Indira Gandhi
National Open University
School of Engineering and Technology

OEY - 002
RENEWABLE ENERGY TECHNOLOGIES AND THEIR USES

Block

5

SOLAR HEATING AND COOLING OF BUILDINGS

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SOLAR HEATING AND COOLING OF BUILDINGS

Buildings consume a substantial amount of commercial energy at every stage starting from the materials to be used in constructing the buildings to creating comfort conditions for human being. We are living in an era where there is a huge gap between demand and supply of commercial energy in all energy using sectors; the buildings are no exception to this. Thus, energy conservation and energy substitution in buildings could play an important role in providing a realistic solution to this problem.

There can be almost infinite number of combinations of design alternatives, small and large, that can be assembled to realise the conservation of commercial energy in the buildings. Architects, engineers, interior designers and other building design professionals may play a significant role in finding a potential solution to the problem.

Many people associated with building industry like architects and interior designers are of the view that energy conservation in a building is the task of mechanical engineers. This is not a proper view because a major part of the opportunity for energy conservation in buildings is directly within the traditional domain of architectural and interior design. An architect actually has the control over the ultimate size of the building as well as its shape, orientation, special arrangements, materials and many other factors that affect energy use. It is the architect, who controls building's need for energy while the engineer designs the means to fulfill that need.

Energy consumption in a building during its operation over the entire life span can be drastically reduced by employing solar features in the building. A passive building design tries to make use of natural sources of energy and less dependence on commercial energy. Such buildings are now called solar passive buildings or energy-conscious buildings. Solar active buildings use mechanical devices like pumps and fans etc to distribute sun's captured energy amongst the areas of living spaces. Solar passive buildings, on the other hand, do the similar work naturally without making use of mechanical devices.

You will learn about various aspects of solar passive and active buildings in this course. You will also learn about the green buildings and the rating system for their evaluation as a part of this course.

CERTIFICATE IN ENERGY TECHNOLOGY AND MANAGEMENT (CETM)

COURSE STRUCTURE SUMMARY

Course Code	Course Title	Credits
OEY 001	Energy Resources and Conversion Processes	4
OEY 002	Renewable Energy Technologies and Their Uses	6
OEY 003	Energy Management: Audit and Conservation	6
OEYP 004	Energy Projects	4

OEY 002	**Renewable Energy Technologies and Their Uses**

Block /Unit	Block / Unit Title
Block 1	**Solar Thermal Technologies**
Unit 1	Solar Radiation and Radiation Characteristics of Materials
Unit 2	Solar Cooking Devices
Unit 3	Solar Water Heaters
Unit 4	Solar Air Heaters
Unit 5	Solar Still
Block 2	**Solar Photovoltaic Technologies**
Unit 1	Photovoltaic Effect
Unit 2	Solar Photovoltaic Technologies for Domestic Applications
Unit 3	Solar Photovoltaic Hybrid Power Generation
Block 3	**Biomass Based Energy Technologies**
Unit 1	Biomass Based Energy Technologies
Unit 2	Biogas and its Utilisation
Block 4	**Solar Drying Systems**
Unit 1	Open Sun Drying
Unit 2	Principles of Solar Drying System
Unit 3	Economics of Drying System
Block 5	**Solar Heating and Cooling of Building**
Unit 1	Basic Principles of Solar Heating and Cooling of Buildings
Unit 2	Daylighting and Climatic Responsive Passive Designs
Unit 3	Solar Building Design Alternatives and Green Buildings
Unit 4	Solar Greenhouse

UNIT 1 BASIC PRINCIPLES OF SOLAR HEATING AND COOLING OF BUILDINGS

Structure

1.1 Introduction

Objectives

1.2 Climatic Zones

1.3 Principles of Building Designs

1.4 Building Orientation

1.5 Direct Gain Passive Systems

1.5.1 Effect of Glass Transmittance

1.5.2 Effect of Window Orientation

1.6 Indirect Gain Passive Systems

1.6.1 Trombe Wall

1.6.2 Roof Pond

1.6.3 Thermosyphon Passive Systems

1.7 Solar Passive Cooling Systems

1.7.1 Night Sky Cooling

1.7.2 Direct Cooling to the Atmosphere: Wind Driven Ventilation

1.7.3 Indirect Cooling: Night Sky Radiation

1.7.4 Effect of Shading Devices

1.7.5 Evaporative Cooling

1.7.6 Earth Air Pipe System

1.8 Let Us Sum Up

1.9 Key Words

1.10 Answers to SAQs

1.1 INTRODUCTION

The energy requirement for lighting, heating and cooling of modern buildings is met by commercial energy sources. The energy consumption is rapidly increasing in this sector. The building could be designed by adopting climate responsive designs for making it energy efficient and reducing its energy consumption. The buildings can also be integrated with various renewable energy devices to generate energy at the point of use, and so further reducing consumption of conventional energy sources. The Ministry of New and Renewable Energy, Govt. of India is promoting solar buildings and use of renewable energy devices through various promotional measures and by providing financial incentives.

A number of buildings having solar passive features have been designed and constructed in the country. Amongst many, some of the prominent solar buildings are the buildings of Solar Energy Centre, MNRE, Gurgaon; State Bank of Patiala and MLAs' hostel at Shimla; Panjab Energy Development Agency, Chandigarh; TERI Retreat, Gurgaon; and, West Bengal Renewable Energy Development Agency Building at Kolkata.

It is interesting to note that the wisdom for designing solar passive buildings is derived from traditional Moghul architecture. This ancient knowledge and experience is quite visible in the construction of now heritage buildings viz. Red Fort of Delhi, forts and havelis in Jaipur, Jaiselmer and Jodhpur. Unlike the modern architecture, which puts emphasis on creating your own space without considering the elements of nature and then resorting to use of energy gadgets to make it livable, you may like to know that the solar architecture works in harmony of nature.

An energy-conscious building design saves money through energy reduction after construction when a building begins operation, but such a design may cost a little more initially. The question to be asked is the viability of the option to pay more initially to save more lately. It has been estimated that many features of solar passive design are very attractive.

In this unit, you will learn important aspects of energy conscious designing of buildings. The unit would also discuss techno-economics and the few methods for estimating energy savings.

Objectives

After studying this unit, you will be able to understand

- Climatic zones in the country,
- Basic principles of designing of solar passive buildings,
- Concepts of direct gain solar passive heating systems,
- Concepts of indirect gain solar passive heating systems,
- Various possibilities of solar passive cooling systems,
- Concept of daylighting. and
- Climatic responsive approach for designing of solar passive buildings.

1.2 CLIMATIC ZONES

In order to design energy efficient buildings, you need to know the climatic conditions like temperature and relative humidity levels. For this, the country is divided into following six climatic zones :

(1) hot and dry

(2) warm and humid

(3) moderate

(4) cold and cloudy

(5) cold and sunny

(6) composite

The mean temperature and relative humidity for the above six zones are given in Table 1.1.

Table 1.1 : Climatic Zones and their Characteristics

Climate	Mean Monthly Temperature (ºC)	Relative Humidity (%)
Hot and Dry	> 30	< 55
Warm and Humid	> 30	> 55
Moderate	25-30	< 75
Cold and Cloudy	< 25	> 55
Cold and Sunny	< 25	< 55
Composite	When six months or more do not fall within any of the above	

As per National Building Code (2005), the two climatic zones representing Cold and Cloudy and Cold and Sunny have been grouped together into Cold, and therefore the total number of climatic zones have been brought down to five.

1.3 PRINCIPLES OF BUILDING DESIGNS

A building works like an enclosure. It interacts with the environment through walls, windows, roof, door and floor, etc. All these building elements constitute the building envelope. If the building envelope is constructed thoughtlessly, the building would be highly energy inefficient.

It is easy to know that climatic conditions are important to take into account while considering energy conscious design of a building. Depending upon the climatic zone in which the location of the building lies, elements of climate such as solar radiation, ambient temperature, wind direction, level of humidity etc are required to be used.

As a major design strategy, we need to resist heat gain (both direct sunlight through windows and other openings and indirect heat gain through walls and roof) and promote heat losses in all buildings to be constructed in climatic zones represented as hot and dry, warm and humid, and moderate. This would mean having light exterior colour of the walls, use of insulation on the interiors, use of suitably sized overhangs for windows, and orientation of openings (door and windows) to facilitate ventilation depending upon wind direction.

In cold climatic zones, the basic design strategy would be to promote heat gain and reduce the heat losses from the buildings. This means that larger windows (with moveable shutter for night time use) on southern walls and dark exterior colors for all walls would be preferable to absorb more solar heat. Double glazing can also be used on windows where ambient temperature goes low. Roof and wall insulation is also preferred for reducing the heat losses from the building. Special concepts of solar passive heating would be of additional effectiveness.

1.4 BUILDING ORIENTATION

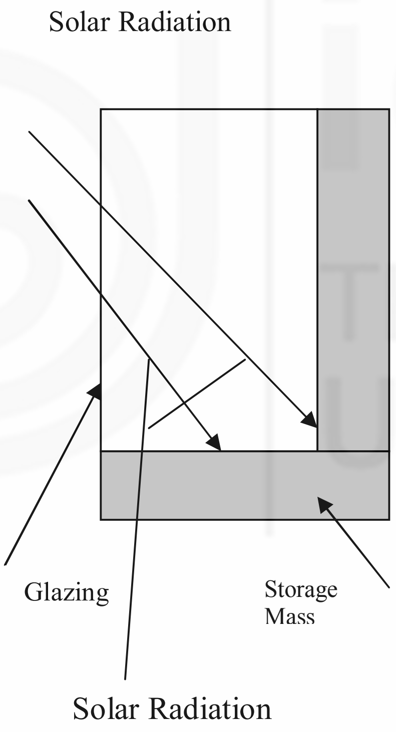
Site conditions, orientation of the building and proper building configuration are the basic elements playing significant role in the building's performance. Site specific conditions, such as, availability of trees and other vegetation, water bodies and open spaces, and the land form (sloped or plain) would enable decision on the strategy to be adopted for building design in the given climatic conditions. ***Best orientation for building would be such that it receives***

maximum solar energy during winter and minimum in summer. East-west orientation is considered most appropriate in all the climates. Regarding shape, it is interesting to know that the square shape is not the best. Depending upon the basic strategy of designing, building form in terms of the height and volume are decided.

The material of construction of the walls and roof determines their heat conductance and therefore their ability to retain or lose heat. This can be better understood through example and details given later in this unit.

1.5 DIRECT GAIN PASSIVE SYSTEMS

The direct gain system is shown in Figure 1.1. This is the simplest passive design technique. The solar radiation is allowed to enter the building through south-facing windows. The solar radiation strikes the building's thermal mass which is either a dark-colored masonry floor and/or walls in the interior space and is absorbed and stored as heat. Depending upon the thermal capacity of the materials used in the construction, stored heat as well as the heat conducted from outside of the walls and roof is released to the inside air for warming the rooms.



Requirements	**Variations**
South facing glazed area to admit solar radiation directly into the building	Storage on exterior building walls
Living space exposed to solar radiation	Storage on internal walls
Floor and/or wall collect and store solar heat for heating	Storage on floor
A method of isolating the storage from exterior climatic conditions	Free standing mass on floor
A proper sunshade to prevent unwanted heat gain	
A moveable insulation on the window glass during night prevents heat loss	

Figure 1.1 : Direct Gain Passive System

1.5.1 Effect of Glass Transmittance

Solar radiation falling over window glass loses a part of it depending upon the latitude of the place and time of the year as these factors determine the angle at which solar radiation strikes it. The amounts of sunlight which goes through the glass and is captured by it as a function of angle of incidence are given in Table 1.1.

Table 1.1 : Transmissivity and Absorptivity of Glass

Angle of Incidence	0	20	40	50	60	70	80	90
Transmissivity-Direct	0.87	0.87	0.86	0.84	0.79	0.67	0.42	0.00
Transmissvity Diffuse	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Absorptivity-Direct	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.00
Absorptivity Diffuse	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

1.5.2 Effect of Window Orientation

Other factor determining the availability of sunlight through a window is the orientation of the wall in which it is located. How a glass window facing away from true south collects solar energy is shown in Table 1.2 for a particular latitude. For other latitudes, these numbers would change.

Table 1.2 : Effect of Window Orientation on Solar Energy Collection

Window Orientation	Degrees from True South	Percentage of maximum of solar radiation received
True South	0	100
South-Southeast	22.5	90
South-Southeast	22.5	90
Southeast	45.0	75
Southwest	45.0	75
East-Southeast	67.5	58
West-Southwest	67.5	58
East	90.0	35
West	90.0	35

SAQ 1

Write down one important requirements of direct gain passive system.

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……………………………………………………………………………………………………
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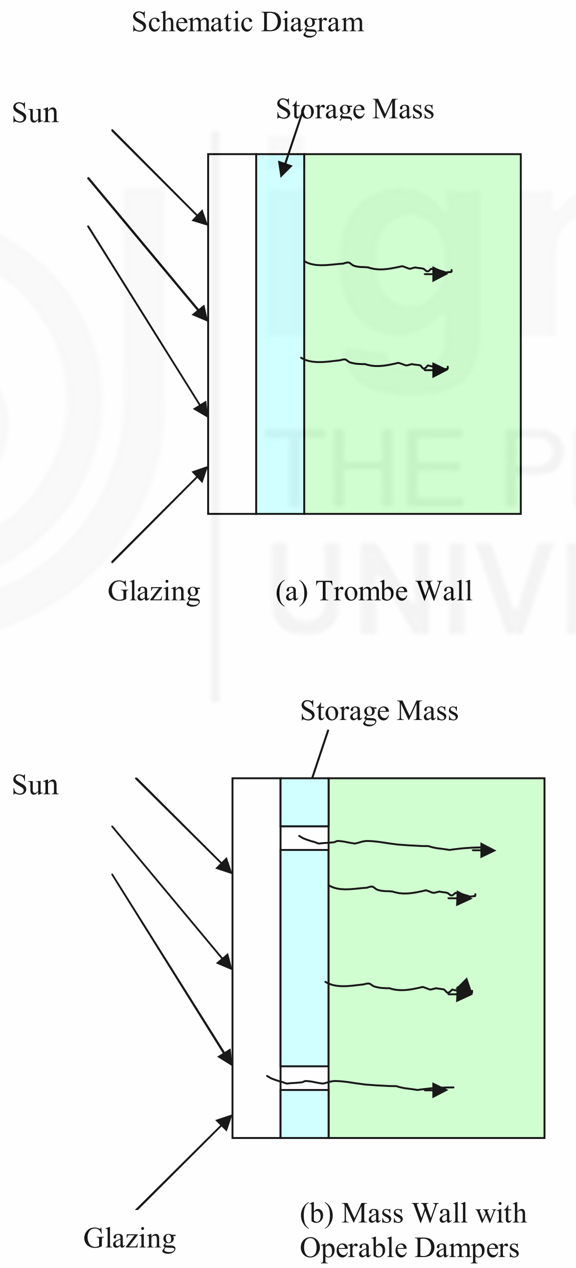
1.6 INDIRECT GAIN PASSIVE SYSTEMS

A number of systems are available which admit solar energy in indirect mode. Some of them are discussed below.

1.6.1 Trombe Wall

Trombe wall, named after a French architect who designed it originally, is an indirect gain solid mass wall. It is constructed to have dark-colored exterior surface covered with a glass cover. It has two thermo-circulation vents, one near bottom of the wall and other near its top. The solar radiation falling on the walls gets absorbed and the air in its contact gets heated up. The warm air moves up and enters the living space. As a result, the colder air from the living space gets displaced from the lower vent in the wall to the exterior space. The wall acts as storage medium of heat also. It releases heat into the living space during night when both the vents are closed. The schematic diagram is shown in Figure 1.2.



