# Energy Saving Analysis In Building Walls Through Thermal Insulation System

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## ABSTRACT

**In this study, we discuss about the energy saving in different type of building walls by using optimum insulation thickness with suitable insulation material. The energy saving is maintained by reducing the energy consumption in buildings. Heat losses from building envelope have a major share in waste of energy. So it is essential to save the energy by using optimum insulation thickness. The insulation thickness and energy savings are calculated by using Life-cycle cost analysis over life time of 10 years of the building. Using proper insulation in building is most effective way of energy saving in building walls. This paper provides an analysis for determining optimum insulation thickness for the different wall types; Brick, Concrete and Stone which are used in building construction in India. Extruded polystyrene (XPS) and Expanded polystyrene (EPS) are selected as insulation material. In this paper, heat load (loss of heat) is calculated by using Degree-Day method.**

**As a result; the optimum insulation thickness varies between 5.2 and 7.4 cm and energy saving varies between 2560 and 5510 Rs/m$^2$, depending on cost of fuel, climatic conditions of Dehradun(India), cost of insulation material and its thermal conductivity.**

**Keywords: Degree-Days, Energy saving, Heat losses, Life cycle cost method, Optimum insulation thickness, Present worth factor.**

## I. INTRODUCTION

The energy consumption is distributed among four main sector: industrial, building (residential/ commercial), transportation and agricultural areas. The building sector is the highest energy consumer area. Energy consumption rate is gradually increase due to urbanization, industrial growth and population growth. Population growth means contracting more buildings, which increases energy expenditure. The heat losses in buildings generally occur through external walls , ceiling, floor , windows and air infiltration. In this paper , we consider the heat losses through external walls only. Heating loads were calculated by degree-day method. Heat loss through the building envelope can be controlled in many different ways i.e. orientation, types of building and optimum insulation thickness.

Both excessive and deficient insulation is not desirable economically. For economical analysis, the value of optimum insulation thickness was calculated by life cycle cost analysis (LCCA). Insulation of the building is an important technology for energy saving. The optimum insulation thickness is that value at which the cost is minimum and it includes the cost of insulation material and cost of energy consumption over the life time of the building. The energy saving is maximum at optimum insulation thickness. Energy saving becomes more beneficial in that regions where costly fuel is used. The energy saving per unit wall area is defined as the difference between the energy need of un-insulated and insulated situations.

