BEEP
BUILDING ENERGY EFFICIENCY PROJECT

THERMAL INSULATION OF BUILDINGS FOR ENERGY EFFICIENCY

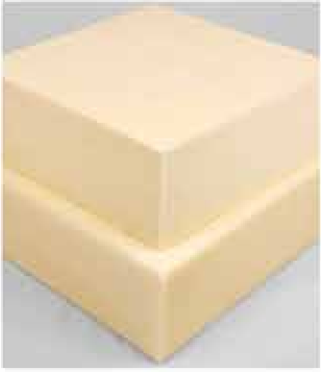
Indo-Swiss Building Energy Efficiency Project









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Thermal Insulation of Buildings for Energy Efficiency

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Ravi Kapoor, Claude-Alain Roulet, Sameer Maithel, and Prashant Bhanware

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FOREWORD

About 33% of electricity consumed in India every year is accounted for by the residential and commercial building sectors. Going by the projection that the country would add 700–800 million square metres annually to its building stock for the next 20 years, one can very well imagine the high quantum of energy consumption anticipated from these sectors over the coming years. While this expected development scenario is welcome for India's progress, the worrisome factor is the increasing energy intensity of buildings that are being constructed today. In a business-as-usual scenario, the building sector is bound to eat up a large share of India's precious energy resources.

In order to achieve a sustainable and climate compatible development path, it is therefore important to control and bring down the energy intensity of buildings that are yet to come. Aware of the situation at hand, the Government of India, through the Bureau of Energy Efficiency, has taken several initiatives towards reducing energy consumption in buildings. One such initiative is the Building Energy Efficiency Project (BEEP), a collaborative project between the governments of India and Switzerland.

BEEP has demonstrated that by adopting appropriate energy-efficiency measures through an integrated building design approach can go a long way in reducing the energy intensity. One such measure is related to thermal insulation. The external surfaces of buildings (roof and walls), which are exposed to direct sunlight, transmit the heat absorbed by them to the inner areas of a building, causing thermal discomfort to its occupants. In colder regions, more energy is required to keep the buildings warm enough for its occupants. By using efficient insulation materials, considerable energy can be saved.

In India, not much attention has been given to the thermal insulation of buildings from the perspective of energy efficiency. This may perhaps be due to lack of awareness among architects and builders or due to lack of R&D on insulation per se in the country. Along with its four Partner Labs and the Indian Insulation Forum, BEEP has done considerable work on this front.

This publication is brought out to bridge the knowledge gaps that exist with respect to various insulation materials and to generate awareness among architects and designers on the importance of proper insulation in building design and construction. We sincerely hope that it will be useful to all stakeholders in the building design and construction industry in India and contribute to future energy savings.

Daniel Ziegerer
Director of Cooperation, Swiss Agency for Development and Cooperation (SDC)

PREFACE

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 9.4% compound annual growth rate, followed by the commercial sector. This has been attributed mainly to the extensive use of air conditioning systems for thermal comforts in buildings in these two sectors of the economy. Building envelope design and construction play an important role in reducing energy consumption in such systems. With incorporation of thermal insulation materials in combination with other construction materials in buildings' 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 of buildings for energy efficiency has not been well recognised by building developers and owners at present. Developed under the Indo-Swiss Building Energy Efficiency Project (BEEP), this publication looks into various important aspects related to building insulation materials, right from the principles of building science to the application of materials in buildings. It carries the specifications and testing standards of building insulation materials developed by the Bureau of Indian Standards and the prescriptive compliance requirements for using insulation in commercial buildings covered under the Energy Conservation Building Code (2007), Ministry of Power.

Besides, it addresses a number of important issues related to insulation materials and the salient initiatives undertaken by BEEP. It also provides practice-oriented background information for building designers, architects, and various other stakeholders in the building construction industry. This publication also summarises the result of about two years of work by BEEP while working closely with Bureau of Energy Efficiency (BEE).

We sincerely express our appreciation for the constant support and guidance extended to us by Mr Sanjay Seth and Mr Saurabh Diddi of BEE; and Mr Daniel Ziegerer and Dr Anand Shukla of the Swiss Agency for Development and Cooperation in this endeavour.

We also gratefully acknowledge the following four Partner Labs across the country and Mr Bruno Binder of EMPA (the lab in Switzerland) for their professional support and active involvement in the testing of building insulation products under BEEP's planned activity.

- CEPT University, Ahmedabad – Mr Yash Shukla
- Isolloyd Engineering Technology Ltd, Baddi – Mr Deepak Rastogi
- Nirma University, Ahmedabad – Dr Vikas Lakhera
- Spectro Analytical Labs Ltd, New Delhi – Mr Vishwa Bandhu Gupta

We sincerely thank the Partner Labs for also sharing their earlier compiled test data on various thermal insulation products and building materials. This includes data generated by the Centre for Advanced Research in Building Science and Energy, CEPT University, made possible by the research grants by Ministry of New and Renewable Energy, Government of India, and the US–India Joint Center for Building Energy Research and Development.

We also sincerely appreciate the whole-hearted cooperation and assistance provided by the India Insulation Forum, especially Mr Isaac Emmanuel, Mr K K Mitra, Mr Ajay Singh, and Mr Murali Mohan.

Ravi Kapoor, Claude-Alain Roulet, Sameer Maithel, and Prashant Bhanware
Indo-Swiss Building Energy Efficiency Project

ABOUT BEEP

Indo-Swiss Building Energy Efficiency Project (BEEP) is a bilateral cooperation project between the Ministry of Power (MoP), Government of India and the Federal Department of Foreign Affairs (FDFA) of the Swiss Confederation. While Bureau of Energy Efficiency (BEE) is the implementing agency on behalf of the MoP, Swiss Agency for Development and Cooperation (SDC) is the agency responsible for the FDFA.

The overall objective of BEEP is to reduce energy consumption in new commercial buildings and disseminate best practices for the construction of residential and public buildings where energy consumption is low. The project contributes to the strengthening of BEE's energy building conservation programme.

BEEP has four components:

- **Component 1:** Design workshops (integrated design charrettes) with public/private builders
- **Component 2:** Provide technical assistance in developing testing infrastructure for building material
- **Component 3:** Lay out guidelines and tools for the design of energy-efficient residential and public buildings.
- **Component 4:** Produce and disseminate knowledge products

For more details, please visit BEEP website <www.beepindia.org>.

Introduction

Residential and commercial sectors account for 22% and 9% of the total electricity consumption in India, respectively.[1] With the rapid ongoing urbanization and economic development in the country, it has been estimated that India would build 700–900 million square metre 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.[2] The Ministry of Power (MoP), Government of India, the Bureau of Energy Efficiency (BEE), and many state government institutions have been making extensive efforts to promote energy efficiency in buildings. As a result of these, in recent years, a number of enlightened building owners and developers in public and private sectors have adopted several energy-efficiency measures to reduce energy intensiveness of their buildings. However, thermal insulation of buildings, as a cost-effective energy-saving measure, has remained in infancy at present.

Energy-Efficient Buildings: Role of Thermal Insulation

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 (Figure 1). 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.

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[1] Central Statistical Organization (CSO). 2013. *Energy Statistics 2013*. New Delhi: CSO, Ministry of Statistics and Programme Implementation, Government of India.

[2] Mckinsey Global Institute. April 2010. India's Urban Awakening: Building Inclusive Cities, Sustaining Economic Growth.

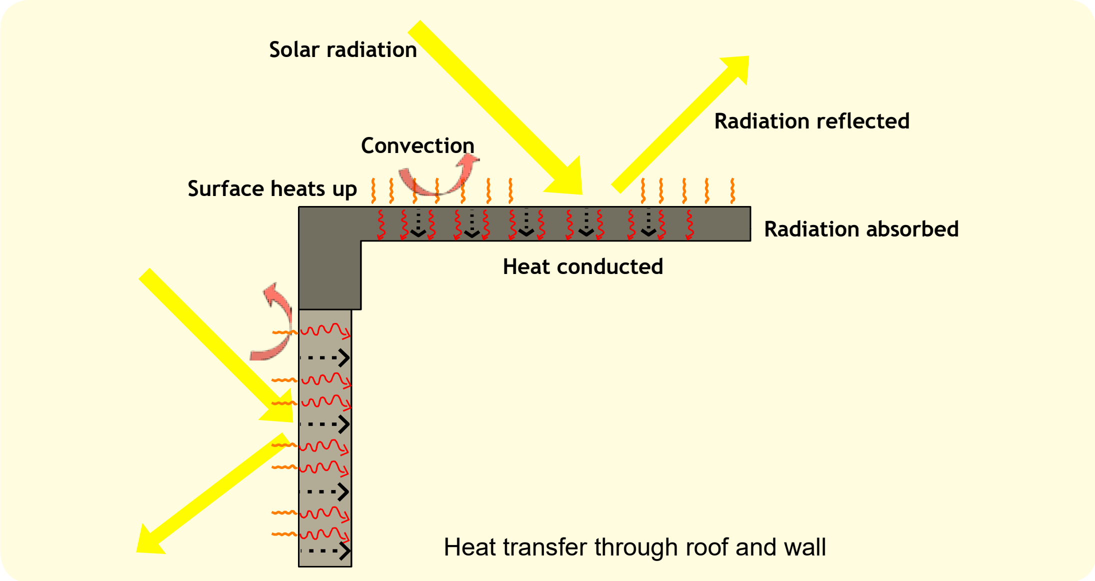


Figure 1 *Exposure of solar radiation on building envelope and thermal heat conduction*

Good thermal comfort at low energy cost can be obtained by adopting an energy-efficient building design – incorporating the use of thermal insulation materials in combination with other building materials – while making the building envelope. All building materials offer thermal resistance to 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. More details about such insulation materials are discussed in this publication.

