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# Impact of Phase Change Material (Butyl Stearate) and other insulation material on thermal performance of building envelope in different climates of India

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ABSTRACT

India is a developing country and thus has to cater to high energy demands in both rural and urban areas. Buildings and construction together account for 36% of global final energy use and 39% of energy-related carbon dioxide (CO2) emissions when upstream power generation is included. In India, the building sector consumes around 30% of the total energy. This research work is divided into two parts. The first one is the comparative evaluation of insulation materials for optimization of energy, and the other one is direct encapsulation of PCM material into the wall. The selection of building insulation materials such as EPS, XPS, PUF, GW and RW etc is based on market availability and suitability to weather conditions at building location. The Indian weather conditions have been classified into 6 different categories as per ISHRAE namely hot and dry, warm and humid, moderate, cold and cloudy, cold and sunny, and composite and similarly classified as Very Hot–Humid (1A), Dry (1B) as per ASHRAE 90.1 2007. Five locations of India with different climatic conditions have been chosen covering all Indian climatic zones which are Delhi (composite), Mumbai (Warm & Humid), Ahmedabad (Hot & Dry), Bangalore (Composite), and Srinagar (Cold). Selected types of insulation materials have been tested for thermal load performance of the building envelope in each of the above weather conditions including life cycle cost (LCC) analysis for 20 year period, carried out to select the best alternative amongst the selected insulation materials for each of the weather conditions. The parameters for the selection of insulation material are based not only on saving energy but also on protecting the environment from harmful gases. In Delhi state, The best suitable insulation material is RW since its payback is 1.08 years with maximum energy saving of 17.82%. In the case of Ahmedabad, GW gives maximum energy saving with optimum thickness, but the payback period is much lesser for Rock Wool viz.,1.06 years. In the case of Bangalore, the suitable material is RW with the payback period of 1.84 years. For Mumbai city, RW is the optimum material with a payback period of 2.02 years.

Selection and peer-review under responsibility of the scientific committee of the 1st International Conference on Energy, Material Sciences and Mechanical Engineering.

## 1. Introduction

The energy demand worldwide is rapidly increasing, due to population and economic growth, especially in large emerging countries, accounting for 90% of the total energy demand growth in the next fifty years. According to the previous studies, almost 60% of the building's energy consumption is due to the heating and cooling energy demand and it is increasing every year by 1.8% [1]. Asan et al. (1998) investigated the impact of thermophysical properties and thickness of the wall on time lag and decrement factor [2]. For this purpose, a one-dimensional transient heat conduction equation was solved for a composite wall using Crank–Nicolson's scheme under periodic convection boundary conditions. Again Asan et al. (2000) enhanced their research work and tried to find out optimum insulation material position in the wall with maximum lag and reduced decrement factor [3]. The same method was used to solve transient heat conduction, i.e., the Crank-Nicolson method, and was modeled on Turkey, which has different weather conditions. Sixteen states were chosen from four different climatic zones and then studied. The heating and cooling degree

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**Nomenclature**

| | |
|---|---|
| As | annual energy saving ($/$m^2$) |
| PUF | Polyurethane foam |
| Cel | Cost of electricity ($/kWh) |
| $C_{enr}$ | Cost of energy ($/kWh) |
| EPS | Expanded polystyrene |
| XPS | Extruded Polystyrene |
| GW | Glass wool |
| RW | Rock wool |
| Ct | Total cost ($/$m^2$) |
| b | Payback period (Year) |
| $C_{ins}$ | Cost of Insulation ($/$m^3$) |
| $L_{ins}$ | Insulation thickness in meter |
| C | cost of energy without insulation ($/$m^2$) |
| $C_t$ | cost of energy with insulation ($/$m^3$) |
| BS | Butyl Sterate |
| PCM | Phase change material |