To fulfill the outline of the present paper, a literature review followed with scope of paper is given as follows. Turki and Zaki [1] investigated the effect of insulation and energy storing layers upon the cooling load. A mathematical model to study the thermal response of multilayer building components is presented. Bolatturk[2] calculated the optimum insulation thicknesses, energy savings and payback periods. The annual heating and cooling requirements of building in different climates zones were obtained by means of the heating degree-days concept. Durmayaz et al.[3]estimated the heating energy requirement in building based on degree-hours method on human comfort level. This paper considers the city of Istanbul in Turkey and presents a detailed account for practical energy requirements and fuel consumption calculations. Hasan[4]optimized the insulation thickness for wall by using the life cycle cost analysis. In his study, transmission load was estimated by using the degree-days concept. Generalized charts for selecting the optimum insulation thickness as a function of degree days and wall thermal resistance are prepared. Farhanieh and Sattari [5]studied the effects of insulation on the energy saving in Iranian building. For this purpose, an integrative modeling is used for simulation of the energy consumption in buildings. Bakos[6] evaluated the energy saving by comparing the energy consumption (in KWH) for space heating before and also after the application of thermal insulation in the structure envelope. A performance comparison like concerning cost and energy saving is studies. Weir and Muneer[7] studied embodied energy of raw materials, manufacturing and associated $CO_2$,$SO_2$ and $No_x$ contents have been estimated for a double- glazed, timber framed window containing an inert gas filled cavity. Sarak and Satman[8] determined the natural gas consumption by residential heating in Turkey by heating degree-day method. The authors also present a case study for the calculations of residential heating natural gas consumption in Turkey in terms of degree-days. Sofrata and Salmeen[9]developed a consistent and more general mathematical model for optimum insulation thickness. He also introduced a program flow chart to select the best insulation thickness. In this study, the life-cycle cost analysis (LCCA) is used to calculate the costs of heating over the life time Ozkahraman and Bolatturk [10]calculated the amount of energy conserved by using porous tuff stone in external walls of buildings. Due to porous structure, tuff stone is a good heat insulator. So considerable energy savings can be achieved by using tuff stone for facing buildings in cold climate zone**.** Mohammed and Khawaja[11]determined the optimum thickness of insulation for some insulating materials used in order to reduce the rate of heat flow to the buildings in hot countries. Important factor that effects the optimum thickness of insulation is the solar radiation energy flowing into the house. In this paper, a solar radiation calculation is done. Sallal[12] explored the effect of different climates on the decision of selecting the insulation type and thickness. It shows the importance of using the life-cycle cost model on the decision of adding more insulation levels and knowing when to stop. Comakli and Yuksel[13] investigated the optimum insulation thickness for the three coldest cities of Turkey by using the degree -days values. Their study was based on the life cycle cost analysis. Papakostas and kyriakis[14]determined the heating and cooling degree-hours for the two main cities in Greece, namely Athens and Thessaloniki ,using hourly dry bulb temperature. Lollint et al.[15]demonstrated the significant economic advantages come out from high-performance building envelope. In this paper, economic analysis and evaluation of the envelope components based on the optimization of the insulating materials thickness. Ozel and Pihtili[16] obtained the optimum location and distribution of insulation for all wall orientations in both summer and winter by consideration of maximum time lag and minimum decrement factor. The investigation was carried out by using an implicit finite difference method for multilayer walls during typical summer and winter days in Elazig, Turkey. Ozel and Pihtili[17]developed a numerical model based on implicit finite difference scheme was applied for 12 different roof configurations during typical winter and summer days. Mohsen and Akash[18] evaluated the energy conservation in residential buildings of Jordan. This paper is intended to provide some insights into the general state of energy consumption in the residential sector and its trends in Jordan. Daouas et al. [19]determined the optimum insulation thickness under steady periodic conditions. Estimated loads are used as inputs to a life-cycle cost analysis in order to determine the optimum thickness of the insulation layer. The optimum insulation thickness is calculated, based on the estimated cooling transmission loads. Sisman et al. [20] determined the optimum insulation thickness for different degree-days (DD) regions of Turkey (Izmir, Bursa, Eskisehir & Erzurum) for a lifetime of N years. In this study, the optimum insulation thickness for a given building envelope was determined by considering the thermal conductivity and price of the insulation material, average temperature in the region, fuel price for the heating and the present worth factor (PWF). Buyukalaca et al. [21] studied the heating and cooling degree-days for Turkey are determined by using long-term recent measured data. The monthly cooling and heating requirements of specific building in different locations can be estimated by means of the degree-days concept. Dombayci[22]investigated the environment impact of optimum insulation thickness. In the calculations, coal was used as the fuel source and the Expanded Polystyrene(EPS) as the insulation material. Al-Sanea et al.[23]investigated the effect of the average electricity tarrif on the optimum insulation thickness in building walls by using a dynamic heat-transfer model and an economic model based on the present-worth method. Mahlia et al. [24] developed correlation between thermal conductivity and the thickness of selected insulation materials for building wall. Lu et al.[25] developed a new analytical method, which provides close-formed solutions for both transient indoor and envelope temperature changes in building. Time-dependent boundary temperature is presented as Fourier Series.

## II. Building material and different external wall structure

In India, the external wall insulation applications are generally made by the sandwiches wall type. The structure of external wall is made by 2 cm internal plaster, different wall materials (Stone, Brick or Concrete), insulation material and 2 cm external plaster. In this analysis, the calculations were carried out for a three different types of walls, which have been constructed with stone (10 cm), brick (10 cm) and concrete (10 cm). The surfaces of the walls are insulated on the external side and plastered on both sides as shown in fig.1.

