ANNEXURE 3

PASSIVE ARCHITECTURE DESIGN SYSTEMS

Eco-housing Assessment Criteria - Version II

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Table of Contents

1 INTRODUCTION

Passive Architecture involves blending conventional architectural principles with solar & wind energy and the inherent properties of building materials to ensure that the interiors remain warm in winter and cool in summer, thus creating a year-round comfortable environment.

In passive building designs, the passive system is integrated into the building elements and materials. It should be understood that passive architectural design does not necessarily mean the elimination of standard mechanical systems. In recent designs however, passive systems coupled with high efficiency back-up systems greatly reduce the size of the traditional heating or cooling systems and reduce the amount of non-renewable fuels needed to maintain comfortable indoor temperatures.

2 CLIMATE ZONES IN INDIA

Passive designs need to be considered in the context of five distinct climatic zones that are identified and used as reference by the National Building Code (NBC) and the Energy Conservation Building Code (ECBC 2007).These are as below –

1. Hot and Dry – e.g. Ahmedabad, Jaipur
2. Warm and Humid – e.g. Mumbai, Chennai
3. Cold (Including Cold and sunny and Cold and Dry) – e.g. Shimla, Leh
4. Composite – e.g. Delhi
5. Moderate/Temperate – e.g. Bangalore

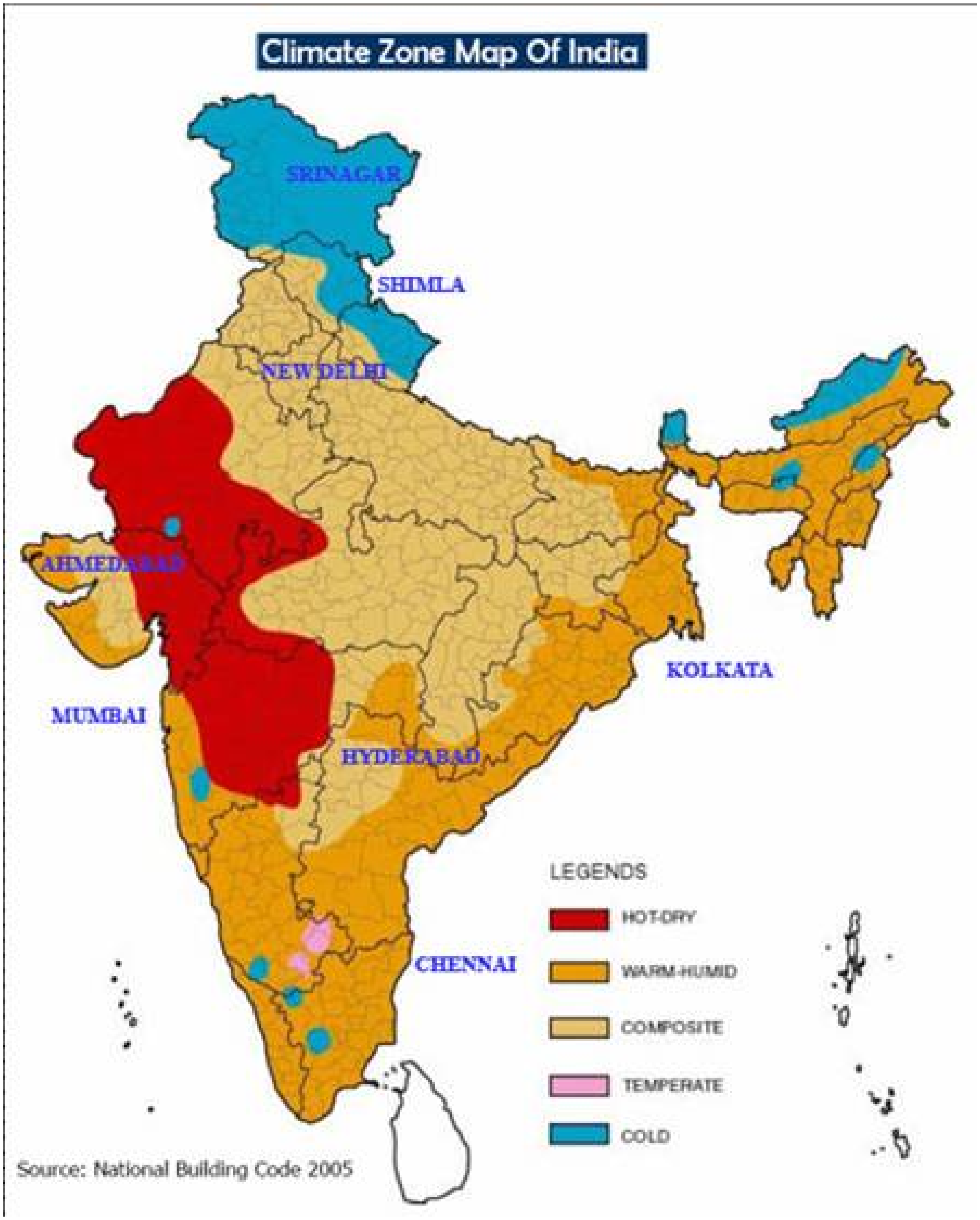

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Figure 1 *Climatic Zones in India*

3 DIFFERENT PASSIVE ARCHITECTURE DESIGN SYSTEMS

The following sections describe various passive technologies that can be adopted in the various climatic zones in India. Each of the passives design systems described, indicates the suitable climatic zone for application. List of passive architecture aspects discussed in this section include the following:

- Thermal mass construction
- Wind towers
- Passive down draft evaporative cooling systems
- Earth tunnel cooling
- Roofing systems
- Roof gardens
- Roof and wall insulation
- Trombe wall
- Solar chimney
- Light shelf

3.1 Thermal Mass Construction

Intent	–	Energy saving in Cooling and Heating
Suitable Climatic zones	–	Hot and Dry, Composite

3.1.1 Technology description/principle

Thermal mass is the ability of a material to absorb heat energy, store it, and at a later time, release it in support of maintaining uniform temperature profiles.

