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 planned so that residents enjoy minimally energy-intensive thermal and visual comforts. By starting with the early design stages of a building and using an integrated design approach, energy-efficiency measures can be efficiently incorporated. Such a strategy balances all energy use in a building; including lighting, air conditioning, and ventilation, while taking the local environment into account. In a hot country like India, the exterior building envelope surfaces, including the roof and walls, which are particularly exposed to direct solar radiation, heat up to temperatures greater than the normal inside temperature.

Thermal conduction transfers heat from the building exterior to the interior surfaces of the roof and walls, providing an unwelcome heat source inside the residents' area. Via convection and radiation, the heat is further disseminated inside the building, making the occupants very uncomfortable. As a result, it is crucial that the inhabitants' space possess the equipment needed to guarantee proper air circulation, ventilation, space cooling, and other necessities. Electrical fans and air conditioning systems typically accomplish these tasks. Along with heat loss due to leaks in the envelope from the warmer interiors to the cooler exterior, buildings in cold climatic regions also lose heat through conduction through walls and roofs. If this heat transmission is not well managed, a lot of heating will be needed to keep the inhabitants' environment at a comfortable temperature.

The skin of a building is called the building envelope, and it is supported by the structural framework of the building. Between the conditioned enclosed space and the outside environment, it serves as a thermal barrier through which thermal energy is transported. It is possible to significantly minimize the amount of energy required for space heating and cooling by limiting heat transfer through the building envelope (Kamal & Bano, 2016). Using an energy-efficient building design that uses thermal insulation in conjunction with other building materials in the building envelope will result in good thermal comfort at a low energy cost. Depending on their thermal conductivity rating, all building materials offer thermal resistance to the conduction of heat. 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’.

The heat flow through a building component is proportional to its thermal conductance under steady-state conditions (U-value). Although outside circumstances change continuously to some degree, the steady state condition is strictly speaking never attained in practice, but the idea might be helpful in figuring out how well air-conditioned buildings function thermally in temperate and humid climates. In addition to its U-value, the thermal capacity of the element also determines the heat flow under non-steady state conditions, which are present in buildings without mechanical heating or cooling in all climates and even in air-conditioned buildings in hot-day climates. Under these conditions, "thermal diffusivity," "time-lag," and "decrement factor" become significant (Kamal, 2016). Decrement factor and time lag are both characteristics of the construction element, not the building materials. Despite the fact that both may have the same U-value, the time lag is greater and the decrement factor is smaller for building elements of huge construction than for lightweight parts (Kamal, 2011).

The most significant areas for heat gain and loss are outside walls that are not insulated. Using the bulk of exterior walls will be more advantageous for insulation purposes (Bryant & Lume, 1997). It is possible to stop 70% of all heat loss by insulating the outer walls (Allder, 1999). The building's dead load must not grow and insulation must be cost-effective. Analysis of polystyrene materials reveals that it is the most cost-effective and lightweight polyethylene material for the same thermal conductivity resistance (Edremit, 1997). Figure 1 show the percentage of plastics in the building industry across the globe (Fisch, 2002).

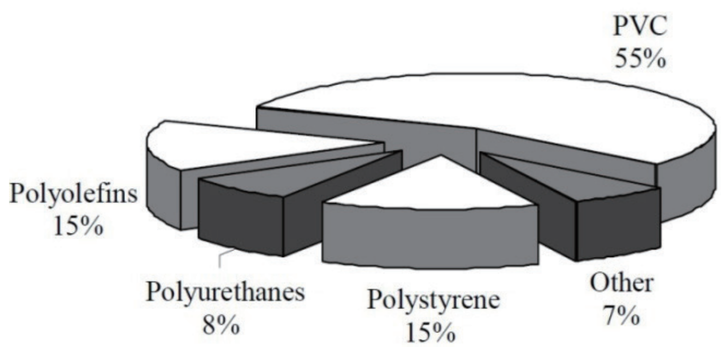

Figure 1. Plastics in building and construction

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.

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).