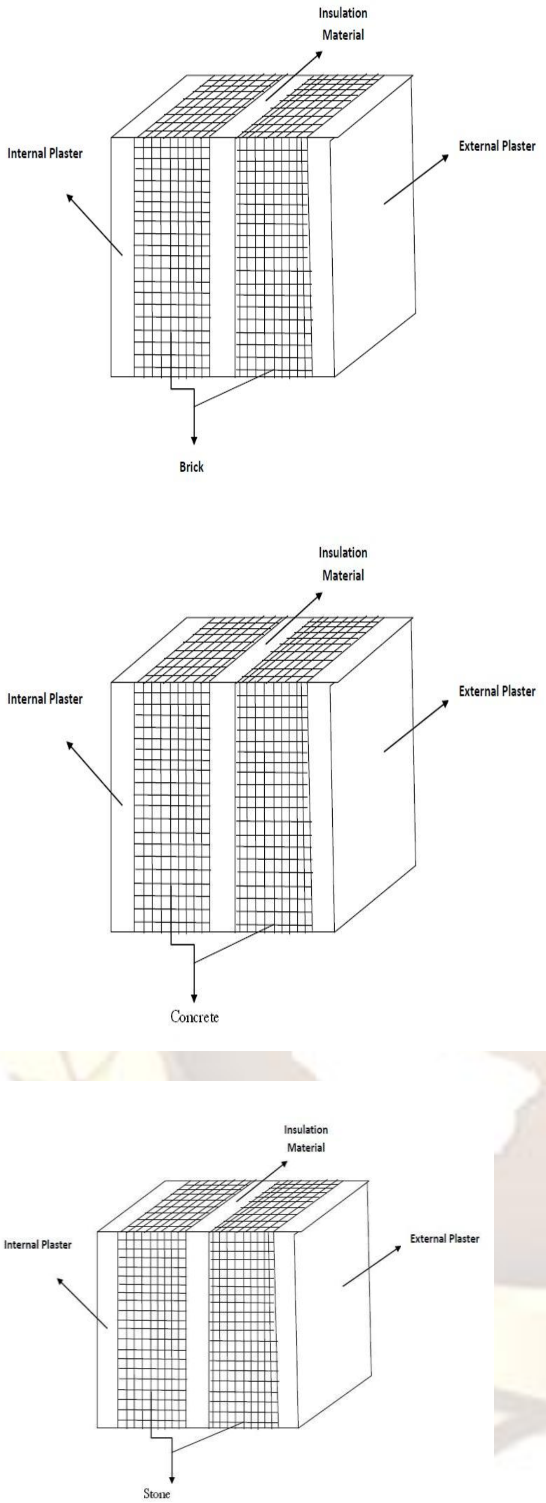


Fig.1. Different external walls structure

### 2.1 Mathematical models for annual fuel consumptions

Heat loss from buildings occurs through surface of external wall, window, ceiling and air infiltration. In this analysis, heating loss is observed only on the external wall surface.

The heat loss per unit area of external wall is$Q=U(T_b–T_a)$ (1)
Where U is the overall heat transfer coefficient. $T_b$ is the base temperature and $T_a$ is mean air temperature.
Annual heating loss per unit area from external wall in the terms of degree-days is
$Q_A=86400DDU$ (2)
Where DD is the Degree- Days. The annual energy requirement is given by
$E_A=86400DD/(R_{tw}+x/k)\eta_s$ (3)
Where $\eta_s$ is the efficiency of space heating system.
And the annual fuel consumptions is
$M_{fa}=86400DD/(R_{tw}+x/k)LHV.\eta_s$ (4)
Where LHV is lower heating value of fuel.

