windward, side. This is advantageous in these cyclone prone regions since cyclones and cool breezes commonly come from an onshore direction.

Other elevations should also include openings because breezes come from a variety of directions and can be redirected or diverted through good design and appropriate window styles, especially casement windows.

Another critical difference is that the designer needs to make an early decision about whether the home is to be ‘free running’ (i.e. passively cooled), conditioned (mechanically cooled) or hybrid (a combination of both).

Free running buildings should not be conditioned at a future date without substantial alteration: this includes reducing the size of openings, adding bulk insulation around the room(s) to be conditioned and condensation detailing.

***Design responses to the challenges of hot humid climates***

High humidity levels in these climates limit the body’s ability to lose heat by evaporating perspiration.

Sleeping comfort is a significant issue, especially during periods of high humidity where night temperatures often remain above those required for human comfort. While acclimatisation helps, it is often inadequate during the ‘build-up’ and wet season — especially in cities with highly transient populations such as Darwin.

Design responses consider shading, air movement, insulation and construction methods.

**Shading**

- Permanently shade all walls and windows to exclude solar access and rain.
- Consider shading the whole building with a fly roof.
- Shade outdoor areas around the house with plantings and shade structures to lower the ground temperature and thence the temperature of incoming air.

**Air movement**

- Maximise exposure to (and funnelling of) cooling breezes onto the site and through the building, e.g. larger leeward openings, smaller windward openings.

- Use single room depths where possible with large openings that are well shaded to enhance cross-ventilation and heat removal.
- Design unobstructed cross-ventilation paths.
- Provide hot air ventilation at ceiling level for all rooms with shaded openable clerestory windows, 'whirlybirds' or ridge vents.
- Elevate the building to encourage airflow under floors.
- Use higher or raked ceilings to promote convective air movement.
- Design plantings to funnel cooling breezes and filter strong winds.
- Install ceiling fans to create air movement during still periods.
- Consider using whole of house fans with smart switching to draw cooler outside air into the house at night when there is no breeze.
- Choose windows with maximum opening areas (louvres or casement) that can be tightly sealed when closed; avoid fixed glass panels. Openable insulated panels and security screen doors can be used instead of some windows.
- Use lighter colours on roof and external walls.

**Insulation**

Use insulation solutions that minimise heat gain during the day and maximise heat loss at night, i.e. use multiple layers of reflective foil to create a one way heat valve effect and avoid bulk insulation.

**Construction**

- Use low thermal mass construction generally.
- Consider the benefits of high mass construction in innovative, well-designed hybrid solutions.
- Mixed climates requiring heating and cooling (Zones 2−6)
- Well-designed Australian homes do not require air conditioning in most climates.

- More than 50% of homes in warm temperate climates are mechanically cooled. This proportion is rapidly increasing — often because inadequate shading, insulation and ventilation, or poor orientation and room configuration for passive cooling and sun control, cause unnecessary overheating.

### 4.9.2 Warm humid climates (Zone 2)

Energy consumption for heating and cooling can account for up to 25% of total household energy use in this climate. Achieving the high levels of passive thermal comfort required to reduce this by as much as 80% is a relatively simple and inexpensive task.

- Design and orientate to maximise the contribution of cooling breezes.
- Use earth-coupled concrete slab-on-ground.
- Provide high levels of cross-ventilation via unobstructed pathways.
- Use ceiling fans and convective ventilation to supplement them.
- Include a well-located and shaded outdoor living area.
- Use lighter colours for roof and external walls.
- Consider whole of house fans in this climate.
- Apply hybrid cooling principles where cooling is used.
- Passive solar heating is required during winter months and varies from very little to significant. Integrate passive heating requirements with cool breeze capture by providing passive or active shading (eaves or awnings) to all windows.
- Employ well-designed shading and insulation to limit heat gain and maximise summer heat loss in response to the specific microclimate.

**Construction**

- Use high mass construction in areas with significant diurnal (day–night) temperature ranges (usually inland) to provide significant amounts of free heating and cooling.
- Use low mass construction where diurnal temperature ranges are low (usually coastal) to increase the effectiveness of passive and active heating and cooling.
- Elevate structures to increase exposure to breezes in warmer northern regions.
- Eliminate earth coupling in southern and inland regions.
- Use bulk and/or reflective insulation to prevent heat loss and heat gain.
- Use glazing with a low to medium solar heat gain coefficient (SHGC) and U-value.

### 4.9.3 Hot dry climates with warm winter (Zone 3)

Use courtyard designs with evaporative cooling from ponds, water features and ‘active’ (mechanical) evaporative cooling systems. They are ideal for arid climates where low humidity promotes high evaporation rates.

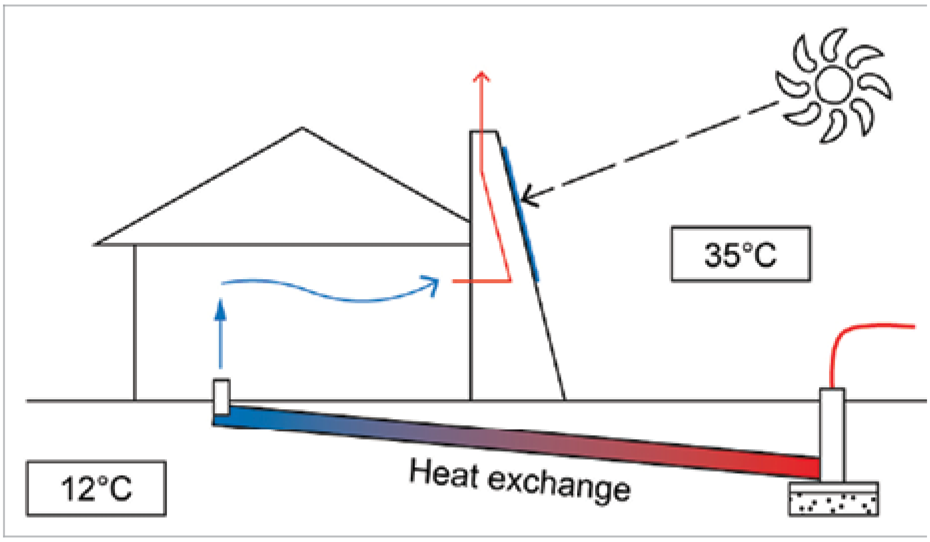
- Use evaporative cooling if mechanical cooling is required.

- Use ceiling fans in all cases.
- Use high mass solutions with passive solar winter heating where winters are cooler and diurnal ranges are significant.
- Use low mass elevated solutions where winters are mild and diurnal ranges are lower.
- Minimise east and west-facing glazing or provide adjustable external shading. High mass living areas are more comfortable during waking hours. Low mass sleeping areas cool quickly at night. High insulation prevents winter heat loss and summer heat gain.
- Consider high mass construction for rooms with passive winter heating and low mass for other rooms.
- Shade all windows in summer and east and west windows year round.
- Use well-sealed windows and doors with maximum opening area to optimise exposure to cooling breezes and exclude hot, dry and dusty winds.

### 4.9.4 Hot arid climates with cool winter (Zone 4)

- Use high thermal mass construction to capitalise on high diurnal temperature ranges by storing both warmth and 'coolth'.
- Use compact forms to minimise surface area.
- Maximise building depth.
- Include closeable stack ventilation in stairwells and thermal separation between floors in two storey homes.
- Use shaded internal courtyards with evaporative cooling features in single storey homes.
- Use smaller window and door openings designed for night-time cooling and cool thermal currents where available.
- Use low U-value double glazing with high SHGC.
- Ensure that the majority of glazing is north facing and passive solar shaded.
- Avoid west windows.
- Evaporative cooling and active solar heating systems reduce the need for large, solar exposed glass areas for heating (i.e. active rather than passive heating).
- Traditional and innovative cooling methods for arid climates

Specialist passive and low energy cooling systems have evolved for hot dry climate areas in other parts of the world. They introduce moisture to building structures (such as roof ponds or water sprayed onto evaporative pads) and incorporate stacks or chimneys that use convection to exhaust rising hot air and draw cooler, low level air into the building. This air can be evaporatively cooled by being drawn over ponds, or through mist sprays or underground labyrinths (these towers are dominant elements and are therefore an integral part of the fundamental architecture of the building).