Insulating materials, due to their low thermal conductivity, can substantially resist transfer of heat from the exterior to the interiors of the building if external temperature is high (Figure 2), and resist heat transfer from interiors to the exterior in a similar way when the external temperature is low.

R-value of Insulation Materials

Any insulation or building material's resistance to conductive heat flow is measured or rated in terms of its 'Thermal Resistance' or R-value. Higher the R-value, greater is the insulating effectiveness of the material. The R-value depends on the material's characteristics, its thickness, and thermal conductivity. The density of the material also affects its thermal conductivity.

The R-value of a given material is expressed numerically as the ratio of its thickness (x) in the direction of heat flow to its thermal conductivity (k).

R-value = Thickness/Thermal conductivity = x/k

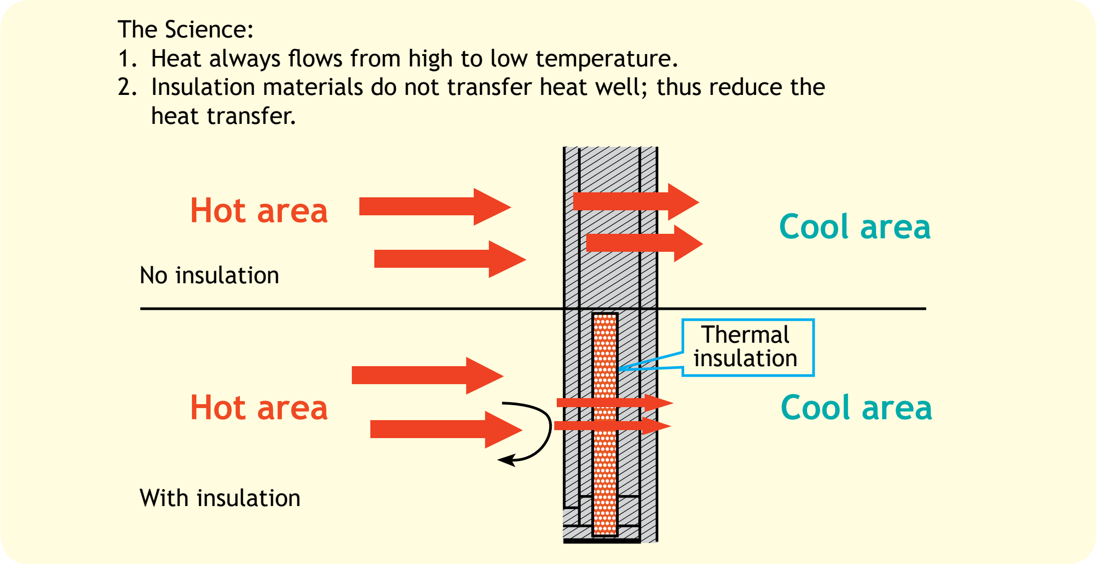


Figure 2 *Effect of thermal insulation*

Units normally used for the above terms are as under:

- Thickness expressed in metre (m)
- Thermal conductivity expressed in ($W/m^2.K$), where W refers to watt and K to Kelvin
- R-value expressed in ($m^2.K/W$)

It implies that the lower the thermal conductivity of the material and larger its thickness higher is its R-value. As insulation material has low thermal conductivity, with its smaller thickness, it can give higher R-value. This factor plays a major role in reducing conduction of heat in buildings.

R-value of Composite Roof and Wall

In a building envelope, the roof and walls of a building are usually composed of a number of layers of building materials. Every building material layer contributes and adds to the combined thermal resistance of the roof and walls, depending upon its thermal conductivity and thickness. As an example, the following equation shows the combined R-value of a roof that comprises three building materials (1, 2, and 3) and one insulation material:

$$R_{roof} = R_1 + R_2 + R_{insulation} + R_3$$

However, in real situations, a thin 'virtual air layer' is also formed both on the external as well as internal surfaces of the roof and walls, which are exposed to the outside and inside temperatures, respectively. These surfaces, due to their temperature differences, promote heat transfer in their vicinity through convection and radiation, while at the same time, resist heat transfer through roofs and walls. These resistances are termed as 'Surface Thermal

Resistance' $R_{(s\text{-}ext)}$ and $R_{(s\text{-}int)}$ for external and internal surfaces, respectively. Therefore, taking these into account, while designing any building, the 'total thermal resistance - $R_{T\,(roof)}$' of a composite roof is calculated as:

$$R_{T\,(roof)} = R_{roof} + R_{(s\text{-}ext)} + R_{(s\text{-}int)}$$

Figure 3 shows an example of a roof with four layers of materials along with their respective R-values and surface thermal resistances. The total thermal resistances $R_{T\,(roof)}$ is the sum of all R-values.

$$R_{T\,(roof)} = R_1 + R_2 + R_3 + R_4 + R_{(s\text{-}ext)} + R_{(s\text{-}int)}$$

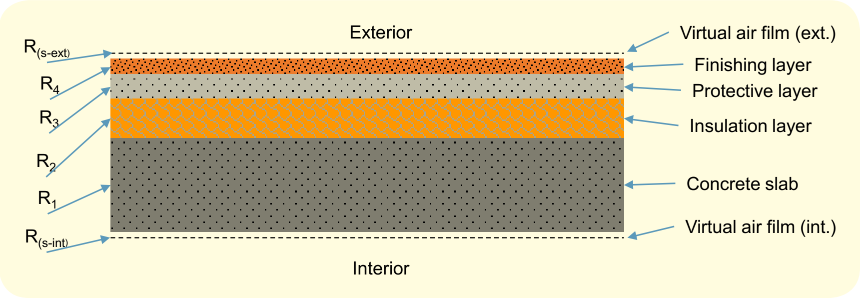


Figure 3
Thermal resistances of layers of different building materials in roof

The total thermal resistance of a composite wall, $R_{T\,(wall)}$, is also worked out in the same way as for $R_{T\,(roof)}$, as explained above.

Table 1 shows the values of exterior and interior surface thermal resistance, as derived from empirical studies.

Table 1 Values of surface thermal resistance based on the direction of heat flow

$R_{s\text{-}int}$ ($m^2.K/W$)			$R_{s\text{-}ext}$ ($m^2.K/W$)		
Direction of heat flow			*Direction of heat flow*		
Horizontal	Up	Down	Horizontal	Up	Down
0.13	0.10	0.17	0.04	0.04	0.04

Source *Energy Conservation Building Code User Guide (April 2011), USAID-ECO III Project.*

U-factor of Composite Wall and Roof

In designing buildings, the U-factor (also called Thermal Transmittance) of a composite wall (or an assembly of wall) and a composite roof (or an assembly of roof) is generally calculated. This factor, in simpler terms, is the reciprocal of the total thermal resistance (R_T) of a composite wall or a composite roof. In practice, a low U-factor is desirable to resist transfer of heat from higher temperature to lower temperature through roof and wall.

$$\text{U-factor of roof} = 1 / R_{T\,(roof)}$$

$$\text{U-factor of wall} = 1 / R_{T\,(wall)}$$

Box 1 highlights the minimum prescriptive requirements for R-value of insulation and U-factor for composite roofs and composite walls in commercial buildings for compliance with the Energy Conservation Building Code (ECBC) 2007 for the five climate zones of India (see Figure 4). However, ECBC is being currently updated by the Bureau of Energy Efficiency (BEE).

BOX 1 ECBC Prescriptive Compliance for Roofs and Walls

The Energy Conservation Building Code (ECBC) 2007, which applies for commercial buildings, prescribes two alternative parameters—minimum R-values of insulation and maximum U-factors for compliance for roofs and walls. These parameters vary depending upon the climate zone in which the building is located and the duration for which the building is used, whether used only during the day or for 24 hours (Table 2).

