# Optimum Insulation Thickness Of The External Walls And Roof For Different Degree-Days Region

Subhash Mishra
*Ph.D Scholar*,
*Mechanical Engineering Department,*
*Jamia Millia Islamia,*
*New Delhi, India,*
(Corresponding Author)

Dr. J .A .Usmani
*Mechanical Engineering Department,*
*Jamia Millia Islamia,*
*New Delhi, India,*

Sanjeev Varshney
*Mechanical Engineering Department,*
*Inderprastha Engineering College,*
*Ghaziabad (U.P.), India,*

## Abstract

*In this paper, the optimum insulation thickness of thermal insulation used to reduce the heat loss through external walls and Roof is investigated. In general, loss of heat in building occurs through external walls, window, ceiling(Roof) and air infiltration. But in this analysis, heat loss through external walls and Roof has been considered. The annual heating and cooling load requirement can be obtained by Degree-Days (DD) method. Fuel consumption costs are reduced by increasing the thickness of external walls and Roof, despite an increase in the investment costs. The Optimum insulation thickness, Energy saving and Payback period are calculated by using Life cycle cost analysis(LCCA) over 10 years of the building life for four different climatic regions. In this analysis, two different insulation (Glass wool and Expended Polystyrene) and LPG as a heating source are selected. A systematic approach for optimization of insulation material thickness for External walls and Roof is developed for different DD regions of India, Imphal(DD:2372),Gwailor(DD:3902),Dehradun(DD : 2614) and Thiruvanthapuram(DD: 4507).*

*As a result, the Optimum insulation thickness varies between 14.46 cm and 20.77 cm, the annual energy saving varies between 500.03 Rs/m$^2$ and 1014.27 Rs/m$^2$ and Payback periods varies between 0.87 and 1.2374 years for External walls depending on climatic condition, Fuel cost and type of insulation.*

**Keywords** : Degree-Days Region; Energy Saving; Life Cycle Cost Analysis; Optimum Insulation Thickness; Payback Period.

## 1. Introduction

The present paper aim is to investigate the Energy saving through External walls and Roof for four different Degree-Days regions by the application of insulation. As we know that the rate of energy consumption increased due to population growth and urbanization. But there is a limited energy sources. Mainly , the energy consumption is distributed among Industrial sector, Building sector, Transportation and Agricultural areas. The Building sector is major energy consumption area. The energy saving is maintained by reducing the energy consumption in building. Heat loss in building takes place through External envelopes. There is some method to reduce heat loss. Thermal insulation is one of the best methods to reduce the heat loss. Building insulation will reduce the heating cost in the terms of initial investment. The life cycle cost analysis (LCCA) is used to calculate the optimum insulation thickness. Heating loads were calculated by Degree-Days method. The number of degree-Days is the difference between the base temperature and mean ambient temperature. This paper demonstrated an analysis for determining Optimal insulation thickness for External walls and Roof of the buildings in India. Increasing insulation thickness will not only increase energy saving but also decrease pollution . Energy saving will gradually increase upto optimal thickness and beyond that energy saving will decrease. It mean insulation thickness is more beneficial at Optimum insulation thickness.

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.

## 2. Design of External walls and Roof structure

Brick and varieties of concrete ( light weight and reinforced) are the common material used for the construction of external walls. For minimize the heat loss the insulation can be placed to the inside, to the outside or in between (sandwich wall). In this analysis the insulation is placed to the outside. In cold region of India, the external walls insulation applications are generally made by the sandwiches wall types. The structure of external walls is made by 3 cm internal plaster, wall materials (Brick), insulation material and 2 cm external plaster. In this paper, the calculations were carried out for a outer insulation types of walls, which have been constructed with Brick (20 cm) . The surfaces of the wall are insulated on the external side and plastered on both sides are as shown in Fig. 1

