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# Investigating the role of insulated tiles as a prospective material for building envelope: thermal performance and energy efficiency

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**Abstract.** The residential and commercial sectors account for nearly one-third of the total electricity consumption in India. During the period from 1971 to 2012, the highest increase in electricity consumption was seen in the residential sector with a 9.4% compound annual growth rate, followed by the commercial sector. This has been attributed mainly to the extensive use of air conditioning for thermal comfort in buildings in these two sectors. Building envelope design and construction play an important role in reducing energy consumption in such systems. With the incorporation of thermal insulation materials in combination with other construction materials in a building's roof and walls, especially in those that are exposed to solar radiation, the energy intensiveness of buildings can be brought down significantly on a long-term basis. Despite the availability of several insulation products in the Indian market, the importance of thermal insulation for buildings for energy efficiency has not been well recognized by building engineers and developers at present. This paper looks into various important aspects related to building insulation materials, right from the principles of building science to the application of materials in buildings. This paper provides a qualitative analysis of insulation materials in the buildings and also provides practice-oriented background information for building designers, architects, site engineers and various other stakeholders in the building construction industry. The paper also evaluates the application of Expanded Polystyrene (EPS) as an insulating material for walls and roofs.

**Keywords:** Building material, energy efficiency, insulation, insulated tiles, sustainable architecture

## 1. Introduction

The residential and commercial sectors account for 22% and 9% of the total electricity consumption in India, respectively (CSO, 2013). With the rapid ongoing urbanization and economic development in the country, it has been estimated that India would build 700–900 million square meters of floor space per year for residential and commercial spaces in the next 20 years or so, leading to an extensive demand for electricity in the coming years (Mckinsey, 2010). Buildings can be designed to ensure that occupants receive thermal and visual comforts consuming minimal energy. Energy-efficiency measures can effectively be incorporated by adopting an integrated approach to the design of a building, starting from its early design phase. Such an approach takes into account the local climate and balances all aspects of energy use in a building, such as lighting, space conditioning, and ventilation. In a hot country like India, the external surfaces of the building envelope, for example, the roof and walls, which are particularly exposed to direct solar radiation, get heated up at temperatures higher than the prevailing temperature inside the building. From the building envelope, the heat gets transferred through thermal conduction to the inner surfaces of the roof and walls, creating an unwanted heat source within the occupants' space. The heat gets distributed inside the building further, through radiation and convection, causing much discomfort to the occupants. Hence, it becomes essential that the occupants' space has the means to ensure good air circulation, ventilation, space cooling, and so on, usually achieved by energy-driven electrical fans and air-conditioning systems. In buildings located in cold climate regions, conduction of heat also takes place through roofs and walls, in addition to the loss of heat from leakages in the envelope from the warmer interiors to the cooler exterior. If this heat transfer is not controlled efficiently, excessive heating would be required to maintain thermal comfort within the occupants' space.

The building envelope is the skin of a building which is supported by the skeleton of the building structure. It acts as a thermal barrier between the enclosed conditioned space and the outside environment through which the thermal energy is transferred. By minimizing the heat transfer through the building envelope the need for energy used for space heating and cooling can be reduced considerably (Kamal & Bano, 2016). Good thermal comfort at low energy cost can be obtained by adopting an energy-efficient building design, incorporating the use of thermal insulation in combination with other building materials in the building envelope. All building materials offer thermal resistance to the conduction of heat depending on their thermal conductivity value. However, compared to several building materials commonly used in construction, such as brick, having a thermal conductivity of 0.5 to 0.7 W/m°K, the thermal conductivity of insulation materials is remarkably low, often less than 0.06 W/m°K.

## 2. Role of insulation on the thermal performance of buildings

Insulation of building envelopes, both opaque and transparent, is an important strategy for building energy conservation. The insulation strategy of a building needs to be based on a careful consideration of the mode of energy transfer and the direction and intensity in which it moves. Hegger et al, have given the methodology to reduce heat transfer and incoming solar radiation along with the geometric optimization of the building envelope (Zeumer, 2012). Martin Evans in his book entitled "Housing, Climate and Comfort", has advised increasing the thermal capacity of the envelope components for accomplishing the objective of reduced heat gain (Evans, 1980). It can be inferred that the common objective and principle of improving the thermal performance of a building envelope is to 'Reduce the Solar Heat Gain'.