Requirements and variations

A large south facing glazed area to admit maximum useful solar radiation

A storage mass (masonry, water wall etc) directly behind the glazing

A provision of controllable dampers

A provision of external movable insulation to reduce wasteful heat loss during night in winters

A provision of shading the glazing to prevent unwanted heating in summer

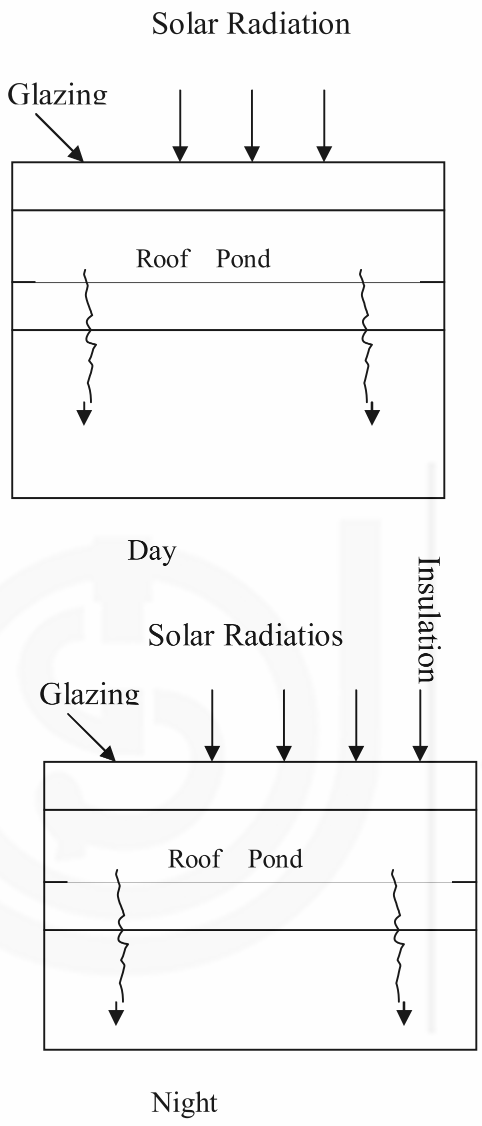
A provision for suitable vent at the top of glazed area to provide induced ventilation for summer cooling of the living space

Figure 1.2 : Indirect Gain Passive Systems

1.6.2 Roof Pond

An indirect gain passive system using roof pond is shown in Figure 1.3.

Schematic Diagram



Requirements and Variations

A body of water (roof pond) located in the roof

A provision to protect the pond exterior with movable insulation to reduce heat loss during wintes and heat gain in summer

A provision of cover to stop loss of water due to evaporation

The system finds application when the space is in direct thermal contact with the thermal storage.

Figure 1.3 : Indirect Gain Passive System : Roof Pond System

SAQ 2

In indirect passive gain system, what should be done for summer cooling?

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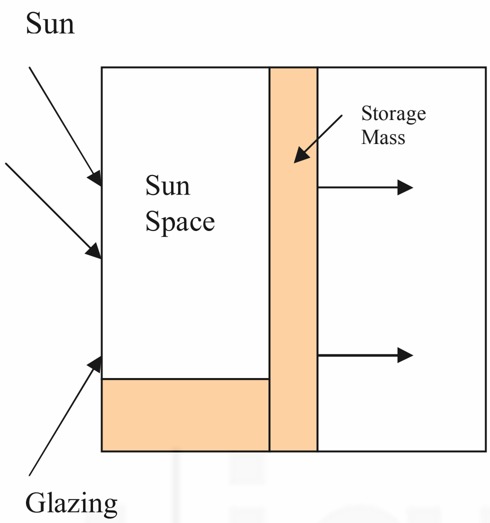
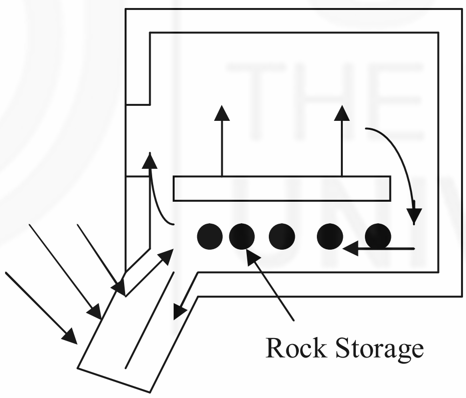
1.6.3 Thermosyphon Passive Systems

Two such configurations are shown in Figure 1.4. One configuration uses a separate solar space (solarium) to store solar heat. A sunspace can be built as part of a new building or as an addition to an existing one. Sunspaces also require a thermal mass to store heat. This stored heat is distributed throughout the building via ceiling and floor-level vents, windows, and doors, sometimes with the addition of fans. Other configuration is to have thermosyphon air panels installed on the south wall of a building. The heat collected by these panels moves to the rock storage by natural flow of air. The storage material radiates this heat through floor to the living space. This is also referred to as isolated gain system.

Schematic Diagram



(a) Isolated Gain



(b) Thermosyphon

Requirements and Variations

A provision of sunspace to collect solar energy. This space is created adjoining the living space

A provision to thermally link sunspace to living space through mass wall for heat retention and distribution

The size of sunspace can be variable in size, may extend up to full size of south exposure

A provision of movable insulation to prevent unnecessary heat losses on winter nights or cloudy days

A provision of shade to prevent overheating of glazed spaces during the summer

Figure 1.4 : Isolated Gain and Thermosyphon Passive System

1.7 SOLAR PASSIVE COOLING SYSTEMS

Underlying principle of solar passive cooling is to prevent heat from entering the building and remove it when it has come into the building. It is accomplished through simple techniques such as listed below :

(1) correct placement of windows for ventilation cooling

(2) proper shading of windows in summer by properly designed shades

(3) light-colored roofs and walls to reflect heat

(4) night time ventilation

(5) use of thermal mass to prevent overheating in hot, sunny weather

(6) use of insulation.

Some of the cooling systems are described below.

1.7.1 Night Sky Cooling

The basic concept is shown in Figure 1.5. Here a provision is made to open the building for the radiation loss to the sky. The building loses its stored energy and hence gets cooled down.

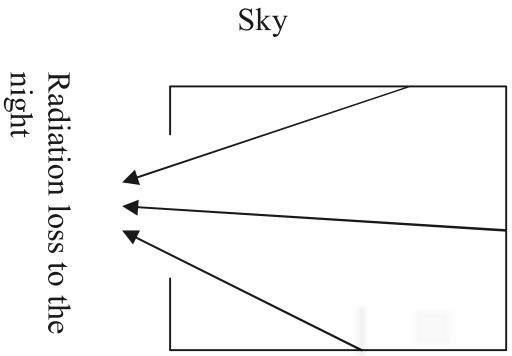


Figure 1.5 : Direct Cooling : Night Sky Radiation

1.7.2 Direct Cooling to Atmosphere : Wind-Driven Ventilation

The basic concept is shown in Figure 1.6. Here a provision is made to open the building for winds to take away the stored energy to the atmosphere. The building looses its stored energy and hence cooled down.

Wind towers are used in hot and dry climates. These are useful only if the location experiences consistent winds. Top of the tower is designed to have large thermal mass. In the presence of wind, the cool air during night goes through the tower to inside the building and provides cooling. During day, the air coming in contact with the tower gets cooled due to its cooler interiors, and flows down to the building. Wind towers can be incorporated in low rise buildings, however, due care is to be taken to prevent entry of birds, dust and insects, etc.

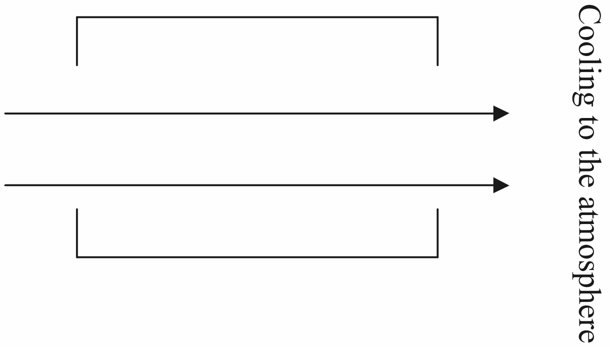


Figure 1.6 : Direct Cooling : Wind Driven Ventilation

1.7.3 Indirect Cooling: Night Sky Radiation

The basic concept is shown in Figure 1.8. Here the building looses its stored energy during night by radiation. You may like to know that the effective sky temperature during night could be several degrees below the ambient air temperature depending upon its clearness.

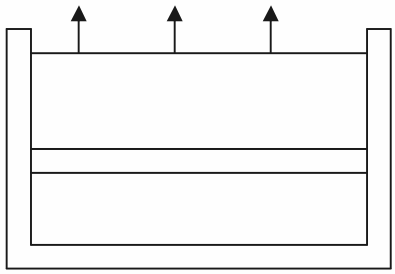


Figure 1.7 : Indirect Cooling : Night Sky Radiation

1.7.4 Effect of Shading Devices

The shading device placed outside or inside the space reduces the heat gain. The effect will be more when the shading device is placed outside the space. About 40% of the radiation absorbed by the glass enters the room. The solar heat gain factor (SHGF) is the ratio of the heat gain of the space through the glass and shading device to the radiation heat through the glass.

Solar heat gain factors and radiation properties (Transmissivity, Tr, Absorptivity, Ar and Reflectivity, Rr of some common shading devices are given in Table 1.3.

Table 1.3 : Solar Heat Gain Factors and Radiation Properties of Shading Device

Device	Tr	Ar	Rr	Solar Heat Gain Factor SHGF
Ordinary Glass	0.86	0.06	0.08	0.96
6.35 mm glass	0.77	0.15	0.08	0.94
Venetian Blind				
Light	0.12	0.37	0.51	0.56
Medium	0.03	0.58	0.39	0.65
Dark	0.01	0.72	0.27	0.75
Cotton Cloth	0.23	0.26	0.51	0.56
Cotton Cloth, Dark Green	0.70	0.02	0.28	0.76
Dacron Cloth White	0.70	0.02	0.28	0.76

SAQ 3

What is solar heat gain factor? Determine by what percentage the solar heat gain factor of light coloured Venetian Blind is less as compared to ordinary glass.

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1.7.5 Evaporative Cooling

Water evaporation cools the air. Efficiency of evaporative cooling depends on the temperature of the air and its humidity. Evaporative cooling has been extensively used in the vernacular architecture of Pakistan, Iran, Turkey and Egypt. One of the ways to use evaporative cooling is to have a tower fitted with wetted pads at the top. Tower catches the wind, which gets cooled due to water evaporation and sinks down to living space for cooling.

Another method of evaporative cooling is by sprinkling water over the roof surface. The roof surface gets cooled to temperatures lower than ambient air temperature, due to evaporation of water. The inside heat therefore, gets conducted out to provide cooling of the living space.

1.7.6 Earth Air Pipe System

You might be aware that as you go deeper into the earth, its temperature remains constant throughout the year. This temperature of earth is about the annual average of ambient air temperature, which is cooler than the summer temperatures and warmer than the winter temperatures. Pipes can be laid at these depths of the earth and air blown through these pipes would provide heating and cooling depending upon the season.

SAQ 4

Describe the concept of direct gain heating and cooling of solar passive buildings. Which materials should be used in such designs?

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SAQ 5

Describe the importance of ventilation in heating and cooling of the buildings.

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SAQ 6

Describe the solar passive cooling systems.

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1.8 LET US SUM UP

Major components of solar passive architecture are orientation of building, sun shades, double-glazed windows, smart glazing window overhangs, thermal storage wall/roof, roof painting, ventilation, evaporative cooling, day lighting, construction materials, and so on. Incorporation of specific components will depend in which climatic zone the building is being constructed.

The solar passive features offer substantial energy saving resulting due to less energy used in thermal comfort conditioning and lighting.

The direct gain systems are the simplest passive design technique. The solar radiations are allowed to enter the building through south-facing windows. The solar radiations strikes the building's thermal mass and are absorbed and stored. During night, as the building cools, heat stored in the floors and walls is allowed to move in the living areas for warming the rooms.

In the indirect gain type design, a dark-colored wall (mass wall and or trombay wall) is placed between a building's south-facing windows and living rooms or working space. The solar radiations falling on the walls get absorbed. The wall acts as the storage of heat and then releases it into the building when the indoor temperature falls below that of the wall's surface.

Solar passive cooling requires simple techniques and are realized through correct placement of windows, proper shading of windows by trees or constructed shade, light-colored roofs and walls to reflect heat, nighttime ventilation and thermal mass to prevent overheating in hot and sunny weather.

1.9 KEY WORDS

Indirect-gain System

A solar passive system in which the glazing is separated from the living space by a heat storage medium like a masonry wall or a water body.

Infiltration

The uncontrolled passage of air from indoors to outdoors and vice versa.

Internal Gains

Various sources of heat within a building like people, lights and appliances.

Conduction

The direct transfer of heat energy through a material.

Conductivity

The rate at which heat is transmitted through a material.

Convection

The transfer of heat by movement of a fluid, like air or water.

Cooling Load

The amount of cooling required to keep a building at a specified temperature.

Passive Solar

Usually called solar passive; a system that uses natural heat transfer processes to transfer captured solar energy to the storage or living space.

Solar Gain

The heat gained in a building due to solar radiations; entering through windows.

Solarium

Also called sunspace, a glazed room or structure used to capture solar energy to heat the building; atrium is solarium in middle of a building.

Sunspace

A glazed room or structure used to capture solar energy to heat the building.

Thermal Mass

The components of a building that store significant quantities of heat.

Thermal Storage

The place in which energy can be stored for use at a later time.

Thermo-circulation Vent

A vent in a Trombe wall; allows air to circulate by natural convection from airspace to living space and back to airspace.

Thermosiphon

A system in which heat is captured by a solar collector and then moved to the living space or storage by natural convection.

Trombe Wall

A solar passive indirect-gain system in which the space is heated by natural convection during the day and radiation from the wall at night.

Vaporization

The process of converting a liquid to a gas, either by addition of heat or reduction of pressure.

1.10 ANSWERS TO SAQS

SAQ 1

One of the most important requirements of direct gain solar passive systems is a large south facing glazed (collector) area to admit maximum useful solar radiation.

SAQ 2

A provision for suitable vent at the top of glazed area should be made to provide induced ventilation for summer cooling of the living space.

SAQ 3

The solar heat gain factor (SHGF) is defined as follows :

SHGF = (heat gain of the space through the glass and shading device)/ the radiation heat through the glass.

From Table 1.5, SHGF for glass = 0.96 and for light coloured venetian blinds is 0.56 which is $(0.96 - 0.56) \times 100/0.96 = 41.7$ % less as compared to glass.

SAQ 4

Direct gain heating and cooling systems require that the buildings be constructed of materials that have good thermal mass such as stone, concrete, masonry or brick, etc. Such materials will absorb and release heat slowly, thus preventing rapid temperature fluctuations. Thermal mass should be located in areas of direct sunlight.

The solar radiations will enter in to the building through the windows and will heat the thermal mass. The heat absorbed by the thermal mass will be released to the living areas. In the summer, you will need to reverse this process i.e. you need to prevent the solar radiations from entering the room in order to stop the thermal mass storing unwanted heat. At night, the thermal mass will cool down and release the stored coolness throughout the next day, reducing the need for air conditioning.

SAQ 5

The ventilation plays an important role in heating and cooling of the buildings. You know that in summer, the hot air moves up and you need it to be released to the environment. This can be done simply by opening windows. However, vents in the roof space may be designed to help dissipate the hot air. Once the hot air has been released away, cooler air can then enter the home via vents or through the windows. In winter, this process needs to be reversed and you wish to keep the heat within your home.