day method is used to calculate the annual heating and cooling load, and five other fuels are used to optimize the insulation material in these selected locations [4]. This study suggested different wall configuration, which is very normal in construction history and is not difficult to apply in practical work. Energy-saving can be done with proper insulation thickness and right position of this material, using heating degree and cooling degree day method. This work's main finding is that the optimum insulation thickness is varied with respect to each type of fuel used [5]. Kurekci et al. [6] calculated optimum insulation thickness, life cycle cost, and payback period by considering 6 types of fuels and 2 insulation materials, using the degree-day method in Turkey. Ozeal et al. (2011) in their work have investigated the effect of dynamic thermal performance and optimum insulation material for different building materials, i.e. applying concrete, briquette, brick, and autoclaved aerated concrete. This study compared the insulated and uninsulated wall material in energy saving by using the degree-day method [7]. Naouel Daouas et al. (2011) did their study for the Tunisian climate, where both heating and cooling weather exists. This study used an analytical method, Complex Finite Fourier Transform (CFFT), taking the different orientation of the wall, the west and east side wall are not showing good results in the winter season, whereas the north side wall is not showing sound results in the summer season [8]. India is a growing country where energy demand increases rapidly, so this research focused on saving energy in the Indian climate zone by using three insulation materials in five selected cities. The authors tried to optimize the insulation material's thermo-economic parameter, and these parameters were insulation thickness, annual electrical energy, annual energy consumptions, etc. [9]. Ashok Kumar et al. (2013) explain that ECBC defined the U value and R factor, but no published data is available. So the author works on these factors and calculates the thermal conductivity of different types of material available in the Indian market with the help of Automatic Guarded Hot Plate Apparatus [10]. B. Belhadj et al. (2015) studied the effect of barley straws addition on the thermophysical properties of sand concrete intended for the construction of an external wall in arid regions. The obtained results show that the addition of barley straws considerably improves the thermophysical properties of sand concrete (thermal conductivity, specific heat, and density). In addition, the results obtained by the use of the "EnergyPlus" software and its application for an external wall made of these materials show that, in the case of SC-BS, the thermal insulation is markedly improved compared to the case of SC-W-BS. [11].

In order to cool a room with a cold night air phase change material, PCM is used in the various parts of the building structure. During the night, the PCM crystallizes, energy is released. During the daytime, the air is circulated in the building, energy is absorbed, and the indoor air is cooled. The characteristic of PCM is that there is an increase of the specific heat over a limited temperature span. An ideal PCM must be characterized by a suitable phase change temperature and a large melting enthalpy. These features have to be fulfilled in order to store and release heat [15]. Jin et al. (2016) explained in their mathematical model that the optimum thickness of PCM and the correct position of the PCM layer in the wall directly influenced the PCM properties, specific heat, melting temperature, and inner surface wall temperature [12]. Wang et al. (2018) also explained the type of PCM, thickness, and position in the wall reduced the amount of annual load in Shanghai [13]. Using PCM in a building is a novel, energy-efficient and sustainable method, whereas enhanced building thermal load and maintain a constant temperature inside the building with the help of heat storage capacity characteristic [14]. PCM has a capability that it can store and release the heat at constant temperature due to high-density features. Because of this feature, PCM opened a wide range of applications in the building construction. A wide variety of PCM is available in the market, but in this research work used Butyl Stearate (BS) due to its special characteristic. BS works as a hydrophobizing agent helps in less water absorption and easy removal of water vapor [14]. Butyl stearate as a kind of PCMs works well on heat preservation. It can help reduce the fluctuations of indoor temperature about $1 \sim 2$ °C, lower the maximum temperature about $1 \sim 2$ °C during the daytime, and increase the minimum temperature about $1 \sim 3$ °C at night [16].

In most of the studies done till now, two or three types of insulation materials are used, and the work is done either in summer or winter zone or both of them. However, India has an extraordinary range of climatic regions, starting from tropical in the south to temperate and alpine in the north, surrounded by the great Himalayas. These mountain areas receive sustained winter snowfall; the desert areas experience massive dust storms, and the plateau is subjected to typhoons and has very humid weather. Thus, the nation's climate is strongly influenced by the Himalayas and the Thar Desert. Srinagar is a city situated in the Himalayan region, Ahmedabad, in the desert area, and Mumbai is a famous seaport since the medieval ages. The present study uses five different types of insulation materials along with a PCM and applies them to building structures situated in different climatic zones. The optimization of insulation material is based on total cost, payback period, and maximum energy saving. All the data are taken from the energy conservation building code. The work outlines a comparative analysis between the insulated and un-insulated walls in terms of energy saving.