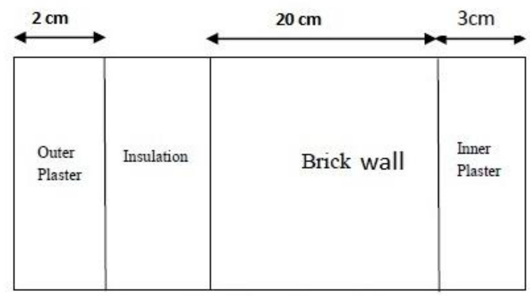


Fig. 1: Cross Sectional View of External Wall

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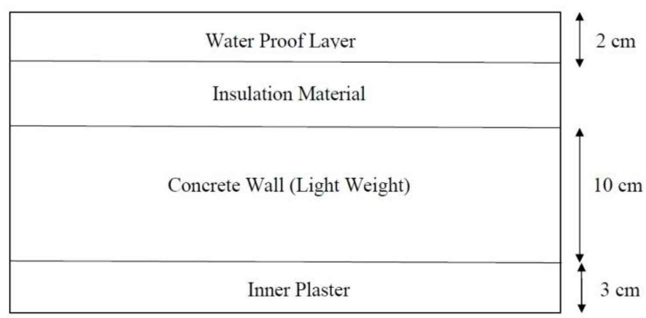


Fig. 2: Cross Sectional view of Roof

Roof structure is shown in Fig 2. The structure of Roof is made by 3 cm inner plaster, Roof material

(Concrete- 15 cm),insulation material and 2 cm water proof layer.

### 2.1 Annual fuel consumption calculation for External walls and Roof

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

The heat loss per unit area of external walls and Roof is given by,

$$Q = U\,(T_b - T_a) \qquad (1)$$

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 walls and Roof in the terms of Degree-days is given by,

$$Q_A = 86400\ DD\ U \qquad (2)$$

Where DD is the Degree- Days. The annual energy requirement is given by,

$$E_A = 86400\ DD / (R_{tw} + x/k)\ \eta_s \qquad (3)$$

Where $\eta_s$ is the efficiency of space heating system.

And the annual fuel consumptions is

$$M_{fa} = 86400\ DD / (R_{tw} + x/k)\ LHV.\ \eta_s \qquad (4)$$

Where LHV is lower heating value of fuel.

### 2.2 Energy saving and Optimum insulation thickness

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 8 % and 10 % 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,

$$PWF = N / (1 + i) \qquad (5)$$

The total heating cost of the insulated building is

$$C_t = C_A\ PWF + C_i\ x \qquad (6)$$

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.

$$X_{opt} = 293.94(DD\ C_t\ PWF\ K / H_U.\ C_i\ \eta_s)^{0.5} - K\ R_{tw} \qquad (7)$$

Pay-Back Period(PP) is calculated by solving the equation (8)

$$C_{ins}/ A_s = (1 + r^{)PP} - 1 / \ r(1 + r)^{PP} \qquad (8)$$

Where $C_{ins}/ A_s$ is the simple Pay-Back Period. Energy saving obtained during the lifetime of insulation material can be calculated as follow:

$$E_s = C_{to} - C_{ins} \qquad (9)$$

## 3. Results

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 insulation thickness of External walls and Roof for different Degree-Days region is calculated with outside insulated wall types building. The optimum insulation thicknesses for different regions specified in table 2. and 3. were calculated by using equation (7) and the values of the parameter are shown in table 1.

**Table 1.Parameters used in the calculation of insulation- thickness**

| Parameter | Value |
|---|---|
| Resistance of Wall | 0.5858 $m^2k/w$ |
| Resistance of Roof | 0.4105 $m^2k/w$ |
| Interest Rate | 10% |
| Inflation Rate | 8% |
| PWF | 9.05 |
| Insulation -Glass wool(GW) | |
| Cost | 4279 $Rs/m^3$ |
| Conductivity | 0.038 w/m k |
| Insulation-Expended Polystyrene(EPS) | |
| Cost | 9421 $Rs/m^3$ |
| Conductivity | 0.032 w/m k |
| Fuel Type | LPG |
| Cost | 70Rs/kg |
| Heating Value | $46.04x10^6$ J/kg |
| System Efficiency (%) | 90 |