A diagram shows the cross-section of a home on the ground. Earth exchange and evaporation pre-cool incoming air drawn by a solar chimney, from 35 degrees Celsius to somewhere closer to the 12 degrees Celsius of the ground temperature.

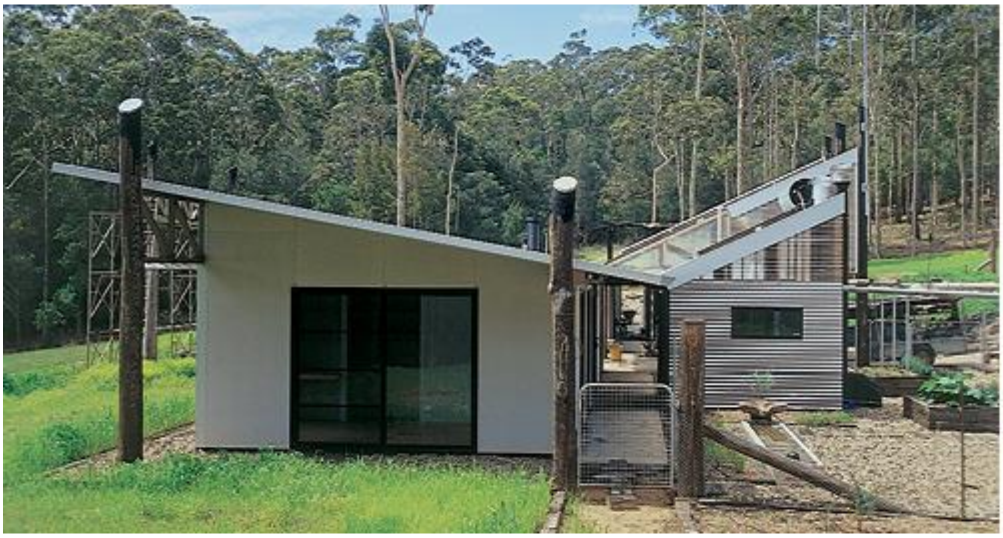
Modern version of an Iranian Badgir cooling system where earth exchange and evaporation pre-cool incoming air drawn by a solar chimney.

**4.9.5 Temperate climates (Zones 5 and 6)**

With good design, temperate climates require minimal heating or cooling. Good orientation, passive shading, insulation and design for cross-ventilation generally provide adequate cooling. Additional solutions from the range explained here can be used where site conditions create higher cooling loads.

- Prefer plans with moderate building depth — two rooms is ideal.
- Design for the impacts of climate change and consider highly efficient heat pump systems to cope with increases in extreme weather events.
- Use thermal mass levels appropriate to the amount of passive cooling available (cool breezes, consistent diurnal variations) and use thermal mass to delay peak cooling needs until after the peak demand period.
- Choose window opening styles and position windows to ensure good cross-ventilation.
- Orientate for passive solar heating and divert breezes.

- Employ larger northern and southern facade.
- Design for moderate openings with the majority to the north.
- Use minimal west-facing glazing (unless well shaded).
- Use moderate east-facing glazing and moderate south-facing glazing except where cross-ventilation paths are improved by larger openings.
- Use bulk and reflective foil insulation.
- Use low to medium U-value and SHGC glazing in milder areas and double glazing where ambient temperatures are higher.



A photo shows a home that is well shaded by eaves. The core of the home is a corridor that is well ventilated by large windows or doors. The orientation of the home takes advantage of winter sun to warm the home through large windows. Temperate climates call for good orientation, passive shading and cross-ventilation.

**4.9.6 Cool and cold climates where heating dominates (Zones 7 and 8)**

Zone 7 requires careful consideration of cooling needs because climate change modelling indicates that it is likely to be impacted by climate change more than most other zones.

This necessitates a shift from the current high thermal mass design practices to moderate or low mass designs with carefully calculated glass to mass ratios to avoid summer overheating. Higher mass solutions remain useful in higher altitude and colder regions where significant diurnal ranges are likely to continue to provide reliable cooling in all but extreme weather events.

- Winter heating remains the predominant need in all but the warmest regions in these zones.
- Passive solar orientation and shading is critical.
- On sites where passive heating or cooling access is limited, consider low mass, high insulation solutions with highly efficient reverse-cycle heat pumps.
- Give increased attention to the design of high level cross-ventilation for night cooling.
- Low U-value double glazing with high SHGC is highly desirable due to its effectiveness in both summer and winter.
- Use a well-designed combination of reflective foil and bulk insulation.
- Use modest areas of glazing with the majority facing north where solar access is available.
- Minimise west-facing glazing.
- Passive and/or active shading of all glazing is essential.

### 4.10. Case Study of Passive Solar Building - PEDA

Designing sustainable buildings in a composite climate is a challenge. The techniques that are effective during summers do not work in winters. But a building in Chandigarh has achieved this. More than 10 years ago, the Punjab Energy Development Agency (PEDA) decided to construct an office building that utilises the movement of the sun for lighting, cooling and heating.

The Rs 5.5 crore building, a pilot, was ready in 2004. Six years later, the Bureau of Energy Efficiency (BEE) awarded it a five-star rating, the highest grade of energy efficiency. With a built-up area of 6,146 sq m, the building incorporates the techniques of passive solar architecture that is based on seasonal and diurnal variations in the sun's movement (see 'Know the building'). Monuments like the Red Fort in Delhi were designed using these techniques. The PEDA office has an energy performance index (EPI) of 14 kWh/m2/year (the lowest in the country) in the category of non-air-conditioned buildings.

EPI is the ratio of the total energy used to the total built-up area. The EPI of commercial buildings is above 180 kWh/m2/year and the benchmark set by BEE for buildings compliant with the Union power ministry's Energy Conservation Building Code (2007) is 140 kWh/m2/year. By following passive solar techniques, the PEDA office has become one of the most energy-efficient buildings without adhering to the code, which came later, says Harsimran

Singh, an architect in Chandigarh. According to the PEDA building's architect, Arvind Krishan, unlike conventional buildings, the office's design is in accordance with the external envelope, which he calls solar envelope.

This envelope refers to the features and materials used in the building's skin that makes it responsive to varying weather conditions. The internal structure has floating slabs which help in air circulation. The building is oriented in the north-south direction, minimising solar exposure on the western and eastern facades. Although a building's southern facade can be shaded, the western façade remains exposed to the setting sun and cannot be shaded, he explains.

A simulation-based study by the University of Nottingham in the UK says the PEDA building functions successfully as a passive solar complex.

The PEDA building, designed for 500 people, is currently occupied by 100 individuals


**1. WALLS**

They are made of two layers of bricks with a 5 cm air gap in between. In southern and western facade, insulation (consisting of 60 cm by 60 cm panels of 5 cm thick rock wool wrapped in polyurethane sheets) has been placed between the layers of bricks in addition to the air gap. This is done to reduce the amount of heat transferred from the outside to the inside through the walls. The combination of a brick wall with air gap reduces heat transfer by 50 per cent as compared to a conventional brick wall. If insulation is added along with the air gap, the heat transfer decreases by 85 per cent.

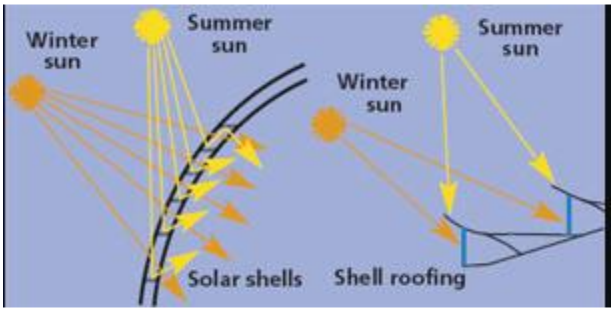
**2. ROOF**

As maximum heat gain is through the roof, a rockwool-and-polyurethane insulation at an air gap of 5 cm from the concrete slab has been placed. Top layer is made of mud phuska and brick tiles for further heat-proofing.