## 2. Study area

This study has been done by selecting five cities in diverse climatic conditions of India, which are Delhi (composite), Mumbai (Warm & Humid), Ahmedabad (Hot & Dry), Bangalore (Composite), and Srinagar (Cold). For the purpose of the analysis, Walls have been chosed as the best suitable element of building envelope for testing the performance of various insulation materials and the

**Table 2.1**
Area details of building envelope.

| Area | $m^2$ |
|---|---|
| Roof | 3054.46 |
| Floor | 9645.79 |
| Wall | 2704.52 |

**Table 2.2**
Description of Indian climate zones.

| Climate zone | Mean monthly maximum temperature (°C) | Mean monthly relative humidity (%) |
|---|---|---|
| Warm & humid | >30 | <55 |
| Composite | >30 | >55 |
| Cold | >25 | >75 |
| Hot & Dry | 25–30 | <75 |
| Moderate | <25 | All values |

PCM. The analysis is based on the materials' performance in terms of energy saving, life cycle cost, building strength, as well as comfort to the occupant. Insulation materials also play an essential role in controlling the fluctuation in temperature inside the buildings. Building surface area details are summarized below in Table 2.1.

Bansal and Minke et al. (1988), in their work, have on Indian climate; have categorized it into six zones, as explained in Tables 2.2 and 2.3:

## 3. Methodology

### 3.1. Wall structure of the building

This study is divided into two phases, the first phase focuses on the construction of the building geometry application of insulation material, and calculation of optimum thickness of the insulation material. At the same time, the second phase deals with the application of the PCM material. The heat transfer model is developed, having N number of layers, one-dimensional transient heat conduction occurs, isotropic and homogeneous properties present in the wall. The outer wall surface is exposed to the outer environment, and the inner surface is exposed to the inner surface of the building.

Fig. 3.2 demonstrates the geometry of the wall with insulation material and wall with PCM, respectively. In both, the cases the insulating material and the PCM is applied outside the surface of the walls and it is covered with a layer of plaster of 15 mm thickness. The general properties of the building materials used in construction are described in Table 3.1. Table 3.2 illustrates the properties of PCM (BS). Other parameters and properties have been defined according to ECBC 2007 (Energy conservation building code).

The relationship between thermal conductivity and temperature are illustrated in Fig. 3.1. It is observed that as the temperature increases, the thermal conductivity decreases, thus implying that more more heat transfer takes place with increase in delta temperature between two surfaces. However, the layer of PCM comes into action and absorbs the heat. The temperature of PCM remains constant during the phase change, which is useful for keeping the subject at a uniform temperature [15].

Heat transfer is considered through the wall only, and it is unidirectional. The wall has different layers and different materials, as shown in Fig. 3.2. It is assumed that the wall is isotropic and homogeneous.

In the absence of an internal heat generation, PCM mathematical model is governed by this eq. (1)

$$\rho C_p \frac{\partial T_j}{\partial t} = \frac{\partial}{\partial t_j}\left(\frac{\partial T_j}{\partial x_j}\right) For\, 0 < x_j < e_j \;\; Where\, j = 1, 2, 3 \ldots N \tag{1}$$

Where, $\rho$, $C_p$ and k are the density, specific heat, and thermal conductivity of the layer, and e is the wall layer's thickness. N is the number of layers in the wall. The latent heat value of the PCM is modeled in the above equation as a high sensible heat value during the phase change process. Usually, all the PCMs change their phase over a range of temperatures. In the present model, uniform cp value is considered during the phase change process, though in actual practice, there is variation in cp value within this small temperature range

The initial temperature and boundary condition of the PCM integrated wall is the same as given in eq. (3, 4 and 5) which means all the mathematical modeling conditions have been kept same across insulation materials for the study. The thermal properties of PCM, used in these equations are described in Tables 3.1 and 3.2.

### 3.2. Modeling for transient heat calculation using different insulation material

$$\frac{\partial^2 Tj}{\partial x^2 j} = \frac{1}{\alpha}\frac{\partial Tj}{\partial t}\, for\, 0 < x_j < L_j\, and\, j = 1, 2, 3 \ldots N, \tag{2}$$

The initial temperature distribution is taken as explained below:

$$T(xj,\ t = o) = To\ for\ j = 1, 2, 3 \ldots N, \tag{3}$$

The inner wall is designed for a fixed temperature, but the external side of the wall is exposed to the solar air radiant temperature. In the external side of the wall, surface heat exchange takes place through convection and radiation. The inside and outside boundary conditions of the walls are as follows

$$-k\frac{dT1}{dx1}x_1 = 0 = h_i[T_i - T_1(x_1 = 0, t)] \tag{4}$$

$$-k_N\frac{dTN}{dx1}x_1 = e_N = h_{c.o}[T_N(x_N - e_{N,t}) - T_a(t)] - \lambda q_s(t) + q_{r.o}(t) \tag{5}$$

Where, $\lambda$ is solar absorptivity and $q_{r,o}$ is the total longwave radiative heat flux, including radiation exchange with the sky, ground and air.