Under steady-state conditions, the heat flow through a building element is proportional to its thermal conductance (U-value). Strictly speaking, the steady state condition is never obtained in practice as outside conditions do change continuously to a greater or lesser extent, but the concept can be useful in determining the thermal performance of air-conditioned buildings in temperate and humid climates. Under non-steady state conditions which are found in buildings without mechanical heating or cooling in all climates and even for air-conditioned buildings in hot-day climates, apart from its U-value, the thermal capacity of the element also determines the heat flow and the 'thermal diffusivity', 'time-lag' and 'decrement factor' become important (Kamal, 2016). Time lag and decrement factor are both properties of the building element and not of the building materials. For building elements of massive construction, the time lag is larger and the decrement factor smaller than for a lightweight element, even though both may have the same U-value (Kamal, 2011).

Not-insulated exterior walls are the most important zones for heat gain and losses. To be insulated economically, it will be more beneficial to use the main mass of exterior walls (Bryant & Lume, 1997). By insulating the exterior walls, 70% of total heat loss can be prevented (Allder, 1999). Insulation must be economic and must prevent an increase in the building's dead load. Analyses of Polystyrene materials show that, for the same thermal conductivity resistance, it is the most economic and most light one in weight in Polyethylene materials (Edremit, 1997). Figure 1 show the percentage of plastics in the building industry across the globe (Fisch, 2002).

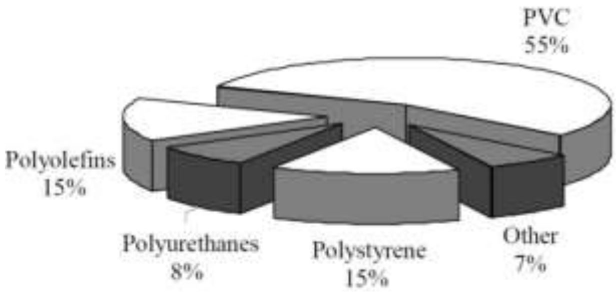


**Fig. 1. Plastics in building and construction.**

Insulating materials, due to their low thermal conductivity, can substantially resist the transfer of heat from the exterior to the interiors of the building if the external temperature is high (Figure 2) and resist heat transfer from the interiors to the exterior in a similar way when the external temperature is low. Figure 3 shows the effect of thermal insulation on heat transfer through walls. Figure 4 and Figure 5 show the details of Roof Insulation above and below the floor slab respectively. Figure 6 and Figure 7 show the wall section with External and Internal Insulation respectively.