SAQ 6

Solar passive cooling is very useful concept. It is an impressive way of reducing building electricity consumption. The solar passive cooling designs stop the building from absorbing too much heat while allowing the maximum heat loss from the building. The following methods may be adopted in order to maximise your home's passive cooling abilities.

- maximise ventilation
- align your home to take advantage of the natural breezes
- design your home so that the living areas are in the coolest areas of the home
- use shade as effectively as possible
- insulate the home
- have the appropriate thermal mass
- use light coloured materials
- use the correct windows

Remember the simple concept. In summer, keep the sun away and in winter allow the sun in to the building.

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UNIT 2 DAYLIGHTING AND CLIMATIC RESPONSIVE PASSIVE DESIGNS

Structure

2.1 Introduction

Objectives

2.2 Daylighting

2.2.1 Climate and Light

2.3 Climatic Responsive Passive Designs

2.3.1 Hot and Dry Climatic Zone
2.3.2 Warm and Humid Climatic Zone
2.3.3 Moderate Climatic Zone
2.3.4 Composite Climatic Zone
2.3.5 Cold and Cloudy Climatic Zone
2.3.6 Cold and Sunny Climatic Zone

2.4 Identification of Climate for Building Design

2.5 Estimated Energy Saving Potential in Passive Designs

2.6 Advantages and Disadvantages of Solar Passive Buildings

2.6.1 Advantages of Solar Passive Buildings
2.6.2 Disadvantages of Solar Passive Buildings

2.7 Active Solar Systems for Heating Purposes

2.8 Active Solar Systems for Cooling Purposes

2.9 Building Integrated Solar Photovoltaic Technology

2.10 Let Us Sum Up

2.11 Key Words

2.12 Answers to SAQs

2.1 INTRODUCTION

You have learnt about energy-conscious building design in the previous unit. Such energy conscious building designs save money through energy reduction after construction when a building begins operation. It has been estimated that many features of solar passive design are very attractive.

In this unit, you will learn more about important aspects of energy conscious designing of buildings like daylighting, climatic responsive designs, active solar systems for heating and cooling of buildings, advantages and disadvantages of solar passive building, building integrated solar PV technologies etc.

Objectives

After studying this unit, you will be able to understand the following

- Concept of daylighting,
- Climatic responsive approach for designing solar passive building,

- Active solar systems for heating and cooling of buildings,
- Advantages and disadvantages of solar passive building, and
- Building integrated solar PV technologies.

2.2 DAYLIGHTING

The ultimate source of daylight is the sun, from which, we also receive a large amount of thermal radiation together with the light. During bright sunshine, the illumination is around 100 klux (100000 lux). Daylighting strongly depends on the externally given conditions and its control is possible by a suitable building design. In our country, which lies in the tropics, daylight may also be accompanied by solar heat. We must, therefore, be cautious to exclude solar heat, whilst admitting daylight.

The eye responds to a very large range of illumination levels extending from 0.1 lux (full moonlit night) to 100000 lux (bright sunshine). For practical situations and various activities, illumination requirements would be different as given in Table 2.1.

Table 2.1 : Requirement of Illumination

Task	Illumination (lux)
Casual seeing	100
Ordinary tasks (e.g. wood machining, general office work)	400
Prolonged tasks (e.g. fine assembly, silk weaving)	900
Exceptionally severe tasks (e.g. watch making)	2000 - 3000

2.2.1 Climate and Light

In high latitude moderate climates, where the sky is typically overcast, the whole of the sky hemisphere acts as a light source. The sky itself has a luminance sufficiently high to provide lighting in normal rooms.

In hot dry climates, sky is usually cloudless and strong direct sunlight is available. The clear sky has the highest luminance near the horizon. The bare, dry, sunlit ground and light coloured walls of other buildings reflect much light, which will be the main source of indoor daylighting. The windows are smaller in these climates, and therefore externally reflected light is used to have adequate daylighting, provided sufficient care is taken to avoid glare.

In warm humid climates, buildings are typically of lightweight construction, with large openings to ensure cross-ventilation and air movement and other shading devices. The sky is bright, could provide sufficient light, but its high luminance would also cause glare. For this reason, view of the sky is screened by shading devices or plants.

In composite climates, wide variations occur in natural lighting between the overcast and clear sky conditions. The approximate reflection factors for various colours are as given in Table 2.2.

Table 2.2 : Reflection Factors for Different Colours

Colour	Reflection Factor (%)
White	80-90
Pale yellow	80
Pale beige, lilac	70
Pale blue, green	70-75
Mustard yellow	35
Medium brown	25
Medium blue, green	20-30
Black	10

The desirable reflection factors for various interior surfaces are given in Table 2.3.

Table 2.3 : Reflection Factors for Interior Surfaces

Surfaces	Reflection Factor (%)
Ceilings	80
End walls in poorly lighted rooms in well lighted rooms	 70 25
Walls containing window (s)	80
Floors	25

A solar building utilizes daylight for interior illumination. Usually, daylighting requires windows that are placed on or near a building's roof, such as skylights. High-level windows and skylights can allow sunlight to reach throughout the building. An effective use of daylighting reduces the need for artificial light substantially.

2.3 CLIMATE RESPONSIVE PASSIVE DESIGNS

The characteristics of each climate differ and accordingly the comfort requirements vary from one climatic zone to another. The proposed building may fall in any of the climatic zones. You have already learnt about different climatic zones in the country. Now, you will learn about their characteristics and design methodology.

2.3.1 Hot and Dry Climatic Zone

The hot and dry zone lies in the western and the central part of India; Jaisalmer, Jodhpur and Sholapur are some of the towns that experience this type of climate. A typical hot and dry region is usually flat with sandy or rocky ground conditions, and sparse vegetation. There are few sources of water on the surface, and the underground water level is also very low. In summer, the maximum ambient temperatures are as high as 40-45ºC during the day, and 20-30ºC at night. In winter, the values are between 5 and 25ºC during the day and 0 to 10ºC at night. The relative humidity is generally very low, ranging from 25 to 40 %.

The design aims at resisting heat gain by providing shading, reducing exposed area, controlling and scheduling ventilation, and increasing thermal capacity. The presence of "water bodies" is desirable as they can help increase the humidity, thereby leading to lower air temperatures. The ground and surrounding objects emit a lot of heat in the afternoons and evenings. As far as possible, this heat should be avoided by appropriate design.

2.3.2 Warm and Humid Climatic Zone

The warm and humid zone covers the coastal parts of the country. Some cities under this zone are Mumbai, Chennai and Kolkata. Due to high humidity, there is abundant vegetation in these regions. In summer, temperatures can reach as high as 30-35ºC during the day and 25-30ºC at night. In winter, the maximum temperature is between 25 to 30ºC during the day and 20 to 25ºC at night. Although the temperatures are not excessive, the high humidity (about 70-90 %) causes discomfort.

Wind is desirable in this climate, as it can cause sensible cooling of the body. The main design criteria are to reduce heat gain by providing shading, and promote heat loss by maximizing cross ventilation. Dissipation of humidity is also essential to reduce discomfort.

2.3.3 Moderate Climatic Zone

Pune and Bangalore are examples of cities under this climatic zone. Areas having a moderate climate are generally located on hilly or high-plateau regions with fairly abundant vegetation. Being located at relatively higher elevations, these places experience lower temperatures. In summers, the temperature reaches 30-34ºC during the day and 17-24ºC at night. In winter, the maximum temperature is between 27 to 33ºC during the day and 16 to 18ºC at night. The relative humidity is low in winters and summers, varying from 20-55%, and going up to 55-90% during monsoons.

The design criteria in the moderate zone are to reduce heat gain by providing shading, and to promote heat loss by ventilation.

2.3.4 Composite Climatic Zone

The composite zone covers the central part of India. Some example cities are New Delhi, Kanpur and Allahabad. The intensity of solar radiation is very high in summer. The maximum daytime temperature in summers is in the range of 32-43ºC, and night time values are from 27 to 32ºC. In winter, the values are between 10 to 25ºC during the day and 4 to 10ºC at night. The relative humidity is about 20-25% in dry periods and 55-95% in wet periods. The design criteria are more or less the same as for hot and dry climate except that maximizing cross ventilation is desirable in the monsoon period.

2.3.5 Cold and Cloudy Climatic Zone

Generally, the northern part of India experiences this type of climate. Most cold and cloudy regions are situated at high altitudes. Ootacamund, Shimla, Shillong, Srinagar and Mahabaleshwar are examples of places in this climatic zone. The intensity of solar radiation is low in winter, and hence, winters are extremely cold. In summer, the maximum ambient temperature is in the range of 20-30ºC during the day and 17-27ºC at night, making summers quite pleasant. In winter, the values range between 4 and 8ºC during the day and from – 3 to 4ºC at night, making it quite chilly.

This region experiences cold winds in the winter season. Hence, protection from winds is essential in this type of climate. Owing to cold winters, the main criteria for design in the cold and cloudy region aim at resisting heat loss by insulation and infiltration, and promoting heat gain by directly admitting and trapping solar radiation within the living space.

2.3.6 Cold and Sunny Climatic Zone

The cold and sunny type of climate is experienced in Leh (Ladakh). The region is mountainous, has little vegetation, and is considered to be a cold desert. The solar radiation is generally intense. In summer, the temperature reaches 17-24ºC during the day and 4-11ºC at night. In winter, the values range from – 7 to 8ºC during the day and – 14 to 0ºC at night. Winters thus, are extremely cold.

As this region experiences cold desert climatic conditions, the design criteria are to resist heat loss by insulation and controlling infiltration. Simultaneously, heat gain needs to be promoted by admitting and trapping solar radiation within the living space.

2.4 IMPLICATIONS OF CLIMATE ON BUILDING DESIGN

The characteristics of each climate differ and accordingly the comfort requirements vary from one climatic zone to another. Implications of climate on building design and how that can be realized are discussed in Table 2.4.

Table 2.4 : Climate and Design Strategy to Realize Thermal Comfort

Climate and design strategy	How to realize the thermal comfort
Hot and Dry Region	
1) Resist heat gain	
• Decrease exposed surface area	Orientation and shape of building
• Increase thermal resistance	Insulation of building envelope
• Increase thermal capacity (Time lag)	Massive structure
• Increase buffer spaces	Air locks/ lobbies/balconies/verandahs
• Decrease air exchange rate(ventilation during day-time)	Weather stripping and scheduling air changes
• Increase shading	External surfaces protected by overhangs, fins and trees
• Increase surface reflectivity	Pale colour, glazed china mosaic tiles etc.
2) Promote heat loss	
• Ventilation of appliances	Provide windows/exhausts
• Increase air exchange rate (Ventilation during night-time)	Courtyards/wind towers/ arrangement of openings
• Increase humidity levels	Trees, water ponds, evaporative cooling
Warm and Humid Region	
1) Resist heat gain	
• Decrease exposed surface area	Orientation and shape of building
• Increase thermal resistance	Roof insulation and wall insulation. Reflective surface of roof.

• Increase buffer spaces	Balconies and verandahs
• Increase shading	Walls, glass surfaces protected by overhangs, fins and trees
• Increase surface reflectivity	Pale colour, glazed china mosaic tiles, etc.
2) Promote heat loss	
• Ventilation of appliances	Provide windows/ exhausts
• Increase air exchange rate (Ventilation throughout the day)	Ventilated roof construction. Courtyards, wind towers and arrangement of openings
• Decrease humidity levels	Dehumidifiers/ desiccant cooling
Moderate Region	
1) Resist heat gain	
• Decrease exposed surface area	Orientation and shape of building
• Increase thermal resistance	Roof insulation and east and west wall insulation
• Increase shading	East and west walls, glass surfaces protected by overhangs, fins and trees
• Increase surface reflectivity	Pale colour, glazed china mosaic tiles, etc.
2) Promote heat loss	
• Ventilation of appliances	Provide windows/ exhausts
• Increase air exchange rate (Ventilation)	Courtyards and arrangement of openings
Cold and Cloudy Region (Applies for Cold and Sunny also)	
1) Resist heat loss	
• Decrease exposed surface area	Orientation and shape of building. Use of trees as wind barriers
• Increase thermal resistance	Roof insulation, wall insulation and double glazing
• Increase thermal capacity (Time lag)	Thicker walls
• Increase buffer spaces	Air locks/ Lobbies
• Decrease air exchange rate	Weather stripping
• Increase surface absorptivity	Darker colours
2) Promote heat gain	
• Reduce shading	Walls and glass surfaces
• Utilize heat from appliances	
• Trapping heat	Sun spaces/green houses/Trombe walls etc.
Composite Region	
1) Resist heat gain in summer and Resist heat loss in winter	
• Decrease exposed surface area	Orientation and shape of building. Use of trees as wind barriers
• Increase thermal resistance	Roof insulation and wall insulation
• Increase thermal capacity (Time lag)	Thicker walls
• Increase buffer spaces	Air locks/ Balconies
• Decrease air exchange rate	Weather stripping

• Increase shading	Walls, glass surfaces protected by overhangs, fins and trees
• Increase surface reflectivity	Pale colour, glazed china mosaic tiles, etc.
2) Promote heat loss in summer/monsoon	
• Ventilation of appliances	Provide exhausts
• Increase air exchange rate (Ventilation)	Courtyards/ wind towers/ arrangement of openings
• Increase humidity levels in dry summer	Trees and water ponds for evaporative cooling
• Decrease humidity in monsoon	Dehumidifiers/ desiccant cooling

2.5 ESTIMATED ENERGY SAVING POTENTIAL IN PASSIVE DESIGNS

The estimated energy savings potential of various designs is given in Table 2.5.

Table 2.5 : Estimated Energy Saving Potential in Passive Designs

Solar Passive Design Features	Estimated Energy Saving Potential (%)
Adding insulation in walls	15-20
Adding insulation in roofs	15-18
Adding double glass	5-7
Heating controls by other means	20-30
Controlled ventilation	5-8
Daylight integration	15-20

2.6 ADVANTAGES AND DISADVANTAGES OF SOLAR PASSIVE BUILDINGS

You are now familiar with the concepts of solar passive buildings and in a position to list down various advantages and disadvantages of such designs. Some of the well known advantages and disadvantages are the following:

2.6.1 Advantages of Solar Passive Systems

- Solar passive designs are highly energy efficient
- The building energy needs for lighting, winter heating, and summer cooling are reduced substantially.
- Solar passive designs utilize the solar energy without consuming the conventional energy. Consequently, the energy bills get reduced substantially.
- Solar passive design helps in conserving fossil fuels (coal, oil and gas).
- Day lighting, a component of many passive solar designs, is one of the key cost-effective means of reducing energy usage in buildings.
- A well-designed constructed passive solar building can be as attractive as conventionally designed buildings and still save energy and money.

- Solar passive design reduces greenhouse gases that contribute to global warming because it relies on solar energy, a renewable, nonpolluting resource.

2.6.2 Disadvantages of Solar Passive Systems

- Solar passive designs costs little more than conventional building design but saves money over the long run.
- Any mistake made in the choice of building materials, especially window glass may give adverse results.
- Room and furniture layouts need to be planned carefully to avoid glare on equipment such as computers and televisions.
- Daylighting may come with heat. During the summer or in warm climates, day lighting could actually increase use of energy in a building if proper care is not taken in its designing by adding to the air-conditioning load.

2.7 ACTIVE SOLAR SYSTEMS FOR HEATING PURPOSES

In solar active systems, solar collectors using electric pump are used to convert sun's energy into useful heat for different applications like hot water requirements and space heating. These are larger capacity systems, as compared to thermosyphon based systems. These systems provide flexibility in the installation of solar collectors and the storage tanks without compromising aesthetics of the building. Solar air heaters are also used for space heating applications, especially during daytime.