**3. SOLAR SHELLS**

These concrete domed structures on the southwestern façade are one of the well-recognised innovations of this project. The domes have horizontal and vertical intersecting fins with glass fixed in the voids. These voids allow natural light with reduced glare. The shading action of the fins allows indirect sunshine to enter the building in summers and direct sunshine in winters

**4. SHELL ROOFING**




A portion of the roof of the atrium (open space in the centre of the building) is covered by a lightweight shell roofing. The roofing consists of 10 cm of high-density EPS (extruded polystyrene) sandwiched between high-grade FRP (fibre-reinforced plastic) sheets reinforced with steel.

In summer the sun is almost overhead at noon while in winter it is at a lower angle. Keeping this in mind, the shell roof is angled in such a manner that the opening beneath the shell is shaded from the summer sun but allows the winter sun to penetrate.

**5. PHOTOVOLTAIC PANELS**

Shell roof (yellow) and the 25 kWp solar photovoltaic plantThere is an integrated 25 kWp solar photovoltaic plant in the building. More than half of the building's electricity requirement is provided by the panels. The panels are placed on the roof of the atrium, in between two sheets of toughened glass. This helps filter daylight.

**6. WATER FOUNTAIN**

These are operational during hot and dry months (April to June) and help decrease the interior temperature through direct evaporative cooling.

**7. VENTILATION**

The wind tower (7) is expected to function as a non-mechanical air-conditioning system, but the mechanical component for the tower (ambiator) is yet to be installed. It will soon be installed, say PEDA officials. The ambiator uses the method of indirect evaporative cooling in which water cools the air without coming into contact with it. This method works well in humid conditions, says Darshi Dhaliwal, responsible for devising the ambiator. Currently, the tower is used to expel hot air from within the building.

Fresh air rushes in from the openings in the envelope, passes over the floor and escapes through the tower top. Due to the building's expanse and workstation panels (8), this flow is inadequate to maintain thermal comfort. So, coolers have been installed.

**DAYLIGHTING**

Sunlight entering through solar shells, shell roofing, glass-integrated photovoltaic panels and windows made of unplasticised PVC meets the building's lighting requirement, including that of the basement.

## 4.11 Case Study - India's first net zero Building

It's India's first net zero energy building that has been constructed with adoption of solar passive design and energy-efficient building materials. The Indira Paryavaran Bhavan is one of the first buildings in India to have deployed energy efficiency and renewable energy technologies at a large scale. It is one of the exemplary projects to be rated under Green Rating for Integrated Habitat Assessment [GRIHA] and has set standards that can be emulated by upcoming buildings in the region.

The building boasts an earthquake-resistant structure with a total plinth area of 31,488 sq. m. It covers only 30 per cent of the total area, while more than 50 per cent area outside the building is a soft area with plantation and grass. The building has a robotic parking system in the basement that can accommodate 330 cars. Thin-client networking system has been provided instead of conventional desktop computers to minimise energy consumption.

"Buildings have an enormous impact on environment, human health and economy. The energy used to heat and power our buildings leads to consumption of large amounts of energy, mainly from burning of fossil fuels, oil, natural gases and coal, which generate significant amounts of carbon dioxide, the most widespread greenhouse gas. The successful adoption of green building strategies can maximise both the economic and environmental performances of buildings.

The building has received GRIHA 5-star (provisional) rating for the following features:

- The design allows for 75 per cent of natural daylight to be utilised to reduce energy consumption.
- The entire building has an access friendly design for differently-abled persons.
- With an installed capacity of 930 kW peak power, the building has the largest rooftop solar system among multi-storied buildings in India.
- The building is fully compliant with requirements of the Energy Conservation Building Code of India (ECBC).
- Total energy savings of about 40 per cent have been achieved through the adoption of energy efficient chilled beam system of air-conditioning. As per this, air-conditioning is done by convection currents rather than airflow through air handling units, and chilled water is circulated right up to the diffuser points unlike the conventional systems.
- Green materials like fly ash bricks, regional building materials, materials with high recyclable content, high reflectance terrace tiles and rock wool insulation of outer walls have been used.

- Use of renewable bamboo jute composite material for doorframes and shutters.
- UPVC windows with hermetically sealed double glass. Calcium Silicate ceiling tiles with high recyclable content and grass paver blocks on pavements and roads.
- Reduction in water consumption has been achieved by use of low-discharge water fixtures, recycling of waste water through sewage treatment plant, use of plants with low water demand in landscaping, use of geothermal cooling for HVAC system, rainwater harvesting and use of curing compounds during construction.

## 4.12 List of Passive solar buildings in India – Zonal approach

**Cold and sunny**

- Degree College and Hill Council Complex, Leh
- Airport and staff housing colony, Kargil
- LEDeG Trainees' Hostel, Leh
- Sarai for Tabo Gompa, Spiti
- The Druk White Lotus School, Shey, Ladakh

**Cold And Cloudy**

- Residence of Mohini Mullick, Bhowali, Nainital
- Himachal Pradesh State Co-operative Bank, Shimla
- MLA Hostel, Shimla
- Himurja Office Building, Shimla

**Composite**

- Bidani House, Faridabad
- Centre for Science and Environment (CSE), New Delhi
- Transport Corporation of India Ltd, Gurgaon
- SOS Tibetan Children's Village, Rajpur, Dehradun
- Redevelopment of property at Civil Lines, Delhi
- Integrated Rural Energy Programme Training Centre, Delhi
- Tapasya Block (Phase 1), Sri Aurobindo Ashram, New Delhi
- Water and Land Management Institute, Bhopal
- Baptist Church, Chandigarh

- Solar Energy Centre, Gwal Pahari, Gurgaon
- National Media Centre Co-operative Housing Scheme, Gurgaon
- ITC Centre, Gurgaon
- CII - Sohrabji Godrej Green Business Centre, Hyderabad
- Monama House, Hyderabad
- Green Leaf Hotel, Jasola

**Hot and dry**

- Indian Institute of Health Management Research, Jaipur
- Sangath – an architect's studio, Ahmedabad
- Torrent Research Centre, Ahmedabad
- Residence for Mahendra Patel, Ahmedabad
- Solar passive hostel, Jodhpur
- College of engineering, Phaltan

**Moderate**

- Residence for Mary Mathew, Bangalore
- TERI office building-cum-guest house, Bangalore

**Warm and humid**

- Nisha's play School, Goa
- Office building of the West Bengal Renewable Energy Development Agency, Kolkata
- Office-cum-laboratory for the West Bengal Pollution Control Board, Kolkata
- Silent Valley, Kalasa
- Vikas Apartments, Auroville
- La Cuisine Solaire, Auroville
- Kindergarten School, Auroville
- Visitors’ Centre, Auroville
- Computer Maintenance Corporation House, Mumbai
- Dormitory Buil ding, Karjat

# 5. GREEN COMPOSITES FOR BUILDINGS

*Concepts of Green Composites. Water Utilisation in Buildings, Low Energy Approaches to Water Management. Management of Solid Wastes. Management of Sullage Water and Sewage. Urban Environment and Green Buildings. Green Cover and Built Environment*

## 5.1 Composites

Composites are biphase or multiphase materials which are made by combining two or more materials differing in composition or form. Due to their low weight and ability to be tailored for specific end use they have gained a considerable ground in high-performance applications. Biopolymers or synthetic polymers reinforced with natural fibres (Sisal, Jute, Silk, Coir, Bamboo, Arecanut and Pundi) frequently termed as "*bio-composites*" can be viable alternatives to glass fibre reinforced composites. "*Green Composite*" is a completely bio-based composite; both matrix and fibre are completely biodegradable and renewable. The components of a composite material are depicted in Figure

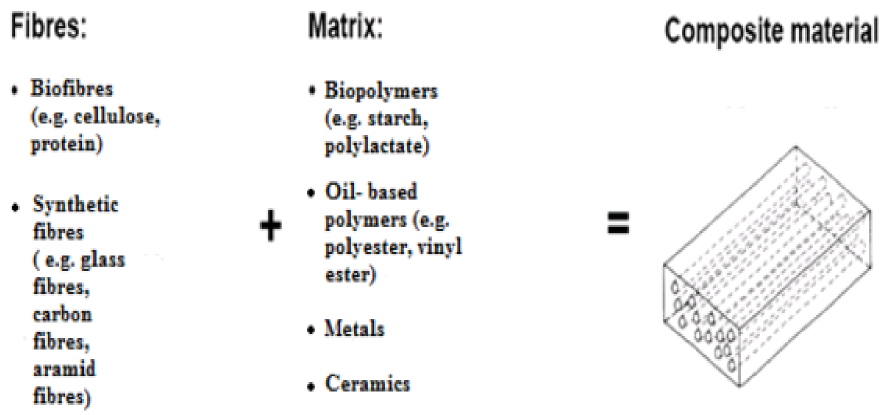



Figure 1: Components of a composite

The resins and fibres used in the green composites are biodegradable, when they dumped, decomposed by the action of microorganisms. They are converted into the form of H2O and CO2. These H2O and CO2 are absorbed into the plant systems. *The two main components of the green composites include:*

1. Biodegradable resin

2. Natural fibres

## 5.2 Green Composites

Green composites are completely bio-based composites in which both matrix and fibre are completely biodegradable and renewable. Natural, vegetable fibres can be applied to reinforce the natural polymers such as starch, lignin, hemicellulose and India-rubber which results in 100% biodegradable material. Essentials for green composites are high strength natural fibres, resins with good bio-degradability and optimum fibre/resin interfacial bonding.