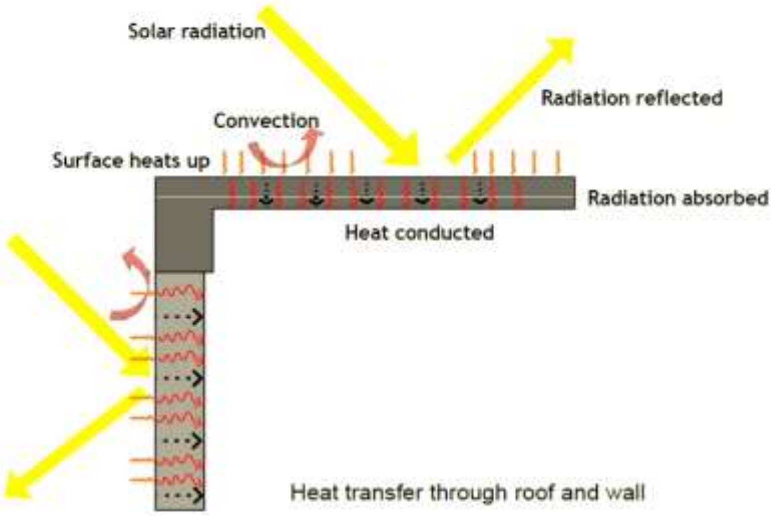


**Fig. 2. Exposure of solar radiation on the building envelope and thermal heat conduction.**

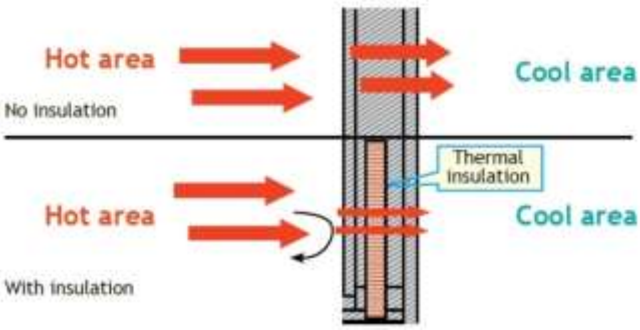


**Fig. 3. Effect of thermal insulation on heat transfer through walls.**

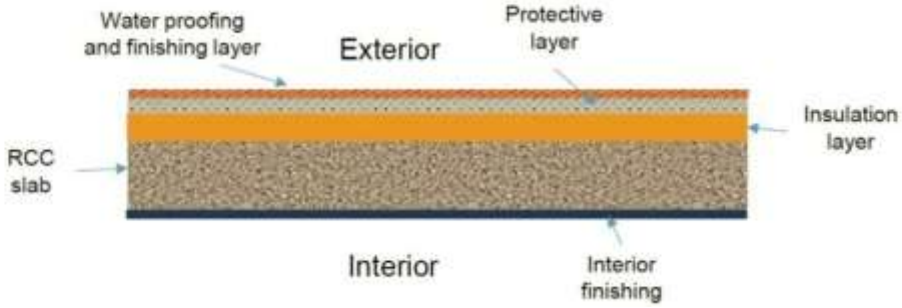


**Fig. 4. Details of roof insulation above the floor slab.**

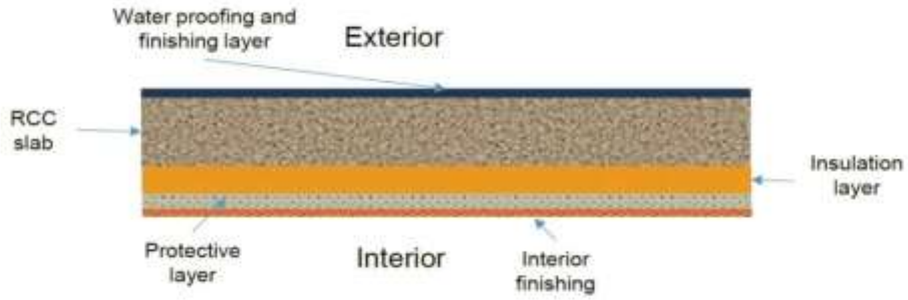


**Fig. 5. Details of roof insulation below the floor slab.**

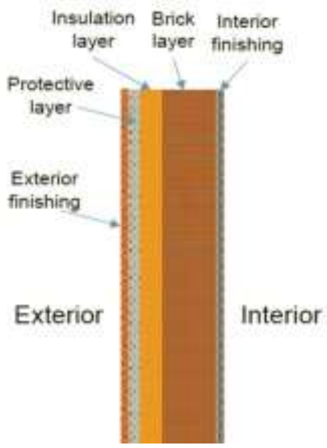


**Fig. 6. Wall with external insulation.**

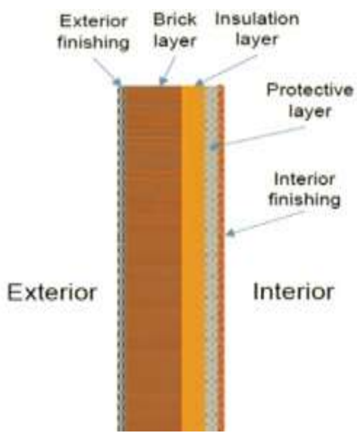


**Fig. 7. Wall with internal insulation.**

An insulating tile has been developed for deck insulation and walling. EPS is sometimes referred to as "molded expanded polystyrene" or "bead-board." This is moderate R-value insulation, from slightly less to slightly more than R-4 per inch, depending upon density (Smith, 2016).

## 3. Typical properties of commonly used insulation materials

Table 1 shows the typical properties of the commonly used insulation materials for climatic responsiveness and energy efficiency in buildings (BIS: SP-41, 1997).

