Overview of ECBC envelope:

The building envelope refers to the exterior façade, and is comprised of opaque components and fenestration systems. Opaque components include walls, roofs, slabs on grade (in touch with ground), basement walls, and opaque doors. Fenestration systems include windows, skylights, ventilators, and doors that are more than one-half glazed. The envelope protects the building’s interiors and occupants from the weather conditions and shields them from other external factors e.g: noise, pollution, etc.

Envelope design strongly affects the visual and thermal comfort of the occupants, as well as energy consumption in the building. The design of the building envelope is generally responsible of the architect. The building designer is responsible for making sure that the building envelope is energy-efficient and complies with the mandatory and prescriptive requirements of the code.

From an energy efficiency point of view, the envelope design must take into consideration both the external and internal heat loads, as well as daylighting benefits. External loads include mainly solar heat gains through windows, heat losses across the envelope surfaces, and unwanted air infiltration in the building; internal loads include heat released by the electric lighting systems, equipment, and people working in the building space. (Figure below)

### Fig 1: External and Internal Heat Loads
(source: ECBC, ECO III, US-AID)

<table>
<thead>
<tr>
<th>Heat/Moisture Losses</th>
<th>Walls</th>
<th>Roof</th>
<th>Window</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimise conduction losses</td>
<td>Use insulation with low U-value</td>
<td>Use insulation with low U-value</td>
<td>Use materal with low U-value</td>
</tr>
<tr>
<td>Minimise convection losses &amp; Moisture penetration</td>
<td>Reduce air leakage &amp; use vapor barrier</td>
<td>Reduce air leakage &amp; use vapor barrier</td>
<td>Use prefabricated window and seal the joints between windows and walls</td>
</tr>
<tr>
<td>Minimise Radiation Losses</td>
<td>Use light coloured coating with high reflectance</td>
<td>Use light coloured coating with high reflectance</td>
<td>Use glazing with low SHGC</td>
</tr>
</tbody>
</table>

### Fig 2: ECBC Compliant Design Strategy for a Building
A well designed building envelope not only helps in complying with the Energy Conservation Building Envelope (ECBC) but can also result in first cost savings by taking advantage of daylighting and correct HVAC sizing. The building envelope and its components are key determinants of the amount of heat gain and loss and wind that enters inside. The envelope protects the building’s interior and occupants from the weather conditions and other external elements. The design features of the envelope strongly affect the visual and thermal comfort of the occupants, as well as energy consumption in the building mentioned below are explained further.

The commonly considered elements of ECBC envelope are:

1. Walls
2. Window
3. Roof

The ECM2 is considered with ECBC envelope + Daylight Integration with optimum WWR

Wall

Walls are a major part of the building. Envelope receives large amounts of solar radiation. The heat storage capacity and heat conduction property of walls are key to meeting desired thermal comfort conditions. The wall thickness, materials and finishes can be chosen based on the heating and cooling needs of the building. Appropriate thermal insulation and air cavities in walls reduce heat transmission into building which is the primary aim in a hot region.

The basic elements of the Wall system are:

1. Exterior cladding (natural or synthetic)
2. Drainage plane(s)
3. Air barrier system(s)
4. Vapour Retarder(s)
5. Insulating Element(s)
6. Structural elements

Thermal storage / thermal capacity:

Thermal capacity is the measure of the amount of energy required to raise the temperature of a layer of material, it is a product of density multiplied by specific heat and volume of the construction layer. The main effect of heat
storage within the building structure is to moderate fluctuation in the indoor temperature.

In a building system, we can understand thermal mass as the ability of a building material to store heat energy to balance the fluctuations in the heat energy requirements or room temperature in the building due to varying outside air temperature. The capacity to store heat depends upon the mass and therefore on the density of the material as well as on its specific heat capacity. Thus, high density materials such as concrete, bricks, stone are said to have high thermal mass owing to their high capacity to store heat while lightweight materials such as wood, or plastics have low thermal mass. The heat storing capacity of the building materials help achieve thermal comfort conditions by providing a time delay. This thermal storage effect increases with increasing compactness, density and specific heat capacity of materials.

Thermal performance of walls can be improved by following ways:

1. Increasing wall thickness
2. Providing air cavity between walls and hollow masonry blocks
3. Applying insulation on the external surface.
4. Applying light coloured distemper on the exposed side of the wall.

**Conductance:**
Conductivity (K) is defined as the rate of heat flow through a unit area of unit thickness of the material, by a unit temperature difference between the two sides. The unit is W/mK (Watt per metre - degree Kelvin). The conductivity value varies from 0.03 W/mK for insulators to 400W/mK for metals. Materials with lower conductivity are preferred, as they are better insulators and would reduce the external heat gains from the envelope.

**Walls-insulation:**
Thermal insulation is of great value when a building requires mechanical heating or cooling insulation helps reduce the space-conditioning loads. Location of insulation and its optimum thickness are important. In hot climate, insulation is placed on the outer face (facing exterior) of the wall so that thermal mass of the wall is likely coupled with the external source and strongly coupled with the interior (Bansal, Hauser, Minke 1994).

<table>
<thead>
<tr>
<th>Material</th>
<th>Conductivity (W/m K)</th>
<th>Specific Capacity (KJ/ Kg. K)</th>
<th>Heat Capacity (Kg/m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick</td>
<td>0.811</td>
<td>0.88</td>
<td>1820</td>
</tr>
<tr>
<td>Mud</td>
<td>0.750</td>
<td>0.88</td>
<td>1731</td>
</tr>
<tr>
<td>Stone</td>
<td>1.5</td>
<td>0.84</td>
<td>2200</td>
</tr>
<tr>
<td>Timber</td>
<td>0.072</td>
<td>1.68</td>
<td>480</td>
</tr>
</tbody>
</table>

**Table 1: Thermal properties of different materials (source: ECBC user guide, BEE)**
**Air Cavities:**

Air cavities within walls or an attic space in the roof-ceiling combination reduce the solar heat gain factor, thereby reducing space-conditioning loads. The performance improves of the void is ventilated. Heat is transmitted through the air cavity by convection and radiation. A cavity represents a resistance, which is not proportional to its thickness. For a thickness $>20$mm, the resistance to heat flow remains nearly constant. Ventilated air does not reduce radiative heat transfer from roof to ceiling. The radiative component of heat transfer may be reduced by using low emissivity or high reflective coating (E.g.: aluminum foil) on either surface facing the cavity. With aluminium foil attached to the top of ceiling, the resistance for downward heat flow increases to about 0.4m²k/W, compared to 0.21m²k/M in the absence of the foil (Bansal, Hauser, Minke, 1994).