**Table 2.3**
Selected state's weather condition.

| | Delhi | Ahmedabad | Shimla | Bangalore | Mumbai |
|---|---|---|---|---|---|
| Humidity (%) | 44 | 33 | 44 | 15 | 43 |
| Summer temp (max.) | 44 | 43 | 35 | 34 | 40.3 |
| Winter temp (max.) | 24 | 28 | 24 | 32 | 32 |
| Monsoon (max.) | 39 | 31 | 20 | 28 | 31.9 |
| Wind speed (km/h) | 13 | 8 | 5 | 13 | 16 |
| Solar radiation (kWh/$m^2$ day) | 4.29 | 5.82 | 5.64 | 5.32 | 5.35 |

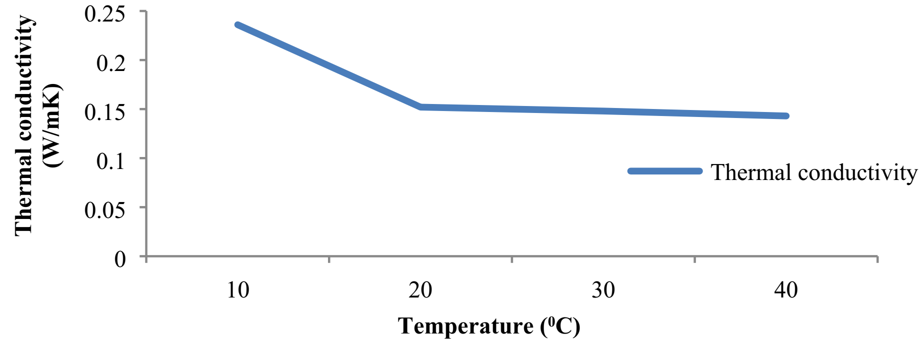


**Fig. 3.1.** Butyl stearate (BS) thermal conductivity and temperature graph.

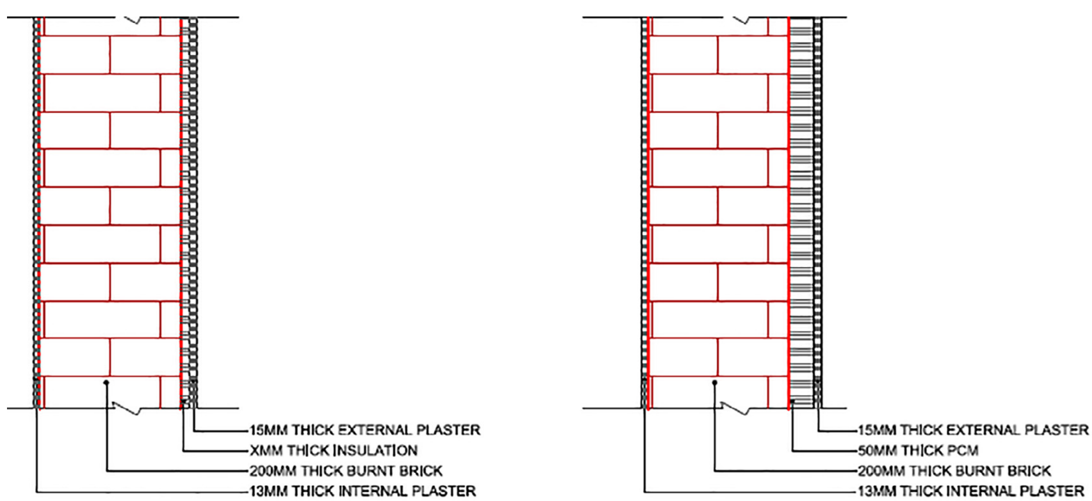


**Fig. 3.2.** Building inside wall structure configuration with (a) insulation layer (b) with PCM layer.

**Table 3.1**
Thermal properties of materials used in building envelope [13].

| Materials | k (W/mK) | $\rho$(kg/m$^3$) | $\alpha\times10^7$ (m$^2$/s) |
|---|---|---|---|
| Brick (230 mm) | 0.69 | 2049 | 3.98 |
| | 0.23 | 1150 | 2 |
| Stone | 1.7 | 2500 | 6.8 |
| Cement plaster | 1.4 | 2200 | 6.3 |
| Cement lime plaster | 1 | 1900 | 5.26 |
| Concrete | 1.65 | 2000 | 8.25 |
| Reinforced concrete | 2.5 | 2400 | 10.41 |