**Table 1. Typical properties of different insulation materials**

| S. No. | Type of Materials | Density kg/m$^3$ | Thermal Conductivity W/m.K | Specific Heat Capacity kJ/kg.K |
|---|---|---|---|---|
| 1 | Expanded polystyrene | 16.0 | 0.038 | 1.34 |
| 2 | Expanded polystyrene | 24.0 | 0.035 | 1.34 |
| 3 | Foam glass | 127.0 | 0.056 | 0.75 |
| 4 | Foam glass | 160.0 | 0.055 | 0.75 |
| 5 | Foam concrete | 320.0 | 0.070 | 0.92 |
| 6 | Foam concrete | 400.0 | 0.084 | 0.92 |
| 7 | Cork slab | 164.0 | 0.043 | 0.96 |
| 8 | Cork slab | 192.0 | 0.044 | 0.96 |
| 9 | Rock wool (unbonded) | 92.0 | 0.047 | 0.84 |
| 10 | Rock wool (unbonded) | 150.0 | 0.043 | 0.84 |
| 11 | Mineral wool (unbonded) | 73.5 | 0.030 | 0.92 |
| 12 | Glass wool (unbonded) | 69.0 | 0.043 | 0.92 |
| 13 | Glass wool (unbonded) | 189.0 | 0.040 | 0.92 |
| 14 | Resin-bonded mineral wool | 16.0 | 0.040 | 1.00 |
| 15 | Resin-bonded mineral wool | 24.0 | 0.036 | 1.00 |
| 16 | Resin-bonded mineral wool | 48.0 | 0.042 | 1.00 |
| 17 | Exfoliated vermiculite (loose) | 264.0 | 0.069 | 0.88 |
| 18 | Asbestos millboard | 1,397.0 | 0.249 | 0.84 |
| 19 | Hardboard | 979.0 | 0.279 | 1.42 |
| 20 | Straw board | 310.0 | 0.057 | 1.30 |
| 21 | Soft board | 320.0 | 0.066 | 1.30 |
| 22 | Soft board | 249.0 | 0.047 | 1.30 |
| 23 | Wallboard | 262.0 | 0.047 | 1.26 |
| 24 | Chipboard | 432.0 | 0.067 | 1.26 |
| 25 | Chipboard (perforated) | 352.0 | 0.066 | 1.26 |
| 26 | Particle board | 750.0 | 0.098 | 1.30 |
| 27 | Coconut pith insulation board | 520.0 | 0.060 | 1.09 |
| 28 | Jute fibre | 329.0 | 0.067 | 1.09 |
| 29 | Wood wool board (bonded with cement) | 398.0 | 0.081 | 1.13 |
| 30 | Wood wool board (bonded with cement) | 674.0 | 0.108 | 1.13 |
| 31 | Coir board | 97.0 | 0.038 | 1.00 |
| 32 | Saw dust | 188.0 | 0.051 | 1.00 |
| 33 | Rice husk | 120.0 | 0.051 | 1.00 |
| 34 | Jute felt | 291.0 | 0.042 | 0.88 |
| 35 | Closed cell flexible elastomeric foam – NBR | 40-55 | 0.043 | 1.20 |

## 4. Criteria for selecting insulating materials for building designers

Thermal insulation materials/products can play an important role in enhancing thermal comfort in non-air-conditioned buildings and in reducing the need for energy-intensive cooling or heating requirements in air-conditioned buildings. The importance of thermal insulation materials is now being realized by building designers and developers who are conscious of the thermal comfort and energy performance of buildings. The application of thermal insulation for any building project needs an in-depth analysis of several parameters and considerations, which can influence the selection of insulation product(s) and its optimum thickness. While selecting an insulating material, it is important to select materials having high R-value and low U-factor for composite roofs and walls, but the selection should also take into consideration various other characteristics (e.g., fire resistance, compressive strength, traction strength, vapor diffusion, etc.) and the suitability of insulation materials for a particular application (Kapoor et al., 2016). While designing new buildings, thermal insulation should not be seen as a single and independent measure but as a part of an overall design strategy comprising other passive and active measures to improve the thermal comfort and energy efficiency of buildings. In the case of existing buildings, retrofitting insulation is also possible in many situations. Computer-aided building energy simulation software can help in decision-making while designing an energy-efficient building.

Laboratory testing facilities are available in the country to measure the thermal conductivity and other properties of insulation materials as well as the U-factor of the composite roof and wall sections as per Indian or international standards. In several cases, it may be important to get the material tested before deciding on their procurement for applications in a building project. Special skills are required and care should be taken while applying any insulation product at the building site. These may include the right preparation and pre-treatment of surfaces where it is being applied along with the incorporation of binding, waterproofing, and other protective layers to get long-term benefits of insulation. It is, therefore, essential to follow application instructions and guidelines provided by insulation manufacturers for good results.

