IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Energy Conservation in Different Walls Construction in India by the Application of Insulation

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Abstract

The energy conservation has become an important aspect in building construction. The energy in building may be considered from two different perspectives. Firstly the energy that goes into the construction of the building using a variety of materials. Secondly the energy that is required to create a comfortable environment within the building. Energy saving due to thermal insulation of brick walls construction in India for a representative room of size 5 m x 4 m x 3.5 m are consider. This investigation indicates the importance of the roof insulation, which results in a reduction up to 79 % of the heating load. The house is studied with brick wall material and insulation(Expanded Polystyrene) on wall and roof. Study suggests that brick wall with insulation reduce the energy requirement by 20 %. For same thickness of insulation, energy savings are much more with roof insulation than wall insulation. In this analysis an approach for selecting the most economic insulation material is calculated. Expanded Polystyrene is the highest economical material among the four insulation material (i.e Expanded Polystyrene EPS , Extruded Polystyrene XPS , Foamed Polyurethane and Glass Wool). Optimum insulation thickness of brick wall construction will calculated by Degree-Day method.

Keywords: Energy Savings, Thermal Insulation, Degree- Day, Cooling Load, Optimum Insulation Thickness.

Introduction

A considerable energy saving can be obtained by using proper thickness of insulation in buildings wall. Using proper insulation in building is most effective way of energy conservation in residential application. Insulation reduces fuel consumption, undesirable emissions from the burning of fossil fuels and increases thermal comfort by minimizing heat losses from building. Because of the limited energy sources, higher cost of fuels and environmental pollution coming from using the fuels, energy saving has become compulsory. The energy saving is maintained by reducing the energy consumption in buildings. Building insulation will reduce the running cost of space heating at the expense of an increase in the initial investment by the added insulation material. Insulation as single investments pays for itself many times over during the life cycle of a building.

Energy consumption is rapidly increasing due to increasing population, urbanization, migration to large cities and improvement in standard of living. The building sector is the largest energy consumer following the industrial sector. In general, heat losses occur in building mainly from external walls, roofs, windows, doors, ventilations and infiltration. By minimizing the heat losses from building walls, the energy will conserved. Heat loads are used as input to an economic model for the determination of optimum insulation thickness. Building with mud bricks as a thermal insulation and environmentally friendly. The mud bricks aim to save energy. A mud brick is a fire free brick, made of a mixture of clay, mud, sand and water mixed with binding material such as rice husks or straw. Mud brick acts as a thermal mass. Mud brick has ability to absorb heat, store it and at a later time release it. Mud brick walls are known for their ability to balance the relative humidity inside building and to provide thermal mass, reducing the heating and cooling requirement. The high thermal mass of mud bricks considerably reduces heat transfer, performing particularly well in summer. It is observed that the temperature of mud wall is higher in winter and lower in summer compared with the ambient air temperature. The comfort condition in buildings is affected by large fluctuations in ambient air temperature.

In this study, the heating/ cooling potential of mud brick construction and brick wall construction has been calculated by Degree -Day Method.

ISSN: 2277-9655
Impact Factor: 1.852

Location and Climatic Conditions

New Delhi is located in northern part of India, latitude 28.58º N and a longitude of 77.02ºE and at an altitude of 216 m above mean sea level. The climate of Delhi is a monsoon-influenced humid subtropical climate with high variation between summer and winter temperatures. In the climatic zone of New Delhi, the cooling period is larger than the heating period. Cooling is required for eight months. In rest four months, heating is required. During summer, cross ventilation is a better option for cooling of the room.

Summers start in early April and peak in May and June, with average temperatures near 38ºC. In some days of summer, temperatures are around 46ºC due to heat wave. The monsoon starts in early July and last until mid-September, with about 650 mm of rain. The temperature varies between 25ºC to 35ºC on rainy days. Winter starts in November and end in mid-February. Winter is peaks in January, with average temperature around 10-14ºC. There is heavy fog during the winter season in Delhi between Mid-December to Mid-January in early morning and at late night. Extreme temperatures have ranged from 4ºC to 48ºC.