A lot of heat energy is required to change the temperature of high density materials like concrete, bricks and tiles. They are therefore said to have high thermal mass. Lightweight materials such as timber have low thermal mass. Thermal mass acts as a 'thermal battery'. During summer, it absorbs heat, keeping the house relatively cool. In winter, the same thermal mass can store the heat from the sun to release it at night, helping the home stay warm. Higher the density of the material, higher is the heat storage capability.

Thermal mass is not a substitute for insulation. Thermal mass stores and re-radiates heat. Insulation stops heat flowing into or out of the building. A high thermal mass material is not generally a good thermal insulator.

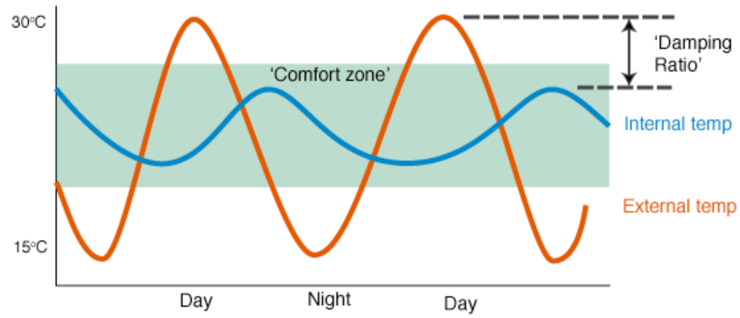

Figure 2 *Effect of thermal mass in moderating internal temperature, Source-The Low Carbon House, National Green Specifications 2007, http://www.greenspec.co.uk*

3.1.1.1 Properties of a good thermal mass

a. Moderate to High Density - The more dense the material (i.e. the less trapped air) the higher its thermal mass. For example, concrete has high thermal mass and light weight plaster has low thermal mass

b. Moderate Thermal Conductivity - The material must allow heat to flow through it. For example, rubber is a poor conductor of heat; brick is good, reinforced concrete is better. But if conductivity is too high (e.g. steel) energy is absorbed and given off too quickly to create the lag effect required for diurnal moderation.

c. Low Reflectivity - Dark, matt or textured surfaces absorb and re-radiate more energy than light, smooth, reflective surfaces. (If there is considerable thermal mass in the walls, a more reflective floor will distribute heat to the walls).

3.1.1.2 Measurement

Thermal mass is measured in terms of 'Volumetric heat capacity'. Volumetric heat capacity is the quantity of heat per unit volume per degree of temperature change or kJ/m^3K.

The effectiveness of Thermal Mass to absorb and emit heat is measured in terms of thermal conductivity. High conductivity implies a more rapid ability to absorb and emit heat. Conductivity is the quantity of heat transmitted in time through a thickness due to a temperature difference or W/mK. Thermal mass properties are presented in table 1 below.

Table 1 *Thermal Mass Properties of different materials*

Material	Conductivity W/mK	Vol. heat capacity kJ/m^{3}K
Water	1.9	4186
Cast concrete (dense)	1.4	2300
Granite	2.1	2154
Dense concrete block	1.8	2000
Sandstone	1.6	1800
Clay tiles	0.52	1770
Rammed earth	1.1	1675
Clay plaster	0.91	1650
Brick	0.72	1360
Dense plaster	0.05	1300
Flooring screed	0.41	1000
Plasterboard	0.17	800
Lightweight plaster	0.16	600
Lightweight concrete block	0.11	600
Fibreboard	0.06	300
Timber flooring	0.14	780
Carpet	0.07	260
Rockwool insulation	0.035	42
Fibreglass insulation	0.04	

Source –The Low Carbon House, National Green Specifications 2007, http://www.greenspec.co.uk

3.1.2 Application

Thermal mass is most appropriate in climates with a large diurnal temperature range. As a rule of thumb, diurnal ranges of less than 6°C are insufficient, 7°C to 10°C can be useful depending on the climate; and where they exceed 10°C, high mass construction is desirable. Exceptions to the above rule occur in more extreme climates. Correct use of thermal mass can delay heat flow through the building envelope by as much as 10 to 12 hours, producing a warmer house at night in winter and a cooler house during the day in summer.

In India, Hot and Dry climates have large diurnal temperature ranges. Composite climates also have relatively large diurnal temperature changes. High thermal mass construction is most appropriate in these climates. Traditional architecture, seen in the desert regions of Rajasthan and Gujarat also use high thermal mass construction in the form of thick mud or masonry walls.

3.1.2.1 Locating Thermal mass

As a rule of thumb the best place for thermal mass is inside the insulated building envelope. Insulation levels required will depend on the climate. A better insulated envelope will mean more effective thermal mass. Thermal mass can also be used without insulation; however insulation improves the efficiency of the thermal mass. The insulating layer should be towards the exterior and the thermal mass on the interior, exposed to interior air. Thermal mass can be located in the following building elements as indicated -

- Walls - Insulated Masonry walls provide good thermal mass. Recycled materials such as concrete, gravel or re-used bricks can be used to build the thermal mass. Insulation improves the efficiency of the thermal mass, provided it is placed on the exterior.
- Floor Slab - Floor slab in contact with the ground, can act as a good thermal mass
- Roof – Thermal mass in the roof will greatly reduce the solar heat gain.

In hot and dry climates, thermal mass is most effective on southern and western rooms, which face maximum solar heat gain in the day and also have exposure to cooling night breezes.

In summer, providing adequate shading from sun to the thermal mass wall in the day time and providing night time natural ventilation to draw out the stored heat will create thermal comfort during day and night.