## 5. Expandable polystyrene (EPS) Kool tiles for walls and roof insulation

One such brand name is ' Kool tiles' developed in India by Reliable Insupacks P. Ltd. They are molded from a foamable plastic resin called Expandable Polystyrene (EPS). These tiles are lightweight as they are molded from polystyrene foam. The insulated EPS tile replaces the conventional mud-phuska laid over the concrete slab. The insulated EPS tile is rectangular with a tongue and groove joint provided to enable locking together all tiles on their edges thus providing an airtight, monolithic insulation layer. The tile has an in-built surface, shaped for uniform bonding with a screed or finishing layer. The top surface of the insulated EPS tile is provided with lateral and longitudinal indentions of 10 mm depth to provide a shuttering surface for covering a layer of mud or PCC for grouting the final/top layer of brick or other tiles (Kooltile, 2014). Figure 8 shows the various dimensions for varying thicknesses of insulated EPS tiles of size 800 mm x 600 mm.

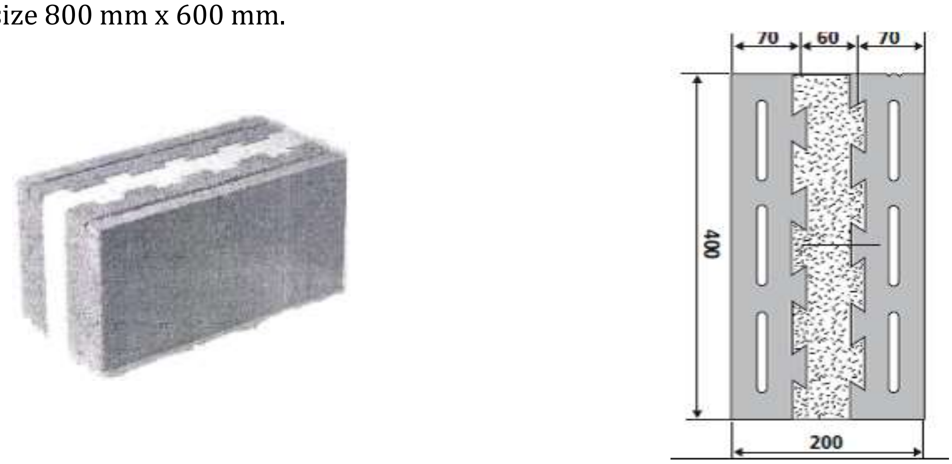


**Fig. 8. View of a block and a sectional plan of a Kool Tile.**

A difference in temperature up to 24°C can be achieved between the inside and outside temperatures. Figure 9 shows the section of a tile wherein each layer of material assists in thermal resistance and Figure 10 shows the Insulated EPS tile with the interlocking arrangement for airtight insulation.