Composite properties depend on the properties of the constituents, i.e. the fibres and resins used. The strength and stiffness of the composites are directly a function of the reinforcing fibre properties which carry most of the load, and their volume content. The resin helps to maintain the relative position of the fibres within the composite and, more importantly, transfers the load from broken fibres to the intact fibres. As a result, fibre/resin interfacial properties are also important and have a significant effect on composite properties, including toughness and transverse fracture stress. In summary, to fabricate high strength composites all three factors, namely, fibre properties, resin properties as well as the fibre/resin interface characteristics are critical.

### 5.2.1 Reinforcing Fibres

In biocomposites, the bio-fibres serve as a reinforcement by enhancing the strength and stiffness of the resulting composite structures. Sources, origin, nature, as well as the physical and chemical composition of different natural fibres, have been reviewed. The conventional fibres like glass, carbon, aramid, etc., can be produced with a definite range of properties, whereas the characteristic properties of natural fibres vary considerably. This depends on whether the fibres are taken from plant stem or leaves, the quality of the plants' locations, the age of the plant and the preconditioning. Depending on their origin, the natural fibres may be grouped into leaf, bast, seed, and fruit origin.The best-known examples are:

- Leaf: Sisal, pineapple leaf fibre (PALF), and henequen;

- Bast, Flax, ramie, kenaf/mesta, hemp and jute;
- Seed: Cotton;
- Fruit: Coconut husk, i.e., coir.

The natural fibres are lignocellulosic in nature. Lignocellulosic materials are the most abundant renewable biomaterial of photosynthesis on earth. In terms of mass units, the net primary production per year is estimated to be $2X10^{11}$ tons as compared to synthetic polymers by $1.5X10^{8}$ tons.

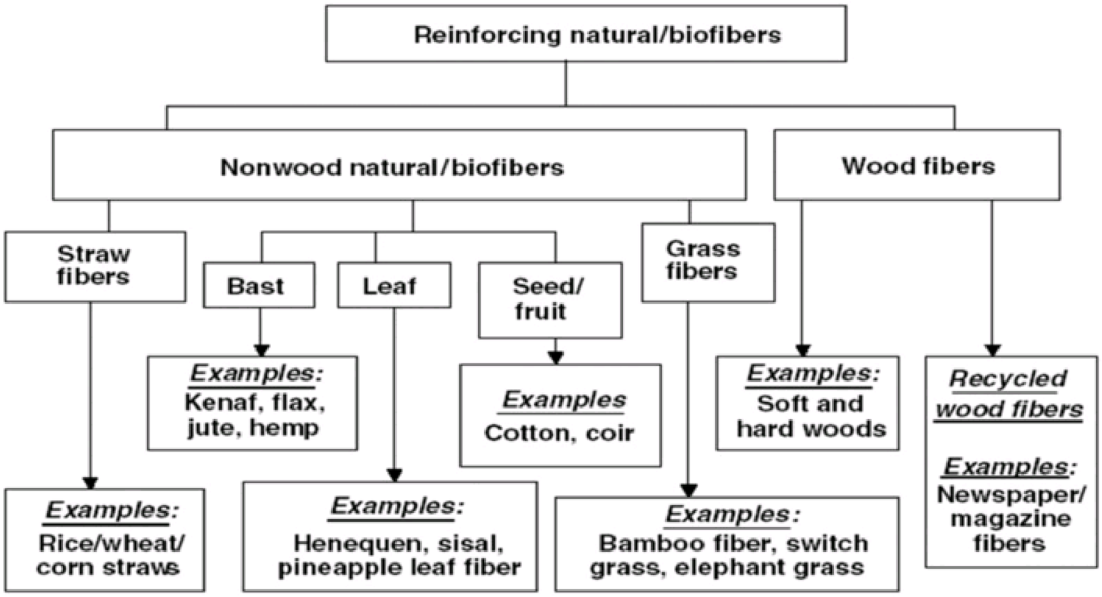



*Figure 2 Schematic representation of reinforcing natural/bio fibres classification.*

Lignocellulosic materials are widely distributed in the biosphere in the form of trees (wood), plants and crops. Cellulose, in its various forms, constitutes approximately half of all polymer utilized in the industry worldwide. The below figure gives the classification of natural fibres which are used as reinforcing materials in composites. The properties of some of the natural fibres are listed in **Table** . Photographs of some natural fibres are shown below.

| Type of Fiber | Density (g/cm³) | Tensile Strength (MPa) | Elongation at Break (%) |
|---|---|---|---|
| Jute | 1.3-1.45 | 393-773 | 1.16-1.5 |
| Sisal | 1.45 | 468-640 | 3-7 |
| Coir | 1.15 | 131-175 | 15-40 |
| Silk | 1.33 | — | 17-25 |
| Kenaf | — | 930 | 1.6-2 |
| Cotton | 1.5-1.6 | 287-800 | 7-8 |
| Flax | 1.5 | 345-1100 | 2.7-3.2 |
| E glass | 2.5 | 2000-3500 | 2.5 |
| Carbon | 1.7 | 4000 | 1.4-1.8 |
| Aramid | 1.4 | 3000-3150 | 3.3-3.7 |

**Natural / Bio-fibers may be classified in two broad categories:**
Non-wood fibres

Wood fibres

In automotive applications, non-wood fibres such as hemp, kenaf, flax and sisal have attained commercial success in the design of **bio-composites.**

## 5.3 Methods of Manufacturing Composites

- Filament winding
- Lay up methods
- Resin transfer moulding
- Injection moulding
- Vacuum bonding
- Autoclave bonding.

**Filament Winding**

Filament winding is a process is which continuous fibre (either pre-pregnated with resin, or coated during winding) are pulled from a large spool and wound on to a rotating mandrel after sufficient layers have been built up the wound form is curved and the mandrel removed. The parts most commonly made by this method are cylindrical pipes, drive shafts, portables air raft water tanks, spherical pressure tanks and yacht masts.

**Lay-up Methods :**

Layers of prepreg fabrics are built upon a mould, in unidirectional or multi axial form. They are then subjected to' a consolidating force and cure them. The process can be done either by hand, or by automated lay-up which decreases the manufacture time significantly. Complicated shapes can be credited in this way.

**Resin Transfer Bonding :**

In this method, dry reinforcement fibre is held in a closed mould, and then resin is pumped through the mould at high pressure. This is a more time consuming process, as it involves labour intensive preparation and lay-up but it has many advantages, as the mould is closed, harmful emissions are reduced and a void-free laminate and complex parts can be created in this method.

**Vacuum Bonding**

In vacuum bonding, the composite (usually large sandwich structures) is first placed over a mould then a vacuum bay is placed over the top, the air is removed from the vacuum, which forces the bag down onto the lay-up with a pressure of 1 bar. The whole assembly is then placed inside an oven to cure the resin, and the material is produced in a relatively short time. This method is used in conjunction with either filament winding or lay-up techniques.

**Autoclave Bonding :**

An autoclave is a pressure vessel, which controls exact pressure temperature and vacuum conditions. The technique is very similar to that of vacuum bonding except that the over is replaced by an autoclave. This means that wring condition can be controlled accurately to give high quality composites for a specific purpose. The process takes much longer than others, and is relatively expensive.