### 2.2 Optimization of insulation thickness and energy saving

The life-cycle cost analysis (LCCA) is used in this analysis. It determines the cost analysis of a system. The total cost of heating over the life time of the insulation material which was taken as 10 years. Total heating cost is indicated together with life cycle (N) and presents worth factor (PWF). PWF can be calculated by using inflation rate g and interest rate i. Inflation and the interest rate are taken as 10 % and 8 % respectively.
The interest rate adapted for inflation rate r is given by
If i>g then,
$r = ( i – g )/ ( 1+ g )$
If i <g then,
$r = ( g – i )/ (1+ i)$
and
$PWF = (1 + r )^N – 1 / r (1 + r )^N$
If i = g then,
$PWF=N/(1+i)$ (5)
The total heating cost of the insulated building is
$C_t = C_A PWF + C_i x$ (6)
The optimum insulation thickness is obtained by minimizing total heating cost of insulation building ($C_t$). So the derivative of $C_t$ with respect to x is taken and equal to zero from which the optimum insulation thickness $X_{opt}$ obtained.
$X_{opt} = 293.94(DD C_t PWF K / H_U. C_i \eta_s)^{0.5} – K R_{tw}$
(7)
Energy saving obtained during the lifetime of insulation material can be calculated as follow:
$E_s = C_{to} - C_{ins}$ (8)

## III. RESULTS AND DISCUSSION

The optimum insulation thickness for three different types of wall is calculated, when Extruded polystyrene (XPS) and Expanded polystyrene (EPS) is selected as insulating materials. For energy saving, it is essential to select the proper insulating material and optimum insulation thickness value for different types of wall. As we know that energy saving is maximum at the optimum insulation thickness value. The optimum insulation thickness for various wall types according to insulation material is given in table 1. Optimum insulation thickness varies between 0.068 m and 0.074 m for Expended polystyrene (EPS) and optimum thickness varies between 0.052 m and .057 m for Extruded polystyrene(XPS), depending on the fuel and wall type.

Table 1 Optimum insulation thickness for various walls structures

| Wall Type | Resistance ($m^2K/W$) | Optimum insulation thickness (m) | |
|---|---|---|---|
| | | XPS | EPS |
| Wall Type I (Brick) | 0.4789 | 0.052 | 0.068 |
| Wall Type II (Concrete) | 0.3213 | 0.057 | 0.073 |
| Wall Type III (Stone) | 0.2998 | 0.057 | 0.074 |

The value of optimum insulation thickness for wall types II (concrete) and wall type III (stone) are almost same. Since cost of concrete wall is less than stone wall. So concrete wall is selected for wall construction in India. Energy saving for different types of wall construction and for different types of insulating material are shown in table 2.

Table 2

Energy saving for different type of walls construction in India

| Wall Type | Energy Saving (Rs/$m^2$) | |
|---|---|---|
| | XPS | EPS |
| Wall I (Brick) | 2560.099 | 2947.976 |
| Wall II (Concrete) | 4627.48 | 5046.47 |
| Wall III (Stone) | 5084.03 | 5510.55 |

Some typical wall structures for building in India and their thermal properties are shown in table 3.

Table 3

Wall structure and thermal characteristic of materials

| Wall Type | Thickness(cm) | Thermal Conductivity (w/m k) | Resistance ($m^2K/W$) |
|---|---|---|---|
| Wall I<br>Inner Plaster<br>Brick<br>Outer Plaster | 2<br>10<br>2 | 0.698<br>0.465<br>0.872 | 0.4789 |
| Wall II<br>Inner Plaster<br>Concrete<br>Outer Plaster | 2<br>10<br>2 | 0.698<br>1.74<br>0.872 | 0.3213 |
| Wall III<br>Inner Plaster<br>Stone | 2<br>10 | 0.698<br>1.7 | 0.2998 |

The optimum insulation thicknesses for the various wall types specified in table 1 were calculated by using equation (7) and the values of the parameter are shown in table 4.

Table 4

Parameters used in the calculation of insulation-thickness

| Parameter | Value |
|---|---|
| Degree day, °c days | 3587, Dehradun |
| Fuel | Natural Gas |
| Cost | 23.97 Rs/$m^3$ |
| Heating Value | 34.526x106 j/$m^3$ |
| System Efficiency | 0.93 |
| Interest Rate | 8% |
| Inflation Rate | 10% |
| PWF | 9.05 |
| Insulation | |
| Extruded Polystyrene (XPS) | |
| Cost | 15211.5 Rs/$m^3$ |
| Conductivity | 0.033 w/m k |
| Expended Polystyrene(EPS) | |
| Cost | 9421 Rs/$m^3$ |
| Conductivity | 0.031 w/m k |

Fig. 2 shows the annual heat loss with respect to insulation thickness for different types of wall when EPS is selected as insulating material. Initially much heat loss will occur with increase of insulation thickness. Further increase of insulation thickness less heat loss will occur. For energy saving, less heat loss will be required. So less insulation thickness is not prefers due to much heat loss From fig. 2 , it can be concluded that the heat loss is gradually decrease with increase of insulation thickness.