**Window**

Windows are very important component of the building envelope, in addition to providing physical and visual connection to outside; it also allows heat and light in and adds beauty to the building. Solar radiation coming in through windows provides natural lighting, natural air and heat gain to the space inside, thus significantly impacting the energy usage of the building. The main purpose of a building and its windows is to provide thermal and visual comfort to the occupants and if this can be achieved using less energy, so much the better.

Proper location, sizing, and detailing of windows and shading form are important part of the bio-climatic design as they help to keep the sun and wind out of building or allow them when needed. The location of openings for ventilation is determined by prevalent wind direction, openings at higher levels naturally aid in venting out hot air. Size, Shape and orientation of openings moderate air velocity and flow in the room, a small inlet and a large outlet increase the velocity and distribution of air flow through the room. When possible, the house should be so positioned as the site that it takes advantage of prevailing winds. The prevailing wind direction is from the south/south-east during summer. The recommendation is IS: 3362-1977 code of practices for the design if windows for lightly and ventilation. There should be sufficient air motion in hot-humid and warm-humid climates. In such areas, fans are essential to provide comfortable air motion indoors, fenestrations having 15% - 20% of floor area are found adequate for both ventilation & day lighting in hot & dry, and hot & humid regions. Natural light is also admitted into a building through glazed openings. Thus, fenestrations design is primarily governed by requirements of heat gain and losses, ventilation and day lighting. The important components of a window are the glazing systems and shading devices.
Primary components of a window which have significant impact on energy and cost of the building for which guidelines are provided in this section are as follows:

1. **Window size, placement**
2. **Glazing**
3. **Frame**
4. **Shading (external & internal)**

**Window size & placement:**

*Height of window head:*

The higher the window head, the deeper will be the penetration of daylight.

*Sill height (height from floor to the bottom of the window):*

The optimum sill for good illumination as well for good ventilation should be between the illumination workspace and head level of a person. Carrying out any task, the suitable work plane levels are to be 1.0 to 0.3 m high respectively.

- Strip windows provide more uniform daylight
- Punched windows should be paired with work areas to avoid creating contrasts of light and dark areas.
- Avoid big windows close to task areas since they can be source of thermal discomfort.

Also larger the windows, the more important glazing selection and shading effectiveness are to control glare and heat gain.

*Use separate apertures for view and daylight*—for good day lighting and glare control separate the view and light windows. Light window should have clear glass for maximum daylight penetration. Tinted glass could be used below for glare control. The structure in between the two provides a visual break and an opportunity to attach light shelf or shading device.

1. **Glazing systems:**
The most commonly glazing material used in openings is glass, although recently polycarbonate sheets are being used for skylights. Before recent innovations in glass, films and coatings, a typical residential window with one or two layers of glazing allowed roughly 75% - 85% of the solar energy to enter a building.

Internal shading devices such as curtains, or blinds could reflect back some of that energy outside the building. The weak thermal characteristics of the windows became a prime target for research and development. In an attempt to control the indoor air temperature of buildings windows admit direct solar radiation and hence promote heat gain. This is desirable in cold climates, but is critical in hot climates. The window size should be kept minimum in hot & dry regions. The primary properties of glazing that impact energy are:

- Visible reflectance (affecting heat and light reflection)
- Thermal transmittance or U-value (affecting conduction heat gains)
- Solar heat gain (affecting direct solar gain)
- Spectral selectivity (affecting daylight and heat gain)
- Glazing colour (affects the thermal and visual properties of glazing systems and thus energy usage)

Visible transmittance (VLT %) or daylight transmittance
This is the percentage of normally incident visible light transmitted through the glazing. Glazing with a high visible transmittance is clearer in appearance and provide sufficient daylight and views. Clear glass however, can create glare problem. Glazing with low visible transmittance give better glare control, but offer minimal daylight integration and diminished views.

**Visible reflectance or daylight reflectance**

This is the percentage of incident light that is reflected back. Most manufacturers provide both outside reflectance (exterior daytime view) and inside reflectance (interior mirror image at night). Treatments such as metallic coating increase the reflectance. Reflective glazing reflects a large portion of the solar radiation incident on it, thereby restricting heat gain inside the building, which is advantageous.

Disadvantage is these reflective glazing allows low visible transmittance and thus minimal daylight integration.

An ideal spectrally selective glazing admits only the part of the sun’s energy that is useful for daylighting.

<table>
<thead>
<tr>
<th>Type</th>
<th>U value</th>
<th>VLT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear glass</td>
<td>3.16</td>
<td>79%</td>
</tr>
<tr>
<td>Body tinted</td>
<td>3.24</td>
<td>65%</td>
</tr>
<tr>
<td>Hard coated: solar control</td>
<td>3.27</td>
<td>24%</td>
</tr>
<tr>
<td>Soft coated: solar control</td>
<td>3.08</td>
<td>15%</td>
</tr>
<tr>
<td>Low E</td>
<td>2.33</td>
<td>61%</td>
</tr>
<tr>
<td>Solar control+ low E</td>
<td>1.77</td>
<td>41%</td>
</tr>
</tbody>
</table>

Table 7: Typical optical and thermal properties for high-performance glazing options

**Solar heat gain coefficient (SHGC or shading coefficient)**

These are the indicators of total solar heat gain through a glazing. SHGC is the ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation. Solar heat gains include directly transmitted solar heat and absorbed solar radiation, which is then re radiated, conducted or convected into the space. These indices are dimensionless numbers between 0 and 1 that indicate the total heat transfer of the sun’s radiation. These properties are widely used in cooling load calculations. Glass with a lower SHGC or SC (Shading coefficient) helps in reducing cooling loads in hot climate zones.
However, glass with a low SHGC also usually has low VLT. Hence use of glass with spectral selectivity is recommended for day use air conditioned buildings to enhance day lighting and reduce cooling loads. In air conditioned buildings, it is mandatory to achieve SHGC lower or equal to that recommended by ECBC for various window wall ratios.