### 5.3.1 Methods of Manufacturing Green Composite Boards

In general there are various methods existing by which the green composite particleboard can be produced. This chapter mainly includes various methods of manufacturing particleboards with examples of several natural composite boards.

**Three-layer particle board**

This type of manufacturing is mainly known for producing three-layer particleboard. More recently, graded density particleboard has also evolved. It contains particles that gradually become smaller as they get closer to the surface such manufacturing can also be produced by this process.

**Manufacturing Process of three Layer Particle Board :**

Particleboard is manufactured by mixing wood particles or flakes together with a resin and forming the mix into a sheet. The raw material to be used for the particles is fed into a disc chipper between four and sixteen radially arranged blades. The particles are first dried, after which any oversized or undersized particles are screened out. Resin, in liquid form, is then sprayed through nozzles onto the particles.

There are several types of resins that are commonly used. Urea formaldehyde resin is the cheapest and easiest to use. It is used for non-water resistant boards. Melamine formaldehyde resin is significantly more expensive. Phenol formaldehyde is also fairly expensive. It is dark coloured and highly durable. These resins are sometimes mixed with other additives before being applied to the particles, in order to make the final product **waterproof**, fireproof, insect proof, etc. Once the resin has been mixed with the particles, the liquid mixture is made into a sheet.

A weighing device notes the weight of flakes, and they are distributed into position by rotating rakes. In graded density particleboard, the flakes are spread by an air-jet which throws finer particles than coarse ones. Two such jets, allow the particles to build up from fine to coarse and back to fine. The sheets formed are then cold-compressed to reduce their thickness and make them easier to transport. Later, they are compressed again, under pressures between two or three mega pascals and temperatures between 140°C and 220°C. This process sets and hardens the glue. All aspects of these process must be carefully controlled to ensure the correct size, density and consistency of the board. The boards are then cooled, trimmed and sanded.

**Method of Bamboo Composite Board**

This method is adopted for manufacturing of a particleboard with the bamboo fibre. This technique is the most suitable for processing such hard fibres. The steam-exploded fibre is agitated using home-use mixer and flocculent fibre along with PLA resin (dispersion type) is mixed and dried at a temperature of 70 C for about 15 hours. And finally hydraulic pressing is done at a temperature of 180 C for 10 minutes.

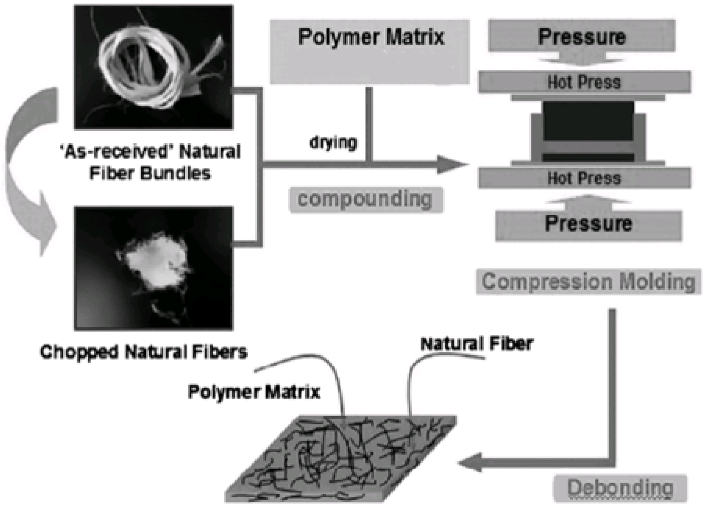


Figure-5: Processing of green composites

The similar process is followed with various fibres such as banana fibre and bagasse and so on. But depending upon the fibre used, the time of drying and pressing will vary.

**Soy source for Green Composites :**

Researchers in the US have developed an environmentally friendly, biodegradable material from soy flour resin and flax yarn. It is made from plant fibres and resins -- renewable sources -- making the composite material a greener alternative to petroleum-derived materials. This composite has good physical and mechanical properties compared to similar materials made from renewable resources - the yarn reinforces the resin, which is also cross-linked to improve its strength. The resin-yarn material is strong and durable enough for low-load indoor applications. Resin and yarn are expected to degrade easily at the end of the composite material's life.

Minimizing waste by composting is a considerable benefit of this material over traditional plastics, whose very strength and stability make them difficult to degrade and adds large volumes of waste to landfill sites. Flax yarn's low density makes it an attractive fiber-reinforcement material for applications where weight is a consideration. However, natural fibres might limit these materials' widespread use.

Reliable and predictable mechanical performance is also critical to structural applications and the quality of the raw materials needs to be consistent. Natural fibres are not uniform and those from a single species of plant change with the climate and growing season. Processing raw materials with consistent dimensions and properties is probably the main challenge.

### 5.3.2 Advantages of Green Composites over Traditional Composites

1. Less expensive.
2. Reduced weight.
3. Increased flexibility.
4. Renewable resource.
5. Sound insulation.
6. Thermal recycling is possible where glass poses problems.
7. Friendly processing and no skin irritation.

### 5.3.4 Disadvantages of Green Composites

1. Lower strength properties (especially impact strength).
2. Good moisture absorption causing swelling of fibres.
3. Lower durability.
4. Poor fire resistance and irregular fibre lengths are the disadvantages. However, recent fibre treatments have improved these properties.

### 5.3.5 Application and End Uses of Green Composites

Green composites are applied to various components with moderate and high strength such as cars, mobile phones, etc. Various problems associated with green composites include effects of moisture and humidity, strength reliability, enhancement in fire resistance, etc. Moreover, there are some concerns over natural fibre quality and consistency, fogging and odour emission and processing temperature limits (200 C).

**Some of the other areas in which the Green Composites are used:**

- False ceilings
- Partition purposes
- Doors
- Furniture
- Boxes for agriculture purposes

**Other Miscellaneous Applications:**

- Rims
- Mobile panels
- Toys
- Aircraft

- Ships and so on .

**Automobiles**

The **automotive** market is becoming increasingly competitive; The latest European legislation limits the emission of $CO_2$ and requires car designers to take into account pedestrian safety in case of impact. These influences are forcing the automotive industry to change the habits and to “Think composites” more and more, although composites will only be employed more extensively if those materials and technologies are competitive.

Composites made from natural fibres are attractive because of ecological concerns and also because they allow a decrease of the weight of parts and have good mechanical properties. Green composites are used in door panels, headliners, package trays, dashboards and trunk liners, based on natural fibre composites with thermoplastic or thermo set matrix, challenging the glass fibre reinforced composites.

With natural fibre composites, car weight reduction up to 35% is possible. This can be translated into lower fuel consumption and the lower environmental impact. Natural fibre based composites also offer good mechanical performance, good formability, high sound absorption and cost savings due to low material costs. Moreover their “Green look” as well as ecological and logistical benefits of the natural fibre based technologies looks more attractive.

In 2000, more than 23,000 tonnes of natural fibres have been used in the automotive sector alone. Natural fibres in automotive should experience a sustainable growth as EU regulations regarding recycling and “End of life vehicle” directives set car recycling targets to 95% by 2015.

**Aircrafts and Ships**

The green composites are used in aircrafts and ships as because the weight is less and also it is eco-friendly which is also biodegradable. It is known that the fuel consumption will come down certainly if the weight of the vehicle is decreased. Also these types of green composites are also used in trains for the above reason.

**Mobile Phones:**

Green composites are used for mobile phone’s body. For example kenaf and PLA composites are applied to mobile phone parts in Japan to reduce the amount of $CO_2$ emissions during fabrications. NTT Docomo is one of the models of mobile phones in Japan in which green composites are used for such purposes.

**DecorativePurposes:**

Green Composites are used for indoor structural applications in housing. The composite used for the interior decorations is banana fibre and its composites. The board used for flooring can be seen in the image. Also the walls can be covered with the boards, which will be attractive and will decrease the cost of construction.

## 5.4 Water efficiency in Buildings

According to the EPA, "water efficiency is the smart use of our water resources through water-saving technologies and simple steps we can all take around the house. Using water efficiently will help ensure reliable water supplies today and for future generations."

As residential, commercial, industrial, and other development expands, so does the use of the limited potable water supply, water that is suitable for drinking. Most buildings rely on municipal sources of potable water to meet their needs, from flushing toilets to washing dishes and landscape irrigation. High demand strains supplies and under extreme conditions necessitates water rationing.