In winter, the thermal mass will absorb heat during the day and re-radiate it to the interior at night keeping the rooms warm at night. In winter the thermal wall should not be ventilated with exposure to cold night breezes.

3.1.2.2 Area of Thermal Mass

The amount of useful thermal mass is determined by multiplying a material's volumetric heat capacity (See Table 1) by the total accessible volume of the material (of the surface area exposed to the heat source)

Example:

A living room has 20 m^2 of thermal mass walling comprising exposed 100mm brickwork.

Volume of brickwork = 20 x 0.1 = 2m^3

Volumetric heat capacity of brick = 1360 kJ/m^3K

Therefore the amount of useful thermal mass = 2 x 1360 = 2720 kJ for every increase in degree of temperature.

3.1.3 Construction Methodology

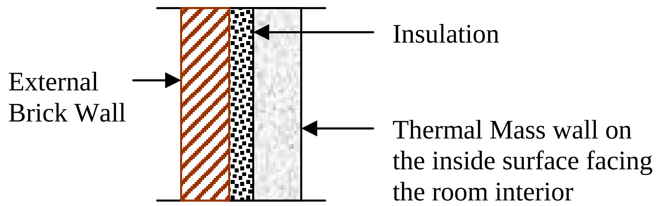

Figure 3 *Schematic Cross section of an external wall with insulation and thermal mass*

The cross section consists of a layer of the external brick masonry, followed by an insulation layer and an exposed thermal mass wall towards the interior. The insulation improves the efficiency of the thermal mass.

3.2 Wind Towers

Intent – Energy saving in Cooling and Ventilation
Suitable Climatic zones – Hot and Dry, Composite

3.2.1 Technology description/principle

The wind tower works on the principle of ventilation induced as a result of differential air pressure and temperature The simplest design for a wind tower is a vertical construct that projects above its surroundings and has an open top. This will ensure negative pressure and provide suction in all wind directions. If the ingress of rain is a problem, a cover can be placed above the top. Alternatively, an oast wind tower (L-bend) will reduce the effect of interference at the opening and provide a greater degree of protection from the weather. However, if an oast tower is expected to work in all wind directions, it must be omnidirectional. A number of other devices can be incorporated into the basic chimney design, to create a greater negative pressure around the opening, but generally these must also be omnidirectional.

The hot ambient air enters the tower through the openings in the tower and is cooled when it comes in contact with the cool tower and thus becomes heavier and sinks down. When an inlet is provided to the rooms with an outlet on the other side there is a draft of cool air. After a whole day of heat exchange, the wind tower becomes warm in the evening. During night the reverse happens, i.e. the cooler ambient air comes in contact with the bottom of the tower through the rooms; it gets heated up by the warm surface of the wind tower and begins to rise due to buoyancy, and thus an air flow is maintained in the reverse direction.

3.2.2 Application

This system can work very effectively in hot and dry types of climate, where daily variations in temperatures are high with high temperatures during the day and low temperatures during the night. As a result of clear sky conditions during the night, radiative losses are high.

The openings of the wind tower provided in the direction of the wind, and outlets on the leeward side take advantage of the pressure difference created by wind speed and direction. Normally, the outlets have thrice the area of the inlet for better efficiency. The inlet should be properly designed for uniform distribution.

3.2.3 Construction and design Details

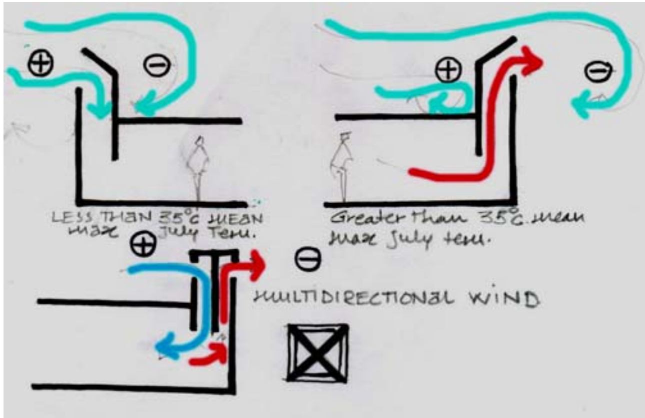

Figure 4 *Alternatives of wind tower designs for various conditions.*

In **Fig. 4**, three alternatives of wind towers are given. When a wind springs up, which is typical on a summer afternoon; air moves down or up the wind tower; depending on the direction of both the prevailing wind and the orientation of the tower vents. The multi directional wind shaft plays the role of getting cool air inside and at the same time removing hot air outside.

Figure 5 *A typical View of Wind shaft, source: www.catnaps.org/islamic/gulfarch.html*

3.3 Passive Down Draft Evaporative Cooling System (PDEC)

Intent – Energy saving in Cooling and Ventilation

Suitable Climatic zones – Hot and Dry, Composite

3.3.1 Technology description/principle

This system relies on the principle of evaporative cooling. Large amounts of heat are consumed by water as it evaporates. This is called the latent heat of evaporation. This heat is partially drawn from the surrounding air, causing cooling.

The PDEC system consists of modified wind towers which guide outside breezes over a row of water filled porous pots, mist spray or waterfall. As the air comes in contact with the water it cools and descends down the tower and is let into the interior space. The water is collected in a pool below and can be pumped up into the system to be reused.

3.3.2 Application

Evaporative cooling is efficient in hot and dry climates where relative humidity is low. This system of cooling originated in the desert regions of ancient Persia and can be seen in present day Iran and Turkey.