**Adjusted SHGC**

Adjusted SHGC is the cumulative solar heat gain coefficient of the window with both the glass and shading devices (overhang, vertical fin or both).

Adjusted SHGC, which accounts for overhang and or side fins, is calculated by multiplying the SHGC of the unshaded glass times a multiplication factor (M).

\[
\text{Adjusted SHGC} = M \times \text{SHGC of glass}
\]

The multiplication factor (M) is identified for various projection factors (as per ECBC guidelines); whenever the fenestration is provided with overhangs and/or vertical fins, a separate “M” factor shall be determined for each orientation and unique shading condition. The multiplication factor is derived from the projection factor and it is calculated based on the four ranges of PF (such as from 0.25 to 0.49, 0.50 to 0.74, 0.75 to 0.99 and 1.00 or more).

**Glazing types and materials:**

Until recently, single pane clear glass was the primary glazing material used in windows. The past few decades have seen immense changes in glazing technology. Several types of advanced glazing systems are available to help control heat loss or gain. The advanced glazing include double and triple pane windows with coatings such as low - e (low emissivity)/ spectrally selective, heat absorbing (tinted), or reflective, gas filled windows and windows based on combination of these options.

Substantial improvements in glazing performance are expected from new materials and techniques. The creation of vacuum or partial vacuum in the cavity of a double glazed unit and the use of Aerogel to fill the cavity can lower the U-value considerably. Air space between glass layers Thermal resistance provided by the air cavity between glass layers increases with increase in cavity width upto 12mm. Convection currents, which form in wider cavities, lead to a drop in thermal resistance.
Insulated glazing units

Insulating glazing units are hermetically sealed, multiple pane assemblies consisting of two or more glazing layers held and bonded at their perimeter by a space bar typically containing a desiccant material. The glazing used in IGUs could be clear, tinted or coated or reflective as mentioned above. The spacer serves to separate the panes of glass and to provide a surface for primary and secondary sealant adhesion, since heat transfer at the edge of the IGU is greater than its centre. The choice of material for spacer is critical to the IGUs performance. It is advisable to use SS, galvanized steel, polymers or foamed silicon which have lower conductivities than aluminium. The hermetically sealed space between glass panes is most often filled with air, argon and krypton being two other alternatives.

Latest trends in glazing systems

a) Switchable glazing: Switchable glazing will enable the user to change the optical or thermal properties of sealed glazed units. The most useful and potentially applicable switchable property is the chromogenic phenomenon in which materials change their reflectivity and absorptivity. Examples of chromogenic processes are: thermochromic, electrochromic and photochromic materials. Thermochromic glazing changes optical properties in response to temperature changes. It consists of mainly liquids or gels sandwiched between layers of glazing. Thermochromic windows are designed
to block solar gain. A drawback is that they reduce visible light transmission as well. Electrochromic glazing changes optical properties when an electric current goes through the unit. A thin metallic film is deposited on the glass similar to low emissivity coatings. Another technique involves sandwiching a liquid quartz film between two layers of glazing. Photochromic materials change their properties in response to light. Photo gray sunglasses are best example. When photochromic materials change their transmittance, the absorptivity is increased, thus causing glass to absorb more heat. On sunny, cold days, they absorb solar heat and room source heat and then radiate some heat back to the surroundings. On sunny, hot days, they do not reject as much solar heat as reflective glass.

b) Evacuated glazing: Evacuated, sealed insulated glazing is designed to achieve higher levels of thermal performance by using a vacuum to inhibit any kind conductive or convective heat losses.

Flip windows for improved performance in summers and winters. The double pane absorptive glazing system for hot climates has a useful feature for regions of warm & humid climate, having both heating and cooling seasons.

If the positions of the two glass panes are flipped over from their summertime positions during the cold winter, the system converts to a solar radiant heater. In the cold day position, solar radiation passes through the clear outer pane is absorbed by the inner pane, which heats up and then this heat is transmitted to the inside, warming the building. The low - e coating on the inner pane now reduces the radiation of heat from this hot inner pane to the cold outer one, trapping the heat inside. Flipping it back over makes it a hot climate glazing system since the solar heat is now absorbed in the outer pane of glass, which is insulated from the interior of the building.

Frame

The type and quality of window frame affects a window’s air infiltration and heat gain / heat loss characteristics. There are three kinds of framing material mostly used which are metal, wood and polymers.

- Wood has a good structural integrity and insulating values but low resistance to external weather conditions.
- Metal frames have poor thermal performance, but have excellent structural characteristics and durability.
- Aluminium is the most preferred metal for frames, but it is highly conductive and its thermal performance can be improved with a thermal break (a non metal component which separates the metal frame exposed to the outside from surfaces exposed to the inside.)
- Vinyl window frames which are primarily made from polyvinyl chloride (PVC) offer many advantages. Available in wide range of style and shapes PVC frames has high R– value (Resistance value) and low maintenance.

**U-value:**

Table below shows how with the usage of different frame materials, overall U– value varies. The below exercise was carried out using WINDOW 5 as a tool, where glass and window size was not changed, only on changing the frame difference in U– value was observed. It should also be noted that the U-value of glass is lesser than the overall u-value of the entire window, which is calculated by the area weighted method, which includes the U– value of both glass and frame.
Daylighting and Window design:

Day lighting is utilization of light from the sun and sky to complement or replace electric light. Appropriate fenestration and lighting controls can be used to modulate daylight admittance and to reduce electric lighting, while meeting the occupants’ visual comfort. During day time when natural light, in outside, is available in abundance, window can be utilized as a tool to harness natural light from sun and sky to light the space. Buildings, in which artificial lighting is integrated with the day lighting, can reduce their energy bills significantly. Good day lighting in a building depends upon the following factors –

- External shading (Refer Technical Information on ECM1)
- Internal shading
- Solar control glass

Internal shading devices:
If properly adjusted, they can allow diffuse sunlight to penetrate inside the space. However, they are not proffered over external shading, as they do not keep solar heat out.