**Table 3.2**
Property of BS PCM.

| Description | Butyl Stearate |
|---|---|
| Thermal conductivity (W/mK) | 0.152 |
| Density (kg/m$^3$) | 861 |
| $\alpha\times10^7$ (m$^2$/s) | 1.19 |
| Thermal storage capacity (J/g) | 134.2 |
| Melting temp. | 29 °C |
| Boiling Point (°C) | 418 |
| Viscosity @ 30 °C (cp) | 7 |

### 3.3. Calculation of optimum insulation thickness

In this research work, energy plus software has been used to analyze the building's thermal behavior, which is a dynamic tool developed by the US Department of Energy. This software has different methodologies to calculate heat transition through walls, windows, and roof. But in this work, only the wall is considered for heat transition calculations, and CTF (conduction transfer function) algorithm is used. Energy Plus calculates the building energy loads (Heating, cooling, light, etc.), based on inside, outside wall surface conditions and transient heat conduction into the building. For the mathematical simulation, EnergyPlus uses a weather file for a particular location. It is available in the EPW format, which includes direct normal, global horizontal, and diffuse solar radiation, dry bulb temperature, and wind velocity, precipitation values and other useful parameters [12].

The EnergyPlus uses cartesian coordinate system for definition of surfaces of the building and no alternate user interface is currently present, therefore, the geometry of the building has been designed using DesignBuilderTM and the input data file (IDF) has been generated for further analysis using EnergyPlus. The EnergyPlus user interface is not only modular but also provides a block level input definition opportunity to the user. After the definition of parameters, multiple simulations have been carried out to arrive on the required results.

### 3.4. Calculating energy cost and payback period

The changing insulation thickness has direct effect on the heating and cooling load of the building. Thus, this work is done by only using the heating and cooling load to calculate the total energy cost and payback period. To calculate the PWF Equations. 6 & 7 are used:

$$r = \frac{i-g}{i+g} \tag{6}$$

$$PWF = \frac{(1+N)^N - 1}{r*(1+r)^N} \quad (7)$$

PWF helps to calculate the approximate energy consumption cost of the building over a 20 yr life span. Hence, the life cycle cost of the building per unit area, including PWF with the insulation of the building, is calculated by using equation (8) [13]:

$$C_t = C_{energy} + C_{ins.} = PWF * \left(\frac{Q_c}{COP}\frac{Cel}{3.6*10^6} + \frac{Qh}{Hu.ns}C_g\right) + L_{ins.} * C_y \quad (8)$$

The Payback period (b) is the number of years needed to return the extra cost of expenditure incurred on the Energy Conservation Measure (ECM) used in the construction of the building. This amount is available in the form of energy-saving after applying insulation materials and PCM material. But it also directly depends on insulation or PCM material cost, as is clearly understood from equation (9)

$$b = L_n[1-(g-i)C_{ins.}L_{ins}i \neq g \quad (9)$$

$$L_n * \left(\frac{1+i}{1+g}\right)$$

$$b = (1+i)\frac{Cins.Lins}{As} i = g$$

Where $A_s$ is the annual energy saving; $A_s$ = C- $C_t$. Annual saving is the difference between annual energy cost without insulation to the energy cost with insulation. Table 3.3 illustrates all the relevant data used in the getting the results from equations 1–9.

**Table 3.3**
Parameter used in calculations.

| Interest rate (i) | 8.25% |
|---|---|
| Inflation rate (g) | 7.91% |
| Life span (N) | 10 |
| PWF | 9.05 |

## 4. Results

### 4.1. Insulation effect on thermal load

In the new or retrofitting construction mortar is replaced by insulation and it changes the whole characteristic of the building wall and finally enhances the thermal stability. Every insulation has different characteristic which presents different results under the same conditions and thickness. So due to this characteristic all insulation materials have a distinct critical thickness and different energy saving. The optimum thickness is not based on the percentage of the maximum saving of energy, but also the insulation expenditure on the building. The optimum thickness is shown below Table 4.1:

The optimum thickness for Delhi is for two insulation materials XPS and RW of 70 mm. However, the minimum payback period is for RW, and the maximum saving is for PUF (18.3%). The PCM thickness is the same for all the cities because when the temperature increases, PCM absorbs heat in an endothermic process and changes phase from solid to liquid, whereas as the temperature drops, PCM releases heat in an exothermic process, and returns to its solid phase. The reduction percentage of change of annual energy is 15.83%, 16.1%, 18.3%, 16.1% and 17.82%, respectively. PCM helps in saving energy among all of them (including insulation), which is 18.26%, and payback year is 1.53 yr, as shown in Tables 4.2 and 4.3.