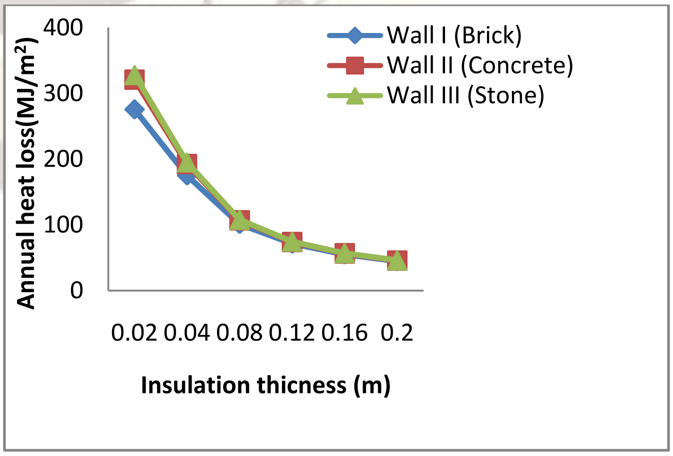


Fig. 2 Annual heat loss vs Insulation thickness for different types of wall-EPS insulating materials.

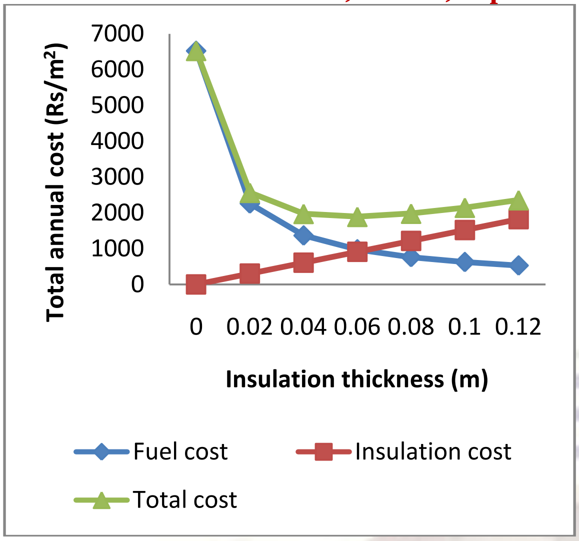


Fig-3(a) Variation of total annual cost with insulation thickness for XPS insulation-wall II concrete.

Fig. 3(a and b) shows variation of total annual cost with insulation for Extruded polystyrene (XPS) and Expended polystyrene(EPS) insulation material in the case of wall type II(concrete). Total cost of heating consists of two cost parameter, one is fuel cost and other is insulations cost. We all knows that heat loss through building walls will be decrease with increase of insulation thickness. But more money will invest, when more insulation thickness will used. So there is a thickness value at which the total cost is minimum. At this thickness, increase in insulation cost is compensated by decrease in fuel cost. At optimum insulation thickness, energy saving is maximum and total cost is minimum. The results show that optimum insulation thickness is 0.057 m for XPS while it is 0.073 m for EPS , when wall type II (concrete) will consider.

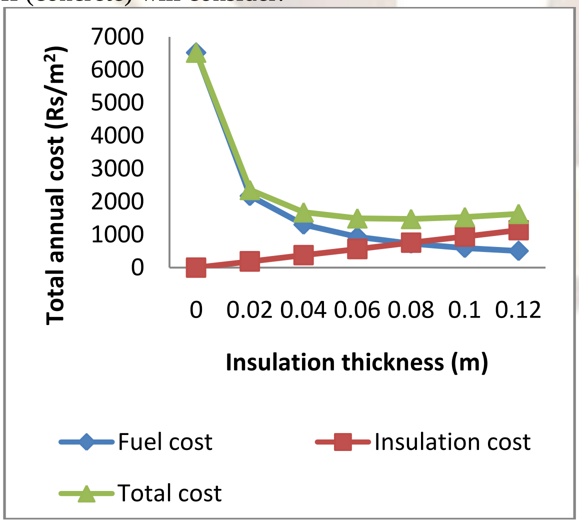


Fig-3(b) Variation of total annual cost with insulation thickness for EPS insulation-wall II concrete .