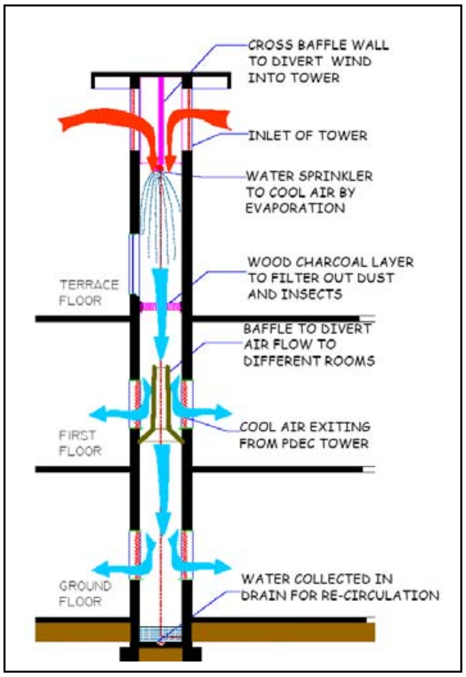

Figure 6 *Cross Sections of a PDEC system, Source -Design Guidelines For Energy Efficient Buildings, Architect Jiten Prajapati , Mumbai, September 2006*

As can be seen from the figure above, water sprayed into the wind tower of a building, cools the air creating a downward draw which leads to a drop in temperature down the tower and introduces cooled air into the building space, while warmer air gets vented out from openings in the adjacent walls of the building.

3.4 Earth Tunnel Cooling

Intent	–	Energy saving in Cooling and Ventilation
Suitable Climatic zones	–	Hot and Dry, Composite, Moderate and Warm and humid

3.4.1 Technology description/principle

The cooling process is based on the fact that the temperature a few meters below the ground is almost constant throughout the year. Daily temperature variations hardly affect the earth's temperature at a depth of more than one meter, while the seasonal variations of the ambient temperature are strongly dampened by the earth. The earth's temperature up to a depth of 6 to 8 m is influenced by the annual ambient temperature variations with a time delay of several months. It is seen that in Delhi the earth's temperature at a depth of about 4 m is nearly constant at around 23°C throughout the year. A tunnel in the form of pipes or otherwise will acquire the same temperature at its surface causing the ambient air ventilated through this tunnel to get cooled.

3.4.2 Application

Although this technique is essentially used for cooling the air in hot and dry climates, it can also be used for winter heating. Earth-air tunnels may be considered as special types of wind towers connected to an underground tunnel. A wind tower is connected to the underground tunnel, which runs from the bottom of the wind tower to the basement of the building. The wind tower catches the wind which is forced down the tower into the tunnel. The temperature of the tunnel, being lower than that of the ambient temperature, cools the air before it is circulated into the living space. In winter, the temperature of the air tunnel is higher than the ambient temperature and hence warms the air passing through it.

Sensible cooling can be aided by evaporative cooling. To reduce the underground temperature, the ground can be shaded using vegetation and can be wetted by sprinkling water. This water seeps through and dampens the tunnel walls. Consequently, air from the tunnel is evaporatively cooled as it passes through the tunnel. Another variation possible is to use buried pipes instead in place of a tunnel.

3.4.3 Construction details

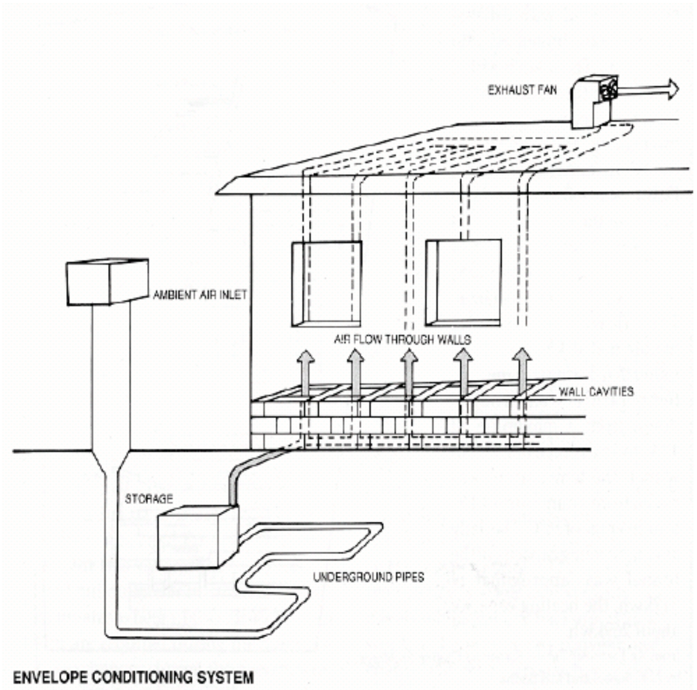

Figure 7 *Earth Air Tunnel Cooling System, Source - Passive Solar Architecture: Basics, J.K. Nayak*

Clay pipes with a diameter of 300-600 mm sunk in a loop perhaps 3 to 8 meters deep could draw air from external spaces like garden, well or just through the earth as shown in **Fig.7.** These will ensure that air introduced from such a loop will be at least 5˚ C cooler than ambient air. The exhaust fan at the top of the roof will remove hot air from the internal space.

3.5 Roofing Systems

The roof of a building receives the maximum solar radiation and contributes greatly to internal heat gain. The roofing systems mentioned in this section include various techniques to minimize heat gain.

3.5.1 Ventilated Double Roof

Intent	–	Energy saving in Cooling and Ventilation
Suitable Climatic zones	–	Warm and Humid, Composite

A ventilated double roof when used in a warm and humid climate helps to draw away warm air between the roof and the ceiling, thus preventing excessive heat gain from the roof. The radiative heat transfer from the roof to the ceiling can be reduced by using low emissivity or high reflective coating (e.g. aluminum foil) on either surface facing the cavity. With aluminum foil attached to the top of ceiling, the resistance for downward heat flow increase to about 0.7 m2k/w, compared to 0.21m2/k in the absence of the foil.