You have already learned that there are two basic types of solar water heating systems-open loop and closed loop. An open loop system circulates water itself, through the collector. In closed loop systems, the circulating fluid is kept separate from the system used for water supply (Figure 2.1). The closed loop systems are less efficient as the heat exchanger used in the system causes a loss of temperature of water. They are relatively expensive because of the extra cost of the heat exchanger as well as the circulating pump.

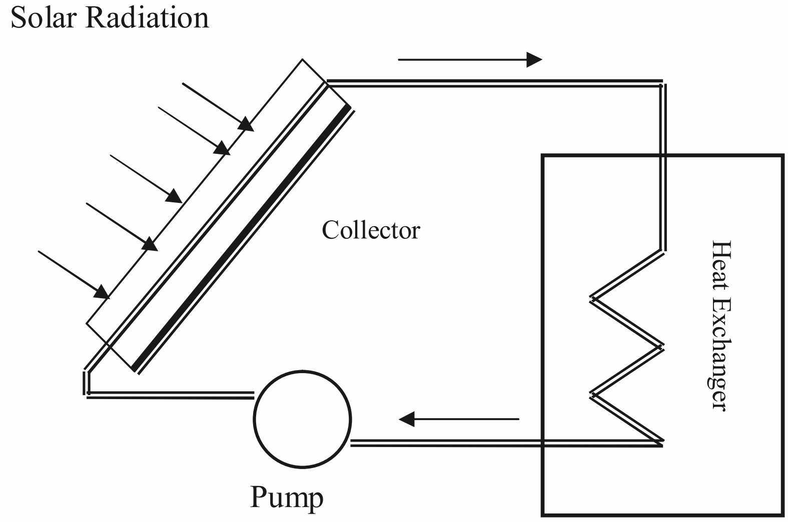

Figure 2.1 : Solar Water Heater with Heat Exchanger

In thermosyphon systems, the water circulates from the collector to the storage tank by natural convection and gravity. As long as the sun is shining, the absorber keeps collecting heat and water continues to be heated in the collector. The heated water rises into the storage tank, placed slightly above the collector level. The cold water in the tank runs into the collector to replace the water discharged into the tank. The circulation stops when solar radiation is less. Thermosyphon systems are simple, relatively inexpensive and require little maintenance and can be used for domestic applications.

SAQ 1

Describe the difference between open and closed loop solar water heating systems.

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2.8 ACTIVE SOLAR SYSTEMS FOR COOLING PURPOSES

In areas where solar radiation insolation is high during large part of the year, heating requirements are easily met but cooling in summer months becomes a difficult task. You are aware about the requirements of increasing demand of energy for meeting thermal comfort conditions on one side and less availability of fossil fuels on the other side. An extensive work has been reported in the literature to utilize renewable energy sources for comfort conditions. Solar energy is the front runner among all the renewable energy sources for meeting comfort conditions inside the building.

The solar cooling systems require a thermodynamics cycle between the solar collector and the building as shown in Figure 2.2.

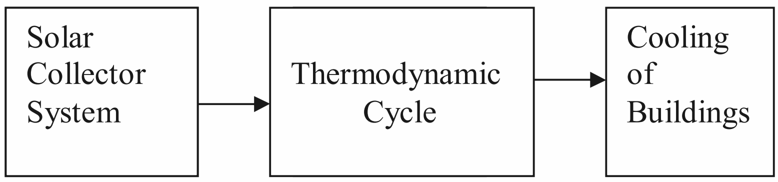

Figure 2.2 : Solar Cooling System

Some of the well known thermodynamic cycles used in solar air conditioning are Vapour-Absorption (V-A), Vapour-Compression (V-C) and Evaporating Cooling (E-C).

Vapour-Compression (V-C) : A V-C refrigeration cycle consists of a compressor, a condenser, an expansion device and an evaporator.

Vapour-Absorption (V-A) : A V-A cycle is identical to a V-C cycle in which the compressor is replaced by an absorber and generator assembly. The absorption cooling systems are used to transfer a heated liquid from the solar collector to run a generator or a boiler activating the refrigeration loop which cools a storage reservoir. The cool air from this reservoir is drawn into the living space for thermal comfort.

Evaporating Cooling (E-C) : It is used in dry regions.

A detailed study of such systems is beyond the scope of this unit.

2.9 BUILDING INTEGRATED SOLAR PHOTOVOLTAIC TECHNOLOGY

You have already learned in detail about solar photovoltaic technology (SPV) in Block 2. It involves the direct conversion of solar radiation into electrical energy. You have also seen that SPV technology is a clean source of energy, produces no noise, smoke, acid rain, water pollutants, carbon dioxide, etc. because it relies on the power of the sun for its fuel. As a result, the environmental impact of activities associated with fossil fuels (coal, oil and gas) such as mining, exploration, production and transportation, and the hazards are eliminated. However, the drawbacks of such systems are their high initial cost and low efficiency, which results in high module area requirements.

SPV can be integrated with almost every possible building structure. The development of PV products for building integration is mainly in the following three areas :

- **Integral roof modules :** Roof integration has been the most popular application. The reason being that SPV modules can collect maximum solar radiation and hence can provide the highest power output.
- **Roofing tiles :** Building integrated SPV modules produced in the same size as building materials like roof tiles or glass and other cladding panels have dual advantage. They can replace these materials efficiently and simultaneously can provide much needed energy.
- **Vertical facades :** Vertical curtain walls can replace traditional cladding materials like glass.

SPV can play following additional multiple roles in the design of solar passive buildings :

- SPV light shelf can shield direct sun while filtering comfortable diffused, indirect light into the interior.
- An opaque SPV module can shade the interior portions of the building from direct sunlight and reduce cooling expenses.
- SPV roof modules can eliminate the need for daytime electric lighting by providing indirect daylight.

SAQ 2

Describe the areas for SPV integration into buildings.

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2.10 LET US SUM UP

A solar passive building utilizes daylight for interior illumination. An effective use of day lighting reduces the need for artificial light substantially.

The various climatic zones and the implications of climate on building design have been discussed in detail.

2.11 KEY WORDS

Daylighting

The use of sunlight to supplement or replace artificial lighting.

Diffuse Radiation

A portion of solar radiation, scattered by water vapor, dust and other particles as it passes through the atmosphere; higher on hazy or overcast days than on clear days.

Direct Radiation

A portion of solar radiation that has traveled a straight path from the sun.

Renewable Energy

Energy resources that constantly renew themselves or that are regarded as practically inexhaustible; include solar, wind, geothermal, hydro and wood.

Renewable Resources

Renewable energy resources are virtually inexhaustible in duration; include biomass, hydro, geothermal, solar, wind, ocean thermal, wave, and tidal.

2.12 ANSWERS TO SAQS

SAQ 1

An open loop system circulates water itself, through the collector. In closed loop systems, the circulating fluid is kept separate from the system used for water supply. The closed loop systems are less efficient as the heat exchanger used in the system causes a loss of temperature of water.

SAQ 2

SPV can be integrated into the buildings by the following three main areas :

(1) **Integral roof modules :** Roof integration has been the most popular application. The reason being that SPV modules can collect maximum solar radiation and hence can provide the highest power output.

(2) **Roofing tiles :** Building integrated SPV modules produced in the same size as building materials like roof tiles or glass and other cladding panels have dual advantage. They can replace these materials efficiently and simultaneously can provide much needed energy.

(3) **Vertical facades :** Vertical curtain walls can replace traditional cladding materials like glass.

UNIT 3 SOLAR BUILDING DESIGN ALTERNATIVES AND GREEN BUILDINGS

Structure

3.1 Introduction

Objectives

3.2 Solar Building Design Elements

3.3 Solar Building Design Evaluation Process

3.3.1 Solar Building Design Philosophy

3.3.2 Solar Building Design Procedure

3.4 Energy Considerations

3.4.1 Thermal Energy Flows

3.4.2 Luminous Energy Flows

3.5 Solar Building Design Alternatives

3.5.1 Landscape

3.5.2 Building Form

3.5.3 Building Components

3.5.4 Energy Supply Augmentation

3.6 Heat Gain through Glass

3.7 Embodied Energy of Materials

3.8 Green Buildings

3.9 Green Building Rating Systems

3.9.1 LEED Rating System

3.9.2 GRIHA Rating System

3.10 Let Us Sum Up

3.11 Key Words

3.12 Answers to SAQs

3.1 INTRODUCTION

You have already learned about concepts of solar passive heating and cooling of buildings. Under various situations, solar passive measures may not be sufficient enough to provide desired level of comfort. Operational requirements of certain category of buildings might also need adherence to specific temperature and humidity levels. Solar active systems which would require energy from conventional sources for their operation provide possibilities of using renewable energy in the buildings and thus leading to reduction in overall consumption of energy.

Solar active architecture makes use of solar collectors to capture the sun's heat and other renewable energy systems like biomass and biogas etc to support the solar passive features. They also allow a greater degree of control over the internal climate and make the whole system more attractive. Active solar systems use solar panels for heat collection and electrically driven pumps or fans to transport the heat or cold to the required spaces. Electronic devices are used to regulate the collection, storage and distribution of heat within the system. Hybrid systems using a balanced combination of active and passive features provide the best performance.

In this unit, you will learn all important aspects of solar active and passive buildings. You will also learn various passive designs that could be adopted during the development of energy-conscious and environment friendly buildings and their techno-economics. The principal methods for estimating energy saving possible in passive designs as well as their techno-economics are included. You will also learn about green buildings which are getting wide spread attention globally and in our country also. The concepts of green building and the rating systems are very effective in conservation of resources including energy and water and leading to reduction in greenhouse gas emissions.

Objectives

After studying this unit, you should be able to understand

- Solar active buildings,
- Some design features of solar active buildings,
- Basic design concepts of solar passive buildings,
- Embodied energy of materials,
- Green buildings, and
- Rating of green buildings.

3.2 SOLAR BUILDING DESIGN ELEMENTS

The buildings systems may be broadly classified into three categories as mentioned below :

(a) Passive building

(b) Active building

(c) Hybrid building

The relative features of these buildings are given in Table 3.1.

Any building can be designed to make use of sun's energy. The basic philosophy in solar building design is that it uses structure's windows, walls, and floors to collect, store, and distribute the sun's heat in the winter and reject solar heat in the summer. It also maximizes the use of daylight for interior illumination.

In order to understand solar design features, you must remember that any solar building includes five distinct design elements. These are :

A Collector : It is the large glass area through which sunlight is allowed to enter the building.

An Absorber : It is the dark surface of the storage element that absorbs the solar heat.

A Thermal Mass : The material that stores the absorbed heat. This can be masonry materials such as concrete, stone, and brick or a water tank.

A Heat Distribution System : The heat distribution could be natural using the concept that heat flows from warmer materials to cooler ones (through conduction, convection, and radiation) until there is no longer a temperature difference between the two. This could also be done with the help of fans, ducts, and blowers etc. to circulate the stored heat (Active System).

A Control Mechanism : This is needed to regulate the amount of sunlight entering the building. This can be as simple as roof overhang designed to allow more sunlight to enter in the winter, less in the summer.

Table 3.1 : Broad Features of Buildings

Building Systems		
Passive Systems	**Hybrid Systems**	**Active Systems**
Energy collection and storage is by natural means	Energy collection and storage can be by natural means	Energy collection and storage is by forced means
Energy distribution is by natural means	Energy distribution from collector to storage or from storage to living space is by mechanical means	Energy distribution is by forced means
The system mostly work without external power	The system uses external power	The system works with external power
Daylight is extensively used	Daylight is extensively used	Less use of daylight
Passive cooling and heating can be inherent in the building construction	Passive cooling and heating can be inherent in the building construction	Heating and cooling systems and their controls are not an integral part of the building construction
Energy flow by natural means	Energy flow from collector to storage or from storage to living space is forced type	Energy flow within the system is by forced means

SAQ 1

Describe two main features of three main types of buildings.

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There are three basic solar designs for heat regulation, each of which incorporates these five elements in different ways. These are solar heating, cooling and daylight (Figure 3.1). The mechanisms employed under these three categories are listed in Figures 3.2 to 3.4. Figure 3.2 gives various mechanisms for solar heating, Figure 3.3 for solar cooling and Figure 3.4 for daylight.

To be Remembered :

The goal in solar building is the optimal balance of mass, glass, and insulation for a particular site and house design.

You have learned earlier that the active solar heating systems use mechanical and electrical devices, such as pumps, fans, or electrical controls for circulating the solar heat.

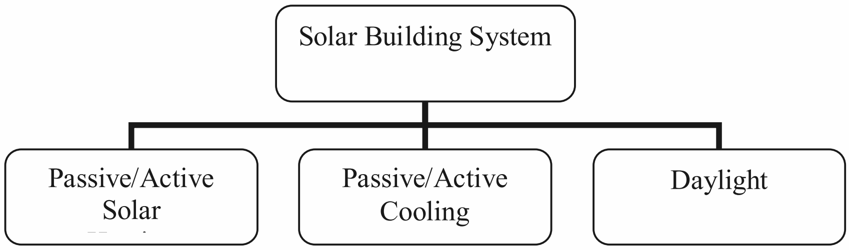

Figure 3.1 : Solar Building Systems

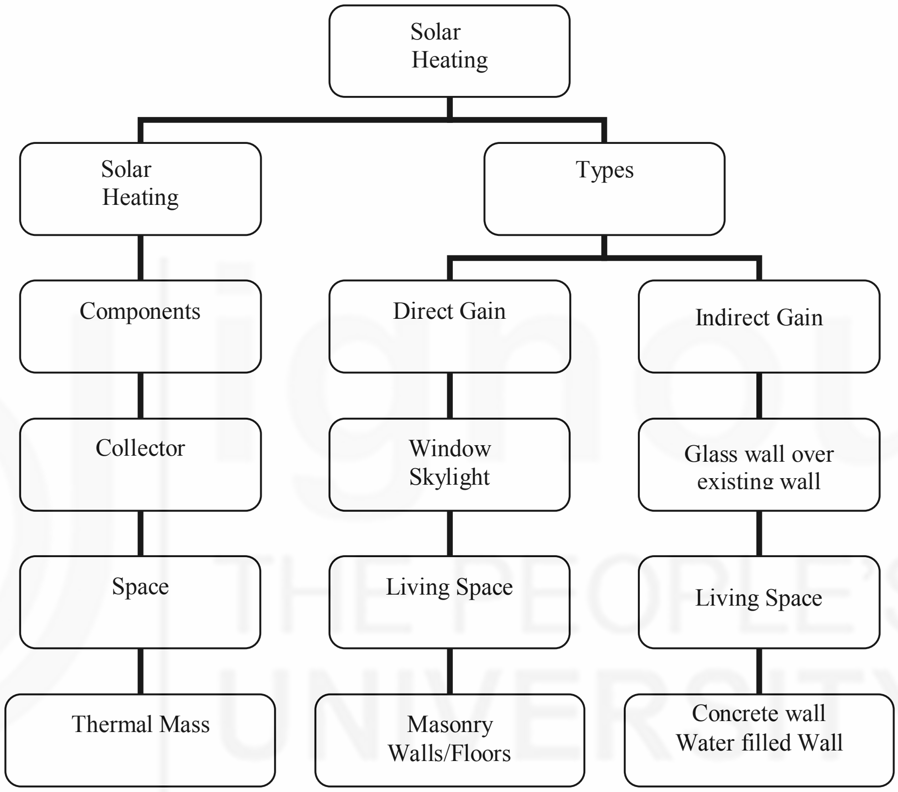

Figure 3.2 : Solar Heating Systems

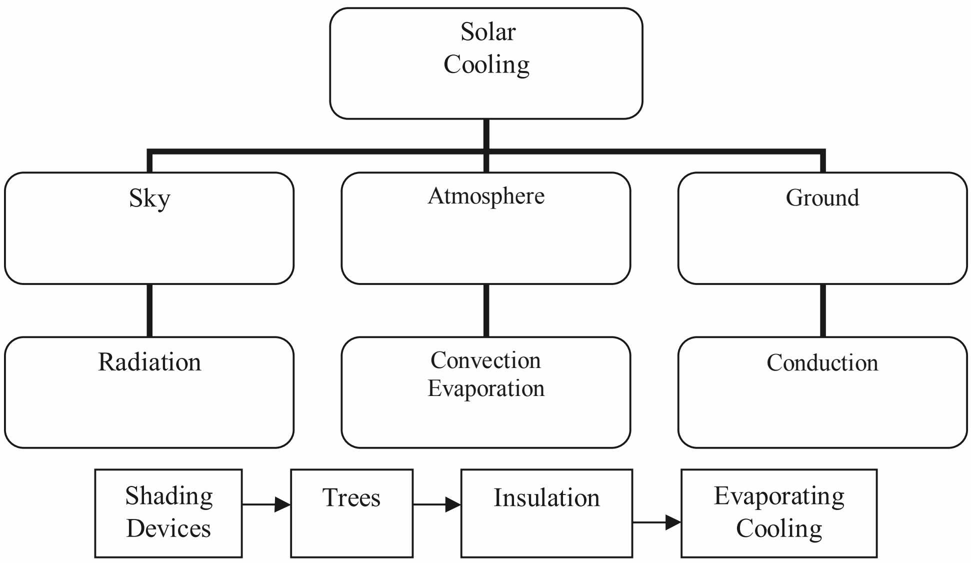

Figure 3.3 : Solar Cooling Systems

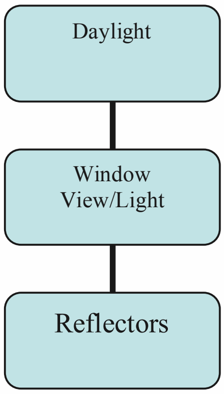

Figure 3.4 : Building Systems

SAQ 2

Explain the design elements of solar buildings.