Good shading devices also reduces cooling loads. They also modify the intensity and distribution of daylight entering the space.

Solar control glazing:

They are very effective against heat flow across the window but can reduce transmission of light inside the space.

Light shelves:
- The function of light shelf is to protect the occupants from direct sunlight in summer and allow sufficient light in winter.
- The light shelf is placed above the eye level so that reflections do not get into eyes of occupants. Uniform daylight is also achieved as light is reflected deep into the room.
- The light shelf should be sufficiently projected outside so as to protect the window.
- The angle of the light shelf is also important as tilting helps in deeper light penetration but also reflects light back.
- The finishes should be reflective as matte surface reflects back about half light backwards
- The top of the shelf should be matte white or diffusely specular, and not visible from any point in the room.
Conventional Roof Insulation Practices
In India Roof Insulation with conventional materials like Foam Concrete, Mud Faska, Brick Bat Coba has been practiced since ages. However these products are quite heavy and add dead load to the roof slab. Moreover the thermal conductivity value is very high which results into higher thickness application without much benefit. These products have the tendency to develop cracks and as a result water absorption takes place. Moreover, the products are open cell and porous type which results into water absorption. This application also calls for good workmanship.

What types of roofing products are available?
Products for low-slope roofs, found on commercial and industrial buildings fall into two categories: single-ply materials and coatings. Single-ply materials are large sheets of pre-made roofing that are mechanically fastened over the existing roof and sealed at the seams. Coatings are applied using rollers, sprays, or brushes, over an existing clean, leak-free roof surface. Products for sloped roofs are currently available in clay, or concrete tiles. These products stay cooler by the use of special pigments that reflect the sun’s infrared heat. In India, lime coats, white tiles grouted with white cement, special paints, etc. are used as cool roofing materials.

Energy efficient roof insulations:
The roof requires significant solar radiation and plays an important role in heat gain/losses, day lighting and ventilation. Depending on the climatic needs, proper roof treatment is essential. In a hot region, the roof should have enough insulating properties to minimize heat gains. A few roof protection methods are as follows:
A cover of deciduous plants or creepers can be provided. Evaporation from roof surfaces will keep the rooms cool. The entire roof surface can be covered with inverted earthen pots. It is also an insulated cover of still air over the roof shading device. This can be mounted close to the roof in the day and can be rolled to permit radiative cooling at night. The upper surfaces of the canvas should be painted white to minimize the radiation absorbed by the canvas and consequent conductive heat gain through it Effective roof insulation can be provided by using vermiculite concrete.
Heat gains through roofs can be reduced by adopting the following techniques.
Green roof concept
A roofing system through shading, insulation, evapotranspiration and thermal mass, thus reducing a building’s energy demands for space conditioning. The green roof moderates the heat flow through the roofing system and helps in reducing the temperature fluctuations due to changing outside environment. Green roof is a roof of a building that is partially or completely covered with vegetation and soil that is planted over waterproofing membrane. If widely used green roofs can also reduce the problem of urban heat island which would further reduce the energy consumption in urban areas.

Use of high reflective material on roof top.
Use light coloured roofs having an SRI (solar reflectance index) of 50% or more. The dark coloured, traditional roofing finishes have SRI varying from 5 - 20%. A good example of high SRI is the use of broken china mosaic and light coloured tiles as roof finish, which reflects heat off the surface because of high solar reflectivity and infrared emittance, which prevents heat gain and thus help in reducing the cooling load from the building envelope.

If the roof is exposed to Solar heat it will input continuous heat inside the building which in turn will add to the A.C. machinery load. This concept of protecting the roof is termed as Roof Insulation. There are many different types of insulation materials to choose from when applying on a commercial roof or reproofing an existing structure. The function of roof insulation is to insulate the building against heat in flow from outside during the day.

Use of higher albedo materials/cool roof:
Higher albedo materials can significantly reduce the heat island effect. Higher the albedo larger will be the amount of solar radiation reflected back to the sky. Roofs provided with high reflective coatings remains cooler than those with low reflectance surfaces and are known as cool roofs. Cool roofs can reduce the building heat gain and can save the summertime air conditioning expenditures. These paints are highly efficient, energy-saving, flexible coatings, made from water-based pure acrylic resin system filled with vacuumed sodium borosilicate ceramic micro spheres of less than 100 microns in size. Each micro sphere acts as a sealed cell and entire mastic acts as a thermally efficient blanket covering the entire structure. These coatings are non-toxic, friendly to the environment, and form a monolithic (seamless) membrane that bridges hairline cracks. They are completely washable and resist many harsh chemicals. Roof Coats have high reflectance and high remittance as well as a very low conductivity value. They offer UV protection and low VOC’s. They display excellent dirt pick-up resistance and retain their flexibility after aging. These roof Coats reduce noise transmission and have an effective use range from -40 Deg C (~-40 Deg F) to 375 Deg C (700 Deg F) (Reference: www.thermoshieldindia.com)

Thermal insulation for roof:
Well insulated roof with the insulation placed on the external side is an effective measure to reduce solar heat gains from the roof top. The insulated materials should be well protected by waterproofing. For air conditioned spaces, Energy Conservation Building Code (ECBC) recommends the thermal performance for external roof for all the five climate zones in India.
Over deck Insulation
In this system a thermal barrier or insulation is provided over the RCC, so that the heat of the sun is not allowed to reach the RCC slab of the roof at all. In this way we can preserve the RCC from getting heated up. Once the RCC is heated up there is no other way for the heat to escape other than inside the building. So even though the thermal barrier is provided under the RCC, as in underdeck insulation, some heat passes through it and heats up the ambience of the room. This decreases the comfort level of the room and if the building is centrally AC, increases the AC load. Hence we can safely conclude that overdeck insulation has its own advantages over underdeck insulation. Overdeck Insulation material should have adequate compression resistance, low water absorption, resistance to high ambient temp. and low thermal conductivity. Overdeck insulation applications are carried out by either –
• Preformed insulation materials
• In-situ application