Furthermore, large amounts of wastewater can overwhelm treatment facilities, and the untreated overflow can contaminate rivers, lakes, and the water table with bacteria, nitrogen, toxic metals, and other pollutants. To avoid this damage to the ecosystem, additional municipal supply and treatment facilities must be built, at public cost. Water pumping and treatment, both to and away from the project, also require energy, whose production generates additional greenhouse gas emissions.

Green building encourages innovative water-saving strategies that help projects use water wisely. Project teams can follow an integrated process to begin assessing existing water resources, opportunities for reducing water demand, and alternative water supplies. Effective strategies include:

- Install efficient plumbing fixtures.
- Use non-potable water.
- Install submeters.
- Choose locally adapted plants.
- Select efficient irrigation technologies.

## 5.5 Management of Sullage Water and Sewage

Water is used for various domestic purpose like washing, drinking, flushing, cooking, bathing watering lawns etc. all this water of use is termed as wastewater which is a mixture of all water discharges within the household including bathroom sinks, bathtubs, toilets, kitchen sinks, and laundry wash-water sources. This wastewater is characteristically divided into three sub-categories related to the organic strength or level of contaminants typically contained in the water: blackwater; dark-grey water, and light-grey water.

Blackwater comes from toilets and contains high concentrations of disease causing microorganisms and high levels of organic contaminants.

Dark-grey water primarily originates from kitchen sinks, which can also contain disease-causing microorganisms and have high levels of organics contaminants from food waste and grease/oils.

Light-grey water typically consists of drainage from bathroom sinks, tubs, showers, and often laundry. It can also contain disease causing microorganisms but they are usually in much lower numbers than the other two wastewater categories. Although light-grey water is generally also considered to have lower concentrations of organic contaminants than the other two wastewater subcategories, the level of organic contaminants can be comparable to the other two depending on the circumstances.

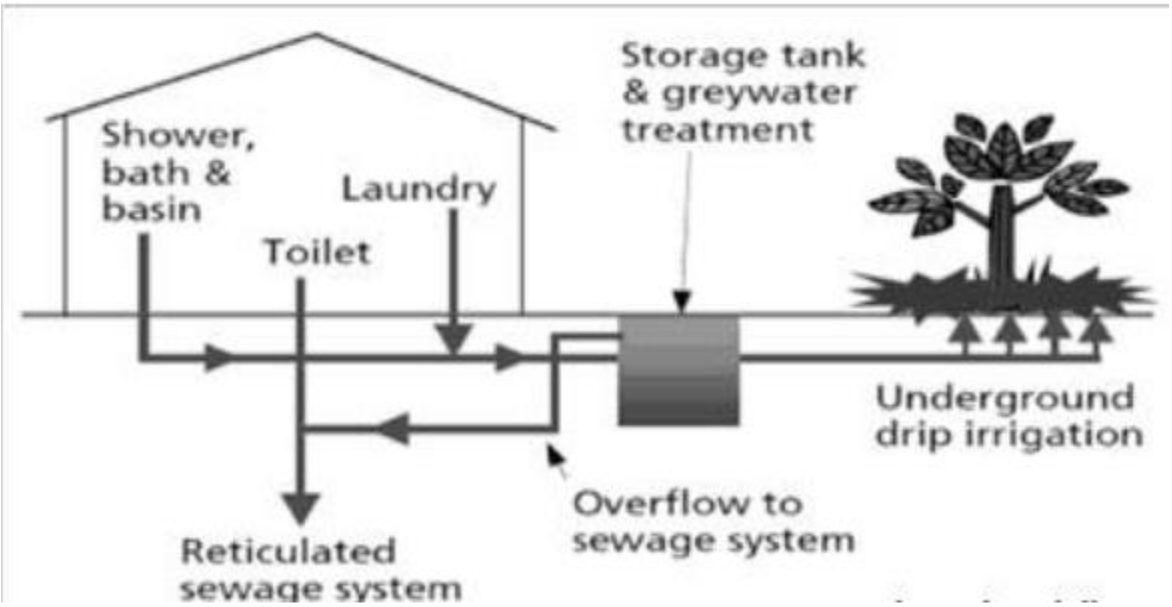
### 5.5.1 Grey water Reuse

There are various methods that can be used for Grey water treatment right from simple low-cost devices that route grey water directly to applications such as toilets and garden irrigation, to highly complex and costly advanced biological treatment processes incorporating sedimentation tanks, bioreactors, filters, pumps and disinfection systems. There are a number of grey water systems commercially available, and may include one or more components including: primary solids separation, oil and grease removal, filtration, aerobic biological treatment, coagulation and flocculation, and disinfection.

Some of these systems are able to remove pollutants and bacteria from grey water and the better systems include settling tanks, biological reactors and sand filters, enabling the treated grey water to be stored until needed without adverse conditions occurring (like foul odours, corrosion, etc.) but the method which should be followed must be most effective and economic or in other words optimum in nature. Grey water reuse system can be broadly classified into two:-

***Primary grey water systems***

These systems directly reuse virtually untreated domestic grey water from a single family dwelling for sub-surface lawn and/or garden watering with minimal treatment as shown in the Figure 2.These systems do not allow storage or treatment, apart from some surge storage and coarse screening/filtration which removes hair, lint and coarse particles. Grey water diversion systems which falls under this category, can be either designed-in to new homes, or retrofitted to many existing homes. Such systems use a diversion device is probably the simplest and most common method of grey water reuse. Various Diversion Technologies are available in the market under trade names such as Clivus Multrum, Envirosink®, Grey water Saver, Aquatron Separator, Nature Clear "Nature Loo", Biolytix "Grey Water Recycler" AquaClarus "Simply Natural" etc.




***Pros***

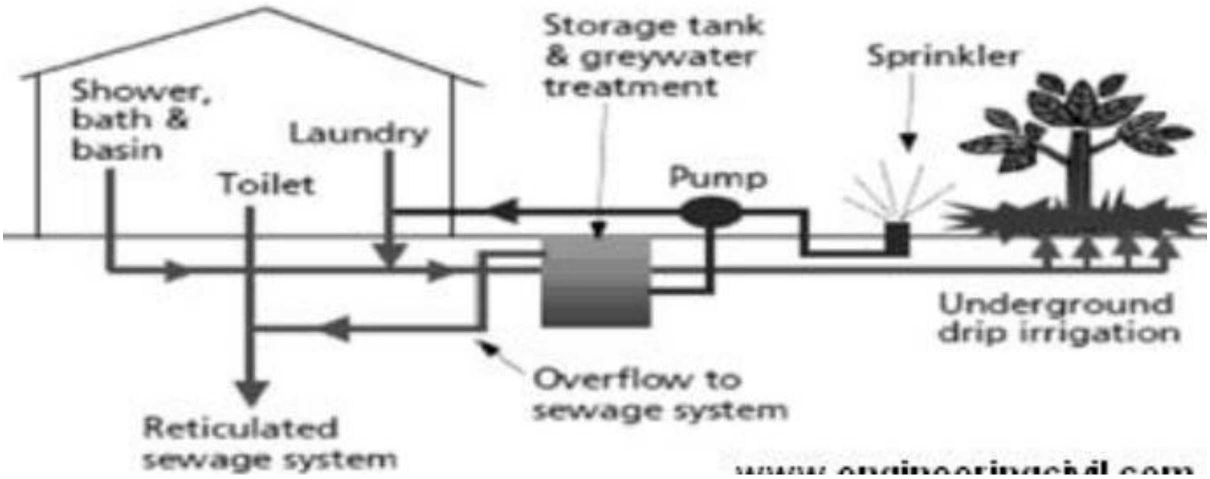
Simple manual (hand adjust or preset) operation ,Very low maintenance requirements (period manual screen cleaning) ,Ability to divert grey water for immediate reuse as required or desired, Very low capital and operating cost.

***Cons***

No or limited (screening) treatment provided, Cannot be stored without risk of odour and other problems Does not kill or reduce the number of disease-causing microorganisms (pathogens) that may be present, Reuse application typically limited to immediate sub-surface irrigation only.