Table 2 Prescribed minimum R-values of insulation and maximum U-factors for roofs and walls

Envelope	*Climate zone*	*Buildings used for 24 hours (hospitals, hotels, call centres)*		*Buildings used at daytime and other types*	
		Max. U-factor (Composite)	*Min. R-value of insulation alone*	*Max U-factor*	*Min. R-value of insulation alone*
		W/(m²K)	*m² K/W*	*W/(m²K)*	*m² K/W*
Roofs	Composite	0.261	3.5	0.409	2.10
	Hot and dry	0.261	3.5	0.409	2.10
	Warm and humid	0.261	3.5	0.409	2.10
	Moderate	0.409	2.1	0.409	2.10
	Cold	0.261	3.5	0.409	2.10
Walls	Composite	0.440	2.1	0.440	2.10
	Hot and dry	0.440	2.1	0.440	2.10
	Warm and humid	0.440	2.1	0.440	2.10
	Moderate	0.440	2.1	0.440	2.10
	Cold	0.369	2.2	0.352	2.35

For ECBC compliance, the building designer needs to meet either the ‘minimum R-value of insulation alone’ or the ‘maximum U-factor of composite roof and composite wall assemblies’. For more details, refer ECBC 2007 or its updated version (if any).

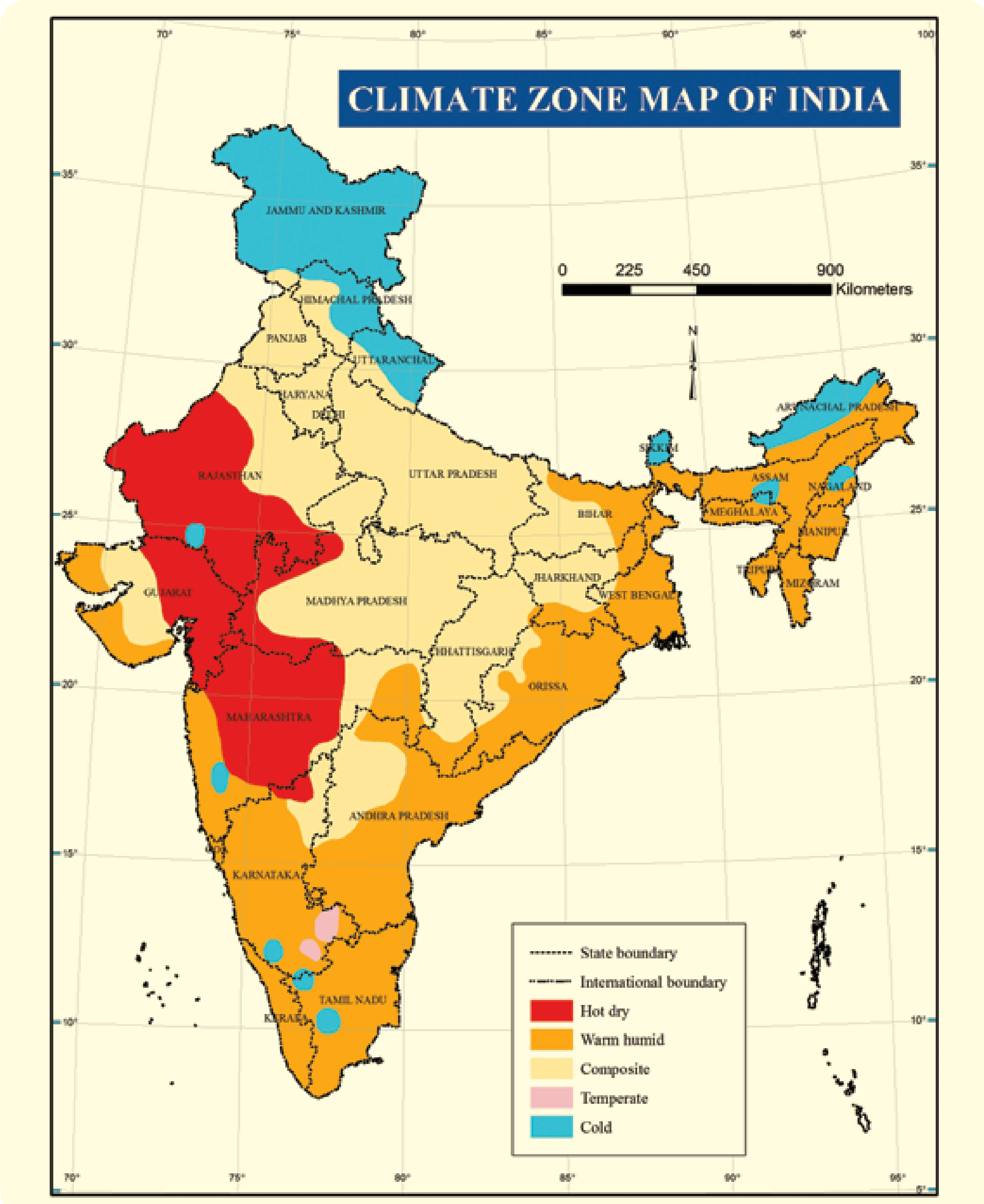


Figure 4 *Climate zone map of India*
Source *National Building Code 2005, Part 8, Figure 2*

Historical Development of Building Insulation Materials

The need for insulation is as old as building construction activity. Pre-historic people built their shelters and dwellings from the same materials that they used for clothing to protect themselves from the extreme climate conditions. The most common materials were animal skins, fur, wool, and natural plant-related materials like reed, flax or straw, and so on, but they had limited durability. With the development of agriculture, subsequent generations looked for inclusion of more durable materials for housing such as wood in combination with earth and stone for their dwellings. This was followed by many naturally obtained materials, which were suitably processed and used for insulation to improve thermal comfort in their homes.

Box 2 provides a brief overview of the history of the development of building insulation products derived from various substances and materials. This overview has been drawn and adapted from a research article of *Periodica Polytechnica* – 'The Historical Development of Thermal Insulation Materials' by David Bozsaky .

BOX 2 History of Development of Building Insulation Products

- For thousands of years, native inhabitants of tropical areas built their hutments from vegetable fibre such as dried eelgrass or reed.
- Indigenous people by the Caribbean Sea built their huts from dried eelgrass (*Zostera marina*) which had good insulating qualities similar to reed or straw.
- In medieval times, in colder climates, walls were stuffed with straw and mud plaster to keep out the cold.
- During the twelfth and thirteenth centuries, thatched houses with roofs made from straw and walls of clay and straw were built in Europe and America. Dry and hollow fibre of straw and reed provided thermal resistance.
- In the Middle Ages, monks in Spain and Portugal, while building monasteries, sheathed the inner side of the walls with cork. A few tribes in North Africa also used a special mixture of clay and cork bark to construct their dwellings.
- The first cork insulating panels were produced in the 1870s. People used them for sheathing the inner side of façade walls.
- In the late nineteenth century, for the first time, several organic materials such as reed, cork, flax and so on were processed and made into insulated panels. They were cheap, but the main problem was their high hygroscopic ability.
- In the beginning of the twentieth century, reed panels appeared with bituminous coatings but could not survive their use because of their flammability and unreliable quality.
- Cellulose, made from straw or other organic material and one of the oldest forms of insulation, is still in use as loose-fill insulation, along with additional processing of several other materials.
- Insulating panel made of bagasse, a by-product of sugar manufacturing plant, was introduced in 1920 in USA. It was used as thermal insulation in home construction. Later, owing to their high inflammability, one or both sides of the panel were coated with asbestos cement.
- In the early twentieth century, wood shavings and sawdust became popular as insulation products because they were inexpensive and readily available. These materials were often mixed with various chemicals to increase their resistance to water absorption, fire, and mould.

Box 2 contd...

BOX 2 Contd...

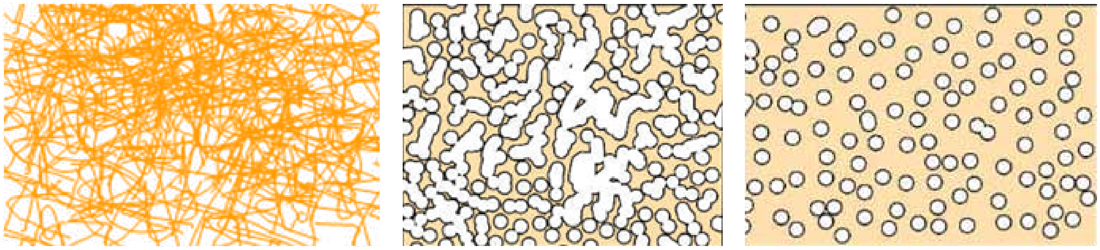
- In the beginning of the twentieth century, the first hollow building bricks appeared. The initial products had poor mechanical strength and insulating qualities but their quality progressively improved. They are still produced in huge quantities.
- The early twentieth century also saw the development of rock wool and slag wool as insulation materials.
- Fiberglass was discovered in 1932. Over the next decade, this material was made into insulation blankets and began to be used widely to help make homes and other buildings in America more energy efficient and comfortable.
- Glass foam was introduced in 1943 and gained popularity as an insulation product because of its many advantages such as its light weight, rigidity, as well as resistance to fire, water, rodent, and insects.
- In the last 50 years, many building insulation products using various insulation materials have been developed and applied. The appearance of plastic foams such as polystyrene and polyurethane created a huge revolution in the market of insulation materials in the 1940s and 1950s. From this point onwards, these man-made insulation materials and glass foam overtook the natural insulation materials and forced them back. After the oil crisis of the 1970s, their application accelerated and today such materials represent about 90%–95% of the total thermal insulation material production.