Climate of New Delhi has been classified into four weather condition on the basis of sunshine hours:

(a) Clear day: If diffuse radiation is less than or equal to 25% of global radiation and sunshine hour is more than or equal to 8 h.
(b) Hazy day: If diffuse radiation is less than 50% or more than 25% of global radiation and sunshine hour is between 6 h and 8 h.
(c) Hazy and cloudy : If diffuse radiation is less than 75% or more than 50% of global radiation and sunshine hour is between 4 h and 6 h.
(d) Cloudy day: If diffuse radiation is more than 75% of global radiation and sunshine hour is less than 4 hours.

Method to Reduce the Total Energy Use in Building Environment

1. By reducing use of energy intensive materials, optimizing thickness of walls, high height of roofs.
2. By replacing energy- intensive materials with low-energy alternatives wherever available, such as
    - Lime- Pozzolana motars in place of conventional cement motars.
    - Sun-Dried blocks, stabilized-soil blocks instead of kiln fired bricks.
    - Light- weight block instead of dense concrete blocks.
    - Effective utilization of waste materials such as Gypsum-based plasters instead of cement based plasters.
3. By selecting lower-energy structural systems such as load-bearing masonry.
4. Use of materials locally available to reduce transportation costs.

On the other hand, the disposal of a variety of industrial wests such as coal ash from thermal plants, phosphor gypsum from fertilizer factories, red-mud from aluminium plants, lime-sludge from quarries slang from steel industries was creating greater problems. These bye products of industrial processes were generally used for dumping and causing substantial damage to the environment.

Structure of Building and its Materials

Mud has a number of properties which make it a perfectly suitable material for construction which aim at achieving thermal comfort at a low cost. These houses were constructed without any mechanical means. Energy saving due to mud wall construction in rural region of india for a representative room size is 5m x 4m x 3.5m is consider. Timber, Bamboo, Clay, straw, cow dung and a special variety of grass is used to bulid houses. Mud is mixed with cow dung, chopped straw and gravel to make the raw material for the walls. Fibrous ingredient like straw are used to improve tensile strength of mud brick. The external wall is formed by applying a thin coating of mud plaster on both sides of mud brick. Mud is act as a insulation. The roof rested on eight wooden post erected in three row. The mud wall construction usually has a thatch roof. Bamboo sticks formed the mullions to support the thatch. The thick thatch used as roofing material prevented rain from entering the house and at the same time provided insulation to the roof. This type of housing construction is commonly found in rural areas. The roof loads are directly supported by the walls, whose loads are supported by the wall foundations. Walls are provided with wooden posts at the corners. The door and windows opening of mud wall construction building are very small. The doors are typically of size 1.75m x 0.75m. Both gravity and lateral loads are resisted by mud walls. The building material for walls is mud and roof material is khapra. The structure of external wall of mud Wall is made by 2.5 cm internal mud plaster, 36 cm mud brick thick and 2.5 cm outer plaster without insulation. Mud house with pitch roof structure building as shown on fig.1.

In red brick construction, for minimize the heat loss, the insulation can be placed to inside surface, outside surface or between the wall. In this study, the insulation is placed on the outside surface of the wall.The structure of external wall of red brick construction is made by 3 cm internal plaster, 18 cm red brick, optimum insulation thickness of insulation material and 3 cm external plaster. In this study, the calculation were carried out for a two different types of walls, brick wall construction and mud wall construction. The surfaces of the brick wall are insulated on the external side and plaster on both sides.

The construction specifications, which are used for various components of the adobe house, are given in Table 1. The exterior plastering of the building is made by mud mortar with conventional cow dung and sand. External surface of the building is also treated with spray of a hydrophobizing agent, which reduces
the surface tension, and not allows water to stay on plaster.