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3.3 BUILDING DESIGN EVALUATION PROCESS

3.3.1 Solar Building Design Philosophy

In order to understand solar building design features, you must remember that any solar building includes five distinct design elements discussed in Section 3.2.

Before we proceed to look into energy - conscious designs, it would be worth to mention again that passive design concepts involve methods of collecting, storing, distributing, and controlling thermal energy flow through the natural principal of heat transfer. In other words, passive concepts allow energy flow through a building to be manipulated by the building itself. The architect and builder can manipulate existing building components to produce a building which is also its own energy system.

It must be clearly understood that passive design is not a style of building or a packaged technological system that can be plugged into any building type. Passive design is determined by how a building works to store and give off heat from the sun, and how it cools and provides ventilation. Passive design represents a sophisticated response to the environment.

Solar active systems can however be integrated into the building depending upon the requirements and availability of sunlit space.

3.3.2 Solar Building Design Procedure

A typical process for evaluating energy-conscious design procedure is shown in Figure 3.5 and consists of several steps which are elaborated below :

Step 1 : (a) Identification of comfort needs; temperature, humidity, fresh air and light intensity.

(b) Identification of climate resources and constraints; wind, solar radiation, humidity levels, temperature (day time, night time and seasonal).

Step 2 : Identification of energy-conscious designs incorporating thermal aspects as well as luminous aspects. The thermal aspects include orientation, wind break, reflector, sunscreen, greenhouse, insulation, etc. while luminous aspects include skylight, windows, reflectors, etc.

Step 3 : Identification of energy flows of the proposed design. If the design affects thermal energy flows, the specific type of flow (radiation, conduction, convection) as well as season (winter, summer) must be identified. On the other hand, if the design affects the lighting of the building, the source, direction and intensity of the natural light must be identified.

Step 4 : Estimating energy consumption.

Step 5 : Identification of solar active systems which can be integrated into the building to meet part load of the energy requirements.

Step 6 : Identification and evaluation of energy saving resulting from thermal as well as lighting considerations.

Step 7 : Evaluation of cost of the proposed design. Thereafter, comparison of cost of the design with resulting energy savings.

The above steps could be easily demonstrated by taking an example. Suppose that you have decided to build a square shape building. Thereafter, you decide to consult energy-conscious architecture who proposes to you an alternate rectangular design. The consequences of the proposed design could be as follows :

(a) An increase in natural-light levels and decrease in artificial lighting. This would be possible due to placing interior work areas closer to widows.

(b) An increase in the perimeter of the building and thus creating more surface area to heat transfer.

(c) An increase of solar radiation into the building.

The designer now applies energy-conscious design steps and estimates winter conductive heat loss and radiative heat gain, summer conductive heat gain, direct and diffuse natural lighting, etc. and come out of the following recommendation :

(i) Additional winter heating required (additional energy cost) : (-) Rs. 15,000.

(ii) Less summer air conditioning load and hence less energy cost due to lower heat load of the artificial light : (+) Rs. 3,000.

(iii) Energy savings in less required artificial lighting : (+) Rs. 24,000.

(iv) Net savings realized as a result of less consumption of energy : (+) Rs. 12,000.

(v) Additional cost due to exterior wall foundation, and heating and cooling equipment : Rs. 1,00,000.

(vi) Simple return of the investment

$$\frac{12,000 \times 100}{1,00,000} = 12\%$$

The designer now explains to you that simple return on your investment is 12 percent per year. He also tells you that the analysis has ignored the time value of the money and future increase in energy prices which will further push up the benefits.

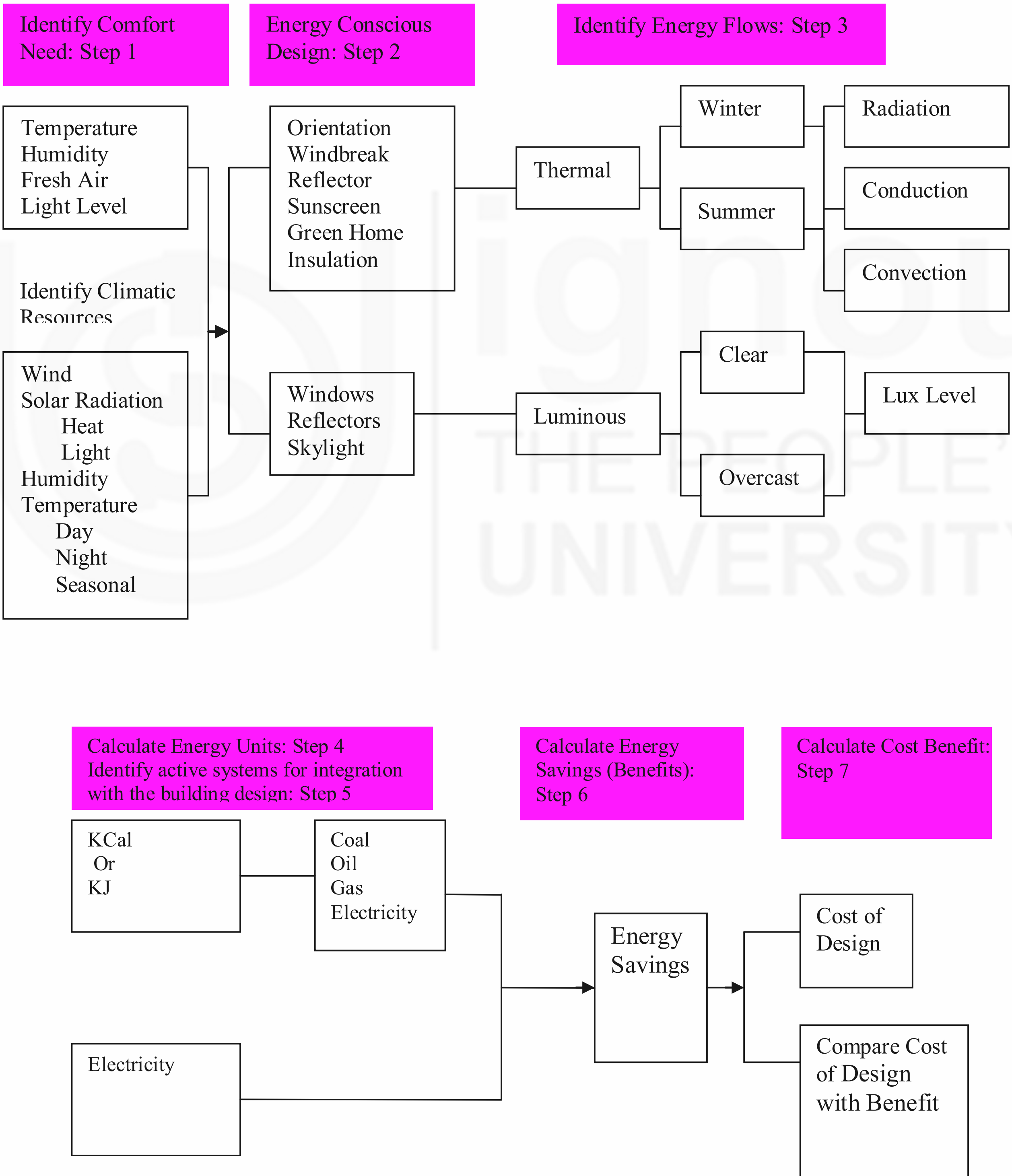

Figure 3.5 : Passive Building Design Evaluation Procedure

3.4 ENERGY CONSIDERATIONS

A designer should be familiar with the thermal as well as luminous (light) energy flows in order to estimate energy savings. A detailed description of these energy flows is beyond the scope of this unit. A brief description is, however, given below.

3.4.1 Thermal Energy Flows

Thermal energy flow is due to conduction, convention and radiation.

Conductive Heat Transfer

Conductive heat transfer is shown in Figure 3.6. It can be represented by the simple relation.

$$q = U\,A\,(T_w - T_c) \qquad \ldots (3.1)$$

where, q = Rate of heat transfer, W,

U = Overall beat transfer efficient of the material through which heat is conducted, W/m^2°C,

A = Cross-sectional area of material, m^2,

T_w = Temperature of the air next to the warmer surface, °C, and

T_c = Temperature of the air next to the cooler surface, °C.

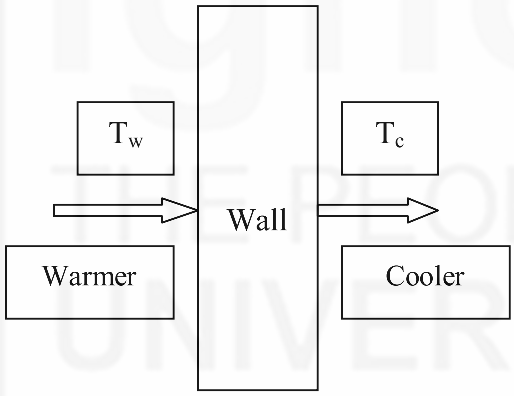

Figure 3.6 : Conductive Heat Transfer

The overall beat transfer coefficient, U depends on the conductivity of the material and thickness of the material and is given by

$$\frac{1}{U} = \frac{1}{U_i} + \frac{1}{(k/l)} + \frac{1}{U_o} \qquad \ldots (3.2)$$

where k = Thermal conductivity of the material, W/m°C,

U_i = Inside heat transfer coefficient, W/m^2°C,

U_o = Out side heat transfer coefficient, W/m^2°C, and

l = Thickness of the material, m.

The thermal conductivity, k, of various building materials is given in Table 3.2. Eq. (3.1) may be written in terms of the thermal resistance, R, in the following form :

$$q = \frac{A\,(T_w - T_c)}{R} \qquad \ldots (3.3)$$

where R = 1/U.

Table 3.2 : Thermal Properties of Selected Building Materials

Material	Description	Specific Heat (KJ/Kg°K)	Density (Kg/m²)	Thermal Conductivity (W/m°K)
Bricks	Common	0.84	1600	0.77
	Face brick	0.84	2000	1.32
	Firebrick	0.96	2000	1.04 to 1.09
Woods	Ply	-	544	0.1
	Hard	2.39	720	0.158
	Soft	2.72	512	0.1
Masonry Materials	Concrete	0.88	1920	1.73
	Plaster, Cement	0.796	1885	8.65
Glass	Window	0.84	2700	0.78
Insulating Materials	Mineral or Glass wool	0.67	24-64	0.038
	Rock wool	-	64	0.067
	Fibre glass Board	0.7	64-144	0.038
	Cork board	1.884	104-128	0.038
	Earth	-	320	0.061
	Asbestos	0.816	470-570	0.154

A designer can cause a change in conductive heat flow by playing with the following variables.

- The values of q can be decreased by decreasing U value or vise-versa.
- The values of q can be decreased by decreasing A value or vise-versa.
- The values of q can be decreased by increasing thickness or vise-versa.
- The values of q can be decreased by reducing temperature difference between the two surfaces or vise-versa.

Convective Heat Transfer

The convective beat transfer is referred to as the movement of heat through fluids or gases. It is associated with phenomenon like infiltration, evaporative cooling, etc. It is expressed as follows :

$$q = h\,A\,\Delta T \qquad \ldots (3.4)$$

where q = Convective heat transfer rate, W,

h = Convective heat transfer coefficient, W/m²°C,

A = Area of surface, m², and

ΔT = Temperature difference of the surface and air, °C.

Radiative Heat Transfer

Radiative heat transfer takes place between two bodies and depends on the surface conditions of both emitting as well as receiving surface. In fact when thermal energy falls on a surface, a fraction of it gets reflected, a fraction gets absorbed and the balance gets transmitted such that

$$\gamma + \alpha + \tau = 1 \qquad \text{. . . (3.5)}$$

where γ = reflectance of the surface,

α = absorptance of the surface, and

τ = transmittance of the surface.

3.4.2 Luminous Energy Flows

Lighting is responsible for about 10 to 18% of total residential energy consumption. Daylight can make internal lighting unnecessary during day time.

It is estimated that with the use of proper colours in the walls, energy efficient CFL, LED and daylight; the lighting consumption can be reduced significantly. Any improvements in window placements and addition of windows, skylights and reflectors etc. can improve lighting quality. Lighting energy needs can be decreased by about 20-40% simply by painting inside walls white or light colour.

Day lighting is an environmental technology, and the concerned architect or designer must be able to analyze the performance characteristics of the system in terms of lighting, comfort, energy use and cost.

Efficacy of the Light Sources

Luminous flux is the amount of light output from a source and is measured in lumen (lm). The lumen output per watt of power consumption is known as efficacy of the lighting source. The lumen output received on a meter square of a surface area is referred to as lux. The efficacy of day light even during overcast day is about 110 1m/W whereas for incandescent lamps it is 10 to 20 1m/W and for fluorescent lamps it is 55 to 90 1m/W.

3.5 SOLAR BUILDING DESIGN ALTERNATIVES

An architect can visualize a number of designs for reducing energy consumption in buildings. Some designs may create a reduction in the energy flow while creating an increase in other, some design may affect changes in more than one energy flow. The broad areas which needs to be considered are the following :

- landscape
- building form
- building components which include walls, glazing, roofs, interiors, etc.
- energy substitution

A conceptual description of such design changes is given in Figure 3.7 and discussed below.

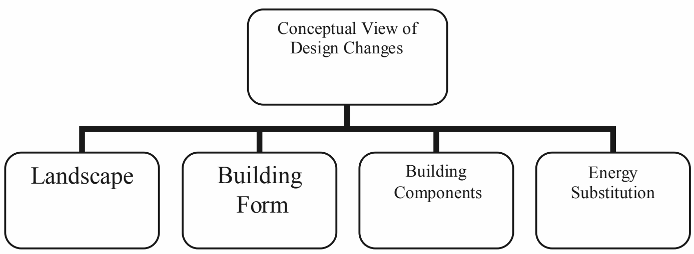

Figure 3.7 : Conceptual View of Design Changes

3.5.1 Landscape

Landscape (Ground reflectance absorption)

Ground surface treatment may be optimized to take maximum advantage of natural day light and solar heat gain. Light coloured ground surfaces for building with interior daylight controls may be ideal for office building. For residential buildings, however, dark colour surface immediately adjacent to windows and light colour further away may be ideal. This combination will take care of winter as well as summer sun. More natural light will be reflected to the building interior.