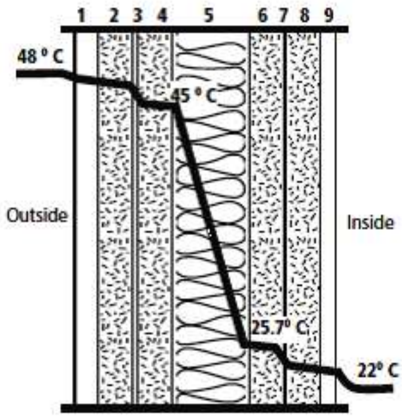


**Fig. 9. A Section of an insulated EPS Tile.**

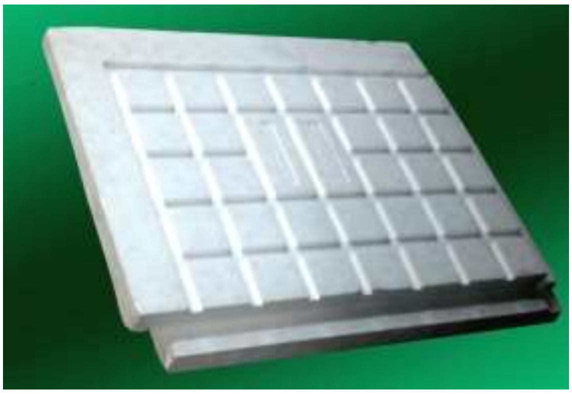

**Fig. 10. Insulated EPS tile with the interlocking arrangement for airtight insulation.**

## 6. Manufacturing Process of Expandable polystyrene (EPS) Kool tiles

The resin is foamed using saturated steam in a fully automatic Batch pre-expanding machine, to the specified density and conveyed pneumatically through a fluidized bed drier into air-permeable silos. The beads are matured in these silos for a predefined maturation period and conveyed into material distribution bins for checking the density of these pre-expanded beads. These beads after assessment of the density and manual intervention (by mixing higher or lower density beads (if required) are conveyed pneumatically into a hopper of a fully automatic molding machine. An aluminum die with the required shape for the insulated EPS tile is fitted onto this molding machine. Beads are drawn into this die in a pre-programmed sequence. The steam passed through the beads to mold the beads into the required shape, the molding stabilized, die cooled and finally the insulated EPS tile was ejected onto a nylon slope for conveying to the finishing room (through a hot dry room). After visual inspection of dry molded pieces, the product is packed in lots and shifted to the assigned store. Thereafter, inspection by the Quality Control team is done and the material is dispatched (Adlakha, 2019).

## 7. The installation procedure of Expandable Polystyrene (EPS) Kool tiles

### *7.1. For External Roof*

The following steps are involved in the installation of Insulated EPS tiles for the external Roof (Figure 11).

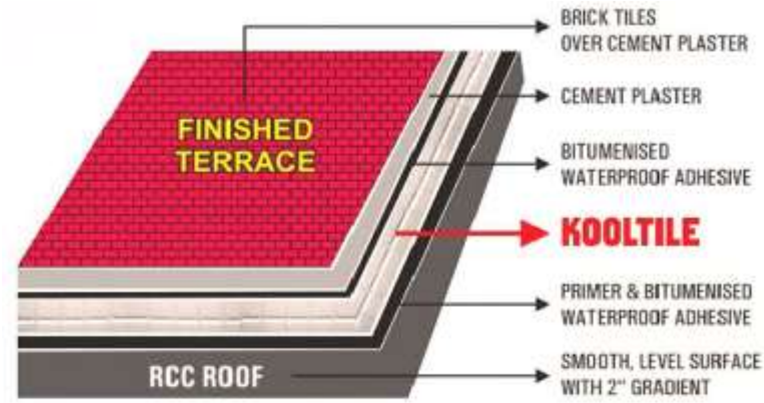


**Figure 11: Section of a terrace covered with insulated EPS tiles.**

a) Keep the roof surface smooth, dry and clean with a brush or with compressed air to make a dust and dirt-free roof.

b) Apply uniformly two coats of asphalt-based polymerized waterproofing chemical or bituminous cold emulsion on the smooth surface (Figure 12).

c) Fix and join the tiles along with the slotted tongue and groove edges on the roof, and press the tiles to make bitumen ooze out from the joist. Figure 13 shows the view of a roof-insulated EPS tile with an interlocking arrangement to achieve airtight insulation by joining slotted tongue and groove edges.

d) Apply a base layer of cement screed over tiles for a minimum of 50 mm gradient.

e) Fix brick tiles/mosaic / ceramic tiles over cement screed for a terrace finish or any other finish of choice (Figure 14).

**Fig. 12. The insulated EPS sheets are laid on the terrace over a bituminous coat.**

**Fig. 13. The interlocking insulated EPS sheets laid on the terrace.**

**Fig. 14. The final finished roof surface with insulated EPS tiles.**

### *7.2. For External Wall*

Figure 15 shows the different layers applied on the wall surface. The procedure for installing the insulated EPS tiles on the wall is given below:

a) Keep the wall smooth for protection and ease of adhesion.

b) Apply uniformly two coats of bituminous cold emulsion on the smooth waterproof surface.

c) Fix and join insulated EPS tiles along with the slotted tongue and groove edges on the wall (Figure 16).

d) Hammer dowel nails at all four ends to fix insulated EPS tiles.

e) Apply a base layer of cement screed over tiles for a minimum thickness of 4 mm.

f) Apply paint / exterior finish on the plastered wall.