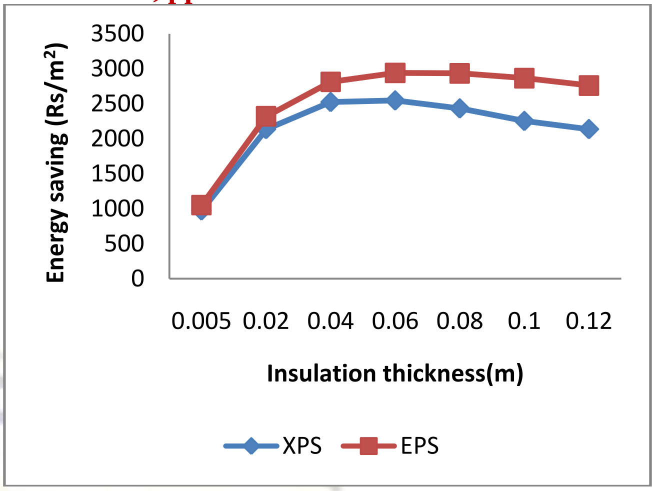


Fig. 4(a) Variation of energy saving vs insulation thickness for different insulation materials (XPS and EPS)- wall I Brick.

Fig. 4(a, b and c) shows variation of energy saving with insulation thickness for different type of walls when XPS and EPS is selected as insulating materials. From fig. 4(a, b and c), it can be concluded that for any types of walls, EPS insulation is more efficient with respect to XPS insulation material. For EPS insulation material, energy saving is more as compare to XPS insulation material. From fig. 4 , it can be concluded that at optimum insulation thickness the energy saving is maximum.

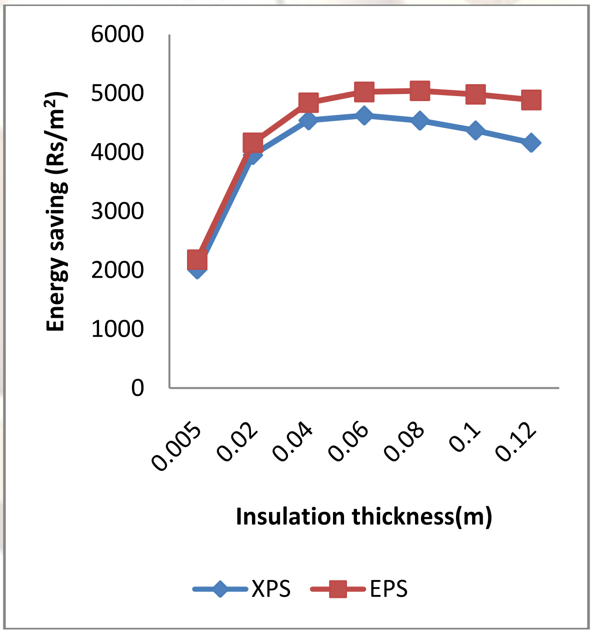


Fig. 4(b) Variation of energy saving vs insulation thickness for different insulation materials (XPS and EPS)- wall II Concrete.