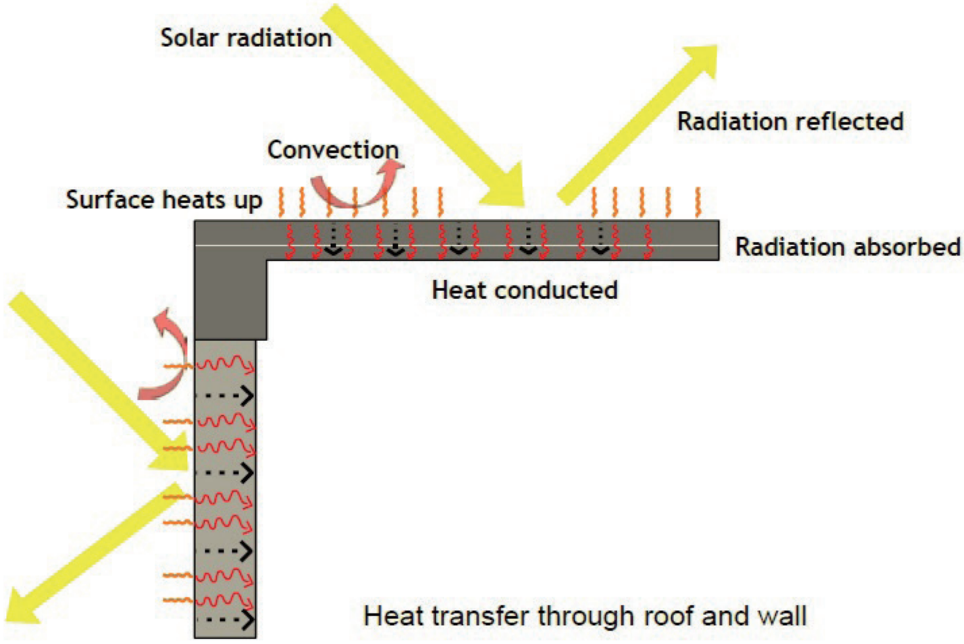

Figure 2. Exposure of solar radiation on the building envelope and thermal heat conduction