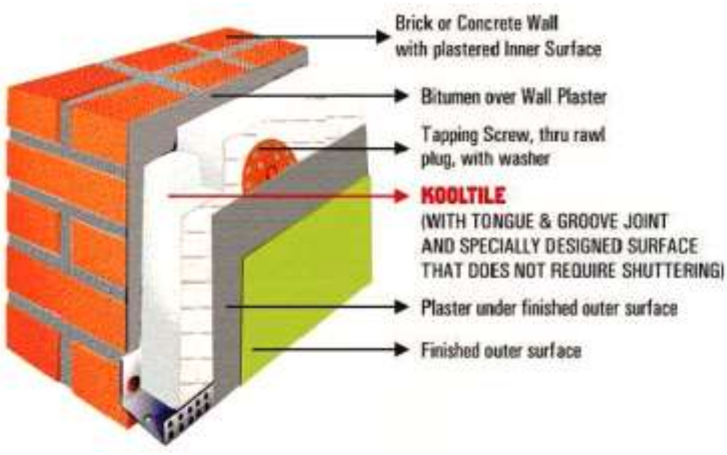


**Fig. 15. Section showing the procedure of installing insulated EPS tiles on the wall surface**

**Fig. 16. The insulated EPS tiles cladding on external walls.**

## 8. Precautions

Following precautions shall be taken while using these tiles on the roof:

a) The base of the roof slab/ wall shall be smooth for proper adhesion of the tiles, else air-pockets can lead to poor and uneven insulated surface

b) A minimum gradient of 1:120 shall be provided in the screed laid over the roof to avoid water logging which may lead to seepage and cracks on the roof.

c) Due to leaking water pipes/tanks etc. on the roof, rainwater outlets shall not be allowed to be blocked to avoid water logging which may lead to seepage and cracks on the roof.

d) Proper grouting over brick tiles / ceramic tiles shall be laid to avoid damage to the roof and structure due to loose tiles.

e) Tiles of lower density than specified by the manufacturer shall not be used as these may not be adequate to support heavy loads such as water tanks, movement of Diesel Generator sets, etc. on the terrace.

## 9. Advantages of insulated EPS tiles

The followings are the advantages of insulated tiles for the treatment of roofs:

### *9.1. Roof Treatment*

a) Individually molded roof insulation tiles give the entire roof a uniform insulation value.

b) Tiles are molded and not cut from an EPS block. Hence, each tile has got molded water-repellent finish on both surfaces, unlike the cut surfaces of sheets which may absorb some water through the porosities on the cut surface.

c) The benefits of a double layer are insulation provided by the interlocking joints of each tile to ensure water-tight joints of the concrete tiles, thus giving the perfect sealing effect.

d) There is a tremendous saving in costs. Other competing products with similar critical properties, like XPS or PUF, are three to five times as expensive.

e) The Comfort level of the top floor is significantly improved as the roof is insulated against the blistering heat in summer.

f) There is a 40-50% Electricity saving in the case an air conditioner is used. With 40% savings in a one-year payback of insulation, the cost is <1 year.

g) There are no aging cracks in the waterproofing of the roof (even for bitumen-based ones) and hence there is no seepage/dampness after heavy rains.

h) The structure is protected due to the lifetime durability and reliability of roof insulation treatment with insulated EPS tiles.

### *9.2. External Walling*

a) Provides an insulated weatherproof, durable architectural façade

b) It Helps conserves energy and reduces the building's overall CO2 emissions

c) Help reduce heat loss or gain

d) Reduces the risk of condensation

e) Helps eliminate thermal bridging

f) Provides a substantial reduction in sound transmission

g) Improves internal comfort levels even without ACs

h) Provides beneficial cost savings for life

i) Suitable for both new constructions and old

j) Reduces recurring investment in building maintenance

## 10. Limitations of insulated EPS tiles

There are many benefits of using insulated tiles for the treatment of roofs and walls, but there are a few limitations also while using these tiles. The solvent-based adhesive and hot asphalt disintegrate EPS. Hence, if either of these is used, a suitable cover board needs to be installed over the EPS. EPS can also be decomposed or melted at high temperatures.

The limitations of insulated EPS tiles are summarized as followings:

a) Lower-density tiles may not be adequate to support heavy loads such as multiple water tanks of a capacity of more than 5000 liters, movement of DG sets, etc. on the terrace.

b) Waterlogging may lead to seepage and cracks on the roof unless a screed at the base is provided at a gradient of 1:120.

c) EPS, being a water vapor permeable material, may cause dampness and structural damage due to a cracked surface.

d) Limited options for using only cement concrete or high-end finishing materials as heat penetration stops at the insulation layer, leading to cracks on the finishing surface.

e) There is uncertainty among building designers with regard to durability of the insulation, attainment of energy saving and payback period on additional investment.