A) Preformed insulation material:
Preformed Insulation material are further classified as under:
• Expanded Polystyrene slabs
• Extruded Polystyrene slab
• Polyurethane / Polyisocyanurate slabs
• Perlite boads

(i) **Expanded polystyrene** (EPS, Thermocol)- is a lightweight cellular plastic foam material composed of carbon and hydrogen atoms. It is derived from petroleum and natural gas by products. Molded EPS does not involve the use of CFCs. Polystyrene is highly economical EPS meets most of the performance

(ii) **Extruded Polystyrene** - Extruded Polystyrene is an improvement of Expanded Polystyrene material. This material is also comprise of beads / globules which are compressed to form slabs and pipessections. Incase of Extruded Polystyrene the beads are very closely linked to each other so that the material become rigid and there is no air gap between the beads. It is a close cells material and a skin is formed on the top which stops water absorption.

(iii) Polyisocyanurate / Polyurethane foam slab – These are urethane foam insulation materials having low thermal conductivity, low smoke emission & low water absorption. The product confirms to IS:12436 & BS 5608.

(iv) **Perlite** – Perlite insulation is an organic rigid board insulation. It is composed of expanded volcanic glass and wood fibres bonded with asphaltic binders. This makes a
rigid board light in weight, dimensionally stable and good in compressive strength. In western countries at one time perlite was most common insulation material used for roof insulation. Although still popular, its low ‘R’ value, high ‘K’ value and tendency to absorb moisture have lessened its popularity.

The application procedure for overdeck insulation featuring preformed insulants are:
- Cleaning of the roof surface to be free of dirt and loose particles
- Providing a primer and adhesive coat
- Adhering of insulation with adhesive, taking care to seal all the joints between insulation also with a sealant.
- Providing a protective plaster layer with reinforcement
- Providing an elastomeric membrane or felt type waterproofing treatment on top.

**Insitu Technology**

(i) **Spray applied Polyurethane:** Unlike preformed materials, this is applied directly over the roof by spraying. This eliminates separate fixing procedure. It is formed spontaneously when Isocyanate and Polyol are mixed in the presence of a blowing agent to create close cell homogenous jointless insulation cover of the roof. It is designed to combine highly efficient thermal insulation with great ease of application. It is ideal for a wide range of insulation application particularly for roofs and walls of the building. By nature liquid applied foam polyurethane adheres strongly to almost any surface regardless of form. The seamless and monolithic nature of spray foam provides a full proof method of sealing cracks and rendering any surface moisture resistance and drought proof. The excellent adhesion of the sprayed material makes mechanical fastening redundant. The comparatively low density of material adds little weight to overall loading. Besides external use, sprayed foam can be applied internally as well. (The foam can also be sprayed on the under side of roofs and suspended floors and on inner surface of walls).

**Insulation**

The first set of mandatory requirements addresses the proper installation and protection of insulation materials. It is recommended that insulation materials be installed according to the manufacturer’s recommendations and in a manner that will achieve the rated insulation R-value. Compressing the insulation reduces the effective R-value and the thermal performance of the construction assembly.

**Substantial Contact**

It is recommended that insulation be installed in a permanent manner and in substantial contact with the inside surface of the construction assembly. If the insulation does not entirely fill the cavity, the air gap should be on the outside surface. Maintaining substantial contact is particularly important (and problematic) for batt insulation installed between floor joists. Without proper support, gravity will cause the insulation to fall away from the floor surface, leaving an air gap above the insulation. Air currents will ultimately find their way to the gap, and when they do, the effectiveness of the insulation will be substantially reduced.

**Insulation above Suspended Ceilings**

It is not good practice to install insulation directly over suspended ceilings with removable ceiling panels. This is because the insulation’s continuity is likely to be disturbed by maintenance workers. Also, suspended ceilings may not meet the ECBC’s infiltration requirements unless they are properly sealed. Compliance with this requirement could have a significant impact in some parts of the country, as it is common practice to install insulation over suspended ceilings. Many building codes will consider the space above the ceiling to be an attic and require that it be ventilated to the exterior.
If vented to the exterior, air in the attic could be quite cold (or hot) and the impact of the leaky suspended ceiling would be made worse.

**Insulation Protection**

It is strongly recommended that insulation be protected from sunlight, moisture, landscaping equipment, wind, and other physical damage. Rigid insulation used at the slab perimeter of the building should be covered to prevent damage from gardening or landscaping equipment. Rigid insulation used on the exterior of walls and roofs should be protected by a permanent waterproof membrane or exterior finish. In general, a prudent designer should pay attention to moisture migration in all building construction. Vapor retarders prevent moisture from condensing within walls, roofs, or floors but care should be taken to install them on the correct side (warmer or cooler side) of the walls and roofs to prevent water damage. Water condensation can damage the building structure and can seriously degrade the performance of building insulation and create many other problems such as mold and mildew. The designer should evaluate the thermal and moisture conditions that might contribute to condensation and make sure that vapor retarders are correctly installed to prevent condensation. In addition to correctly installing a vapor retarder, it is important to provide adequate ventilation of spaces where moisture can build up.
Cool Roof:
Depending on the material and construction, a roof will have different properties that determine how it conducts heat to the inside of the building. “Cool roofs” are roofs covered with a reflective coating.
that has a high emissivity property that is very effective in reflecting the sun’s energy away from the roof surface. These “cool roofs” are known to stay 10°C to 16°C cooler than a normal roof under a hot summer sun; this quality greatly reduces heat gain inside the building and the cooling load that needs to be met by the HVAC system. Box below discusses how solar heat radiation is reflected, absorbed and emitted from the roof and how these concepts are used in developing cool roofs.