Source *Adapted from David Bozsaky (2011),* Periodica Polytechnica—*'The Historical Development of Thermal Insulation Materials', 4 July.*

How Thermal Insulation Functions

As mentioned earlier, several insulation materials, over a long period of time, have been converted to useful insulation products for buildings. To understand how these insulation products were developed, it is necessary to know how thermal insulation functions.

Gases and air are poor thermal conductors as compared to liquids and solids, and thus make good insulation materials if they can be trapped in the material. In order to further augment the effectiveness of a gas (such as air), it can be disrupted into small cells, which cannot effectively transfer heat by natural convection (Figure 5). Convection involves a larger flow of gas driven by buoyancy and temperature differences. It does not work well in small cells where there is little density difference to drive the gas flow. In fibrous materials (Figure 5), the fibres within the material add friction to the movement of air and thus reduce the convection of heat, though heat transfer through radiation and conduction also takes place within the fibres.



Fibrous material | Open cell foam | Closed cell foam

Figure 5 *Fibrous material and insulation foams*

To accomplish the formation of small gas cells in man-made thermal insulation, glass and polymer materials can be used to trap air or gas in a foam-like structure. The same principle is used in making insulation products from glass wool, mineral wool, and other man-made insulators such as plastic foams. Rigid foam insulation products are normally classified in two categories of configuration: (a) Open cells and (b) Closed cells (Figure 5).

Open Cell Insulation

In open cell insulation foam, most of the millions of bubbles or cells share walls with one another, making the product soft, airy, and light. Only a small percentage of the finished product is plastic and the rest is air/gas trapped within the structure. The cells in this insulation are mostly interconnected, meaning air/gas can travel through them, and thus allow heat to get transferred through the material by convection, though very slowly. Like fibrous materials, heat transfer through radiation and conduction also takes place among the cells. The general definition in the industry for open cell foam is that greater than 50% of the cells in such foam are open.

Closed Cell Insulation

Closed cell foam is made in a similar manner, but most of the cells in closed cell foam are independent from the other cells in that they have their own structure and do not generally share the same with other cells. Thus, the gaps in the insulation are not well connected; therefore, air or other gas (such as carbon dioxide or Freon), with comparatively lower thermal conductivity in the closed cell, cannot pass its heat to the next one easily. The most high performing insulations will have closed cells and typically a ratio of around 95%–97% air (or gas) to material structure, making the transfer of heat through them extremely low. For this reason, the closed cell insulation is a better performing insulation compared to the open cell insulation. The general definition in the industry for closed cell foam is that greater than 90% of the cells in such foam are closed.

A typical situation has also shown that at a working mean temperature of 30 °C, the thermal conductivity of trapped air is 0.026 $W/m^2.K$ while the apparent thermal conductivity of air in a cavity wall with air gap of 50 mm is 0.052 $W/m^2.K$.

In recently developed insulation products, to enhance insulation effectiveness further, apart from trapping gas with very low thermal conductivity in cells, the walls of the cells are being made highly reflective by the use of graphite to reduce the effect of radiation within the product substantially.

Building Insulation Products

A number of insulation products, referred here as 'Ready-to-use finished insulation materials having specific shape and dimensions', are available in the market. However, most commonly used materials/products that have good application potential in buildings are presented below. However, it is important to mention here that various insulation products available in the market may have different appearance and colour as compared to what has been shown in below.

Glass Wool Insulation

Glass wool is an insulating material made from extremely fine fibres of glass, arranged into a texture similar to wool by using a binder. The process traps many small pockets of air between the glass, which ensures high thermal insulation. Glass wool is normally available in three different forms—blanket (batts and rolls), loose-fill, and rigid boards (Figure 6). It may also be produced as a material that can be sprayed or applied on the surface to be insulated.

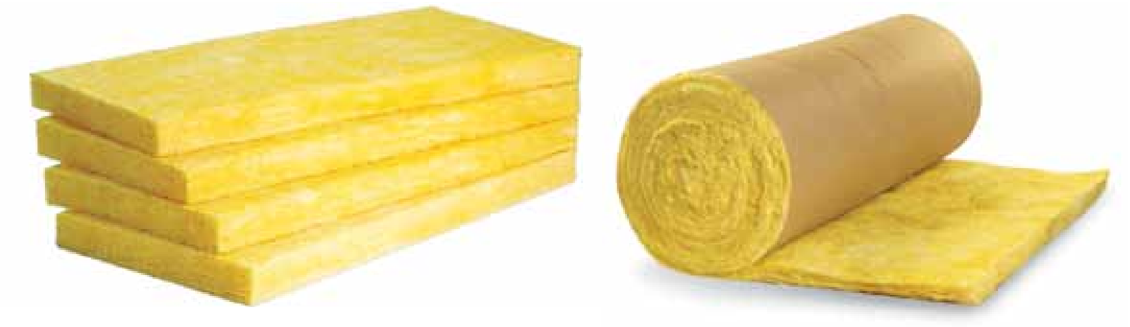


Figure 6 *Glass wool insulation*

Mineral Wool Insulation

Mineral wool typically refers to two types of insulation materials:

- Rock wool (Figure 7), a man-made material consisting of natural minerals like basalt or diabase
- Slag wool, a man-made material from blast furnace slag (the scum that forms on the surface of molten metal).

Figure 7 *Mineral wool insulation*

These insulation products are commonly available as blanket (batts and rolls) and loose-fill insulation. Mineral wool materials with resin binders are also converted to slab and boards.

Polystyrene Insulation

Polystyrene is a colourless and transparent thermoplastic material and is commonly used to make foam board or bead board insulation. It is also procured as a type of loose-fill insulation consisting of small beads of polystyrene.

Moulded expanded polystyrene (MEPS), commonly used for foam board insulation, is available as small foam beads. These beads can be used as a pouring insulation for concrete blocks or other hollow wall cavities, and they are extremely lightweight.

Other polystyrene insulation materials similar to MEPS are expanded polystyrene (EPS) (Figure 8) and extruded polystyrene (XPS) (Figure 9). EPS and XPS are both made from polystyrene. EPS is composed of small plastic beads that are fused together. XPS comprises a molten material that is pressed out of a form into sheets. EPS and XPS are most commonly used as foam board insulation.

Figure 8 *Expanded polystrene insulation*

Figure 9 *Extruded polystyrene insulation*

Polyisocyanurate Insulation

Polyisocyanurate (PIR) or Poly-iso is a thermosetting type of plastic, closed-cell foam that contains in its cells a hydro-chlorofluorocarbon-free (non-HCFC) gas of low conductivity (Figure 10). Poly-iso or PIR insulation is available as liquid, sprayed foam, and rigid foam board. It can also be made into laminated insulation panels with a variety of facings.

Figure 10 *Polyisocyanurate insulation*

Over time, the R-value of polyisocyanurate insulation can drop as some of the gas escapes and air replaces it—a phenomenon that is known as thermal drift. Experimental data indicates that most thermal drift occurs within the first two years after the insulation material is manufactured; thereafter, it remains unchanged unless the foam is damaged.

Polyurethane Insulation

Polyurethane (PUR) is a foam insulation material that contains in its cells a gas of low conductivity (Figure 11). Polyurethane foam insulation is available in closed-cell and open-cell configuration. With closed-cell foam, the high-density cells are closed and filled with a gas that helps the foam to expand and fill up the spaces around it. Open-cell foam cells are not as dense and are filled with air, which gives the insulation a spongy texture.