Table 1
Specifications for various components of the building

Component of the Mud House	Specification
Foundation	Soil with less clay contents, Smaller piece of red brick, Binding material like rice husk.
Walls	Mud, Sand, Clay, water, Binding material such as rice husks or straw
Roof	Straw Bale, Khapra, Skeleton framework of wood, Bamboo
Exterior Finish	Mud-cow dung motar
Interior Finish	White Wash

The percentage distribution of the different materials used in construction of Mud House(Fig. 2) is 83.05% (Soil with clay), 8.15% (Cow dung) , 4.15% (Wood or Bamboo), 3.2 % (Straw Bale), 0.95 % (White wash)and 0.5% (Hydrophobizing agent).

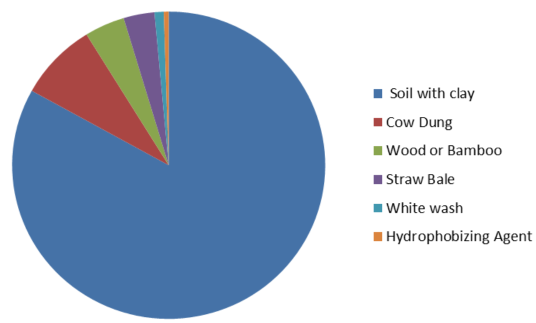

Fig. 2 percentage distribution of the different materials used in construction of Mud House

Mathematical Models For Annual Fuel Consumption

Heat gain from buildings occurs through surface of external wall, window, roof, human occupants, lighting load, infiltration, doors and heat loss occurs from ventilation. In the climatic zones of Ghaziabad, the cooling period is larger than the heating period. Cooling is required for eight months. In rest of the four months, heating is required. During the summer, cross ventilation is good option for cooling of the house.
The general energy balance equations for room air can be written as follow,

$$M_a C_a \frac{dT_r}{dt} = \sum Q_{gain} - Q_{loss} \tag{1}$$

M_a is isothermal mass , C_a is specific heat of air , T_r is room temperature , t is time, Q_{gain} is rate of thermal energy gained by air , Q_{loss} is rate of thermal energy lost by air .

$$Q_{gain} = Q_{wall} + Q_{roof} + Q_{window} + Q_{door} + Q_{floor} + Q_{human_{occupants}} + Q_{lighting_{load}} + Q_{\inf iltration}$$

$$Q_{loss} = Q_{ventilation} \tag{2}$$

Q_{wall} is rate of thermal energy gained by air through wall , Q_{roof} is rate of thermal energy gained by air through roof , Q_{window} is rate of thermal energy gained by air through window, Q_{door} is rate of thermal energy gained by air through door, Q_{floor} is rate of thermal energy gained by air through floor, $Q_{human\ occupant}$ israte of thermal energy gained by air through human occupant, $Q_{infiltration}$ is rate of thermal energy gained by air through infilitration and $Q_{ventilation}$ is the rate of thermal energy losses by ventilation.

 ISSN: 2277-9655
Impact Factor: 1.852

Total heat accumulated inside the room=

$$Q_{gain} - Q_{loss} = Q_{NE} + Q_{SE} + Q_{NW} + Q_{SW} + Q_{W} + Q_{W-Solar} + Q_{Roof} + Q_{L} + Q_{0} + Q_{F} + Q_{Inf} + Q_{Door} + Q_{Window} + I_{Roof} + I_{Wall} + Q_{Ground} - Q_{Ventilation} \quad (3)$$

Optimization of Insulation Thickness and Energy Saving

Heat loss occurs from each wall, roof and building envelope because of temperature difference between indoors and atmosphere. The heat loss occurs in a unit of the surface of external wall is calculated by

$$Q_L = U \times (T_r - T_a) \quad (4)$$

Where U is the heat transfer coefficient, T_r is the room temperature and T_a is the atmospheric temperature.
The overall heat transfer coefficient (U) for a wall is given by

$$U = \frac{1}{R_i + R_w + R_{Ins} + R_O} \quad (5)$$

Where R_i and R_O are the inside and outside air film thermal resistance respectively. R_w is thermal resistance of the wall without insulation and R_{Ins} is the thermal resistance of the insulation layer.