Reflectance, Absorptance, and Emissivity
The heat transfer process involved in the roof, is similar to the heat transfer that takes in a wall. Heat transfer across the roof is more prominent compared to the wall because of higher incidence of solar radiation. Depending on the properties of the roof material and construction, the roof reflects part of the solar radiation back to the environment, and absorbs the other part of the heat in the roof (See Figure 4.9). Finally, portion of the absorbed heat in the roof is emitted as long-wave radiation back to the environment and the remaining part of the absorbed heat is conducted inside of the building. This heat transfer process is governed by the Solar Reflectance and Emissivity (Thermal Emittance) properties of the roof material, apart from the thermal conductivity of the materials used in the roof.

Heat Transfer Through Roof

Solar Reflectance and Absorptance
The solar reflectance is the fraction of solar radiation reflected by roof. The complement of reflectance is absorptance; whatever radiant energy incident on a surface that is not reflected is absorbed in the roof. The reflectance and absorptance of building materials are usually measured across the solar spectrum, since these are exposed to that range of wavelength. Reflectance is measured on a scale of 0 to 1, with 0 being a perfect absorber and 1 being a perfect reflector. Absorptance is also rated from 0 to 1, and can be calculated from the relation: Reflectance + Absorptance = 1.

Emissivity or Thermal Emittance
Emissivity (or thermal emittance) of a material (usually written $\varepsilon$ or $e$) is the ratio of energy radiated by a particular material to energy radiated by a black body at the same temperature. It is a measure of a material’s ability to radiate the absorbed energy. A true black body would have an $e = 1$ while any real object would have $e < 1$. Emissivity is a dimensionless quantity (does not have units). In general, the duller and blacker a material is, the closer it’s emissivity is to 1. The more reflective a material is, the lower its emissivity. The emissivity of building material, unlike reflectance, is usually measured in the far infrared part of the spectrum.

Ideal Exterior Surface
An ideal exterior surface coating of a building in hot climate and under indoor cooling would have reflectance near 1, and absorptance near zero, and Emissivity near 1 to radiate absorbed heat back to the sky.
(Source: ECBC User Guide, BEE, ECO-III)

If designing a cool roof, requirements for minimum solar reflectance and initial emittance levels are specified in the ECBC specifications of U-factor:
Roofs with slopes less than 20° shall have an initial solar reflectance of no less than 0.70 and an initial emittance no less than 0.75. Solar reflectance shall be determined in accordance with ASTM E903-96 and emittance shall be determined in accordance with ASTM E408-71 (RA 1996).

In hot climates, cool roofs (or high emissivity or thermal emittance roof surfaces) are an effective way to reduce solar gains and cut building owners’ energy costs. Because cool roofs gain less heat than normal roofs, they reduce the need for air conditioning and make buildings more comfortable to the people inside. The light color reflects sunlight and heat away from the building, and the high emissivity or thermal emittance allows heat to escape to the atmosphere when the surface becomes heated. Although some surfaces, such as galvanized metal, have a high reflectance, they have a low emittance.

These surfaces reflect heat, but heat that is absorbed cannot escape. Other surfaces, such as dark paint, have a high emittance but a low reflectance. These surfaces allow heat to escape, but do a poor job of reflecting heat that strikes the surface.

Most cool roof materials for low-sloped roofs are white or another light color. For steep-sloped roofs that are often visible from the ground, roofing material manufacturers have developed popular roof colors other than white that will still reflect solar radiation or emit the sun’s energy away from the building.

Cool roofs have other benefits in addition to reducing operating absorbed heat costs. For building owners, they can cut maintenance costs and increase the life expectancy of the roof. For society in general, cool roofs can even help to reduce the urban heat island effect and slow down global warming that makes our cities hotter and produces unhealthy air.

**MANUFACTURERS LIST**

Manufacturers list of materials that comply with ECBC for wall, window and roof are mentioned below.

**Manufacturers list of Wall Insulations:**

Some of the manufacturers of solar lights and equipments are as mentioned below. The list mentioned below is not extensive and has to be checked in the market for more updates and more information.

- BEARDESELL LIMITED
- U.P TWIGA FIBERGLASS LIMITED
- TROCELLEN
- NANOGEL
- CANI MERCHANDISING PVT.LTD
- SANROK
- DOW CHEMICAL INTERNATIONAL PVT.LTD
- WACKER POLYMER SYSTEMS GMBH & CO. KG
- LLOYD INSULATIONS (INDIA) LTD
- FIBREX INDUSTRIES
- SUNSULATE INSULATION PVT. LTD
- SUZERAIN INSULATORS
- SUD AND WAREN PVT LTD
- PERFECT PAPERS
- MAG HARD INSULATORS
- AGNI FIBER BOARDS PVT. LTD
- S.S INSULATION
- ROCKWOOL (INDIA) LIMITE
- KONIFER INDIA
- UMANG BOARDS PRIVATE LIMITED
- SIGMA SEALING & INSULATION PRIVATE LIMITED
### List of Manufacturers:

Some of the important manufacturers list of glass and glass products is mentioned below. The list of manufacturers mentioned below is not comprehensive and needs to be checked with the updated list in the market.

- SAINT-GOBAIN GLASS INDUSTRIES
- GARWARE POLYSTER LIMITED
- MEHLER TECHNOLOGIES GMBH
- SEJAL GLASS
- ASAHI INDIA GLASS LTD
- DAFFODIL GLASS
- GLASS CONSORTIUM
- UNIVERSAL GLASS TRADERS
- INDO ALUSYS INDUSTRIES LIMITED
- SUPERIOR GLASS
- GLASS AND GLAZING SYSTEMS (P) LTD.
- HINDUSTAN GLASS WORKS LTD

### Manufacturers list of Roof Insulations:

Some of the manufacturers of solar lights and equipments are as mentioned below. The list mentioned below is not extensive and has to be checked in the market for more updates and more information.