***Secondary grey water systems***

In these systems grey water has to be treated and stored for toilet/urinal flushing and/or lawn and garden watering including surface watering methods as depicted in Figure 3. Grey water from all sources after comprehensive treatment (eg. screening, sedimentation, biological treatment, sand and/or carbon filtration, membrane techniques and disinfection) aims to achieve high quality of the treated grey water. Secondary grey water systems may be used for multiple occupancy buildings.




***Pros***

Potential for high degree of biological treatment,High degree of operations flexibility to accommodate varying grey water strength,Suitable for treating mixed wastewater for reuse applications if effluent is filtered and disinfected – which also allows the reuse water to be stored

**Cons**

• Complex operational requirements, High operating cost , High capital cost

• Can be subject to process upsets due to high grey water flows or chemicals present, resulting in poor effluent quality or discharge of large quanities of solids (sludge) that may block downstream irrigation pipe or create problems for reuse applications (e.g.sludge or sediment buildup in toilet tanks, reduced disnifection effectiveness etc.)

### 5.5.2 Advantages And Disadvantages Of Grey Water Use

*Advantages*

1. The obvious key advantage of domestic grey water use is that it replaces or conserves potable water use, and can reduce the cost of potable water supply.

2. Appropriately applied, grey water may contain nutrients (e.g. phosphorus and nitrogen from detergents), benefiting plant growth and resulting in more vigorous vegetation.

3. Offers potential cost reductions for regional sewage treatment facilities. Removing grey water from residential wastewater drainage to sewer decreases the flow through the sewer and to the treatment plant and enables the existing infrastructure to service more connections.

4. Grey water reuse applications require limited or no treatment, and where the grey water otherwise would have to be pumped to a centralized treatment plant and treated.

5. Grey water could supply most, if not all, of the irrigation needs of a domestic dwelling landscaped with vegetation in a semiarid region.

6. In addition to applications for outside irrigation, grey water can also be used for toilet flushing and, if treated to an advanced secondary or tertiary level, can also be used for awide range of domestic water uses including bathing, showering, and laundry.

*Disadvantages*

1. Grey water may contain sodium and chloride, or other chemicals that can be harmful to some sensitive plant species. Additionally, grey water is alkaline (high pH) and shouldn't be used to irrigate acid-loving plants such as rhododendrons or azaleas.

2. Resulting diminished sewer flows from domestic grey water could potentially result in insufficient sewer flows in some circumstances to carry waste to the sewer plant (e.g. pipes with low slopes), or may result in a high strength sewage that combined with lower flow may lead to odour and corrosion problems in the centralized sewerage systems.

3. Concern regarding the public health implications of grey water reuse and the need for research to determine the risks of grey water reuse.

4. Cost of treatment and diversion/transfer pipe & pumps.

### 5.5.3 Components Of Grey Water Reuse Systems

The system should be as simple and easy to use and maintain as possible. The system Also,should minimize risks tohuman health, either by providing for adequate treatment of the grey water, or by with humans. The system also should minimize the risks to plants, which may arise from some of the contaminants in the grey water such as from chemicals contained in soaps or detergents (e.g. boron, bleach, and sodium), which could adversely affect plant health. The primary components for grey water reuse system intended to generate reuse water for surface irrigation or indoor useage with potential for human contact include:

1. Filters to remove hair, lint and coarse solids particles

2. Sedimentation tanks to separate and remove grease, oils & settleable solids from the grey water;

3. Aerobic biological treatment to remove soluble organic contaminants

4. Final clarification or filtration to remove solid particles and bacteria generated during biological treatment

5. Disinfection to remove pathogenic micro-organisms

6. Reuse water storage tank.

## 5.6 Green Buildings for urban environment

Altering the surface cover of an area causes the change in the environment. By erecting buildings change in the flow of energy and matter through the urban ecosystems occurs creating multiple environmental problems. Built areas exert considerable influence over their local climate, amplifying problems such as heat waves, air pollution, and flooding. Greening the building envelope these problems can be partially mitigated. By combining nature and built areas in their designs, architects and urban planners can respond to these serious human health and welfare issues and restore the environmental quality of dense urban areas. Green living systems are not the only solution for new designs. Retrofitting existing buildings by altering the buildings' surficial properties can reduce buildings' energy consumption in case of older buildings with poor existing insulation. Implementation of green living systems in the building envelope, greening horizontal surfaces with intensive and extensive green roofs or using vegetation in vertical greening systems for facade, is a strategy that provides ecological, economic and social benefits.

Urban areas detrimentally invade natural landscapes impacting the entire planet, more than 50% of the human population is nowadays residing in cities and it is predicted to rise up to 70% in 2030. Also by the year 2030 average global air temperature rise of 2°C is predicted. The continuous temperature increase in the cities, affected by the undeniable climatic change, is escalating the energy problem of cities and amplifying 2 the pollution problems. The thermal stress is increased, thus both the indoor and the outdoor thermal comfort levels are decreased and health problems are enhanced. The optimization of buildings performance and enhancement in the green infrastructure are the key issues to reduce global energy demand and provide cleaner air and water, while improving living environments. Greening the building envelope is innovating technology in architecture that can regain losses of natural environment produced by erecting buildings. Adapting the existing building envelope into a green living system is an efficient and sustainable solution for improving the environmental balance of cities and limiting the major negative effects of urbanization providing better comfort at building and urban level.

### 5.6.1 Green walls

Green wall technologies may refer to all forms of vegetated wall surfaces. Two major categories can be identified: Green Facade and Living Walls.

***Green Facade***

Green facade are a type of green wall system in which climbing plants or cascading groundcovers are trained to cover specially designed supporting structures (Figure 1.), rooted at the base of these structures in the ground or in intermediate planters. Technological innovations in Europe and North America have resulted in the development of trellises, rigid panels and cable systems to support vines and aggressive plants that can damage unsuitable walls, while keeping them away from walls and other building surfaces. The plants typically take 3–5 years before achieving full coverage.

**Figure 1. The Green Façade Singapore Changi Airport Terminal 3, Singapore, Singapore**

**Figure 2. The Living Wall Europa Congress Palace Convention Center, Vitoria-Gasteiz, Spain**

***Living Walls***

Living wall systems are composed of prevegetated panels, vertical modules or planted blankets that are fixed vertically to a structural wall or frame (Figure 2.). These panels can be made of plastic, expanded polystyrene, synthetic fabric, clay, metal, and concrete, and support a great diversity and density of plant species Due to the diversity and density of plant life, living walls typically require more intensive maintenance, due to fertilization and irrigation, than green façade.

### 5.6.2 Green living roofs

The model of the green roof consists of three main components:

- Structural Support
- Soil Layer
- Foliage Layer.

The structural support includes all the layers between the inner plaster and the drainage layer or filter layer. In most cases the structural layer is treated as a single layer with constant thermal properties and the specific value of thermal conductance.

The soil layer is complex consisting of the solid phase (organic and mineral material), the liquid phase (water) and the gaseous phase (water vapor and air). The foliage layer (canopy) is composed of the leafs and the air within the leafs.

Green roof construction mimics in a few centimeters what normal soil does in a couple of meters. The green roof accomplishes the natural balance through several layers, beside the three main layers, depending on its complexity.

The drainage layer provides water for upper layers in relatively small space and with light weight. Excess water overflows and easily passes underneath it away and down the roof drain. The growing medium, filter and protection layer act to support plants and protect lower levels. The foliage layer depends on the plant selection.

There are two main classifications of green roofs: Extensive Green Roofs (EGR) and Intensive Green Roofs (IGR).

***Extensive Green Roofs (EGR)***

Extensive Green Roofs are lightweight structures with a thinner substrate and feature succulent plants like sedums that can survive in harsh conditions (Figure 3.). Extensive roofs are used mainly for environmental benefit, require little maintenance once they are established and are generally cost effective, particularly in commercial and public buildings with long life spans.