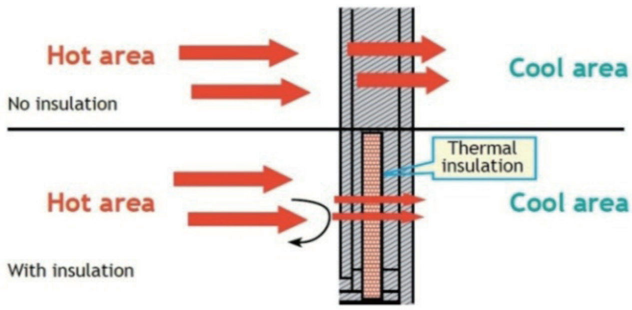

Figure 3. Effect of thermal insulation on heat transfer through walls

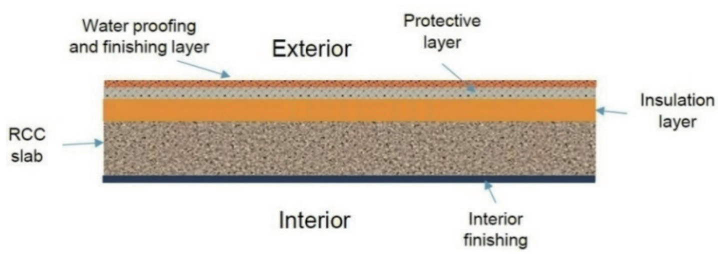

Figure 4. Details of roof insulation above the floor slab

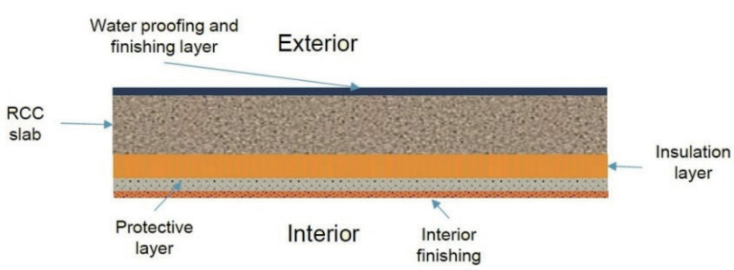

Figure 5. Details of roof insulation below the floor slab

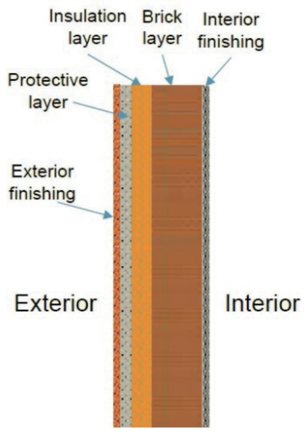

Figure 6. Wall with external insulation

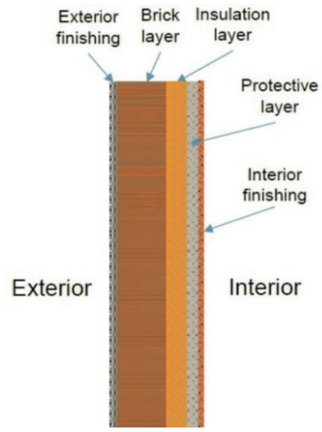

Figure 7. Wall with internal insulation

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

In addition to improving thermal comfort in non-air-conditioned buildings, thermal insulation materials and technologies can also significantly lower the need for energy-intensive cooling or heating in air-conditioned structures. Building designers and developers who are concerned with the thermal comfort and energy efficiency of buildings are now realizing the importance of thermal insulation materials. Any building project requiring the use of thermal insulation requires a thorough investigation of a number of factors and variables that may affect the choice of insulation product(s) and its ideal thickness. For composite roofs and walls, it is crucial to choose insulating materials with high R-value and low U-factor, but the choice should also consider a number of other characteristics (such as fire resistance, compressive strength, traction strength, vapour diffusion, etc.) and the suitability of the insulation materials for a given application (Kapoor et al., 2016).

Thermal insulation should not be viewed as a stand-alone measure when developing new structures, but rather as a component of a larger design approach that also includes other passive and active measures to raise buildings' thermal comfort and energy efficiency. Retrofitting insulation is another option for structures that already exist in many cases. Making decisions when developing an energy-efficient building can be facilitated by computer-aided building energy modeling software.

To assess the thermal conductivity and other characteristics of insulation materials as well as the U-factor of the composite roof and wall sections in accordance with Indian or international standards, laboratory testing facilities are available in the nation. When choosing to buy the material for use in a building project, it may be necessary in a number of situations to have it tested. Every application of insulation at a construction site requires special expertise and caution. In order to receive the long-term advantages of insulation, these may include the proper cleaning and pre-treatment of the surfaces where it is being applied, as well as the incorporation of binding, waterproofing, and other protective layers. For best results, it is crucial to adhere to the application instructions and recommendations given by insulation manufacturers.

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). Because they were moulded from polystyrene foam, these tiles are thin and light. The traditional mud-phuska that was placed over the concrete slab is replaced with the insulated EPS tile. The rectangular, airtight, monolithic insulation layer is created by locking together all of the insulated EPS tile's edges using a tongue and groove joint. A surface integrated into the tile is tailored for consistent bonding with a screed or finishing coat. A layer of mud or PCC is provided on the top surface of the insulated EPS tile with lateral and longitudinal indentions of 10 mm depth to serve as a shuttering surface for covering the top/final layer of brick or other tiles with grout (Kooltile, 2014). Figure 8 shows the various dimensions for varying thicknesses of insulated EPS tiles of size 800 mm x 600 mm.

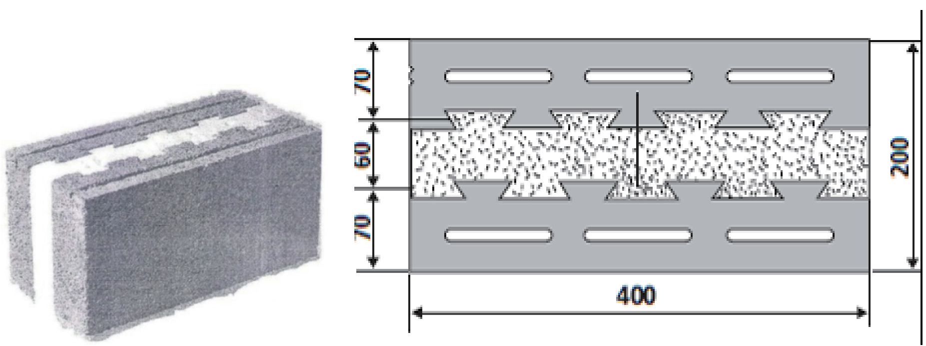

Figure 8. View of a block and a sectional plan of a Kool Tile

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.