In Ahmedabad climatic zone, the optimum thickness is 65 mm for glass wool (GW) as shown in Table 4.2, but the maximum saving occurs with XPS. The payback period is 3.2 years, but when compared to all the other insulating materials, RW has a minimum payback period, as shown in Table 4.2. The annual saving after applying all insulation materials are 8.8%, 8.9%, 8.6%, 8.7%, 8.6%, and 8.5%. The saving after applying PCM material is 21.8%, and payback is 3.45 yr (Fig 4.1).

For the climatic zone at the seashore where Mumbai is situated, the optimum thickness is 50 mm for Rock wool (RW), as shown in Table 4.2. Still, the maximum saving occurs with PUF due to the high installation cost in the total cost of PUF, which is 39.18$/m$^2$. It is the highest of all other materials. The annual saving after applying insulation is as 15.56%, 16.82%, 17.3%, 15.9%, and 13.7% and payback period for RW is 2.02 yr. The PCM is much effective as compared to insulation and helped to give a saving of 18.31% of annual energy and payback period is 1.8 yr which is also minimum among them.

**Table 4.1**
Optimum thickness value of different insulation materials in different region of India.

| Region | Insulation material | | | | | PCM |
|---|---|---|---|---|---|---|
| | EPS | XPS | PUF | GW | RW | |
| Delhi | 80 | 70 | 90 | 80 | 70 | 50 |
| Mumbai | 75 | 65 | 50 | 85 | 50 | 50 |
| Bangalore | 75 | 56 | 79 | 100 | 85 | 50 |
| Ahmedabad | 68 | 70 | 65 | 65 | 75 | 50 |
| Sri-Nagar | 80 | 100 | 27 | 50 | 58 | 50 |

All thickness in mm

**Table 4.2**
Payback-period of All states.

| State/Insulation | EPS(Yr.) | XPS(Yr.) | PUF(Yr.) | GW(Yr.) | RW(Yr.) | PCM(Yr.) |
|---|---|---|---|---|---|---|
| Ahmedabad | 4.76 | 6.4 | 8.8 | 3.2 | 1.06 | 3.45 |
| Mumbai | 3.1 | 3.7 | 4.23 | 2.4 | 2.02 | 1.8 |
| Bangalore | 2.13 | 2.28 | 3.53 | 1.86 | 1.84 | 1.49 |
| Srinagar | 2.16 | 2.92 | 1.76 | 1.5 | 1.65 | 1.56 |
| Delhi | 3.5 | 4.11 | 6.8 | 2.5 | 1.08 | 1.53 |