3.5.2 Roof Shading

Intent	–	Energy saving in Cooling
Suitable Climatic zones	–	All climatic zones except cold

Shading the roof surface is an easy and cost–effective way of reducing solar heat gain. Surface shading can be provided as an integral part of the building structure or as a separate cover. Shading can be provided by white washed inverted earthen pots or a cover of deciduous plants or creepers.

An effective roof-shading device is a removable canvas cover. This can be mounted close to the roof in the daytime and at night; it can be rolled up to permit radiative cooling. The upper surface of the canvas should be painted white to minimize the amount of absorbed radiation by the canvas and the consequent conductive heat gain through it.

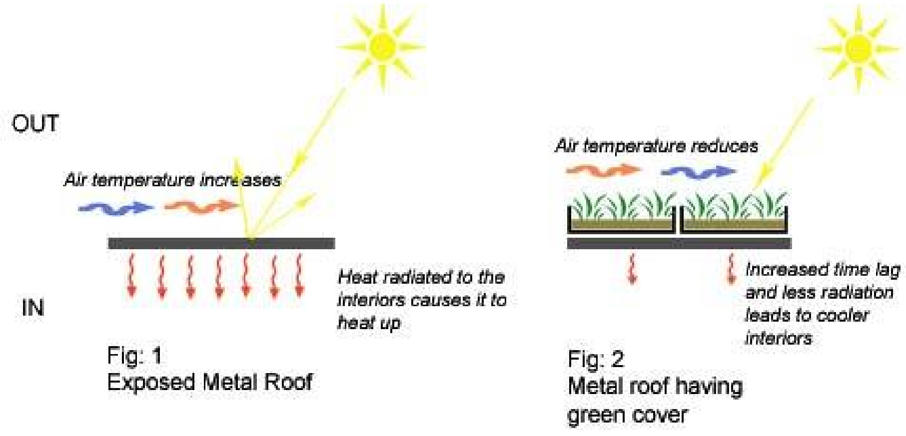

Figure 8 *Alternatives of roofing systems; Source: Landscape architecture.*

3.5.3 Pergolas

Intent – Energy saving in Cooling

Suitable Climatic zones – All climatic zones except cold climate

Pergolas are framework-imitating walls and ceiling without obscuring the view. Pergolas are often used in gardens to create vertical interest or to obscure or distract from unattractive underlying attributes. But they can be used as alternate roofing system to obstruct direct heat gain from the sun; especially on open terraces.

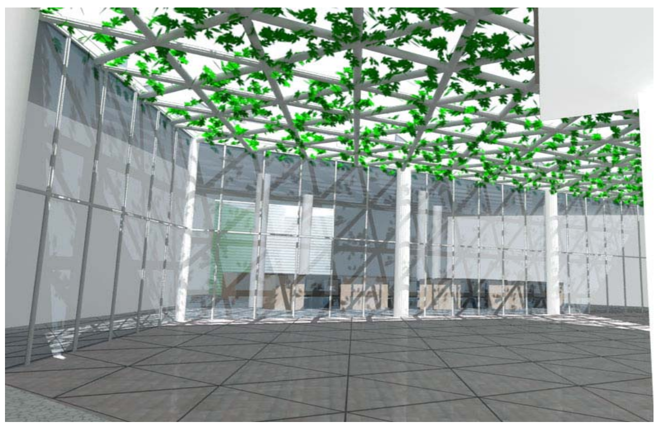

Figure 9 *Pergolas- creating a semi-open terrace.*

3.5.4 Reflective surfaces, paints and coatings (Cool Roofs)

Intent – Energy saving in Cooling

Suitable Climatic zones – All climatic zones except cold climates

Light coloured roofs reflect heat and solar radiation, thus minimizing heat gain. Light coloured tiles and paints greatly reduce heat gain in buildings. If the external surfaces of the building are painted with such colours that reflect solar radiation (in order to have minimum absorption) and the emission in the long wave region is high, then the heat flux transmitted into the building is also reduced considerably.

Spectrally selective (heat-reflective) paints and coatings are now available. These are called cool roof coatings which are made of transparent polymeric materials such as acrylic and white pigment such as titanium dioxide which makes the coating opaque and reflective. These coatings (cool roofs) typically reflect 70 to 80% of the suns energy. Cool roof coatings are also called thermal barrier paints.

3.6 Roof Garden

Intent	–	Energy saving in cooling and heating, reducing urban heat island effect
Suitable Climatic zones	–	All climatic zones

3.6.1 Technology description/principle

Green roofs also known as roof gardens or vegetated roof covers, play multiple roles as follows -

- Reduce urban "heat island" effect
- Reduce CO_2 impact
- Reduce energy consumption in cooling and heating
- Treat nitrogen pollution in rain
- Negate acid rain effect
- Aesthetically pleasing

3.6.2 Construction details

Roof Gardens are constructed of a lightweight soil media, underlain by a drainage layer, and a high quality impermeable membrane that protects the building structure from seepage. The soil is planted with a specialized mix of plants that can thrive in the harsh, dry, high temperature conditions of the roof and tolerate short periods of inundation from heavy rains.