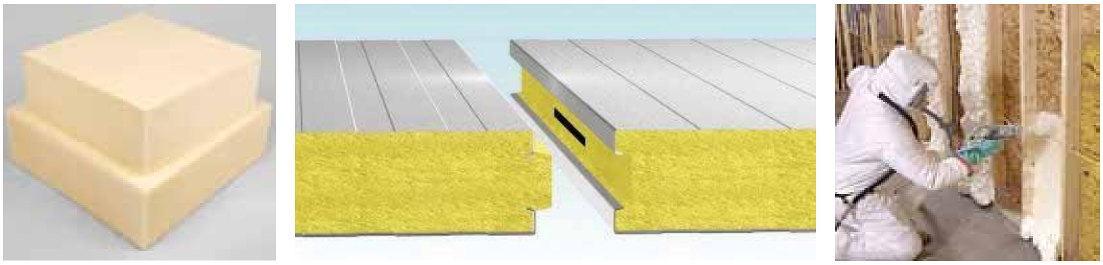


Figure 11 *Polyurethane insulation*

Like polyisocyanurate foam, the R-value of closed-cell polyurethane insulation can also drop over time owing to thermal drift when some of the gas with low conductivity escapes and air replaces it. Like PIR, most thermal drift occurs within the first two years after the insulation material is manufactured; thereafter, the R-value remains unchanged unless the foam is damaged.

Polyurethane insulation is available as a liquid sprayed foam and rigid foam board. It can also be made into laminated insulation panels with a variety of facings. All closed-cell polyurethane foam insulation products made today are generally produced with a non-HCFC gas as the foaming agent.

Insulation Facings

Facings are fastened to insulation materials during the manufacturing process. A facing protects the insulation's surface, holds the insulation together, and facilitates fastening to building components. Some types of facings can also act as an air barrier, radiant barrier, and/or vapour barrier and some even provide flame resistance. Common facing materials include Kraft paper, white vinyl sheeting, and aluminium foil, which normally act as an air barrier and vapour barrier.

Table 3 gives typical density and thermal conductivity values of a few thermal insulation

Table 3 Typical properties of commonly used insulation materials

Insulation material	*Density*	*Thermal conductivity*
	kg/m³	*W/m².K*
Boards and Slabs		
Expanded polystyrene - Moulded beads	16–32	0.037–0.033
Expanded polystyrene - Extruded (CFC/HCFC)	29–56	0.029
Cellular polyurethane (CFC–11 exp.)	24	0.023–0.026
Cellular polyisocyanurate (CFC–11 exp.)	24–40	0.020–0.026
Cellular phenolic (open cell)	32	0.033

Table 3 contd...

Table 3 Typical properties of commonly used insulation materials *(contd...)*		
Insulation material	*Density*	*Thermal conductivity*
	kg/m³	*W/m².K*
Cellular phenolic (closed cell CFC–11, CFC–13 exp.)	29-35	0.017
Cellular glass	136	0.050
Glass fibre–organic bonded	64–140	0.036
Spray Applied		
Polyurethane foam	24–40	0.023–0.026
Urea formaldehyde foam	11–26	0.032–0.040
Loose-Fill		
Mineral fibre (rock wool, slag wool) and Glass fibre (glass wool)	9.6–32	—
Perlite expanded	32–180	0.039–0.060
Blanket and Batt		
Mineral fibre (rock wool, slag wool) and Glass fibre (glass wool)	6.4–32	—
Source *Adapted from ASHARE Fundamentals Handbook (2001), as given in ECBC 2007 (Energy Conservation Building Code 2007), Ministry of Power, Government of India*		

materials, which have been drawn from ECBC 2007 and can be used only as reference.

Indian Standards on Building Insulation Products

Many insulation materials and products are available in the Indian market, but may have different specifications on density and thermal conductivity values. The Bureau of Indian

Table 4 Indian standards on specifications of building insulation products	
Insulation Material	Reference Indian Standard
Expanded polystyrene plastic foam	IS : 4671–1984 (Reaffirmed 1989): Specifications for expanded polystyrene for thermal insulation purposes
Polyurethane foam	IS:12436–1988: Specification for Preformed Rigid Polyurethane (PUR) and Polyisocyanurate (PIR) foams for thermal insulation
Polyisocyanurate foam	IS : 12436–1988: Specification for PUR and PIR foams for thermal insulation
Phenolic foam	IS 13204–1991: Specification for Rigid Phenolic Foam for thermal insulation
Cellular glass	IS 11307–1985 (Reaffirmed 2001): Specification for cellular glass block and pipe thermal insulation
Mineral wool (bonded) (rock, slag and glass bonded with a binder)	IS 8183: 1993 (Reaffirmed 2004): Specification for bonded mineral wool
Un-bonded rock and slag wool	IS 3677 (1985): Reaffirmed 2010: Specification for un-bonded rock and slag wool for thermal insulation

Standards has developed a few standards, which provide specifications of the following insulation products for buildings (Table 4).

Insulation Application in Roof and Walls

Normally, buildings are conventionally built with brick walls and reinforced cement concrete (RCC) slabs as ceilings. In recent years, autoclave aerated concrete (AAC) blocks are also being used in place of brick walls. Though such building materials can provide sufficient structural strength to the building, they have relatively high thermal conductivity. Therefore, such materials offer lesser thermal resistance as compared to that provided by several insulation materials and products discussed in earlier sections, unless their thicknesses are increased substantially to attain desired thermal comfort. Needless to say, adopting larger thicknesses of walls may reduce the available carpet area required to meet the functional requirements of the building space. However, if thermal insulation materials are used, thermal comfort and energy efficiency can be attained even with comparatively thinner roofs and walls.

Insulation products can be applied on the external or internal surfaces of the components of the building envelope, namely the roof and walls, or within the space between two thin walls, as shown in Figures 12, 13, and 14.