**Table 4.3**
Effects of insulation material in terms of energy saving.

| Region | LoadIn kWh | EPS Before ins | EPS AfterIns. Energy | EPS %,Saving of Energy | XPS AfterIns. Energy | XPS %,Saving of Energy | PUF AfterIns. Energy | PUF %,Saving of Energy | GW AfterIns. Energy | GW %,Saving of Energy | RW AfterIns. Energy | RW %,Saving of Energy | PCM Butyl stearate | PCM % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delhi | Heating | 2342.96 | 1170.73 | 15.8% | 1142.20 | 16.1% | 809.76 | 18.3% | 1125.35 | 16.01% | 885.96 | 17.82% | 1063.87 | 18.26% |
| | Cooling | 277529.22 | 256760.75 | | 256021.9 | | 250147.88 | | 256316.39 | | 251478.0 | | 250088.06 | |
| Mumbai | Heating | 0 | 0 | 15.56% | 0 | 16.82% | 0 | 17.3% | 0 | 15.9% | 0 | 13.7% | 0 | 18.31% |
| | Cooling | 323440.37 | 298987.41 | | 297014.72 | | 296337.47 | | 297923.06 | | 301671.99 | | 290085.74 | |
| Bangalore | Heating | 0 | 0 | 18.6% | 0 | 18.26% | 0 | 18.87% | 0 | 20.47% | 0 | 18.6% | 0 | 18.01% |
| | Cooing | 366976.35 | 320795.92 | | 321969.72 | | 319728.38 | | 317540.14 | | 320739.96 | | 322758.05 | |
| Ahmedabad | Heating | 5152.39 | 5370.0 | 8.8% | 5314.94 | 8.9% | 5353.36 | 8.6% | 5353.56 | 8.7% | 5349.36 | 8.6% | 5321.61 | 8.5% |
| | Cooling | 333482.17 | 321012.71 | | 320168.36 | | 320917.08 | | 320712.75 | | 321078.95 | | 321674.07 | |
| Sri-Nagar | Heating | 233223.11 | 180064.35 | 20.28% | 174896.42 | 21.67% | 174896.42 | 22.3%% | 186537.48 | 18.54% | 188387.61 | 18.2% | 170319.92 | 26.67% |
| | Cooling | 105657.70 | 110399.57 | | 110860.07 | | 110860.07 | | 109819.73 | | 109618.93 | | 106547.77 | |

The optimum thickness for Bangalore condition is 85 mm (RW) as shown in Table 4.2. The payback period is 1.84 yr for a total cost is 21.36\$/m$^2$. The maximum saving occurs through the PUF insulation material, but PUF has a high installation cost. The annual saving after applying insulation are 18.6%, 16.26%, 18.87%, 20.47%, and 18.6%. The PCM is not much effective in this condition and saved only 18.01% of annual energy, and payback period is 1.49 yr.

In Srinagar climatic condition, the optimum thickness is 50 mm (GW), as shown in Table 4.2, but the maximum saving occurs with XPS. The total cost of XPS is 34.34\$/m$^2$, which is very high among all of them. The annual saving after applying insulation is as 20.28%, 21.67%, 21.67%, 18.54%, and 18.06%. The payback - period for GW is 1.5 yr. The PCM is much effective as compared to insulation and saved up to 26.3% of annual energy and the payback period is 1.56 yr which is the minimum among them.

Muruganantham K. et al. (2010) in their work plotted a graph between latent heat storage capacity and temperature is similar as plotted by BS latent heat graph and temp curve Fig. 4.2. So it is the validity of this graph that BS is functioning properly. From this graph can be concluded that solid to liquid transition occur at a temp. of 23–24.9 °C phase change temperature and one more fact concluded that the enthalpy on liquid phase is higher than solid phase.

As already discussed that optimum thickness is based on material cost and energy cost in the building. Fig. 4.3 shows the effect of XPS optimum insulation thickness, which lies in between 45 mm and 50 mm. The material cost is always increasing as the thickness increases and energy cost decrease, but after certain level it's become constant or increase energy load.

## 5. Conclusion

Indian buildings energy sources depend on thermal power plant and they are emitted huge amount of harmful gases. But now a day changing the mode of generation of power means moving towards sustainable energy, using more natural resources and emphasizing to improve the technique to generate more power. In this technique using a heat balance algorithm to calculate building energy load annually, this model is based on involving internal heat balance involving inside face zone of the building. This heat base involves heat conduction through building element, convection to the air, short and long wave radiation and absorption through building elements. In this study calculated optimum insulation material for only heating, for cooling or for both of them. Calculation is based on using five different types of insulation material and this study conducted in five individual weather zones. For the same weather condition, different insulation material exhibit different optimum insulation thickness respectively. In winter zone required a thick insulation layer, mainly insulation thickness is almost mandatory for both heating and cooling load and less mandatory for heating zone only.

The use of PCM in buildings is highly beneficial; PCM can decrease energy consumption, shift the peak loads of cooling energy demand, decrease temperature fluctuations providing a thermally comfortable environment, and reduce the electricity consumption. Phase change material shows a good performance in comparison with insulation material, but the main drawback of PCM is that it is does not stay stable for a long span of time, ether it may leak, evaporate or not work efficiently. However in this study Butyl Staerate is used which is a no leakage PCM. Butyl stearate is the butyl ester of stearic acid is selected as phase change material for this study.

The payback period is maximum in heating zone only otherwise, for cooling and mix zone has low or medium payback value.