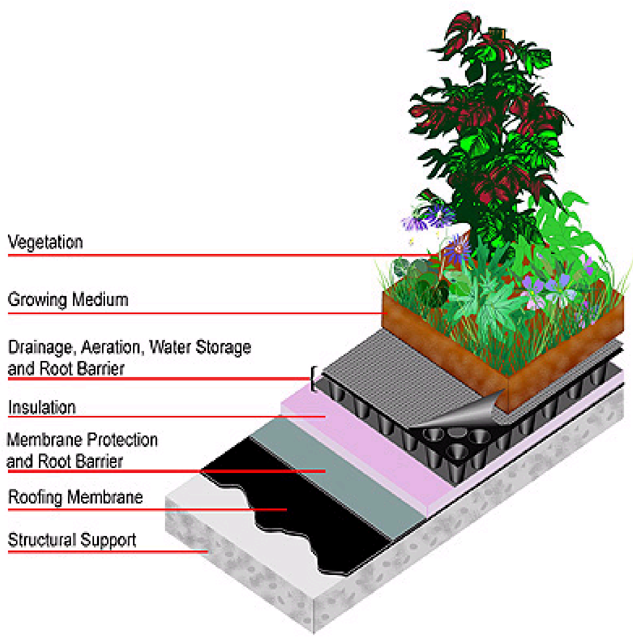

Figure 10 *Schematic Cross Section of a green roof, Source http://www.lid-stormwater.net/greenroofs_home.htm*

3.7 Roof and Wall Insulation

Intent – Energy saving in Cooling and Heating

Suitable Climatic zones – All climatic zones

3.7.1 Technology description/principle

Insulation stops heat flowing into or out of the building. Thermal insulation in buildings is an important factor to achieving thermal comfort for its occupants. Insulation reduces unwanted heat loss or gain and can decrease the energy demands of heating and cooling systems.

3.7.2 Application -Roof Insulation

The main heat flow from the roof to the space below is due to radiation. For downward heat flow, convection is weak and radiation dominates heat transfer across an air space. The roof should be protected against excessive heat gain by appropriate insulation to give the desired U-value (thermal conductivity value). Insulating materials such as Vermiculite concrete, Extruded Polystyrene, Expanded Polystyrene or bonded mineral wool in case of under-deck roof insulation can be used. Resin-bonded mineral wool comprising rock wool and glass wool is available in the form of slabs and rolls of density 24–48 kg/m3 and thickness 25–75 mm. These materials are available with or without lamination of aluminum foil. Aluminum foil acts as radiant barriers and is highly effective for attic spaces in hot climates .Radiant barriers must face an adequate air-gap to be effective.

As can be seen in the figures 11, 12 and 13 below, various design alternatives are also being implemented to provide roof insulation.

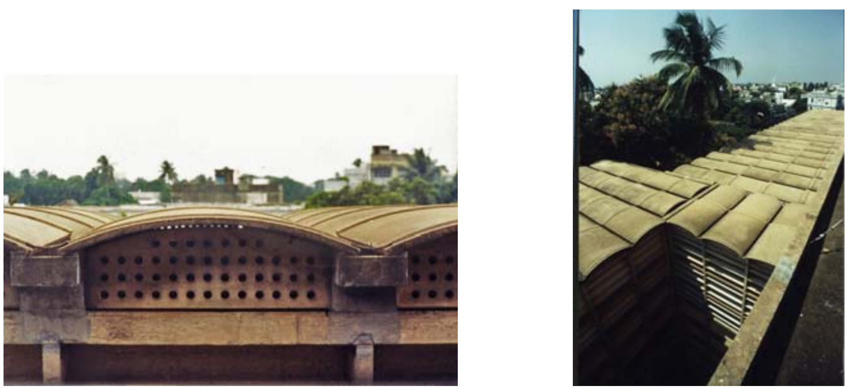

Figure 11 *Air gap acts as an insulation to reduce heat radiation from roof (Golconde, Pondecherri) Source: Bioclimatic Design, Undergraduate Thesis by Ravindra D. Gaekwad*

Filler Slab

Filler slab is also one of the alternatives of roof insulation. The roof is built with hollow burnt clay units, using a minimum of steel as the radiation is far less than a conventional concrete roof. Filler slabs in the form of terracotta pots or burnt clay hollow bricks play a vital role in keep heat penetration from the roof; away.(**Fig. 13.a & 13.b**.)

a)

b)

Figure 12 *Terracotta pots (a) and Burnt clay hollow bricks (b) as a filler slabs on roof; (Creativity, Auroville) Source: Bioclimatic Design, Undergraduate Thesis by Ravindra D. Gaekwad*

Roof Pond system

Another alternative is the roof pond or Skytherm system, invented by Harold Hay in USA. This system consists of water filled polythene bags which are placed on a ribbed metal roof deck and covered with movable insulation panels. In the summer months, during the day, these panels cover the roof and greatly reduce the radiative solar heat gain from the roof. During the night, the insulating panels are slid off the roof to permit radiative cooling.

In winter months or cold climates, the roof pond can be used for heating, by keeping the insulation off during the day time and covering the roof during the night time. Because of its reliance on radiative cooling, roof pond systems are best suited to places of low humidity and clear nights. Typical roof pond systems use a water mass from 100 mm to 250 mm (4 to 10 inches) in depth.

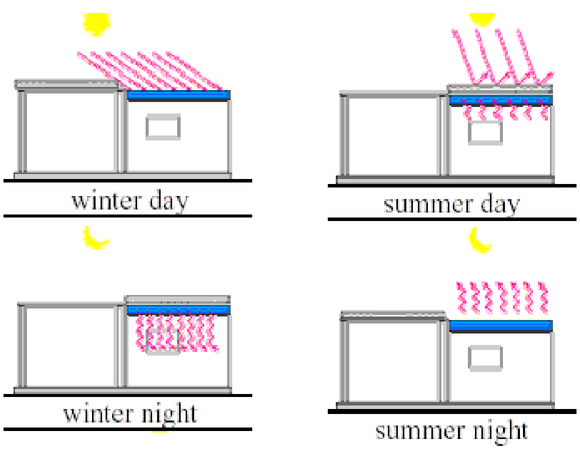

Figure 13 *Skytherm house with roof pond. Source- http://www.solarmirror.com/fom/fom-serve/cache/30.html*

3.7.3 Application – Wall Insulation

In warm climates, the thermal insulation should be placed on the exterior face on the wall, so that the amount of solar radiation penetrating the wall is minimized. Some commonly used wall insulation types like mineral wool slabs, expanded/extruded polystyrene, aerated concrete blocks, etc could be used for this purpose.