Landscape (Trees)

The presence of trees leads to reduced infiltration heat losses in winter, reduced heat gain in winter and summer, and reduced natural daylight. Therefore, trees should be planned in such a way that they provide partial shading of windows during summer, natural light is not reduced significantly and act as winter windbreaks.

Landscape (Earth Berms)

The effect of earth berm structures is that winter heat loss and summer heat gain is reduced.

Landscape (Buried Structures and Underground Ventilation Ducts)

The designs using buried structures, underground pipes may be used to extract earth coolness during summer months. Moisture and odor needs to be controlled. Thus, the cooled air may be used into building interior for cooling purposes.

3.5.2 Building Form

Building Form (Atrium)

Atriums or light courts may be on the interior of deep office building and will lead to enough natural daylight. This will also lead to an increase in building volume. The resulting effect is shown in Figure 3.8.

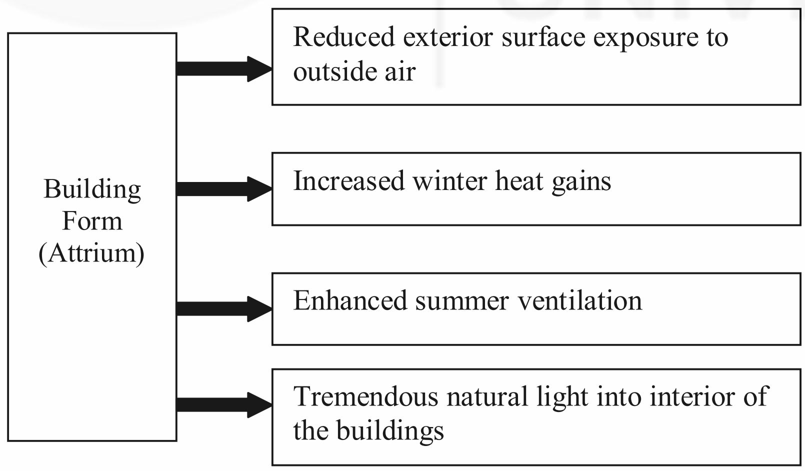

Figure 3.8 : Design Effects of Building Form (Atrium)

Building Form (Configuration)

Building dimensions (length, width and height) may be proportioned to have minimum energy consumption. A large and narrow building will have more access to natural light and hence less electricity consumption for artificial light. The design effects of building forms are shown in Figure 3.9.

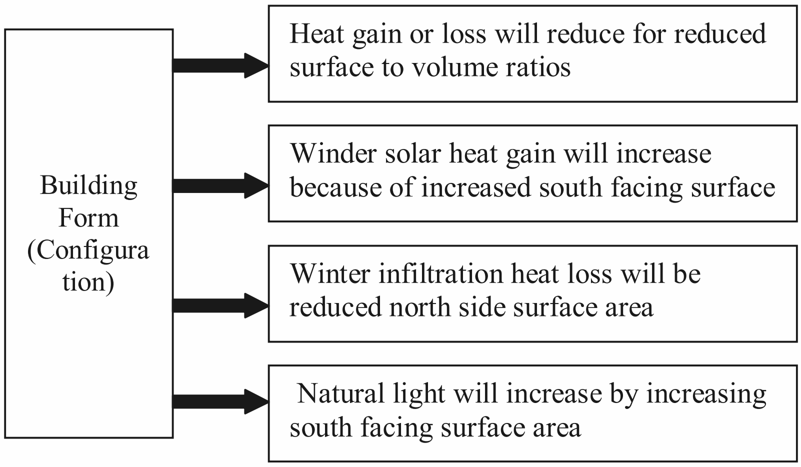

Figure 3.9 : Design Effects of Building Form (Configuration)

Building Form (Orientation)

Orientation is a function of building plan, shape and daylighting controls. All major living spaces such as dining room, study room, living room should face south. The store, kitchen and other utility rooms may be located on north side. The design effects of building orientation are shown in Figure 3.10.

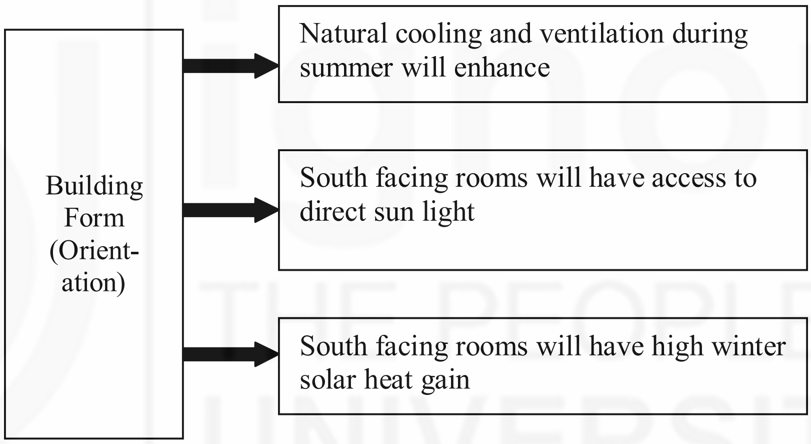

Figure 3.10 : Design Effects of Building Form (Orientation)

3.5.3 Building Components

The details of design changes and the effect of energy flows due to various components are given in Table 3.3.

Table 3.3 : A Conceptual View of Design Changes and Luminous Effect due to Building Components

Sl. No.	Building Component	Design Considerations	
		Luminous Effect	Advantages
1	Exterior shading device	Enhanced lighting because of light reflected from the top of exterior shading	Exterior shading devices are an excellent way to control direct sunlight. A shading device should admit winter sun and keep out summer sun.
2	Reflectors	Increased natural daylight for interior	Suitable reflectors on the south side of a building will increase the amount of natural light. Reflectors may be positioned in such a way that solar radiation is focused on absorbing material inside the building

3	Trombe walls	Natural light is precluded	Trombe wall having glass and masonry will provide solar heat to interior zones.
4	Green Houses	None	Greenhouse on the south side may provide transition living space and plant-growing area. During summer, the glass may need to be shaded by screens.
5	Insulation on Walls	None	Insulation on the interior sides of the wall will help in decreasing heat gain into the building
6	Wall colour	None	Light reflective colour for building where cooling costs are greater than the heating cost and vice-versa.
7	Glazing Area	Natural light will increase with increased glazing area	Increased glazing in office building having daylight controls will reduce artificial lighting need. The heat conductance value of the glazed surface have to be balanced with that of the wall, otherwise heat losses may increase.
8	Glazing Insulation	None	Only during night should be used.
9	Glass Transmission	Tinted or reflective glass will reduce the intensity of natural light	With clear glass, solar heat gain will be more in winter.
10	Window Operation	None	Operative windows will help to increase summer ventilation.
11	Roof Colour	None	White colour roof surface will reduce air-conditioning load and the energy costs.
12	Roof insulation	None	Air conditioning load in summer will be reduced.
13	Roof Pond	None	A roof pond will have cooling effect in summers. Structure strength will need added consideration.
14	Interior Insulating Shades	None	Movable insulations like roll down shades, sliding or hinged shutters etc. will help reduce energy consumption.
15	Air Lock Entrance	None	Air lock entrances will help reduce energy consumption.

3.5.4 Energy Supply Augmentation

Solar water heating systems installed at the roof top of a building will provide hot water as well as shading to the roof, thus reducing summer heating gain and energy consumption. Similarly, roof top solar photovoltaic system will meet part of the electricity load and will result in reducing energy requirements of the building.

3.6 HEAT GAIN THROUGH GLASS

Many passive concepts advocate the use of glass. It is therefore important to analyse how a living space gains heat through glass.

The following factors affect solar heat gain through glass :

(a) Location

(b) Time of the day and year

(c) Orientation of window.

The heat gain comprises :

(i) transmitted solar radiation

(ii) fraction of solar radiation reflected from walls to the room

(iii) heat transmitted as a result of temperature difference between outside and inside.

Let us consider a glass slab shown in Figure 3.11. The heat gain of the space may be evaluated as follows :

(a) solar radiation strikes the glass slab (window)

(b) a part of the radiation is reflected back and a part is transmitted to the room.

(c) A part is absorbed by the glass slab.

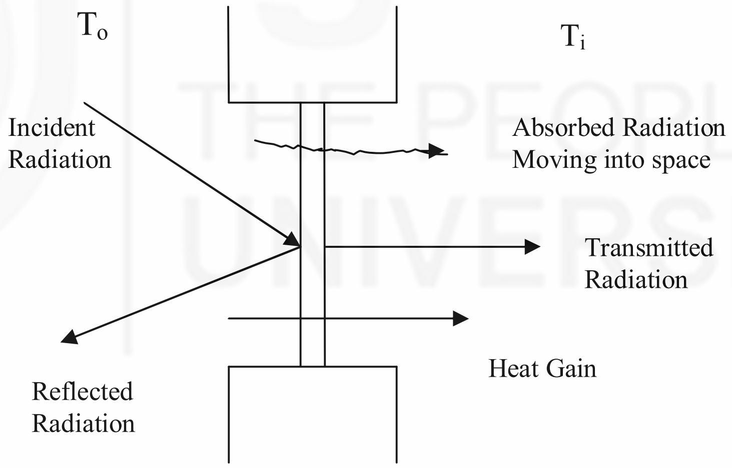

Figure 3.11 : Heat Transfer through Glass Slab

Heat gain into the room through glass slab, Q, is given by

$$Q = U\,A\,(T_o - T_i) \qquad \ldots (3.6)$$

where, Q = Heat transfer (Heat Gain), W,

U = Overall heat transfer efficient, W/m^2 ºC,

A = Cross-sectional area of the glass, m^2,

T_o = Temperature of the air outside the window, ºC, and

T_i = Temperature of the air inside the window, ºC.

The heat transfer coefficient U may be evaluated as discussed in Eq. (3.4).

Example 3.1

For a glass slab shown in Figure 3.12, the following data are given :

Incident solar radiation = 800 W/m^2

T_o = 40 ºC

T_i = 20 ºC

U_i = Inside heat transfer coefficient = 17.5 W/m^2 ºC

U_o = Out side heat transfer coefficient = 11.5 W/m^2 ºC

A = 6 m^2

Thermal conductivity of glass k = 0.78 W/m-ºC

Thickness of the glass l = 0.002 m

Determine the heat gain due to temperature difference on the two sides of the glass slab. If the transmitted heat is 2000 W, determine the total heat gain.

Solution

Let us first calculate the value of U given by Eq. (3.4)

$$\frac{1}{U} = \frac{1}{U_i} + \frac{1}{(k/l)} + \frac{1}{U_o}$$

= 1/17.5 + 1/(0.78/0.002) + 1/11.5

= 0.057 + 0.002564 + 0.0869

= 0.1464

or U = 6.83 W/m^2 ºC

Thus using Eq. (3.6), the heat gain through glass slab is

$Q = U A (T_o - T_i)$

= 6.83 × 6 × (40 – 20)

= 820 W

Thus, the heat gain = 2000 W + 820 W = 2820 W.

3.7 EMBODIED ENERGY OF MATERIALS

The materials used in construction of buildings also consume energy. It is desirable to focus on alternate materials, which consume less energy to reduce the overall energy consumption of a building. Energy in materials is consumed in

- Production of basic raw materials
- Processing of raw materials to make finished product
- Fabrication of Different Building Systems.

Based on energy intensity, which is the sum of three components of energy as indicated above, building materials are categorized into three types :

- High energy materials (energy intensity > 5.0 GJ/tonne) (such as aluminum, steel, plastics, glass, cement, etc.)
- Medium energy materials (energy intensity between 0.5 – 5.0 GJ/tonne) (such as concrete, lime plaster, fly-ash, fireclay bricks, etc.)
- Low energy materials (such as coarse aggregates).

A number of studies have been carried out to evaluate energy intensity of different materials; however, this is outside of the scope of this study. In general, the materials made locally are less energy intensive. The examples of such materials include fly ash, compressed earth blocks, precast hollow concrete blocks, bamboo/timber mat based walls, cement bonded fibre roofing sheets, micro concrete roofing tiles, particle boards.

3.8 GREEN BUILDINGS

Did you ever think that the buildings, in which you live, have major environmental impact? For their construction and during the period of their habitation, natural resources such as ground cover, forests, water, and energy are consumed. Modern day buildings have a tendency to use designs and materials which are resource-intensive and are quite often operate in isolation with the nature. Such buildings are very poor in energy efficiency and generate a lot of waste, adding to faster depletion of natural resources. Thus, buildings are seen today as one of the major pollutants to affect urban air quality and contribute to climate change.

Therefore, you will agree not to allow these practices to continue, especially when you have wealth of experience and wisdom in constructing buildings which work in tandem with nature.

Green Buildings do not refer to buildings which are green in colour, or have been constructed with green parks around. Green buildings refer to a conscious practice of addressing issues of resource conservation in an integrated and scientific manner. **By definition, a green building is one which uses less water, optimizes energy efficiency, conserves natural resources, generates less waste and provides healthier spaces for occupants, as compared to a conventional building.**

A green building depletes very little of the natural resources during its construction and operation. The aim of a green building design is to :

- Minimize the demand on non-renewable resources and maximize the utilization efficiency of these resources when in use maximize reuse and recycling of available resources.
- Utilization of renewable resources.

It maximizes the use of efficient building materials and construction practices; optimizes the use of on-site sources and sinks by bio-climatic architectural practices; uses minimum energy to power itself; uses efficient equipment to meet its lighting, air-conditioning, and other needs; maximizes the use of renewable sources of energy; uses efficient waste and water management practices; and provides comfortable and hygienic indoor working conditions. In particular, the following aspects of the building design are looked into in an integrated way in a green building :

- Site planning.
- Building envelope design.
- Building system design including that of HVAC (heating, ventilation and air conditioning), lighting, electrical, and water heating.
- Integration of renewable energy sources to generate energy onsite.

- Water and waste management.
- Selection of ecologically sustainable materials (with high recycled content, rapidly renewable resources with low emission potential, etc.).
- Indoor environmental quality (maintains indoor thermal and visual comfort and air quality).

It may be true that the cost of a green building is little more, however, it has been proven that it costs less to operate a green building, besides its tremendous environmental benefits and providing better place for the occupants to live and work in. Thus, the challenge of a green building is to achieve all its benefits at an affordable cost.

3.9 GREEN BUILDING RATING SYSTEM

You have learnt about green buildings. But, one of the important questions which the owner of such a building or designer would like to know is how successful he has been in creating such a building. Globally, Building Rating Systems have been developed and found quite effective. Most of the internationally devised rating systems have been tailored to suit the building sector of the country where they were developed.

In India, two rating systems are being practiced. Both the rating systems promote whole-building approach to sustainability and environment protection, and provide tools to design, construct and operate green buildings. These rating systems are not mandatory but are voluntary.

SAQ 3

(a) What are the advantages of green buildings?

(b) What products are used in green buildings?

(c) Are green buildings environment friendly?

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3.9.1 LEED Rating System

LEED Rating system is an adaptation of US based LEED (Leadership in Energy and Environmental Design) Rating System, and is being implemented by Indian Green Building Council. The certification level is as per the points scored by the building based on the specified criterion. The highest rating is Platinum.