$$R_{Ins} = \frac{x}{K} \quad (6)$$

Where x is the thickness and K is the thermal conductivity of the insulation material.
Energy cost for heating per unit area is

$$C_{AH} = Q_L \cdot \left(\frac{C_F}{H_u.\eta_s}\right) = U \times (T_r - T_a) \times \left(\frac{C_F}{H_u \eta_s}\right) = \frac{1}{\left(R_w + \frac{x}{K}\right)} \times (T_r - T_a) \times \left(\frac{C_F}{H_u \eta_s}\right) \quad (7)$$

Similarly for cooling load(C_{AC})

$$C_{AC} = \left(\frac{C_E}{COP}\right) \times Q_g = \frac{1}{\left(R_W + \frac{x}{K}\right)} \times (T_a - T_r) \times \left(\frac{C_E}{COP}\right) \quad (8)$$

Where Q_g is the total heat gain, COP is the coefficient of performance of cooling system, C_E is the cost of electricity, C_F is the cost of fuel, H_u is lower heating value of the fuel, η_s is the efficiency of heating system and Q_L is the total heat loss per unit area.
The total cost of energy is

$$C_A = C_{AH} + C_{AC} \quad (9)$$

The total cost is the sum of cost of insulation material and present worth of the cost of energy consumption over the lifetime of the building.

$$C_t = PWF\left[\frac{C_F}{H_u.\eta_s} + \frac{C_E}{COP}\right] \times \frac{T_a - T_r}{R_W + \frac{x}{K}} + C_i \times x \quad (10)$$

Where C_i is the cost of insulation material per unit volume, x is the insulation thickness and PWF are the present worth factor depending upon the inflation rate g and interest rate i. PWF for the life time of N years

ISSN: 2277-9655
Impact Factor: 1.852

$$PWF = \frac{(1+r)^N - 1}{r(1+r)^N},$$
$$i > g, r = \frac{i-g}{1+g}, \tag{11}$$
$$i < g, r = \frac{g-i}{1+i}$$
$$PWF = \frac{1}{1+r}, i = g$$

The optimum insulation thickness is obtained by minimizing the total heating cost and cooling cost. Hence the derivative of C_t with respect to x is taken as zero for finding the optimum thickness. The expression of optimum insulation thickness x_{opt}

$$X_{opt} = \left[\frac{K \times PWF}{C_i} \left(\frac{C_F}{H_u.\eta_s} + \frac{C_E}{COP} \right) \times (T_a - T_r) \right]^{0.5} - KR_W \tag{12}$$

Pay-back period (pp) is calculated by solving the equation

$$\frac{C_{Ins}}{A_s} = \frac{(1+r)^{pp} - 1}{r(1+r)^{pp}} \tag{13}$$

Where C_{Ins}/A_s is the simple pay-back period. Energy saving obtained during the life time of insulation material can be calculated as follow

$$E_S = C_t - C_{Ins} \tag{14}$$

Optimum Insulation Thickness and Energy Saving

Optimum insulation thickness can be defined as the thickness of insulation for which the cost of added increment of insulation is just balanced by increased energy saving over the life of the project. Insulation application is one of the most important methods to conserve energy in buildings. So choosing the appropriate insulation material and determining the optimum insulation thickness is very important for energy saving. The optimum thickness of two insulation materials (Expanded polystyrene and Mud-Cow dung slurry)) are calculated for two types of building construction. The optimum insulation thickness for various wall structures is given in table 2. Optimum insulation thickness between 0.0402 and 0.0618 m for different wall structures , depending on Insulation materials.

Table 2: Optimum insulation thickness for various walls structures

Wall Type	Resistance (m^2K/W)	Optimum insulation thickness (m)	
		EPS	Mud-Dung Slurry
Wall Type I (Mud Wall Construction)	1.2912		0.0402
Wall Type II (Brick Wall Construction)	0.6767	0.0618	

Energy saving for different types of wall construction and for different types of insulating material are shown in table 3.