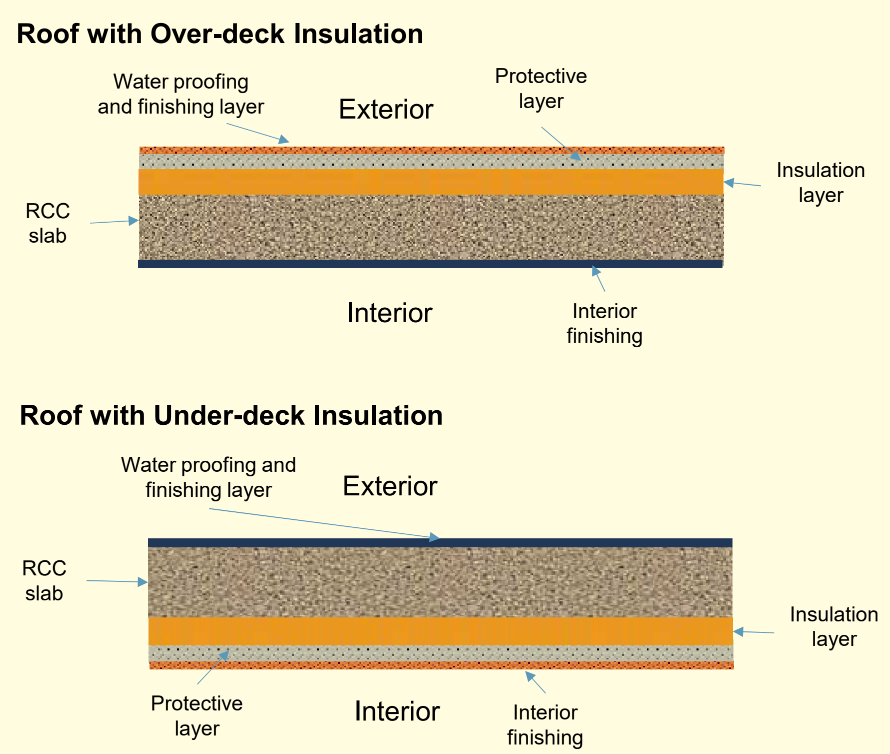


Figure 12 *Roof insulation*

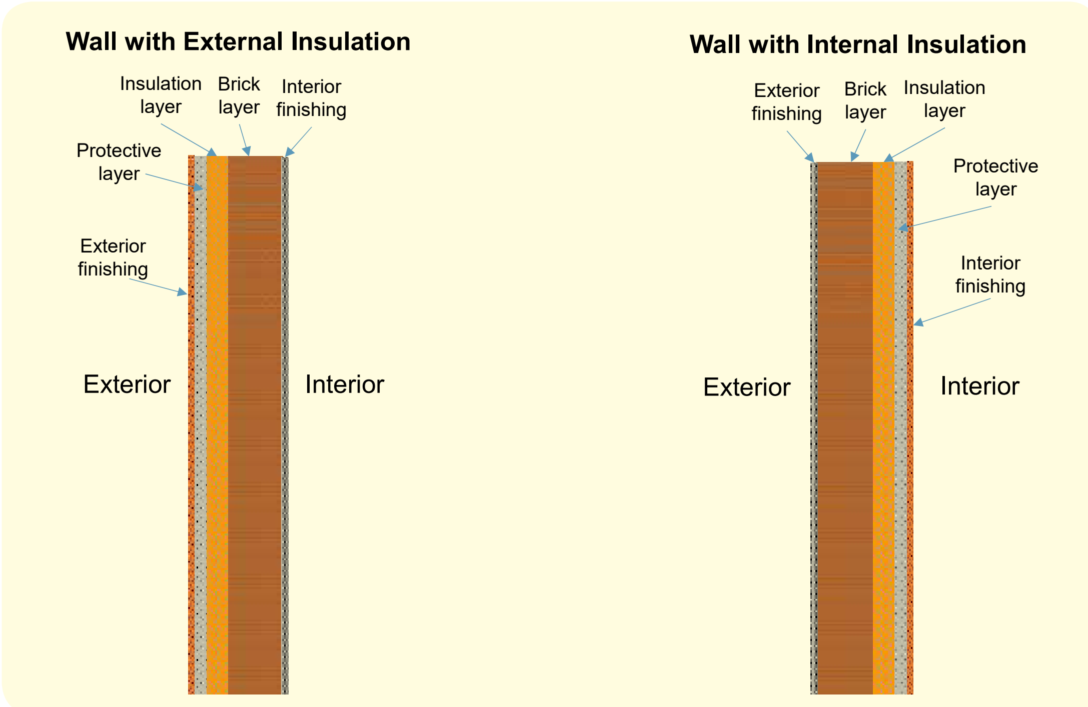


Figure 13 *Wall insulation*

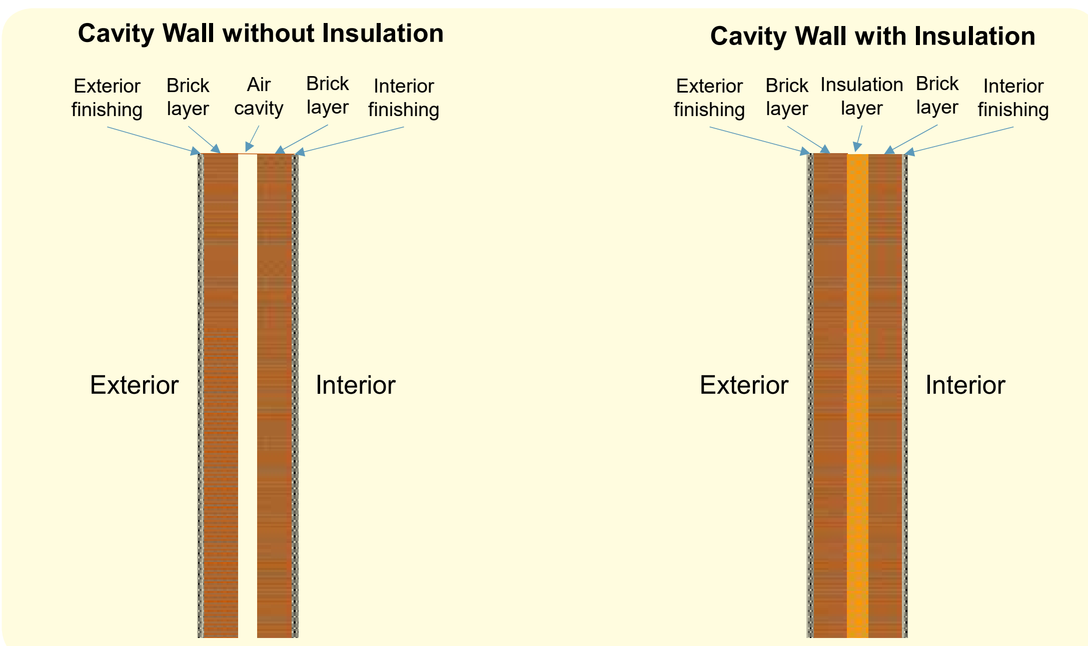


Figure 14 *Cavity wall insulation*

Application of thermal insulation for any building project needs in-depth analysis of several parameters and considerations, which can influence the selection of insulation product(s) and its optimum thickness. Every insulation product also needs special skills and care while applying the same at the building site. These may include right preparation and pre-treatment of surfaces where it is being applied along with incorporation of binding, water proofing, and other protective layers to get long-term benefits of the insulation. It is, therefore, essential to follow application instructions and guidelines provided by the insulation manufacturers for good results.

Arriving at the Optimum Solution for Insulation

Apart from the insulation product's thermal conductivity, the following factors and considerations influence the type and amount of insulation material needed for application in any building project.

Considerations Regarding Building and Climate

- Average climate conditions where the building is located
- Geographical orientation of the building
- Type of building, that is, its use and occupancy hours per day
- External temperatures (high and low) the building is expected to get exposed to
- Internal temperatures (high and low) to be maintained in the building for occupants' thermal comfort
- Window–wall ratio and external shading systems in the building envelope
- Type and number of glass panes used in windows
- Shadows of neighbouring/adjacent buildings that may fall on the building surfaces
- Application of solar thermal/photovoltaic panels on the roof of the building

Products Characteristics and Other Considerations

- Sensitiveness to moisture or water vapour determines product's vulnerability to the degradation of its thermal conductivity
- Compressive strength assessed as resistance of the product against load or compression
- Durability calculated as the product's resistance to degradation from compression, moisture, decomposition, etc.
- Ease of installation of insulation product
- Ease of product's replacement at the end of its life
- Cost effectiveness of insulation
- Toxicity issues of the product
- Inflammability or vulnerability of the product to burn or ignite, causing fire or combustion
- Environmental impact and sustainability

Considering these factors, often a combination of preventive, protective, and supporting material layers are used along with the insulation product. Table 5 provides a comparison

Table 5 Characteristics of a few typical insulating materials used in buildings

Characteristic of insulating materials	Insulating power	Density	Fire résistance	Water vapour diffusion	Resistance to water	Compression strength	Traction strength	Heat resistance	Absorption of vibrations	Absorption of aerial noise	Cost at given insulation	Embodied energy
Light mineral wool	+	- -	++	- -	0	- -	- -	+		++	+	- -
Dense mineral wool	++	+	++	- -	0	0	-	++	++	+	+	0
Glass foam	+	+	++	++	++	++	++	++	- -	-	+++	0
PUR	++	-	0	-	0	+	+	++	-	- -	+	++
EPS	+	- -	+	+	0	+	+	0	-	- -	+++	-
XPS	++	0	+	++	+	+	++	0	-	- -	+	+

++ : Very high; + : high; 0 : average, acceptable; - : low; - - : very low

Source *Modified and adapted from C A Roulet (2004), Health and Indoor Environment Quality in Buildings (in French), Lausanne: PPUR*

of the salient characteristics of commonly used building insulation materials. As can be observed from Table 5, each insulation material has its strong and weak points. Thus, the selection of the insulation product needs to be done taking into consideration its various characteristics and its suitability for a particular application. Many computer-aided software packages are available in the market, which can be used to simulate various conditions and arrive at an optimal solution for the insulation of a building.

Barriers Affecting Use of Building Insulation

Despite availability of a number of building insulation products in the Indian market; their use in many new building projects and in the existing buildings has remained very low in comparison to the actual needs and the potential. This is mainly due to the following barriers:

- Awareness about the benefits of insulation products among the building users has remained very limited. Most building developers and owners finance and/or construct buildings that are to be used by others. Despite knowing the advancements and energy-saving advantages of building insulation products, they do not see any financial benefits in incurring additional costs on insulation. They tend to pass on the recurring cost of energy inefficiency to the building users (for example, buyers and renters).
- Each building project is unique in itself. The climate zone and weather profile of the city where the building is located, govern the type(s) of insulation needed to be applied in

the building. There is limited technical knowledge among building designers to make the right selection and optimum estimation of insulation product(s) most suitable for their building.

- There is uncertainty among building designers with regard to durability of the insulation, attainment of energy saving, payback period on additional investment, and so on. Availability of expert services is also limited at present.
- Insulation manufacturers/suppliers lack initiatives in providing the right scientific and technical advisory services on the benefits and limitations of insulation products.
- There is ignorance or indifference among the building contractors on the adoption of the correct preparations and procedures before applying selected insulation in the building envelope, though normally, such guidelines and instructions are specified by the manufacturers/suppliers.
- In the public domain, the number of case studies (successes and failures), based on actual thermal and energy performance of buildings to raise awareness on building insulation projects, is limited.
- There is inadequate independent/third-party testing facilities in the country to create awareness among building developers, designers, and other stakeholders about thermal characteristics of insulation products and other building construction materials.

BEEP—Promoting Insulation of Buildings

The Indo-Swiss Building Energy Efficiency Project (BEEP), which started in 2012, has addressed several issues discussed, and has taken up the following initiatives to promote insulation of buildings as an important energy-efficiency measure.