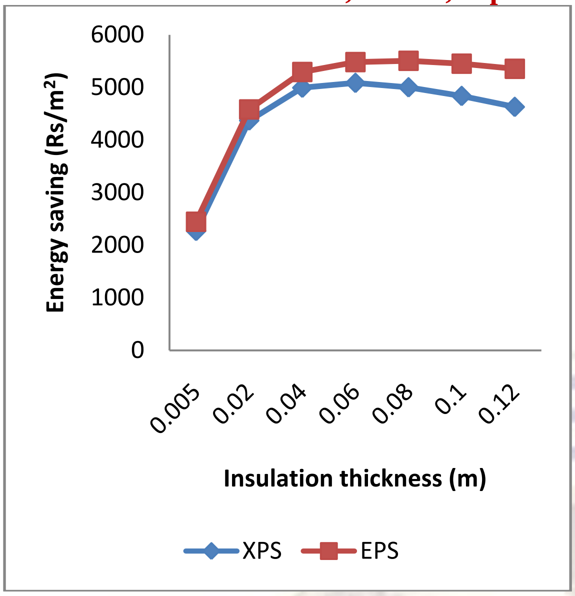


Fig. 4(c) Variation of energy saving vs insulation thickness for different insulation materials (XPS and EPS)- wall III Stone.

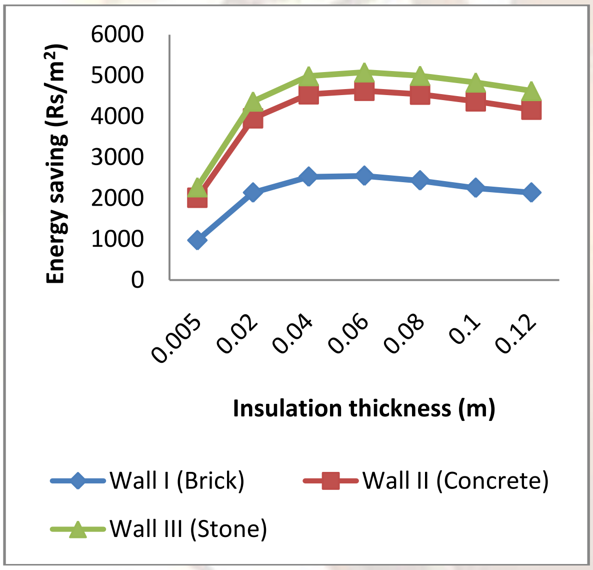


Fig 5 (a) Variation of energy saving vs insulation thickness for different types of walls-XPS insulation material.

Fig. 5(a and b) shows effect of insulation on energy saving for different wall types for two different insulation materials (XPS and EPS). As insulation thickness increases, energy saving gradually increases and it reaches to maximum value at optimum insulation thickness. And after that the energy saving decreased with increasing insulation thickness. On the basis of result analysis from fig. 5(b), it can be seen that wall type III (stone) is better as compared to other types of wall, according to energy saving point of view. Energy saving from lowest to the highest will be brick wall, concrete wall and stone wall respectively.

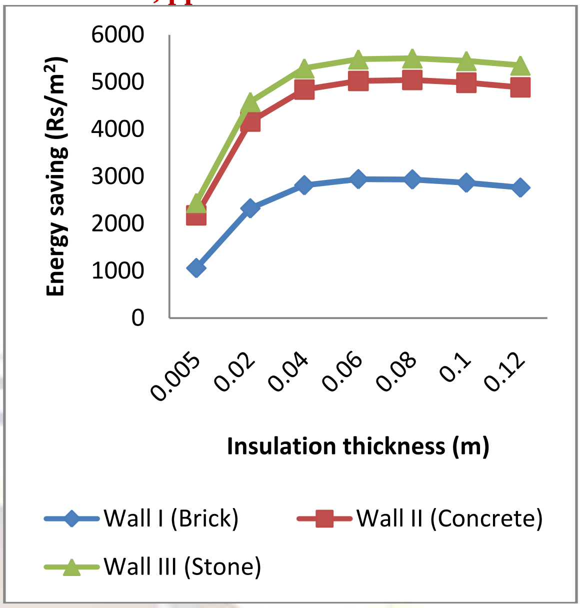


Fig 5 (b) Variation of energy saving vs insulation thickness for different types of walls-EPS insulation material.