Table 3: Energy Saving for different type of walls construction in India

Wall Type	Surface Area(m^2)	Cost of Energy required without insulation	Cost of Energy required with insulation	Energy Saving (Rs/m^2)		% Energy Saving
				EPS	Mud-Dung Slurry	
Wall Type I (Mud Wall Construction)	70	83502	12513		1125	85
Wall Type II (Brick Wall Construction)	111.65	181440	145152	325		20

Some typical wall structures for building in India and their thermal properties are shown in table 4.

Table 4: Wall structure and thermal characteristic of materials

Wall Type	Thickness (cm)	Thermal Conductivity (w/m k)	Resistance (m^2K/W)
Wall Type I			
Mud-Dung Plaster Mud Brick Mud-Dung Plaster	2.5 36 2.5	0.15 0.482 0.15	1.2912
Wall Type II			
Inner Plaster Brick Outer Plaster	3 18 3	0.698 0.465 0.872	0.6767

The optimum insulation thicknesses for the various wall types specified in table 2 were calculated by using the values of the parameter are shown in table 5.

Table 5: Parameters used in the calculation of insulation- thickness

Parameter	Value
Degree day, °c days **Interest Rate** **Inflation Rate** **PWF**	2998,Ghaziabad(28.67°N 77.42°E), India 4% 5% 7.662
Mud-Dung Slurry	
Cost **Conductivity**	500 Rs/m^3 0.15 w/m k
Insulation-Expended Polystyrene(EPS)	
Cost **Conductivity**	9421 Rs/m^3 0.036 w/m k

Fuel Type	Fuel Oil	LPG	Coal	Natural Gas
Cost (Rs/m^3)	30	70	18	26
Heating Value (J/m^3)	40.59x10^6	46.04x10^6	29.29x10^6	34.53x10^6
System Efficiency (%)	80	90	65	90

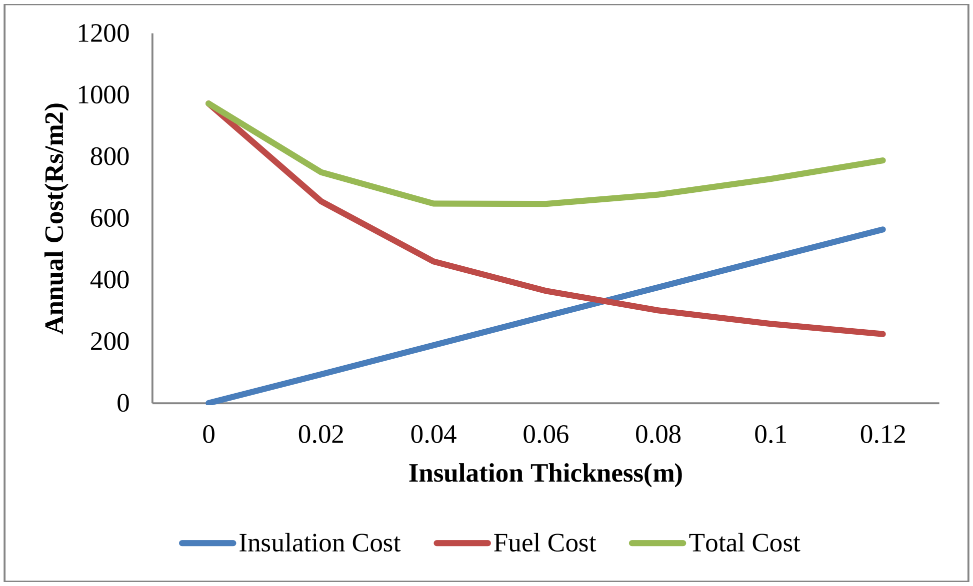

Fig.3 Variation of total cost with insulation thickness for Mud-Dung Slurry insulation for wall constructed of Mud

Fig. 3 shows the effect of insulation thickness on the total annual cost over lifetime of a Mud wall construction in Ghaziabad (28.67°N 77.42°E) , India. Insulation cost increases linearly with insulation thickness. On the other hand, energy cost as well as heat load decreases with increase of insulation thickness. Total cost of heating is the sum of fuel cost and insulation cost. There is a point above which the saving in total cost will not compensate for the extra cost of insulation material. So there must be an optimum insulation thickness at which the total cost is minimum. The Graph show that optimum insulation thickness is 0.0402 m for Mud wall construction, when Mud-Dung Slurry is selected as the insulation material.