- INDUSTRIAL FOAMS (P) LTD
- FALCONN FIBRE
- DUGAR INSULATIONS INDIA (P) LTD
- AMOL DICALITE LIMITED
- MACBERTAN (P) LTD
- LLOYD INSULATIONS INDIA (P) LTD
- EXCEL COATINGS
- SHALAK INTERNATIONAL
- OWENS CORNING (INDIA) LTD
- OZTEN LTD
- SHATEX LUBRZOLE
- ENERCON
Daylight Integration

Day lighting has a major effect on the appearance of space and can have considerable implications on energy efficiency, if used properly. Its variability is subtly pleasing to the occupant in contrast to the relatively monotonous environment produced by artificial light. It helps to create optimum working conditions by bringing out the natural contrast and colour of objects. The presence of natural light can bring a sense of well being and awareness of the wider environment. Day lighting is important particularly in commercial and other non-domestic buildings that function during the day. Integration of day lighting with artificial light brings about considerable savings in energy consumption. A good day lighting system, has number of elements most of which must be incorporated into the building design at an early stage. This can be achieved by considering the following relation to the incidence of day light on the building.

- Orientation, space organization and geometry of the space to be lit
- Location, form & dimension of the fenestrations through which day light will enter
- Location & surface properties of internal partitions that affect the day light distribution by reflection
- Location, form and dimensions of shading devices that provides protection from excessive light and glare
- Light and thermal characteristics of the glazing materials

**Tangible benefits of Natural day lighting integration:**

Live case study;

The below mentioned example is a library building of a research block in IIT, kanpur. These simulation results shown below in figure show lux levels during daytime from windows with all artificial lights switched off. This meets the laboratory requirement of lux levels. Daylight integration in the library block of the research centre in the campus proves that daylight integration saves both energy as well as economy.

![Figure 14: Daylighting inside the library building of IIT, kanpur](image)

Example: (library block of a research centre in IIT, kanpur)

Total connected load = 864W

Annual Savings in Library by switching off artificial lights during day time = 1825kWh

Annual savings in the library = Rs. 9124 (@Rs. 5/- per unit charge)
Relation between WWR and VLT to achieve recommended daylight levels:

Table 10: Recommended daylight factors for interiors as per Bureau of Indian Standards SP:41(S&T). DF 1%=80 lux. Design sky illuminance 8000lux.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Location</th>
<th>Daylight Factor %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dwellings Kitchen</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Living Room</td>
<td>0.625</td>
</tr>
<tr>
<td></td>
<td>Study room</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Circulation</td>
<td>0.313</td>
</tr>
<tr>
<td>2</td>
<td>Schools</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Class room desk top, black board</td>
<td>1.9—3.8</td>
</tr>
<tr>
<td></td>
<td>Laboratory</td>
<td>2.5—3.8</td>
</tr>
<tr>
<td>3</td>
<td>Offices/commercial spaces</td>
<td></td>
</tr>
<tr>
<td></td>
<td>General</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Drawing, typing</td>
<td>3.75</td>
</tr>
<tr>
<td></td>
<td>Enquiry</td>
<td>0.625—1.9</td>
</tr>
<tr>
<td>4</td>
<td>Hospitals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>General wards</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>Pathological laboratory</td>
<td>2.5—3.75</td>
</tr>
<tr>
<td>5</td>
<td>Libraries</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stack room</td>
<td>0.9—1.9</td>
</tr>
<tr>
<td></td>
<td>Reading room</td>
<td>1.9—3.75</td>
</tr>
<tr>
<td></td>
<td>Counter area</td>
<td>2.5—3.75</td>
</tr>
<tr>
<td></td>
<td>Catalogue room</td>
<td>1.9—2.5</td>
</tr>
</tbody>
</table>

As per BIS, the recommended daylight level for an office space, in the centre of the room should be 150lux. To achieve, the above BIS recommended daylight levels in a commercial building (table 1), window optimisation analysis had been carried out by using simulations for various WWR ranging from 10% to 100% and VLT values of glass ranging from 10% to 90% in the project “High performance commercial buildings in India”. Lighting levels were calculated to identify what % of WWR and VLT in combination achieves the daylight levels recommended by BIS and to find out the optimum WWR. From the analysis the following Table is obtained which shows the relation between WWR and VLT to achieve the BIS recommended daylight levels. The following table also helps in selecting the optimum WWR with corresponding VLT of glass to meet the recommended daylight levels in a working space.

<table>
<thead>
<tr>
<th>Visual Light Transmittance of Glass (%)</th>
<th>DF for WWR 10%</th>
<th>DF for WWR 20%</th>
<th>DF for WWR 30%</th>
<th>DF for WWR 40%</th>
<th>DF for WWR 50%</th>
<th>DF for WWR 60%</th>
<th>DF for WWR 70%</th>
<th>DF for WWR 80%</th>
<th>DF for WWR 90%</th>
<th>DF for WWR 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.3</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td>0.8</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>20</td>
<td>0.6</td>
<td>1.0</td>
<td>1.2</td>
<td>1.4</td>
<td>1.5</td>
<td>1.7</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td>30</td>
<td>1.0</td>
<td>1.6</td>
<td>1.8</td>
<td>2.1</td>
<td>2.3</td>
<td>2.5</td>
<td>2.6</td>
<td>2.7</td>
<td>2.7</td>
<td>2.8</td>
</tr>
<tr>
<td>40</td>
<td>1.2</td>
<td>2.1</td>
<td>2.4</td>
<td>2.8</td>
<td>3.1</td>
<td>3.3</td>
<td>3.4</td>
<td>3.6</td>
<td>3.6</td>
<td>3.7</td>
</tr>
<tr>
<td>50</td>
<td>1.5</td>
<td>2.6</td>
<td>3.1</td>
<td>3.5</td>
<td>3.8</td>
<td>4.1</td>
<td>4.3</td>
<td>4.5</td>
<td>4.5</td>
<td>4.6</td>
</tr>
</tbody>
</table>
The highlighted are the cases for each WWR for which the minimum corresponding VLT of glass is required to meet the recommended daylight factor in an office space. It was observed that minimum 10% WWR & 60% VLT of the glass is required to achieve the recommended illumination and daylight factor at the centre of the day lit zone in an office building. Similarly 40% VLT is required for WWR 20% and 30% to meet the required day lit levels. For WWR ranging from 40-90% minimum VLT required is 30% to achieve the day lit levels.