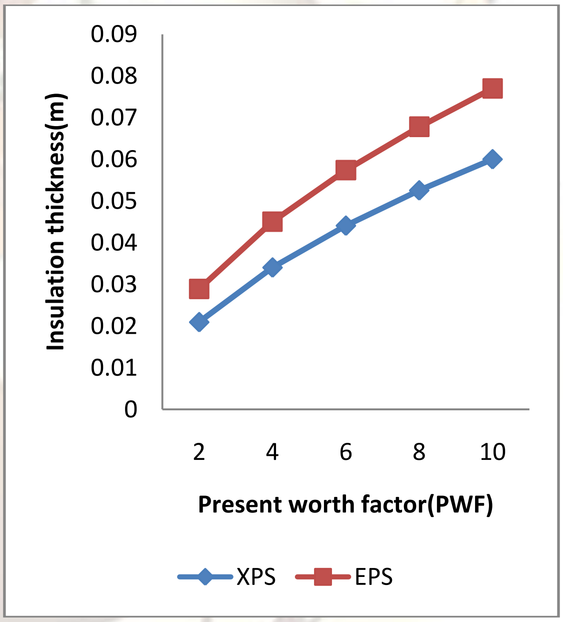


Fig. 6 Effects of present work factor on insulation thickness for different insulation materials(XPS and EPS)-wall II concrete.

Fig. 6 represents the effects of present worth factor(PWF) on insulation thickness when XPS and EPS is selected as insulating material for wall types II(concrete). When the value of PWF is increased, then insulation thickness is also increased. It means that inflation and interest rate has also effect on insulation thickness. From fig. 6 , it can be concluded that for a given value of PWF, building will be insulated with EPS requires more insulation thickness. XPS insulation requires less insulation thickness as compare to EPS insulation for a given value of PWF. Therefore it can be concluded that XPS insulation is more effective as compared to EPS insulation.

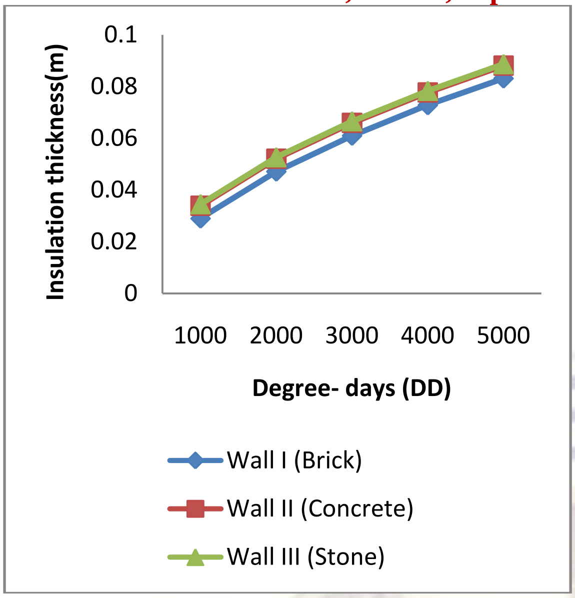


Fig. 7 Effects of degree-days on insulation thickness for different walls when EPS is selected as insulation materials

Fig. 7 shows the effect of degree-days on optimum insulation thickness for different wall types when EPS is selected as insulation material. At a given values of degree-days, walls having lower thermal resistance (wall type-III stone) require more insulation thickness. Wall type III (stone) has lower thermal resistance, so it require more insulation thickness as compared to other type of walls. Applying insulation thickness in climatic conditions having higher degree-days(DD) for heating would be more advantageous. From fig. 7, it can be concluded that when the degree-days value increases then thickness of insulation is also increased.

## IV. CONCLUSION

In this paper, the optimum insulation thickness and annual energy saving are calculated for three different types of external walls, for two types of insulation material and natural gas as a fuel in India. It is seen from fig. (4) that the energy saving rate is higher for expanded polystyrene(EPS) insulation material as compared to Extruded polystyrene(XPS) in any type of external walls. As seen from fig. 3(a and b), choosing a thickness value apart from optimum thickness will increase the total cost. So according to economic point of view, optimum insulation thickness must be applied to the building. Optimum insulation thickness increased with increasing the Degree- Days(DD) values and inflation rate, which is related with present worth factor(PWF). Results show that optimum insulation thickness varies between 5.2 cm and 7.4 cm and energy saving in the term of money varies between 2560 Rs/m$^2$ and 5510 Rs/m$^2$ depending upon climatic condition, types of wall, insulation thickness and cost of fuel.

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