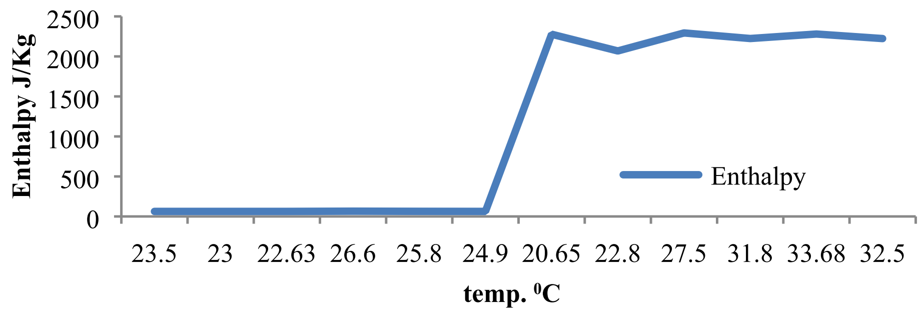


**Fig. 4.1.** Enthalpy and temperature graph.

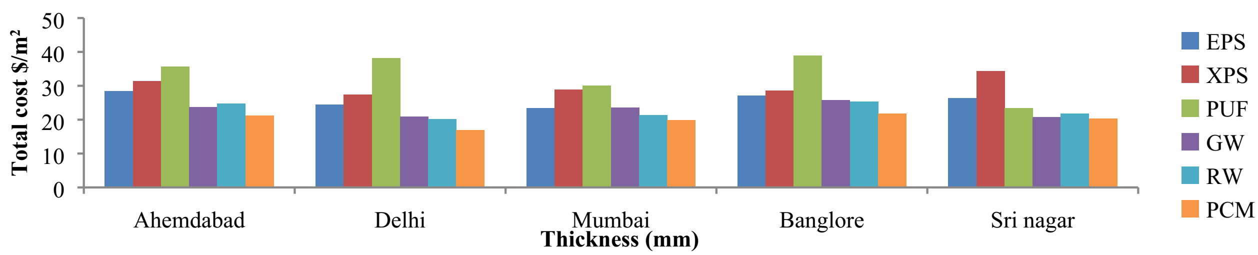


**Fig. 4.2.** Plot between total costs to the optimum thickness.

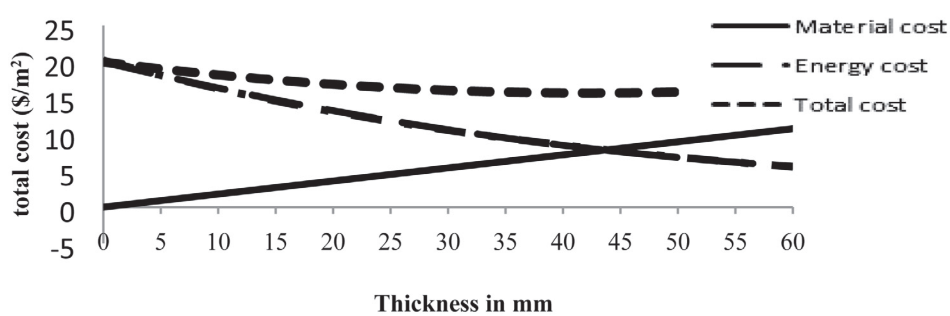


**Fig. 4.3.** Optimum thickness of XPS insulation material.

In PCM case only Ahemdabad shows a large payback duration among them otherwise all other states show a low payback period.

Maximum amount of saving is achieved with glass wool and rock wool insulation materials, since they are are so cheap and provide moderate saving of energy. In all cases, either glass wool or rock wool has top ranking among them in terms of total cost per sq. meter. PUF indicates apreciable performance in terms of energy saving, but it is not economically good. However PUF gives effective results in Srinagar case where it saved the highest energy of 21.7%. Basically Srinagar climate is very cold since it is in the Himalayas, and thus it needs a high heating load. Thus, the insulation material restricted the outside heat flow and maintained a constant temperature. The insulation material is applied outside wall surface and it has a major impact on energy savings PCM material have lowest cost persq. meter, but the manufacturing cost of PCM material is much higher as compared with insulation manufacturing cost. The thickness of PCM in all the five zones was kept the same.

## CRediT authorship contribution statement

**Shaheen Hasan:** Conceptualization, Data curation, Methodology, Software, Writing - original draft. **Sabah Khan:** Writing - review & editing. **Saif Uddin:** Supervision.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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