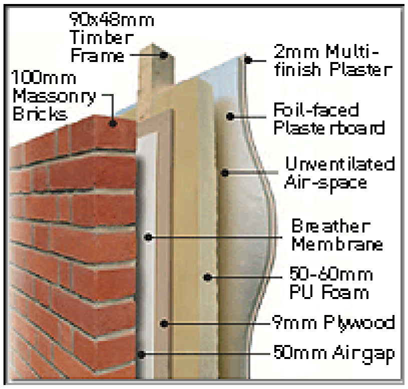

Figure 14 *Wall Insulation, Source:http://www.bufca.co.uk/i/applications/rightimage_newbuild03.gif*

3.8 Trombe Wall

Intent	–	Energy saving in heating
Suitable Climatic zones	–	Cold Climates

3.8.1 Technology description/principle

A Trombe wall combines the principles of thermal mass and a solarium. A trombe wall consists of a sun-facing high thermal mass wall with vents at the top and bottom, placed behind insulated glazing with an air gap in between; together they act as a large solar thermal collector.

3.8.2 Application

Trombe walls are used largely in cold climates on southern facing walls in the northern hemisphere. During the day, the air between the glazing and the thermal mass wall gets heated up and flows through the vents into the interior space via convection, thus warming the interior space. At the same time the thermal mass wall absorbs and stores the incident solar radiation. During the night, the vents are closed and the thermal mass radiates the stored heat into the interior space through conduction and radiation.

Generally, thickness of the storage wall is between 200 mm and 450 mm, the air gap between the wall and glazing is 50-150mm, and the total area of each row of vent is about 1% of the storage wall area (Levy M E, Evans D, and Gardstein C. 1983).

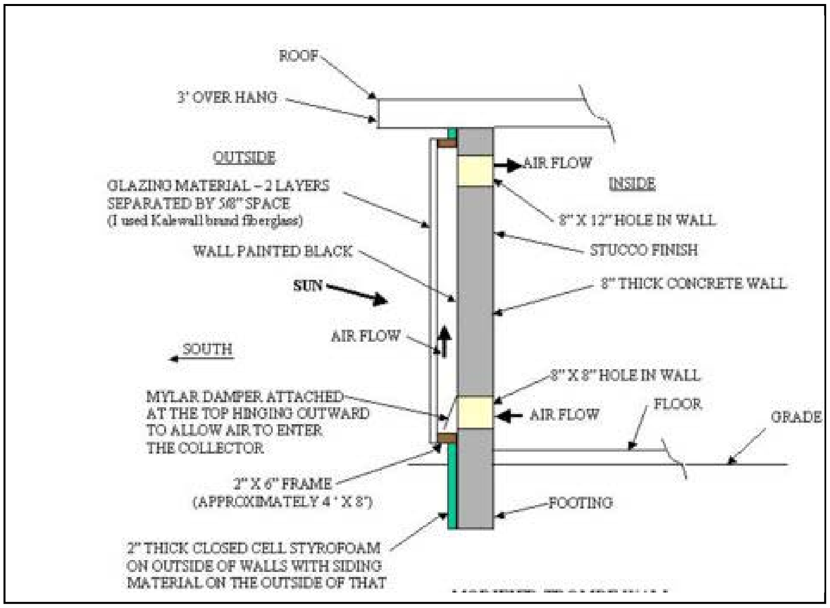

Figure 15 *Cross Section of a trombe wall, Source Trombe wall - Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/Trombe_wall*

Night-time thermal losses through the thermal mass can still be significant. The modern design can be further improved by insulating the thermal mass from the collection surface. The insulation greatly reduces night-time heat losses at the cost of small reductions in daytime heat gain.

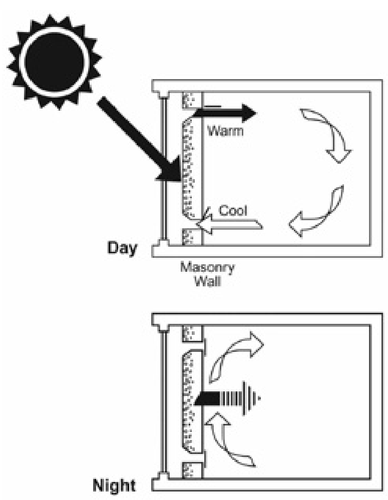

Figure 16 *Working of Trombe wall, Source: http://imgs.ebuild.com/cms/RESIDENTIAL%20CONCRETE%20MAGAZINE/2007*

In Laddakh, the Laddakh Project has promoted the building of Trombe walls in Ladakhi homes and designing them in a manner which complements Ladakh's beautiful traditional architecture. This helped Ladhakis get access to a clean, reliable heating source instead of burning dung, the traditional fuel that produces smoky fires causing many health problems and offer poor relief from the bitter winter temperatures. Ladakh, India receives about 320 days of sun annually, and the traditional building materials - stone and mud brick - provide the thermal mass needed for heat collection in a Trombe wall.

3.8.3 Other Passive Heating Systems

Other systems such as roof – based air heating systems and sun spaces can be used as stand-alone systems or in conjunction with Trombe walls in order to facilitate passive heating. In this system incident solar radiation on a south facing glazed roof is trapped and is used for heating the building interiors

3.9 Solar Chimney

Intent	–	Energy saving in cooling and heating
Suitable Climatic zones	–	All climatic zones

3.9.1 Technology Description/Principle

A solar chimney often, referred to as a thermal chimney is a way of improving the natural ventilation of buildings by using convection of air heated by passive solar energy. In its simplest form, the solar chimney consists of a black-painted chimney, with a partly glazed surface area towards the top. During the day, solar energy heats the chimney and the air within it, creating an updraft of air in the chimney. The suction created at the chimney's base can be used to ventilate and cool the building below through stack effect.