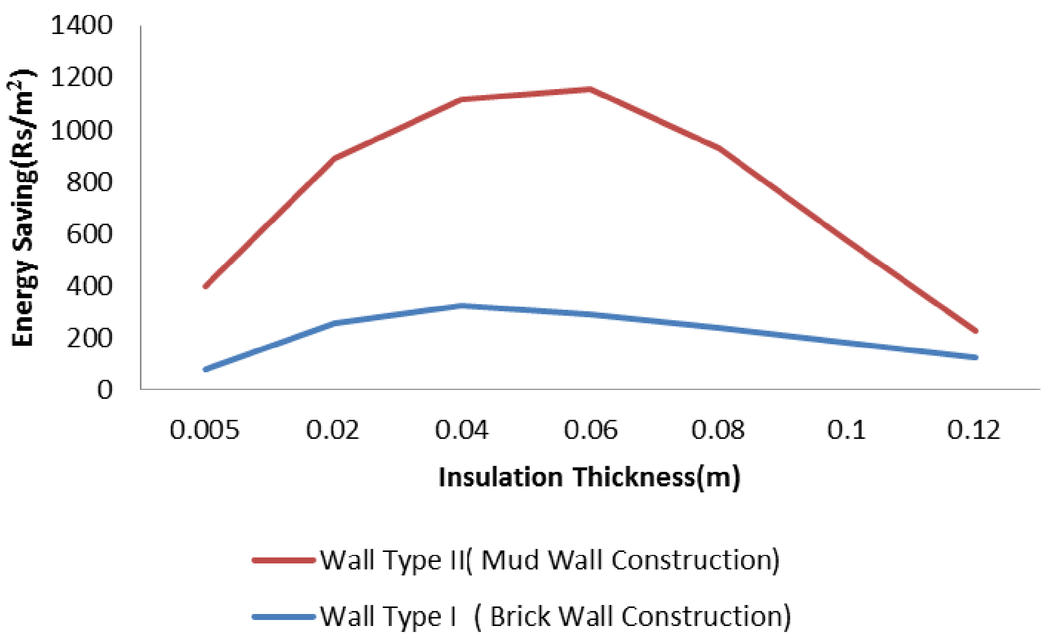

Fig. 4 Variation of energy saving versus insulation thickness for different types of wall and insulation material.

ISSN: 2277-9655
Impact Factor: 1.852

Fig. 4 shows effect of insulation thickness on energy saving for different wall for different insulation materials (EPS and Cow-Dung Slurry). The energy saving gets increased by increasing the insulation thickness up to optimum insulation thickness on building wall. And after that the energy saving decreased with increased insulation thickness. From Fig. 4, it is seen that higher energy saving are obtained for wall type II (Mud Wall Construction). According to energy saving point of view, when thermal insulation is used in wall type II (Mud Wall Construction) then more energy is saved as compared to Brick wall construction, Due to uniform temperature inside the boundary of Mud wall due to Thermal Mass.