<table>
<thead>
<tr>
<th>Window Wall ratio</th>
<th>Minimum VLT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>0.60</td>
</tr>
<tr>
<td>0.20 – 0.30</td>
<td>0.40</td>
</tr>
<tr>
<td>0.40 – 0.70</td>
<td>0.30</td>
</tr>
</tbody>
</table>

**Surface Reflectance:** For daylight integration, the desirable internal and external finish of the building should be light in colour, as light colored surfaces will reflect more daylight than dark surfaces. Desirable reflectance inside a room and common finishes to achieve them are provided in table below.

<table>
<thead>
<tr>
<th>Surface</th>
<th>Desirable reflectance</th>
<th>Typical finish to achieve reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling</td>
<td>0.7—0.8</td>
<td>White colour</td>
</tr>
<tr>
<td>Wall</td>
<td>0.5—0.6</td>
<td>Cream, light green</td>
</tr>
<tr>
<td>Table top</td>
<td>0.35-0.5</td>
<td>Brick colour</td>
</tr>
<tr>
<td>Floor</td>
<td>0.15-0.3</td>
<td>Medium Grey</td>
</tr>
</tbody>
</table>

**Innovative Day lighting systems:**

Day lighting systems help in better daylight integration in the buildings. There are various day lighting systems. Some of them are as explained below:

**Light pipes:**

Light tubes or light pipes are used for transporting or distributing natural or artificial light. In their application of day lighting, they are also called as sun pipes, solar pipes, solar light pipes, or day light pipes. Generally, it may refer to “a tube or pipe for transport of light to another location, minimizing the loss of light.”

They make it possible to transport daylight through thick roof structures and attics. They are easier to install in retrofit applications than skylights. For practical reasons, light pipes are limited to smaller light collection areas.

If the building has an attic, installing skylights in the roof requires building a reflective enclosure to pass the light through the attic. Unless the attic is empty, this may be difficult. Light pipes are easier...
to pass through attics. In effect, a light pipe is a small skylight with an integral reflective enclosure.

- The light pipe has to be made of a solid transparent material, such as glass or plastic.
- The light pipe can be long, and it can have any number of bends.
- To make economical, all the light has to be squeezed into a light piece of small diameter.
- A small conduit is desirable to minimise heat loss and to make the light pipe easy to install.

There are 2 types of light pipes:

1. Simple light pipes: (rigid wall light pipe & flexible wall light pipe as shown in figures below)
2. Sun trackers

1. Simple light pipes:
The pipe may be rigid or flexible. Flexible light pipes are easier to install but they suffer more light loss from increased reflection and scatter inside the pipe

2. Sun trackers:
A movable mirror or refracting system can be used to align the incoming sunlight with the axis of the pipe, minimizing reflecting losses which is called as “sun tracker”

For better daylight integration ECBC also recommends Day lighting controls.

**Day lighting control as per ECBC recommendations:**

Luminaries in day lighted areas greater than 25m² (250ft²) shall be equipped with either a manual or automatic control device that;

- Is capable of reducing the light output of the luminaries in the day lighted areas by at least 50% and;
- Controls only the luminaries located entirely within the day lighted areas

**Day lighting control:**

Day lighting controls are devices that regulate the level of illumination provided by electric lights in response to the presence of day light. They usually consist of a sensing device that monitors either the total light level in the space or the available day light level at the day light aperture, and a control module which receives signal from sensor then switches or dims the electric lighting to maintain the needed illumination with minimal energy use. Day lighting controls also help to achieve uniform illuminance throughout the space and reduce energy consumption.
conditions of over lighting.

For spaces that receive significant day light, Daylight Harvesting Controls can be used to keep lights off, or to dim lights. The simplest systems simply turn off the lighting circuit when a pre-determined level of illumination is achieved through daylight. Because these systems require a high level of daylight throughout the space, systems that turn off only a portion of the lights are often more effective. For example, two lamps in a four-lamp fixture might be turned off, or the row of fixtures nearest the windows might be turned off in response to daylight. Daylight dimming systems are the most elegant, but they require special stepped or continuous dimming ballasts.

Control techniques:

- On/off day light switching is the most economical approach, but may create light level changes in work areas. It is most successful in circulation areas and non critical work areas. (Ex: multilevel switching schemes)

- Dimming systems have higher costs, but will be more acceptable in high work areas. (Ex: Dimming ballasts)

### OPTIMUM WWR

Window Wall Ratio (WWR)

Window Wall Ratio is the ratio of vertical fenestration area to gross exterior wall area. Gross exterior wall area is measured horizontally from the exterior surface; it is measured vertically from the top of the floor to the bottom of the roof.

Example – The wall shown in the figure has width ‘W’ and height ‘H’. The window height is ‘a’ and width is ‘b’ as shown in figure. The WWR for the given facade will be \( \frac{a \times b}{H \times W} \)

Optimisation of Window Wall Ratio (WWR) and daylight integration

Analysis using simulation engines was carried out in this project “High Performance Commercial buildings in India” to observe the impact of various WWR on the cooling energy demand. As expected the cooling energy demand increases with increase in window wall ratio. Therefore ECBC has made glass selection more stringent with higher WWR. The figure below shows a reduction in cooling energy consumption for higher WWR, if a higher performance glass with higher WWR is used.
On comparing the annual energy consumption of a building with various Window Wall Ratios it is observed in the graph above that the lowest energy consumption is in the case of WWR 10%. Window Wall Ratio however is not optimised if daylight integration is not carried out. Optimum Window Wall Ratio would achieve a balance between cooling energy demand and lighting energy demand due to integration of natural daylight. On integration of daylight in the office floor space the following graph is obtained. In the graph below it is observed that minimum electricity consumption is in the case where WWR is in the range of 20-30%. This is due to reduced artificial lighting demand which would also have an impact on cooling energy demand. It should be observed that after integrating daylight, on comparing annual electricity consumption, WWR with 10% has higher electricity consumption due to increased consumption by artificial lighting. Therefore the optimum WWR recommended is 20-30% with daylight integration. *Thus it is very crucial to integrate daylight with artificial lighting when the envelope is compliant with ECBC to take maximum advantage of the ECBC compliant window.*