Integrated Design Charrettes

Under Component 1, BEEP has been providing technical assistance to builders and developers in designing energy-efficient buildings. The technical assistance is provided by conducting design charrettes in the early design phase of the building project. Till August 2016, BEEP has supported 17 building projects in public/commercial and residential buildings owned by government and private organizations. Each project is technically evaluated with energy-simulation exercises for various parameters, including incorporation of insulation and its cost effectiveness over the expected life of the building. Roof insulation in most charrette building projects and wall insulation in several buildings have been recommended.

Case Study of Aranya Bhawan, Jaipur

A new office building of Rajasthan Forest Department in Jaipur was one of the first projects selected in 2012 for its designing under BEEP's Integrated Design Charrette activity. The project, with 14,000 square metre floor area spread across five floors and a basement for parking and services, was implemented by the Rajasthan State Road Development and Construction Corporation Ltd. Initial design proposed by the owners was analysed in depth by Swiss and Indian experts. In addition to several other energy-efficiency measures, insulation features, adopted in the new design of the building over the initial design and the energy-efficiency gains achieved thereby, are presented in a nutshell in Table 6.

Table 6 Result of energy-efficiency measures adopted at Aranya Bhawan, Jaipur

	Before Charrette	*After Charrette*
Roof	Un-insulated RCC slab: 150-mm	150-mm RCC slab + 40-mm polyurethane foam insulation
Wall	Un-insulated brick wall: 230-mm	115-mm brick wall + 50-mm extruded polystyrene insulation + 115-mm brick wall
Windows	Single glazing unit: 5-mm clear glass	Double glazing unit: 6-mm low – e glass + 12-mm air gap + 6-mm clear glass
HVAC System	Air-cooled variable refrigerant volume system with CoP*: 2.75	Centralized water cooled chiller system with CoP: 5.8
Building's EPI**	77 kWh/m^2/year	53 kWh/m^2/year
Construction cost	Rs 30 crore	Rs 30.6 crore

* *coefficient of performance*
** *Energy Performance Index: annual energy consumption per square metre of floor area*

This energy performance of the building has been monitored by BEEP for one year since its occupancy and the energy performance index (EPI) has been found to be 43 kWh/m^2/year, which is lower than the simulated value of 53 kWh/m^2/year.

Design Guidelines for Residential Buildings

Under Component 3, BEEP has prepared publications on 'Design guidelines for energy efficiency in multi-storied residential buildings'. In the context of building insulation, the guidelines emphasize that insulation should not be seen as a single and independent measure but as a part of an overall design strategy to improve the thermal comfort and energy efficiency of the building. For the roof, it recommends over-deck insulation in combination with high reflective paint on its external surface. For walls, the guidelines show that use of insulation material in walls becomes more effective when it is coupled with measures to reduce heat gains from windows by undertaking proper shading systems, and improving natural ventilation to remove heat from the occupants' space. For more details, please refer the publication titled '*Design Guidelines for Energy-Efficient Multi-Storied Residential Buildings in Composite and Hot-Dry Climates*'.

Testing of Insulation Products

As discussed earlier, independent or third-party testing of thermal conductivity of insulation products has remained limited in the country, though Indian and international test standards for such testing have been there for many years. These standards specify the testing conditions and use of specific equipment (Table 7).

Table 7 Indian and international standards for measurement of thermal conductivity

Indian standard	*Thermal conductivity measurement equipment*	*International standard*
IS 3346 (1980) Reaffirmed 2004	Two slab guarded hot plate	ISO 8302, ASTM C 177
IS 9489 (1980) Reaffirmed 1985	Heat flow meter	ISO 8301, ASTM C 518

To enhance testing of building insulation materials and products in India, BEEP under Component 2, and with the overall guidance from BEE, has supported a programme on capacity building of a few labs in India.[3]

Under this programme, Inter-Lab Comparison (ILC) activity using 'Star Robin Testing' for distribution of insulation samples was undertaken wherein EMPA, a lab from Switzerland, participated along with BEEP Partner Labs from the following Indian institutions. The labs that were initially provided training and technical inputs by BEEP to undertake ILC include:

- CEPT University, Ahmedabad
- Isolloyd Engineering Technology Ltd, Baddi
- Nirma University, Ahmedabad
- Spectro Analytical Labs Ltd, New Delhi

The objective of this proficiency testing under ILC activity was to ensure that all the participating labs get the same results, within a given uncertainty margin, on the measurement of thermal conductivity for the same material, when measured at the same temperature. For ILC, five samples of each of the two building insulation products, namely, extruded polystyrene (a rigid product) and rock wool (a soft product), were provided to the labs by the India Insulation Forum through its two insulation suppliers.

Samples of both products were drawn individually from the same production lot by two suppliers. Depending upon the equipment in each lab, the samples were cut to the required sizes and distributed randomly among the labs for testing their thermal conductivity under IS 8301 or IS 8302. Table 8 gives details of equipment in each lab.

[3] This capacity building component of BEEP was led by Prof. Claude-Alain Roulet, who also developed a Training Manual on 'Measuring the Characteristics of Thermal Insulation Materials'.

Table 8 Thermal conductivity measurement equipment in labs

Laboratory	*Type**	*Model*	*Sample size (mm × mm)*
EMPA	GHP	Self-made	500 × 500
CEPT University	HFM	Laser Comp. FOX 600	600 × 600
Isolloyd Engineering	HFM	NETZSCH FM/436/3/IER	300 × 300
Spectro Analytical Labs	HFM	Dynatech K-Matic	300 × 300
Nirma University	GHP	Anter Corporation, USA	300 × 300

**Guarded hot plate (GHP) or Heat flow metre (HFM)*

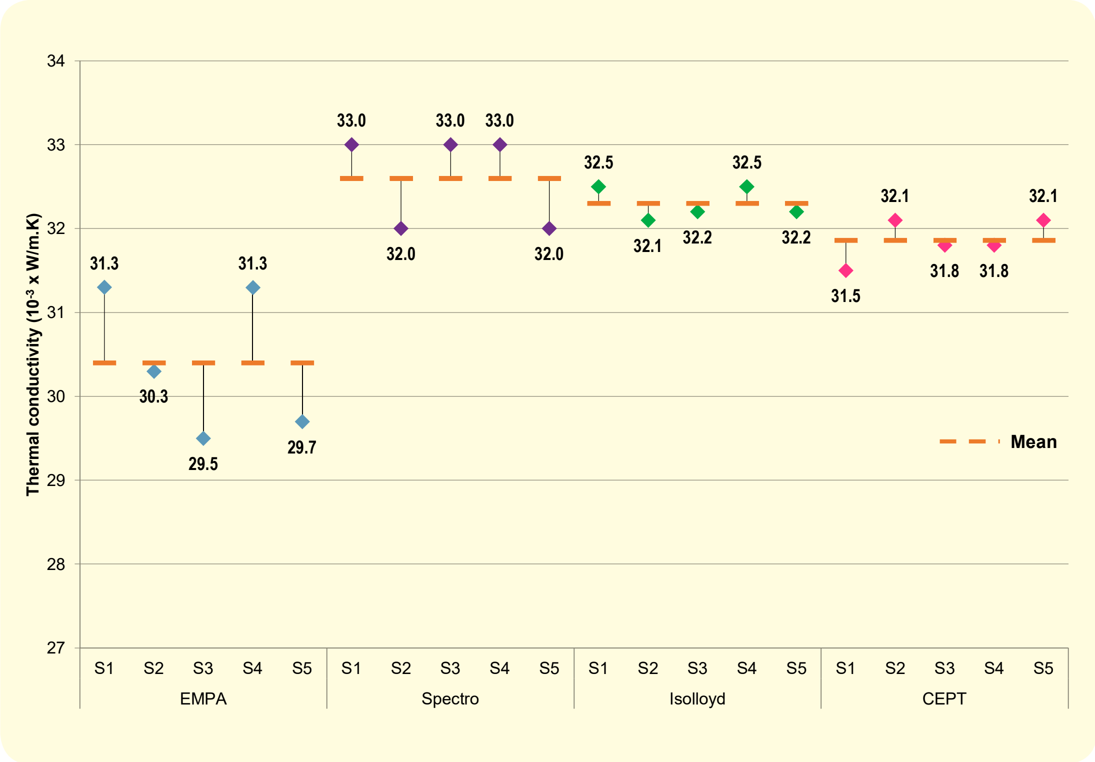


Figure 15 *ILC - Thermal conductivity of extruded polystyrene samples (At mean temp.: 23 ± 1 °C, Mean thickness: 50 mm, Density: 34 kg/m^3)*

Figures 15 and 16 represent the results of thermal conductivity measurements by four labs under ILC. It was observed that the dispersion of the results of thermal conductivity depended much more on the variations in the samples themselves than on the measurement methods. Considering accuracy of measurements and the equipment as indicated by the equipment manufacturers, the results of the measurements of each of the laboratories are generally in close agreement.