Point Scored	LEED Certification level
26-32	Certified
33-38	Silver
39-51	Gold
52 or more	Platinum

3.9.2 GRIHA Rating System

GRIHA, *Green Rating for Integrated Habitat Assessment,* is promoted by The Energy Resource Institute (TERI) and the Ministry of New and Renewable Energy, Govt. of India. GRIHA has a 100 point system consisting of some core points, which are mandatory to be met while the rest are optional points, which can be earned by complying with the commitment of the criterion. Different level of certification (one star to five star) is awarded based on the number of points earned. The minimum points required for certification is 50.

Point Scored	Number of Stars Earned by the Building
50-60	One star
61-70	Two star
71-80	Three star
81-90	Four star
91-100	Five star

3.10 LET US SUM UP

Solar active systems make use of solar collectors to convert sun's energy into useful heat for different applications like hot water requirement and space heating. Solar water heaters are used for hot water applications and space heating purposes while solar air heaters are used for space heating applications.

Solar building includes five distinct design elements. These are :

- **A Collector :** A large glass area through which sunlight is allowed to enter the building.
- **An Absorber :** A dark surface of the storage element that absorbs the solar heat.
- **A Thermal Mass :** The material that stores the absorbed heat.
- **A Heat Distribution System :** The heat distribution could be natural using the concept that heat flows from warmer materials to cooler. This could also be done with the help of fans, ducts, and blowers to circulate the heat (Active System).
- **A Control Mechanism :** This is needed to regulate the amount of sunlight entering the building.

A typical process for evaluating energy-conscious design procedure consists of several steps :

1. Identification of comfort needs; temperature, Humidity, fresh air and light intensity and identification of climate resources and constraints; wind, solar radiation, humidity levels, temperature (day time, night time and seasonal).
2. Identification of energy-conscious designs incorporating thermal aspects as well as luminous aspects. The thermal aspects include orientation, wind break, reflector, sunscreen, greenhouse, insulation, etc. while luminous aspects include skylight, windows, reflectors, etc.

3. Identification of energy flows of the proposed design. If the design affects thermal energy flows, the specific type of flow (radiation, conduction, convection) as well as season (winter, summer) must be identified. On the other hand, if the design affects the lighting of the building, the source, direction and intensity of the natural light must be identified.

4. Estimating energy consumption.

5. Identification of solar active systems which can be integrated into the building to meet part load of the energy requirements.

6. Identification and evaluation of energy saving resulting from thermal as well as lighting considerations.

7. Evaluation of cost of the proposed design. Thereafter, comparison of cost of the design with resulting energy savings.

It is estimated that with the use of proper colours in the walls, energy efficient CFL and daylight; the lighting consumption can be reduced significantly. Any improvements in window placements and addition of windows, skylights and reflectors, etc. can improve lighting quality. Lighting energy needs can be decreased by about 20-40% simply by painting inside walls white or light colour.

The concepts of green buildings are becoming popular, which results in overall conservation of resources in addition to energy conservation. Such buildings use construction materials with less embodied energy, employ energy efficient building equipments, integrate solar active systems, besides waste recycling etc.

Green buildings refer to a conscious practice of addressing issues of resource conservation in an integrated and scientific manner. By definition, a green building is one which uses less water, optimizes energy efficiency, conserves natural resources, generates less waste and provides healthier spaces for occupants, as compared to a conventional building.

A green building depletes very little of the natural resources during its construction and operation.

3.11 KEY WORDS

Active Systems

Energy collection and storage is by forced means.

Efficacy

The term is used for the light sources. The lumen output per watt of power consumption is known as efficacy of the lighting source.

Green Buildings

Green buildings refer to a conscious practice of addressing issues of resource conservation in an integrated and scientific manner. Green building is one which uses less water, optimizes energy efficiency, conserves natural resources, generates less waste and provides healthier spaces for occupants, as compared to a conventional building.

Hybrid Systems

Energy collection and storage can be by natural means.

Luminous Flux

The amount of light output from a source, measured in lumen (lm).

Passive Systems

Energy collection and storage is by natural means.

3.12 ANSWERS TO SAQS

SAQ 1

The two main features of three main types of building are the following :

Passive Systems	Hybrid Systems	Active Systems
Energy collection and storage is by natural means	Energy collection and storage can be by natural means	Energy collection and storage is by forced means
Energy distribution is by natural means	Energy distribution from collector to storage or from storage to living space is by mechanical means	Energy distribution is by forced means

SAQ 2

A solar building has the following distinct design elements :

1. A large glass area through which sunlight is allowed to enter the building. It is called a collector.
2. A dark surface of the storage element that absorbs the solar heat. It is called an absorber.
3. **A** thermal mass that stores the absorbed heat. This can be masonry materials such as concrete, stone, and brick or a water tank.
4. A heat distribution system. This could be natural using the concept that heat flows from warmer materials to cooler ones. This could also be done with the help of fans, ducts, and blowers etc. to circulate the stored heat.
5. A control mechanism for regulating the amount of sunlight entering the building. This can be as simple as roof overhang designed to allow more sunlight to enter in the winter, less in the summer.

SAQ 3

(d) Some of the important advantages of green buildings are :

- Reduced maintenance and replacement costs over the life of the building.
- Energy conservation.
- Improved health and productivity of the occupants.
- Lower costs associated with changing space configurations.
- Greater design flexibility.

(e) The products used in green buildings are :

Building materials typically considered to be 'green' include rapidly renewable plant materials like bamboo and straw, lumber from forests certified to be sustainable managed, recycled stone and recycled metal. Other products that are non-toxic, reusable, renewable, and/or recyclable e.g. sheep wool, panels made from paper flakes, baked earth, rammed earth, clay, vermiculite, flax linen, sisal, sea grass, cork, expanded clay grains, coconut, wood fiber plates and calcium sand stone.

(f) The green buildings are environment friendly because of the following reasons :

- **Energy Efficiency :** Building structures, mechanical and electric systems, heating, and lighting that use minimal energy while providing the same comfort levels as conventional energy systems.
- **Water Efficiency :** Water fixtures; re-use techniques, and other measures that reduce water use while providing the service expected by occupants.
- **Site Use :** Minimization of land used for a building, location near public transportation, erosion prevention, and other techniques that reduce impacts on surrounding land.
- **Material Use :** Recycled, easily regenerated, or efficiently produced materials and building techniques that minimize the materials required for a building.
- **Indoor Environmental Quality :** Use of non-toxic materials, good ventilation, day lighting, and other improvements to the indoor environment that increase occupants' comfort and productivity.

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UNIT 4 SOLAR GREENHOUSES

Structure

4.1 Introduction

Objectives

4.2 Greenhouse Effect

4.3 Impact of Greenhouse Effect in Nature

4.3.1 Greenhouse Gases

4.3.2 Climate Change

4.3.3 Steps for Reducing Greenhouse Effect in Nature

4.4 Solar Greenhouse

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4.4.2 Active Solar Greenhouse

4.4.3 Solar Heat Storage

4.5 Designing of Solar Greenhouses

4.6 Let Us Sum Up

4.7 Key Words

4.8 Answers to SAQs

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4.1 INTRODUCTION

Solar greenhouses are the enclosures where crops, vegetables, flowers and plants can be grown under unfriendly climatic conditions. You know that the plant growth gets affected by availability of light, moisture, ambient temperature and carbon dioxide. It is possible to design enclosures which admits sunlight when it is desired and at the same time controls inside temperature within acceptable range. Usually, solar greenhouse find application in cold areas where vegetation is damaged due to extreme low temperatures. You will be happy to see that the greenhouse effect is a natural process.

You have already studied the solar radiation and its characteristics in OEY-002, Block 1, Unit 1. The amount of solar radiation incident on the earth's surface is almost constant and has the value of 1347 W/m^2 and is called the solar constant. A faction of the solar radiation is reflected back to the atmosphere by the clouds and the earth's surface. The radiation reflected by the clouds is called the albedo and has the value of about 30%. A fraction of the radiation is absorbed by the earth's surface until it emits the same amount of radiation. The radiation emitted by the earth's surface at room temperature is in infrared range.

After studying this unit, you will be able to :

- understand greenhouse effect,
- different types of greenhouses,
- design principles of greenhouses, and
- different uses of greenhouses.

4.2 GREENHOUSE EFFECT

It is only because of greenhouse effect that our life on Earth is possible to a great extent. Imagine for a moment that natural greenhouse in not there. What will be its effect? Without natural greenhouse the Earth's surface temperature would be 33°C cooler – a chilly – 18°C rather than the tolerable 15°C. The natural greenhouse is due to naturally occurring greenhouse gases such as water vapour, carbon dioxide, methane and nitrous oxide. If this is so then you may be wondering why we are so afraid with greenhouse effect. The reason of our worry is that due to rapid industrialization and extensive use of fossil fuels, the concentrations of greenhouse gases are increasing at an alarming rate.

The greenhouse effect is referred to the rise in temperature due to absorption of infrared radiation. You may better understand the greenhouse effect by seeing the Figure 4.1. You can see that earth absorbs the solar radiation. The earth emits long wavelength infrared radiations. These radiations are absorbed by the greenhouse gases and hence can't escape. The net effect is the result of increase of mean annual temperature.

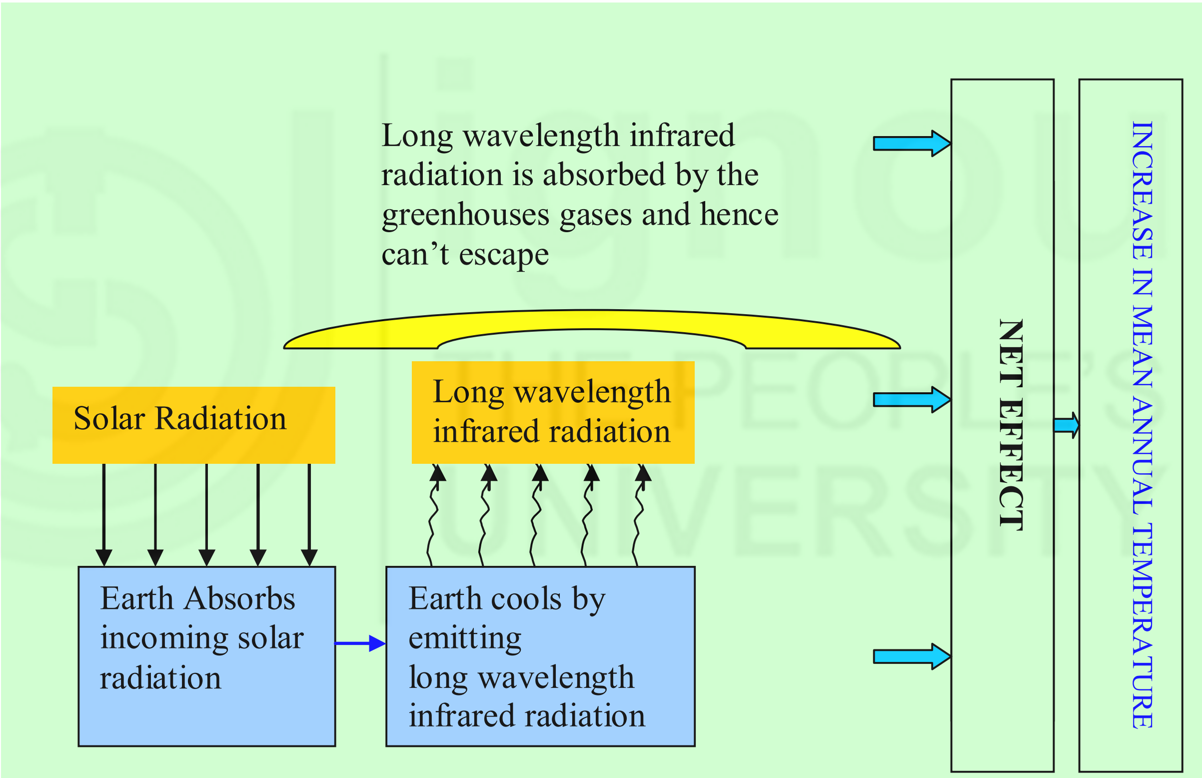

Figure 4.1 : Greenhouse Effect

Let us further understand this by examining the greenhouse effect as depicted in Figure 4.2. The following things are happening :

(1) The solar radiation is incident on the upper atmosphere.

(2) A fraction of it is absorbed by the earth.

(3) A fraction of the radiation absorbed by the earth is radiated towards the atmosphere.

(4) A faction of the radiation absorbed by the atmosphere is reflected back to outer space.

(5) The atmosphere emits radiation towards upper atmosphere and towards earth.

If the atmosphere absorbed all the infrared radiation emitted by the earth and continue to transmit all the incident radiation, the atmosphere will get heat up. The atmosphere radiates into outer space and towards the earth's surface in equal amounts. The earth's surface receives more radiation and gets heat up. This is greenhouse effect.

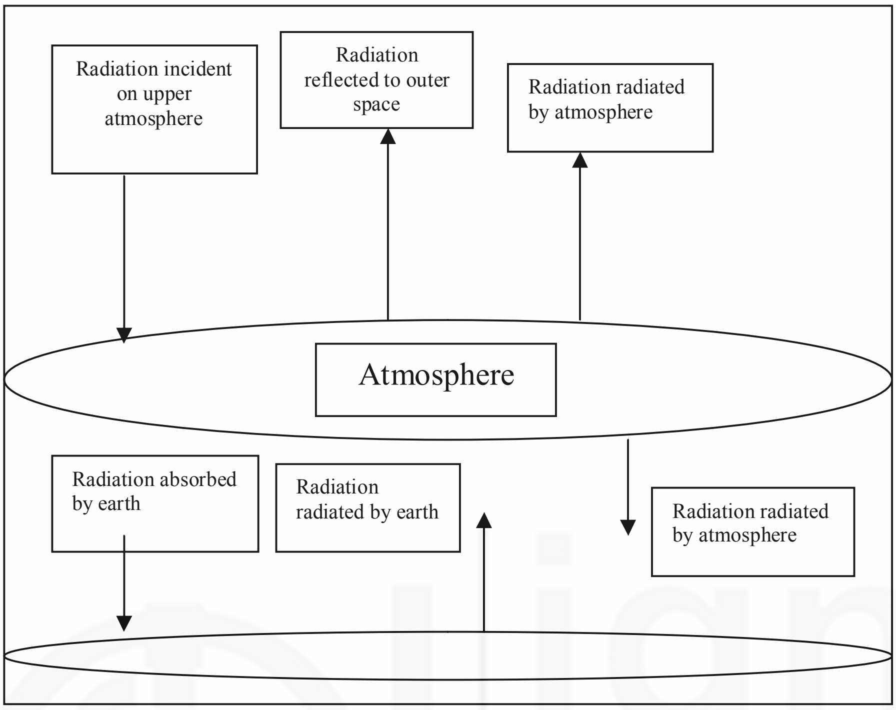

Figure 4.2 : Overview of Greenhouse Effect

4.3 IMPACT OF GREEHOUSE EFFECT IN NATURE

Before discussing details of solar greenhouses, it would be interesting for you to learn how the greenhouse effect in nature is affecting us, and how we can contribute in decelerating its growth.

The impact of greenhouse effect is the Global warming which is turn is affecting entire ecosystem and health of the people. The significant temperature rise is going to have drastic social, economic and ecological implications. The global warming is affecting the human society in many ways like causing the storms, hurricanes, floods and droughts, glaciers and polar ice is melting, sea levels is rising, forest fires cases are increasing and tropical diseases are increasing.

4.3.1 Greenhouse Gases

The naturally occurring greenhouse gases are water vapour, carbon dioxide, methane and nitrous oxide. The man made greenhouse gases are also the same. What actions generate these greenhouse gases is given in Table 4.1.