3.9.2 Application

The basic design elements of a solar chimney are

- The solar collector area: This can be located in the top part of the chimney or can include the entire shaft. The orientation, type of glazing, insulation and thermal properties of this element are crucial for harnessing, retaining and utilizing solar gains
- The main ventilation shaft: The location, height, cross section and the thermal properties of this structure are also very important.
- The inlet and outlet air apertures: The sizes, location as well as aerodynamic aspects of these elements are also significant.
- The use of solar chimneys is advisable for regions where very low wind speeds exist.
- Solar chimneys can be designed for both summer cooling and winter heating as illustrated in the diagram below.

In summer, the external and internal vents are kept open to let the warm air rise out of the building. In winter, the external vents are kept closed so that warm air will circulate in the building interior.

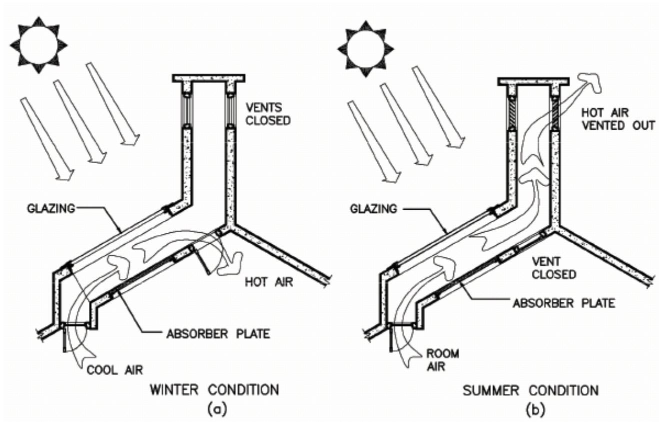

Figure 17 *Cross Section of Solar Chimney, showing functioning in summer and winter,Source: Passive Solar Architecture: Basics, J.K. Nayak*

3.10 Light Shelf

Intent – Even distribution of daylight, energy saving in lighting

Suitable Climatic zones – All Climatic zones

3.10.1 Technology Description/Principle

A horizontal shelf positioned (usually above eye level) to reflect daylight onto the ceiling and to shield direct glare from the sky. It will result in a more even light gradient. This indirect light supplements and/or delays the artificial lighting requirement and thus reduces energy consumption as shown in **Fig.18**

3.10.2 Application

A light shelf is a horizontal element installed within a window to divide it into two sections. The light shelf is opaque, with a highly reflective upper surface and a diffusing white under surface. Generally, the light shelf will split the window with one third of the glazing above and two thirds below. This will allow reflection of both daylight and sunlight up on to the ceiling, whilst not obstructing the view through the window.

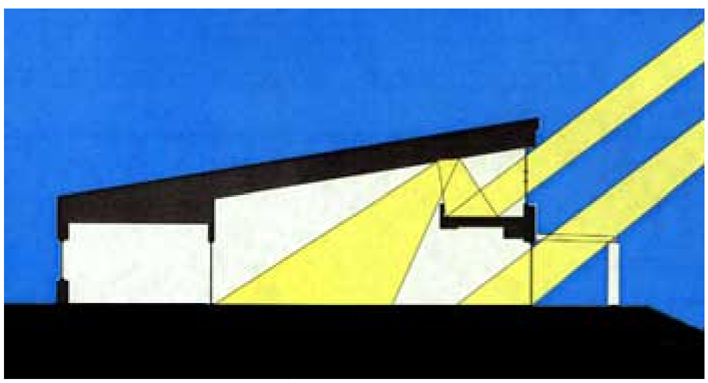

Figure 18 *Schematic Diagram showing functioning of light shelf Source: www.designshare.com/.../10017/10017_Prog.htm*

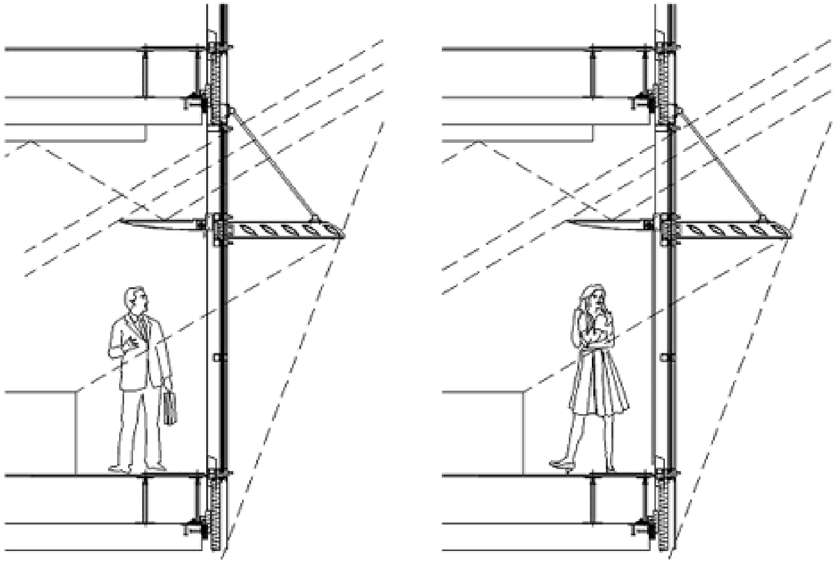

Figure 19 *A combination of external sunshade and light shelf, Source www1.hunterdouglascontract.com/HDWeb/Cultures...*

The combination of external sunshade and light shelf cuts the direct light from the sun and at the same time it gives reflected diffused light to the inner space as shown in **Fig. 19.**

Figure 20 *Vertical light shelf; Source: www.savannahtrims.com/images/Scane.jpg*

Twelve gauge stainless steel curved/perforated sunscreens act as a light shelf as well to reflect the direct sunlight into diffused light for the internal spaces as shown in **Fig. 20**

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