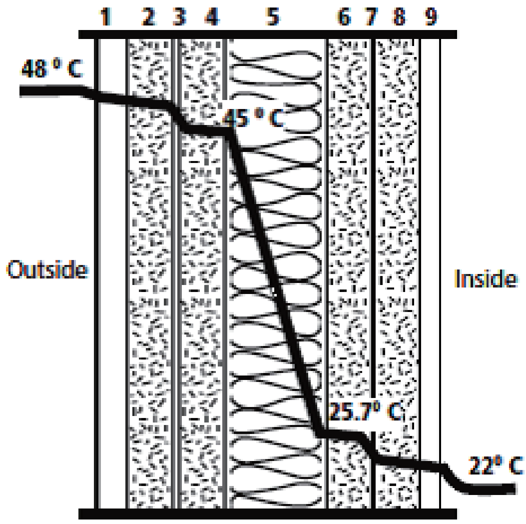

Figure 9. A Section of an insulated EPS Tile

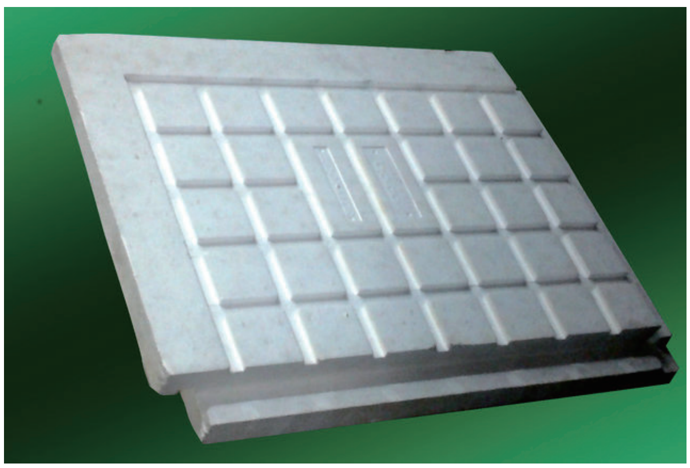

Figure 10. Insulated EPS tile with the interlocking arrangement for airtight insulation

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

With a completely automatic Batch pre-expanding machine, the resin is foamed with saturated steam to the required density before being pneumatically transported via a fluidized bed dryer and into air-permeable silos. The pre-expanded beads are matured in these silos for the predetermined amount of time before being transported into material distribution bins to be checked for density. These beads are pneumatically transported into a hopper of a completely automatic moulding machine following the measurement of the density and manual intervention (by combining greater or lower density beads, if required). This moulding machine is equipped with an aluminium die that has the precise shape needed for the insulated EPS tile. This die draws beads into it in a predetermined order. The insulated EPS tile was ultimately discharged onto a nylon slope for conveyance to the finishing room after the steam had been used to mould the beads into the desired form and stabilized the moulding (through a hot dry room). Dry moulded pieces are visually inspected, and then the product is packed in lots and moved to the designated store. The material is then sent when the Quality Control team has finished inspecting it (Adlakha, 2019).

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

The installation procedure of Expandable Polystyrene (EPS) Kool tiles for walls and roofs are summarized as below.