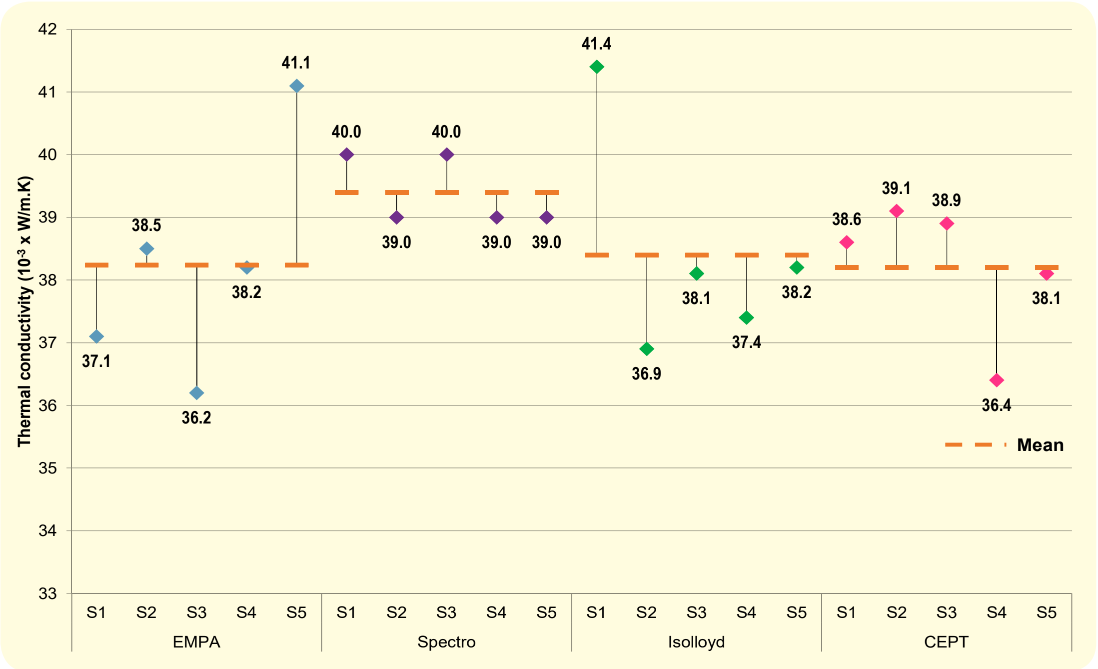


Figure 16 *ILC - Thermal conductivity of rock wool samples*
(At mean temp.: 23 ± 1 °C, Mean thickness: 49 mm, Density: 49 kg/m³)

Thermal conductivity measurements for both the materials, reported by Nirma University lab, were not found close to the other labs. This was attributed to some functional errors in their equipment during ILC. Thus, their test results have not been included in the ILC analysis.

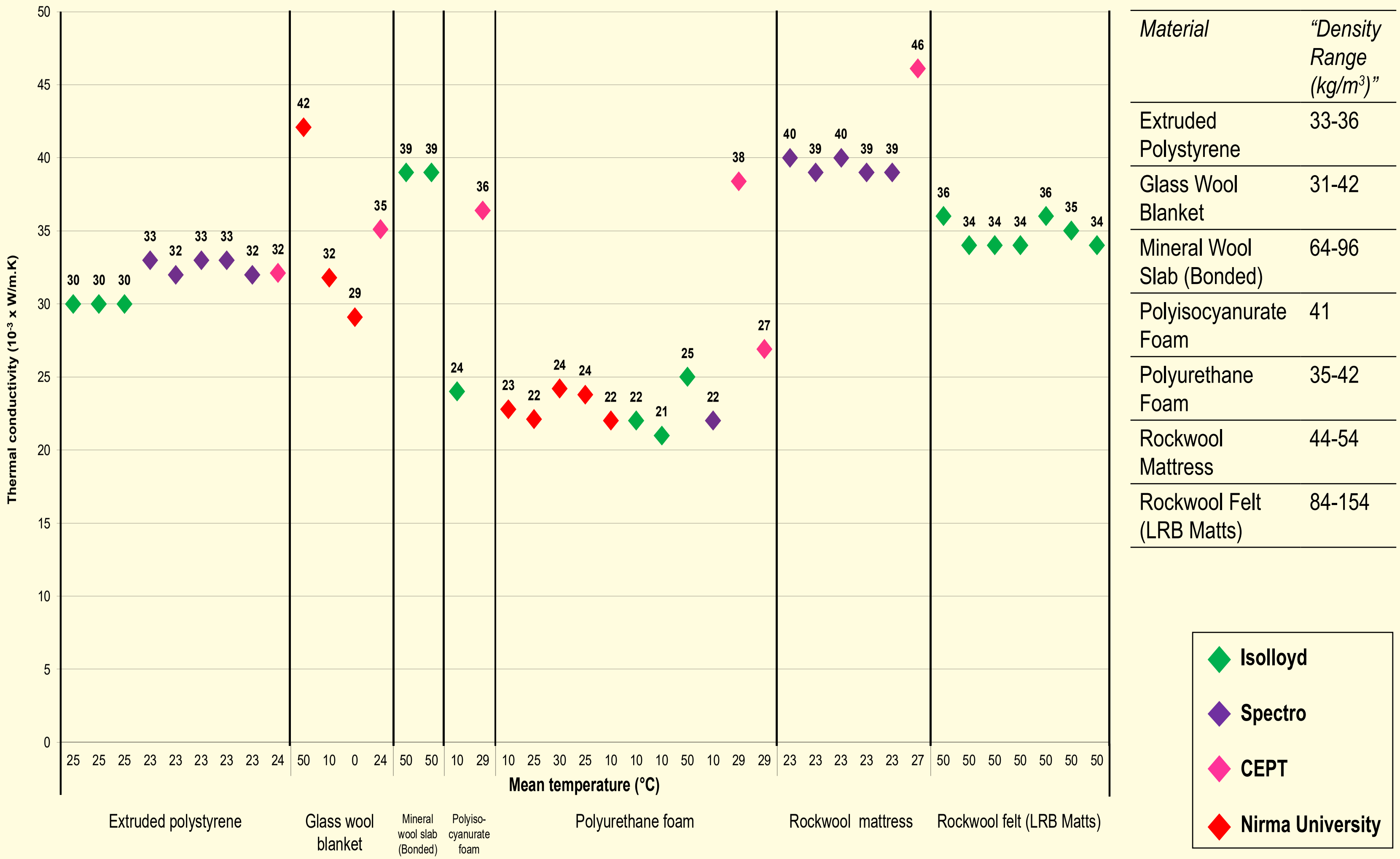
Database on Building Insulation Products

BEEP, in association with its partner labs, has initiated the development of a database on building insulation products and materials on the basis of tests undertaken by the labs for the measurement of their thermal conductivity in recent months. To enhance visibility of such test data among the stakeholders, BEEP plans to upload the database on its website. Figure 17 gives an overview of the data received from the partner labs.

Energy-Efficiency Labelling of Building Insulation Products

Energy-efficiency rating and labelling of products/equipment enhance awareness and knowledge on energy-saving benefits among concerned users and stakeholders. This also facilitates them in taking informed decisions while buying or adopting such products. Keeping this perspective, BEEP is jointly working with BEE on various issues related to the development of a suitable labeling programme for building insulation products. The support of testing labs in terms of verifying manufacturers'/suppliers' energy efficiency claims on their products is crucial for such a programme. Needless to say, the availability of well-equipped test labs in the country is a pre-requisite, before MoP and BEE launch a national labelling programme for building insulation products.

Figure 17 *Thermal conductivity of typical samples of building insulation products - Tested by Partner Labs*



Material	*"Density Range (kg/m^3)"*
Extruded Polystyrene	33-36
Glass Wool Blanket	31-42
Mineral Wool Slab (Bonded)	64-96
Polyisocyanurate Foam	41
Polyurethane Foam	35-42
Rockwool Mattress	44-54
Rockwool Felt (LRB Matts)	84-154

What Building Designers Should Look for

Thermal insulation materials/products can play an important role in enhancing the 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 about thermal comfort and energy performance of buildings.

Application of thermal insulation for any building project needs 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 roof and walls, but the selection should also take into consideration various other characteristics (e.g., fire resistance, compressive strength, traction strength, water vapour diffusion, etc.) and the suitability of insulation materials for a particular application.

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. These software can help the designers in aspects related to insulation also such as in:

(a) making the right selection of insulation product(s);
(b) deciding on how to apply the insulation (e.g., on external surface or on internal surface); and
(c) arriving at the optimum thickness of insulation products required in the building envelope.

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 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 right preparation and pre-treatment of surfaces where it is being applied along with incorporation of binding, water proofing, 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.

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