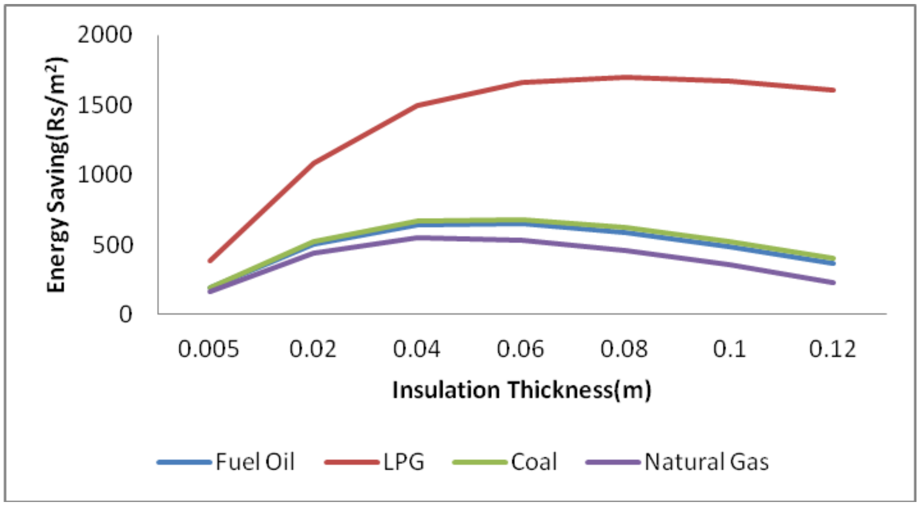

Fig. 5 Effect of insulation thickness on energy saving for different fuel type and Mud-Dung Slurry as an insulation material- wall type I (Mud Wall Construction)

Fig. 5 shows effect of insulation thickness on energy saving for four different energy sources for Mud Wall construction. From Fig. 5, it can be seen that as insulation thickness increases, energy saving increases and reaches its maximum value at optimum insulation thickness. And after that energy saving decreases. Lowest value of energy saving is obtained for natural gas . But highest value of energy saving is obtained for LPG for Mud Wall Construction. As shown in fig 5 , the application of insulation thickness increases the energy saving up to optimum insulation thickness. Energy saving is more important for the expensive fuel. We know that energy saving is proportional to cost of fuel and climatic condition. The highest energy saving is obtained as 1701 Rs/m^2 , when LPG is taken as fuel source.

Method for Selecting the most Economic Insulation Material

An approach of selecting the most economic insulation material, using $\mathbf{C_A}$ index which is calculated by multiplying the thermal conductivity (K_{ins}) with the insulation price per cubic meter (C_i) is developed. The lower the value of $\mathbf{C_A}$, the higher the economical efficiency of the insulation material.

Table. 6 C_A index for different insulating materials

Insulation Materials	Thermal Conductivity (w/mk)	Cost(Rs/m^3)	C_A
Rockwool	0.042	35805	1503
Expended Polystyrene	0.032	4200	134.4
Extruded polystyrene	0.029	15200	4408
Foamed polyurethane	0.033	4950	163.35
Polyvinyl chloride	0.048	7800	374.4
Glass wool	0.038	4250	161.5
Mud with cow dung slurry	0.15	500	75

Mud slurry is the most economic among the Six insulation materials.so it is used as a insulation material for mud wall construction. Expanded polystyrene is economic insulation material after mud slurry.

Conclusion

Choosing the appropriate insulation material and determining the optimum insulation thickness is very important for energy saving. The optimum thickness of two insulation materials (Expanded polystyrene and Mud-Cow dung slurry)) are calculated for two types of building construction. Optimum insulation thickness between 0.0402 and 0.0618 m for different wall structures, depending on Insulation materials.

From Fig. 4, it is seen that higher energy saving are obtained for wall type II (Mud Wall Construction). According to energy saving point of view, when thermal insulation is used in wall type II (Mud Wall Construction) then more energy is saved as compared to Brick wall construction, Due to uniform temperature inside the boundary of Mud wall due to Thermal Mass. the application of insulation thickness increases the energy saving up to optimum insulation thickness. Energy saving is more important for the expensive fuel. We know that energy saving is proportional to cost of fuel and climatic condition. The highest energy saving is obtained as 1701 Rs/m^2 , when LPG is taken as fuel source. It has found that energy saving for Mud Wall Construction is 85 %, when Mud- Slurry insulation is used.

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