Figure 3. EGR, Headquarter Honda, Clermont, FL, USA

Figure 4. IGR, Delft University of Technology Library, Delft, The Netherlands

***Intensive Green Roofs (IGR)***

Intensive Green Roofs allow a greater variety and size of plants such as shrubs and small trees but have higher initial costs. Having a thicker soil layer should be considered as a landscape with plants found in parks and gardens and may require irrigation during dry periods. Because of their thicker soil, intensive roofs require greater structural support than extensive ones. Characteristics of Green roof system is as shown below.

| | Extensive | Simple-Intensive | Intensive |
|---|---|---|---|
| **Soil depth [cm]** | 4 to 20, 10 to 15 typical | 10 to 50 | 10 to 200 + |
| **Plant heights [cm]** | 5 to 30 | 30 to 60 | 30 to 90 + |
| **Roof slopes** | Slopes up to 30 degrees | Only used on low slopes or terraced roofs | Only used on low slopes or terraced roofs |
| **Irrigation** | No | Periodic | Regular |
| **General weights [$kgm^{-2}$]** | 60 to 145 | 120 to 195 | 170 to 500 + |
| **Use** | Ecological protection layer; Usually non-accessible | Designed Green Roof | Park-like Garden; Designed for access (typically) |

## 5.7 Environmental benefits provided by the Green Living Systems

Besides adding aesthetic values to the environment, the functional benefits provided by the Green Living Systems address a number of environmental, economic and social issues arising from increased urbanization. Numerous research studies show that they increase thermal efficiency, provide reduction in stormwater runoff and improve stormwater quality, reduce interior noise levels, help reduce dust and air pollution levels.

Depending on the types of plants and soils, a green roof can provide natural habitat for animals, insects and plants and can help increase the biodiversity of an urban area.

### 5.7.1. Energy savings obtained from Green Living Systems

Possibility to cool the ambient air is important phenomena of the green roof. This thermal benefit is result of the direct shading of roof surfaces and reducing solar heat gain through transpiration and photosynthesis by a foliage layer (canopy), which is composed of the leafs and the air within the leafs. The direct cooling effect is proportional to the green area. Larger the greening area, the better is the effect on cooling and humidification. Measurements of the surface temperature in green roofs reported in, show that in places dominated by thick dark green vegetation surface temperatures are almost 10°C lower.

The indirect cooling effect brought by the green roof is accomplished by using the sun's energy to turn water stored in plants, through transpiration, and soils, through evaporation, into water vapor rather than heat. Releasing a large amount of water vapor into the air increases the humidity level near the green roof. The added thermal mass also helps to stabilize the internal temperatures and reduce the daily oscillations.

In the case of redesigned flat roof the calculated value of heat transfer coefficient U was improved for approximately 0.01%, which is a very low value, but in the same time the calculated value of oscillation damping factor ν was improved for about 300%. Green roofs have been proposed for energy saving purposes in many countries with different climatic conditions, but their cooling and heating potential strongly depends on the climate, plant selection and building characteristics.

In temperate North America, a cost-benefit analysis of an extensive green roof on a retail store found small, but significant, reductions in energy consumption. Green roofs can decrease the surface temperature of the roof 30–60°C according to an experimental study conducted in Japan and over 60% of heat gain for a building could be stopped.

In subtropical southern China, less than 2% of the heat gained by an EGR during a 24h period in summer was retained by the plants and substrate or transferred to the building below. The rest was lost through evapotranspiration, reradiated to the atmosphere, or used in photosynthesis.

For a subtropical Mediterranean climate, office building in Athens, well insulated buildings offer very little energy savings with the addition of a green roof with heating energy savings of 8–9% and cooling energy savings up to 1%, whereas older buildings with no insulation can have substantial energy savings of up to 44%. Simulation of modeled single family residential and low-rise commercial buildings showed that the energy savings effect in Toronto could be over $11 M from the combined effects of cool roofs and shade trees.

Detailed study in Canada shows that the daily surface temperature variation with a green roof was approximately 6°C compared to a variation up to 45°C occurring with a bitumen traditional roof. Even in its starting phase, green living roof with LAI (Leaf Area Index) close to zero during the summer period had the external surfaces heated less than the traditional flat roof. The difference of 14°C, 16°C, and 18°C in 24 hour period for three types of green roof assembly was significantly lower comparing to the conventional roof where difference of 40°C in 24-hour period was consequential and could induce serious damage over time.

In extreme climates with high snow in winters, implementing the green roof, significant reduction of the heat losses was recorded. Many of the benefits of green walls are similar to those of green roofs, such as lower heat loads in buildings. In Hong Kong, covering a concrete wall with modular vegetated panels reduced exterior wall temperatures up to 16°C in summer. In terms of internal wall temperatures, a difference of more than 2°C was recorded, maintained even late at night, indicating that green walls have significant ability to reduce energy consumption for building cooling. Differences in external wall temperatures up to 10°C between vegetated and bare concrete walls were reported at Hort Park in Singapore, where various green wall systems were assessed for their thermal performance.

### 5.7.2 Stormwater Amelioration

Green roofs store rainwater in the plants and growing mediums and evaporate water into the atmosphere. The amount of water that is stored in a green roof and evaporated back is mostly dependent on the growing medium, its depth and the type of plants used. The ability of an extensive green roof to prevent stormwater runoff depends on the amount of stormwater it can retain during a rain event, which, in turn, depends on its ability to release stored water between rain events. Green roof stormwater retention has been shown to vary with climate, storm size, vegetation type, and season. Green roof hydrological performance is usually assessed as the percent of rainfall captured over a defined period. Studies of runoff reduction by green roofs are still less common due to the complexity of capturing and measuring runoff and retention from the vegetation. While the reporting measures were not uniform, all studies reported lower runoff values than the total precipitation.

### 5.7.3 Air pollution removal and air quality control

The process of pollution removal is depended on distinguishing features of various plant species, their habit, habitat, leaf physical parameters and weather conditions present in the areas. The tolerant species can be used for reducing the level of pollution and sensitive species as bio-indicators for monitoring ambient air quality. The mix of both types can be used for developing green belt in polluted areas.

Vegetation removes pollutants directly and indirectly. Plants take up gaseous pollutants through their stomata, intercept particulate matter with their leaves, and are capable of breaking down certain organic compounds such as poly-aromatic hydrocarbons in their plant tissues or in the soil. Air pollution, such as $PM_{10}$ (which refers to particulate matter less than 10μm in diameter), is known to carry carcinogens small enough to bypass defenses in lung tissue and go deep into human lungs.

Plants contribute to better air quality through their ability to catch particulate matter on rough leaf surfaces as the air passes over. A 1000$m^2$ green roofs can capture 160–220kg of dust per year, lowering the dust concentration in the atmosphere for about 25% [26]. Different abilities in dust capturing are mainly due to the difference in the surface properties of the plant leaves, canopy structure, and foliage density. Some plants can have dust capturing abilities 2–3 times higher than the others. The city of Los Angeles conducted the report and it was estimated that 2000$m^2$ of uncut grass on the green roof can remove up to 4000kg of particulate matter showing that one square meter of the green roof could offset the annual particulate matter emissions of one car.

Measuring the concentrations of acidic gaseous pollutants and particulate matters on a 4000$m^2$ roof in Singapore before and after the installation of a green roof Tan and Sia [29] found that after installation of the green roof the levels of particles and $SO_2$ in air above the roof were reduced by 6% and 37%, respectively. This field measurement proved that green roofs can reduce certain air pollutants but it is difficult to extrapolate their results to other places or to a larger scale.

### 5.7.4 Carbon sequestration

When green coverage is less than 10%, the concentration of $CO_2$ in the air would be 40% higher than the one with 40% coverage rate, and when the coverage rate reached 50%, the concentration of $CO_2$ in the air can maintain the rate of 320 ppm. Carbon is a major component of plant structures and is naturally sequestered in plant tissues through photosynthesis and into the soil substrate via plant litter and root exudates. The carbon fixation and oxygen release capabilities of the green roof depends on the plant selection. Trees, bushes and shrubs are better in controlling the $CO_2$ concentration improving the environment and maintaining oxygen balance than the grass. The $CO_2$ absorption rate of a plant in the daytime was much higher compared with the $CO_2$ emission rate at night providing the green roof ability to reduce the $CO_2$ concentration in the nearby region by nearly 2%.

### 5.7.5 Sterilization

Garden plants as the major species in urban greening have the important role in reducing the amount of environmental harmful pathogenic microorganisms and improving the urban environment's ecological value and adding social benefits. Plants can sterilize and inhibit the bacteria and other pathogenic microorganisms in their living environment to varying degrees. High green coverage rate helps to reduce bacterial content in the air. Some tree species produce essential oils called *phytoncides,* which when inhaled, improves mental well-being.