Table 4.1 : Greenhouse Gases and their Source

Sl. No.	Greenhouse Gas	Action Responsible for Generation of Greenhouse Gas
1	Carbon dioxide, CO_2	Burning of fossil fuels
2	Methane, CH_4	Anaerobic bacteria in rice fields, sewage
3	Nitrous Oxide, N_2O	Fossil fuels and fertiliser
4	Chlorofluorocarbon, CFCs	Refrigeration

We are approximately depositing 2 billion extra tonnes of carbon as shown in Figure 4.3.

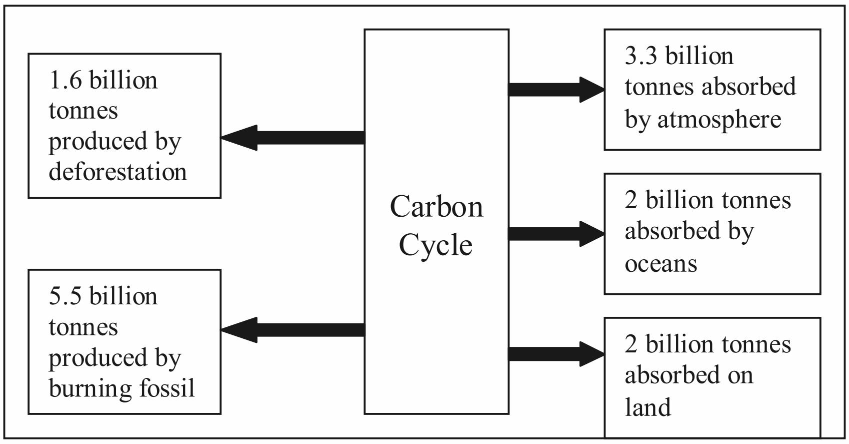

Figure 4.2 : Carbon Cycle

4.3.2 Climate Change

You will be surprised to know that various climatic models developed to predict the atmospheric temperature indicate that the atmospheric temperature is going to increase by between 1.5 and 4.5°C by the year 2100 if significant efforts are not made to control the emissions of greenhouse gases. An increase of about 5°C in the global temperature since the last ice age (10,000 years ago) has already happened. It is estimated that the Earth's average temperature has risen by 0.5 to 0.6°C since 1880 because of emissions of greenhouse gases from burning of fossil fuels and other human activities.

You can see the effect of rising temperature by observing the Figure 4.2. You can see that rising temperature leads to multiple effects like changes in regional wind systems, global rainfall, coral bleaching, destruction of coral reefs, growth in insect populations, negative effect on agriculture and human health, etc.

At this point, you may be in a position to differentiate between the greenhouse effect, global warming and climate change. All these three terms are interlinked. You may understand these terms in better ways by considering a problem and then its consequence or cause and its effect as shown in Figure 4.3. You can see that the greenhouse effect is the cause and global warming and climate change are the consequences. The increase in the temperature of the Earth's lower atmosphere is the global warming. The alterations such as rainfall patterns, evaporation and cloud formation result in climate changes.

4.3.3 Steps for Reducing Greenhouse Effect in Nature

Now you may be thinking what an individual can do about greenhouse effect. Each one of us can help to reduce the impact of greenhouse. Some of the simple steps are listed below :

A : Greenhouse Education

- You should make serious efforts to know all about the greenhouse effect, global warming and climate change.
- You must understand that consumption of the fossil fuels in making our energy requirements produces greenhouse gases which are responsible for greenhouse effect.
- Consuming more energy therefore leads to more greenhouse effect.
- You should make serious efforts to know about alternate energy sources.

B : Energy Conservation

- Energy conservation is in your hands. You should always remember that energy saved is more than the energy produced.
- The main greenhouse gas, CO_2, comes from the burning of fossil fuels. You can help in reducing the emissions of CO_2 by reducing consumption of electricity and energy in transportation.
- A car produces CO_2 roughly 2 tonnes per year.

You will learn more about energy conservation in OEY-003. We will give some tips which you can follow immediately for saving electricity.

C : Save Electricity

- Switch off the lights and any other electrical appliances (like ACs, TVs, radio) when not in use.
- Start making use of energy efficient lamps.
- Always use energy efficient appliances. They may cost more initially but will be more advantageous in long run.

D : Save Petroleum Fuels

- Easiest and more effective way is to reduce private transport. You may adopt a car pool to go to work or elsewhere.
- Make sure that your own vehicle is fuel efficient.

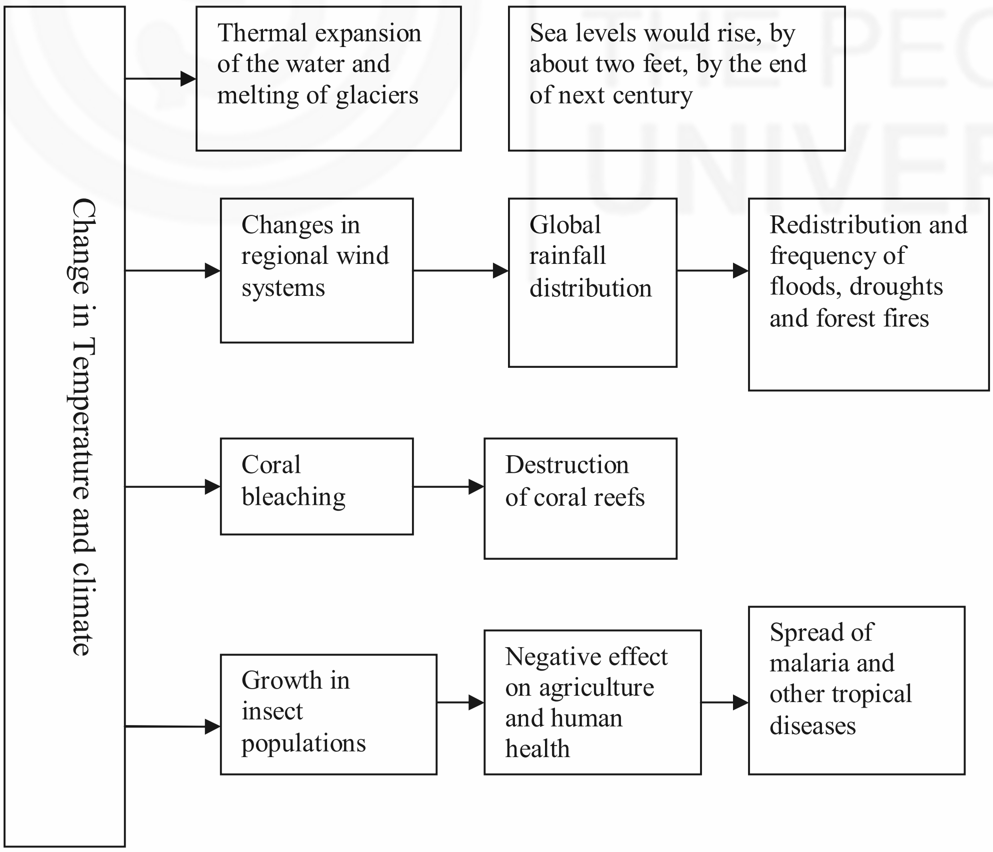

Figure 4.3 : Effect of Change of Temperature and Climate

SAQ 1

Give five steps which you can follow in order to reduce the effect of greenhouse.

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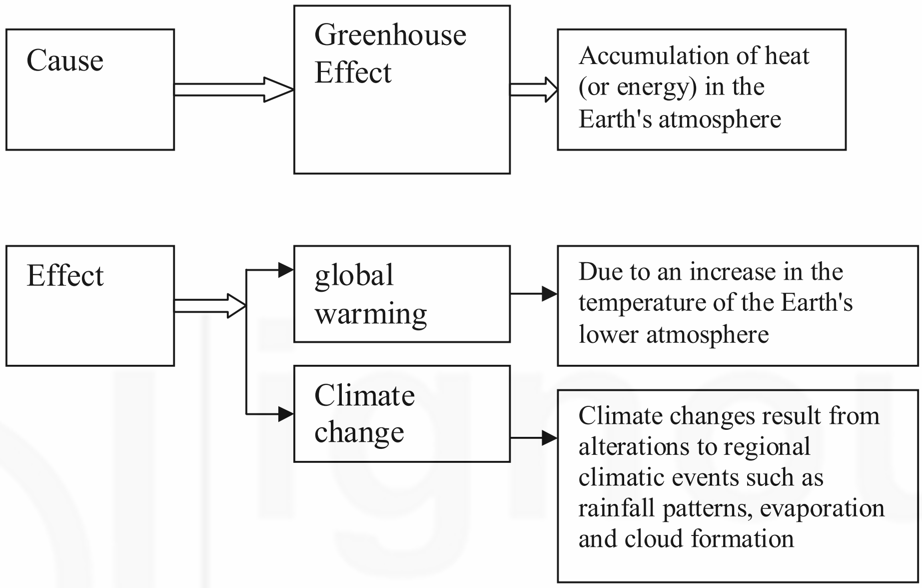

Figure 4.3 : Difference between Greenhouse Effect, Global Warming and Climate Change

SAQ 2

What are the effects of global warming?

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4.4 SOLAR GREENHOUSE

The most important purpose of a greenhouse is to collect solar energy to raise the indoor temperature and also store heat for use during night. Solar greenhouses are climate controlled.

The crops may be grown in solar greenhouses under favorable controlled environment, viz. temperature, humidity, light intensity, ventilation, soil media, disease control, irrigation and other agronomical practices throughout the season irrespective of the natural conditions outside.

The greenhouse technology available today is suitable for :

- Production of vegetable crops.
- Production of off-season flowers, vegetables.
- Production of roses, carnation, cut-flowers, etc.
- Plant propagation, raising of seedlings.
- Primary and secondary hardening nursery of Tissue cultured plant.

The basic principle of solar greenhouses is that the solar radiation coming from sun passes through the glass cover, but the radiation emitted by the heated surfaces present inside the enclosure cannot escape as the glass is opaque for longer wavelength radiation.

SAQ 3

Explain the difference between greenhouse effect, climate change and global warming.

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An interesting thing about solar greenhouses is that there are choices to choose from and to suit the needs for various applications. Solar greenhouses could be of stand alone structure type to cater to larger capacity requirements. Solar greenhouses are also constructed to meet limited domestic requirements of growing vegetables as an attachment to the existing building. Depending upon the use of auxiliary energy source, the solar greenhouses are broadly classified as passive and active greenhouse. These two makes use of different resources, but still serve a same purpose.

4.4.1 Passive Solar Greenhouse

The passive solar greenhouse does not make use of mechanical devices like motors, fans, etc. for transferring the solar heated air from the storage area to the other parts of the greenhouse.

4.4.2 Active Solar Greenhouse

The active solar greenhouse makes use of mechanical devices like motors, fans etc for transferring the solar heated air from the storage area to the other parts of the greenhouse.

4.4.3 Solar Heat Storage

The main feature in designing a solar greenhouse is that there must be sufficient amount of solar heat stored for use when sun is not shining. The solar energy can be stored by making use of rocks or concrete, etc. in the floor and the walls of the greenhouse.

4.5 DESIGNING OF SOLAR GREENHOUSE

Solar greenhouses have the following features :

- Solar greenhouse should be elongated along east-west axis to have longer south side to allow receipt of maximum solar radiation.
- North wall could be made opaque, especially in regions where sub-zero ambient temperatures are experienced.
- To prevent one sided growth of the plants, ceiling and upper part of the north wall should be made white painted to reflect sunlight onto the plants.
- Double glass cover can also be used in regions with severe winters for constructing solar greenhouse.
- Provision of openings to be provided to evacuate extra heat through ventilation during periods of temperatures higher than acceptable.
- Solar greenhouse makes use of heat storing materials to retain solar heat. Pebbles can be provided in the floor with top surface painted in dark colour to capture maximum solar heat. This heat can be blown in during night to keep inside warm.
- Plastic sheets can also be used in place of glass for constructing solar greenhouse, however, these needs to be UV_stabilized to have their longer life.

4.6 LET US SUM UP

While discussing about solar greenhouses, in this unit you have learned all about greenhouse effect, global warming and climate change. You have also learned how to reduce their impact.

The greenhouse effect is referred to the rise in temperature due to absorption of infrared radiation. The Earth absorbs the incoming solar radiation. The earth emits long wavelength infrared radiations. These radiations are absorbed by the greenhouse gases and hence can't escape. The net effect is the result of increase of mean annual temperature.

The impact of greenhouse effect is the Global warming which is turn is affecting entire ecosystem and health of the people. The global warming is affecting the human society in many ways like causing the storms, hurricanes, floods and droughts, glaciers and polar ice is melting, sea levels is rising, forest fires cases are increasing and tropical diseases are increasing.

The naturally occurring greenhouse gases are such as water vapour, carbon dioxide, methane and nitrous oxide. The man made greenhouse gases are more or less similar. The main source of the greenhouse gases is the burning of fossil fuels for various applications. It is estimated that we are adding about 2 billion tons of carbon in the overall carbon cycle.

The rising temperature leads to multiple effects like changes in regional wind systems, global rainfall, coral bleaching, destruction of coral reefs, growth in insect populations, negative effect on agriculture and human health, etc.

The greenhouse effect, global warming and climate change are interlinked. The greenhouse effect is the cause and global warming and climate change are the consequences. The increase in the temperature of the Earth's lower atmosphere is the global warming. The alterations such as rainfall patterns, evaporation and cloud formation result in climate changes.

The solar greenhouse technology available today is suitable for production of vegetable crops; production of off-season flowers, vegetables; production of Roses, Carnation, cut-flowers, etc. plant propagation, raising of seedlings; primary and secondary hardening nursery of tissue cultured plant. This technology has high potential in areas with severe winter conditions.

4.7 KEY WORDS

Carbon Dioxide (CO_2)

A product of combustion.

Carbon Monoxide (CO)

A colorless, odorless, highly poisonous gas made up of carbon and oxygen molecules formed by the incomplete combustion of carbon.

Chlorofluorocarbons (CFSs)

A family of artificially produced chemicals; used as refrigerants, solvents and in the production of foam material; composed primarily of carbon, hydrogen, chlorine, and fluorine.

Greenhouse Gases

The greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and water vapor (H_2O). They allow visible light and ultraviolet light (short-wave radiation) to pass through the atmosphere and heat the earth's surface. This heat is re-radiated from the earth in form of infrared energy (long-wave radiation). The greenhouse gases absorb part of that energy before it escapes into space.

Greenhouse Effect

A warming of the Earth and its atmosphere caused by greenhouse gases and water vapor trapping heat from the sun.

4.8 ANSWERS TO SAQS

SAQ 1

The five steps for reducing the impact of greenhouse effect are :

(1) Greenhouse Education : Know all about the greenhouse effect, global warming and climate change and make others also to know about them.

(2) Know About Alternate Energy Sources : You should make efforts to know renewable energy sources and how to use them.

(3) Adopt Energy Conservation : It is in your hands. Always remember that energy saved is energy produced.

(4) Save Electricity : Switch off some thing some where which is not in use, starting using energy efficient appliances.

(5) Save Petroleum Fuels : Make sure that your own vehicle is fuel efficient.

SAQ 2

Global warming is the consequence of the greenhouse effect and is causing harm to the environment and health of the people. The significance effects of global warming are (1) harm to the entire ecosystems, (2) the storms, hurricanes, floods and droughts are increasing, (3) glaciers and polar ice is melting, (4) sea levels is rising, (5) forest fires cases are increasing and (6) tropical diseases are increasing.

SAQ 3

The greenhouse effect, global warming and climate change are interlinked. The greenhouse effect is the cause and global warming and climate change are its consequences. The increase in the temperature of the Earth's lower atmosphere is the global warming. The alterations such as rainfall patterns, evaporation and cloud formation result in climate changes.

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