## 11. Specifications of insulated EPS tile

### *11.1. Specifications of insulated EPS tiles for wall*

The varied criteria and specifications for selecting EPS Tiles for wall insulation are listed below:

| S. No. | Specifications | Insulated EPS Tile (Regular) | Insulated EPS Tile (HD) | Insulated EPS Tile (Supreme) |
|---|---|---|---|---|
| 1 | Thickness (mm) | 37.5 | 37.5 | 37.5 |
| 2 | Shuttering Thickness for Plaster | 12 | 12 | 12 |
| 3 | Constituent Material | EPS (Self-Extinguishing) | EPS (Self-Extinguishing) | EPS with Graphics (Self-Extinguishing) |
| 4 | Color | White | White | Grey |
| 5 | Density (Kg/cum) | 16 | 18 | 18 |
| 6 | Thermal Conductivity (K Value) as per | 0.37 | 0.35 | 0.31 |
| 7 | Thermal Conductivity (R-Value) | 0.987 | 0.933 | 0.827 |
| 8 | Thermal Resistance ($W/m^2$°C /W) | 1.014 | 1.071 | 1.21 |
| 9 | Water Absorption (% volume on 7 days immersion) | <0.6% | <0.1% | <1% |

### *11.2. Specifications of insulated EPS tiles for Roof*

The varied criteria for selecting insulated EPS Tiles for roof insulation is as listed below:

| S. No. | Specifications | Insulated EPS Tile (Regular) | Insulated EPS Tile (HD) | Insulated EPS Tile (Supreme) |
|---|---|---|---|---|
| 1 | Thickness (mm) | 50 | 50 | 50 |
| 2 | Density (Kg/cum) | 16 | 32 | 40 |
| 3 | Thermal Conductivity (K Value) as per IS:4671 ($mW/m^2$°C) at 10˚ C | 0.33 | 0.315 | 0.31 |
| 4 | Thermal Conductivity (R-Value) for TIL ($W/m^2$°C) at 10°C (Each sqm of the roof exposed-20°C temp diff. (outside 45°C, inside 25°C) will cause a heat loss of 12.4 to 13.2 W) | 0.66 | 0.63 | 0.62 |
| 5 | Thermal Resistance ($m^2$° C /W) | 1.515 | 1.587 | 1.613 |
| 6 | Water Absorption (% Vol. on 7 days immersion) | <0.4% | <0.2% | <0.1% |
| 7 | Compressive Stress at 10 % strain (kPa)(wt. equivalent of 14-35 men (standing over 1 sqft area) to compress insulated EPS tile by 5 mm) | 140 | 250 | 350 |
| 8 | Sustained Compressive load-bearing capacity with 2% (-1 mm compression) strain after 50 yrs (kPa) | 50 | 90 | 150 |

### *11.3. Dimensional stability*

It has the optimal ability to retain volume and shape with changing temperatures.

### *11.4. Thermo stability*

The short-term and long-term thermal stability of insulated EPS Tiles are optimal.

### *11.5. Resistance to rotting/decaying and aging*

Since it is not a naturally occurring organic product, there is no chance of decay or decomposition.

## 12. Conclusions

The reduction in the cooling load by using insulating material in the roof and walls is very important as a means to reduce the electrical energy consumption to cool the space and hence cost saving. The evaluation of the thermal performance of a building envelope design helps in decision-making by architects and building designers regarding various architectural parameters. Roof construction is one of the biggest and most significant disbursements that are made by owners of buildings. These important investments generally comprise repair, maintenance, installation, insulation, a waterproofing membrane, and a roof deck. Designers of roof systems and contractors have been coming to the realization that roofing systems that make use of expanded polystyrene, which is also referred to as EPS, are capable of fulfilling building requirements that are highly demanding. Expanded polystyrene is a resilient, lightweight, closed-cell insulation made of foamed plastic. It can offer dimensional stability, robust water resistance, a long-term R-value, and substantial savings on energy expenditures when it is installed properly and protected from the effects of moisture. Expanded polystyrene insulation is a good match with all commercial roofing systems. Some examples of these expanded polystyrene-compatible roofing systems are modified bitumen, built-up roof, which is also referred to as BUR, and one-ply membrane systems that are fully adhered, mechanically fastened, or ballasted (Polymolding, 2022).

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