7.1 For External Roof

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

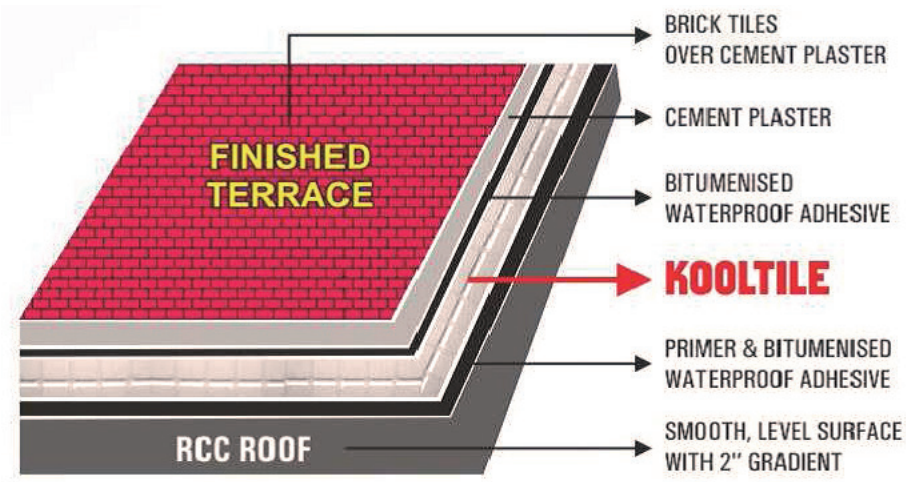

Figure 11. Section of a terrace covered with insulated EPS tiles

(a) To maintain a dust- and dirt-free roof, keep the surface smooth, dry, and clean with a brush or compressed air. Evenly spread two coats of bituminous cold emulsion or an asphalt-based polymerized waterproofing chemical onto the flat surface (Figure 12).

(b) Attach and attach the roof's slotted tongue and groove edges to the tiles, and press the tiles down so that bitumen seeps out of the joists. Figure 13 depicts the view of an EPS tile used to insulate a roof. The interlocking design allows slotted tongue and groove edges to be joined for airtight insulation.

(c) Cover tiles with a base layer of cement screed that has a minimum 50 mm gradient.

(d) Install brick tiles, mosaic, ceramic tiles, or any other finish of your choice over cement screed for a terrace finish (Figure 14).

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

Figure 13. The interlocking insulated EPS sheets laid on the terrace

Figure 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) Maintain a smooth wall for protection and improved adherence.

(b) Spread bituminous cold emulsion in two even layers over the waterproof surface.

(c) Attach the slotted tongue and groove edges of the insulated EPS tiles to the wall (Figure 16).

(d) Drive four dowel nails into the ends of the insulated EPS tiles.

(e) Cover tiles with a base layer of cement screed that is at least 4 mm thick.

(f) Paint or finish the exterior of the plastered wall.

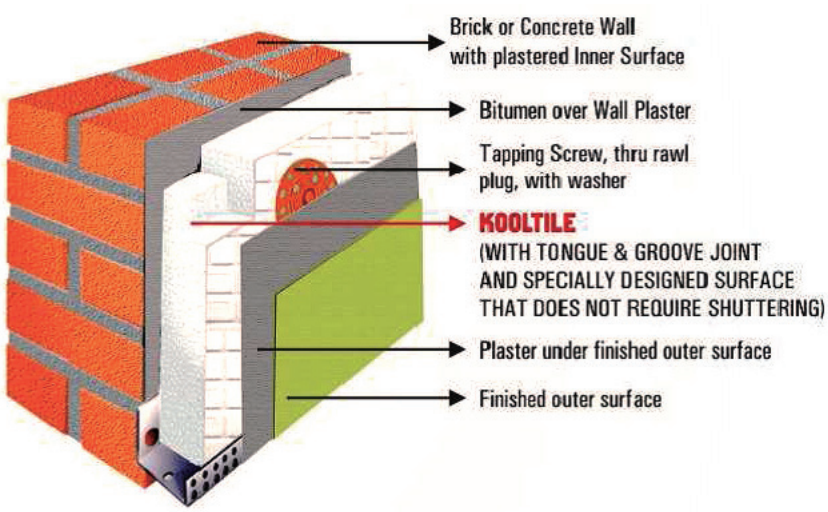

Figure 15. Section showing the procedure of installing insulated EPS tiles on the wall surface

Figure 16. The insulated EPS tiles cladding on external walls

8. Precautions while using insulated EPS tiles

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

(a) The base of the roof slab or wall must be smooth for the tiles to adhere properly; otherwise, air pockets could result in a subpar and uneven insulated surface.

(b) In order to prevent water logging, which could cause seepage and roof cracks, a minimum gradient of 1:120 must be supplied in the screed poured over the roof.

(c) Rainwater outlets must not be blocked due to leaking water pipes, tanks, etc. on the roof in order to prevent water logging, which could cause seepage and cracks in the roof.

(d) Brick tiles and ceramic tiles should be properly grouted to prevent harm to the roof and structure from falling tiles.

(e) It is forbidden to use tiles with a lower density than that recommended by the manufacturer since they might not be strong enough to sustain large loads like water tanks or the movement of Diesel Generator sets 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 moulded roof insulation tiles provide a uniform level of insulation throughout the entire roof.

(b) Instead of being cut from an EPS block, tiles are moulded. In contrast to cut surfaces of sheets, which may absorb some water through the porosities on the cut surface, each tile has a moulded water-repellent finish on both surfaces.

(c) The advantages of a double layer include insulation supplied by the interlocking joints of each concrete tile to guarantee water-tight seams, providing the ideal sealing effect.

(d) Costs are drastically reduced. The cost of alternatives like XPS or PUF, which have similar crucial characteristics, is three to five times higher.

(e) Because the roof is insulated against the scorching summer heat, the comfort level of the top floor is greatly increased.

(f) Using an air conditioner results in a 40–50% electricity savings. Insulation has a payback period of one year and a cost reduction of 40%.

(g) The waterproofing of the roof (even bitumen-based ones) does not have ageing cracks, so there is no seepage or dampness following heavy rains.

(h) The roof insulation treatment using insulated EPS tiles has a lifetime durability and dependability that protects the structure.

9.2 External Wall Cladding

(a) Offers an insulated, waterproof, long-lasting architectural façade.

(b) Aids in energy conservation and lowers overall CO_2 emissions from the structure.

(c) Reduces the possibility of condensation, aids in reducing heat loss or gain.

(d) Aids in removing thermal bridging and significantly reduces sound transmission.

(e) Improves internal comfort levels even without air-conditioners.

(f) Offers valuable lifelong cost savings

(g) It is appropriate for both new and existing constructions

(h) It also reduces ongoing maintenance costs.

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. EPS is destroyed by the hot asphalt and solvent-based glue. Therefore, a suitable cover board must be installed over the EPS if either of these is used. Also susceptible to melting or breakdown at high temperatures is EPS. The limitations of insulated EPS tiles are summarized as followings:

(a) Lower-density tiles could not be strong enough to sustain big loads like moving DG sets or multiple water tanks with a combined capacity of more than 5000 litres on the terrace.

(b) Water logging may cause leaks and cracks in the roof unless a screed with a gradient of 1:120 is placed at the base.

(c) Because EPS is a material that allows water vapour through, a broken surface could result in moisture and structural damage.

(d) Restricted possibilities for employing only high-end finishing materials or cement concrete because heat penetration stops at the insulation layer and causes fractures on the finishing surface.

(e) Building designers are unsure of the insulation's durability, its capacity to provide energy savings, and the length of time it will take for subsequent investments to pay off.

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 operational energy consumption of buildings is greatly increased by heat transmission through roof slabs and exterior walls. Hence, in tropical regions, passive solutions are required to enhance the thermal performance of roof slabs. This essay has discussed the significance of using EPS insulated tile panels to increase the thermal performance of roof slabs and wall efficiency. It is crucial to lower the cooling load by employing insulating materials in the walls and roof in order to save money by using less electricity to cool the area. In order to make decisions about numerous architectural aspects, architects and building designers consider the thermal performance of a building envelope design. One of the largest and most important expenditures made by building owners is the construction of roofs. These significant expenses often include insulation, a waterproofing membrane, a roof deck, repairs, maintenance, and installation. The usage of expanded polystyrene, often known as EPS, in roofing systems has been recognized by roof system designers and contractors as having the ability to meet extremely strict building criteria. Closed-cell, robust, lightweight expanded polystyrene insulation is comprised of plastic foam. When built correctly and shielded from the effects of moisture, it can provide dimensional stability, strong water resistance, a long-term R-value, and significant savings on energy costs. Insulation made of expanded polystyrene pairs well with all commercial roofing systems. Modified bitumen, built-up roofs, fully adherent, mechanically fixed, or ballasted one-ply membrane systems are some examples of these expanded polystyrene-compatible roofing systems (Polymolding, 2022).

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