**Table 2.Optimum insulation thickness, Annual saving and Payback period for different Degree-Days region-External Walls**

| Regions | Optimum Insulation Thickness (m) | Annual Saving ($Rs/m^2$-year) | Payback Period (year) |
|---|---|---|---|
| 1-Imphal | 0.1446 | 500.03 | 1.2374 |
| 2-Gwailor | 0.1917 | 871.08 | 0.94 |
| 3-Dehradun | 0.1529 | 568.54 | 1.15 |
| 4-Thiruvan thapuram | 0.2077 | 1014.27 | 0.87 |

**Table 3. Optimum insulation thickness, Annual saving and Payback period for different Degree-Days region-Roof**

| Regions | Optimum Insulation Thickness(m) | Annual Saving ($Rs/m^2$-year) | Payback Period (year) |
|---|---|---|---|
| 1-Imphal | 0.1512 | 764.52 | 0.846 |
| 2-Gwailor | 0.1983 | 1286.25 | 0.6596 |
| 3-Dehradun | 0.1595 | 846.60 | 0.8061 |
| 4-Thiruvan thapuram | 0.2143 | 1493.802 | 0.61386 |

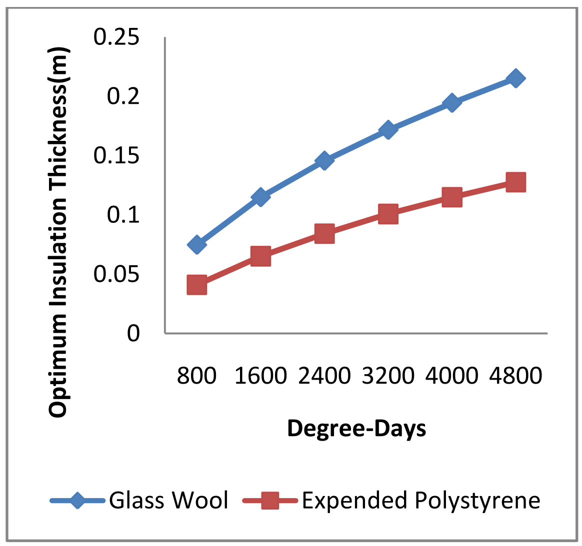


**Figure 3. Variation of optimum insulation thickness of External walls with Degree-Days value**

Fig.3 shows the effect of Degree-Days on optimum insulation thickness for external walls when LPG is selected as heating sources. At a given values of Degree-Days, insulation having lower thermal conductivity requires less insulation thickness. Expended Polystyrene has lower thermal conductivity, so it requires less insulation layer. From Fig. 3 , it can seen that when Degree-Days value increases, the insulation thickness is also increases. Applying insulation in higher Degree-Days region for heating would be more advantageous. From Fig. 3, it can seen that the Optimum insulation thickness varies between 4.09 and 21.50 cm, when Degree-Days values varies between between 800 to 4800. It means optimum insulation thickness depends upon Fuel type, Degree-Days value. Optimum insulation thickness varies significantly for different Degree-Days(DD) region.

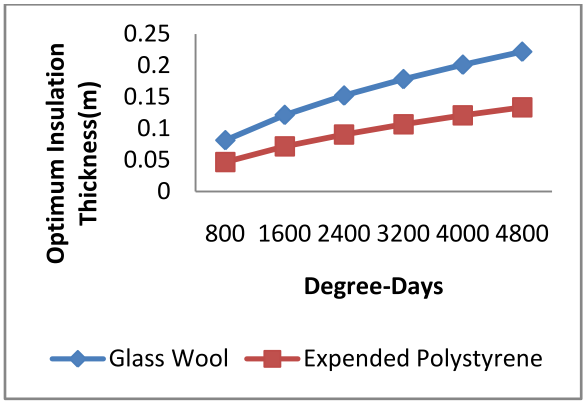


**Figure 4 .Variation of optimum insulation thickness of Roof with Degree-Days value**

The variation of the optimum insulation thickness for Roof with Degree-Days is shown in Fig.4 for LPG fuel type. Optimum insulation thickness increases with increasing the value of Degree-Days. Insulation thickness decreases with the higher values of thermal resistance for a given value of Degree-Days. From Fig.4, it can seen that the optimum insulation thickness varies between 4.67 cm and 22.16 cm, when Degree-Days values varies between 800 to 4800. Applying insulation in region having higher Degree-Days(DD) would be more advantageous.

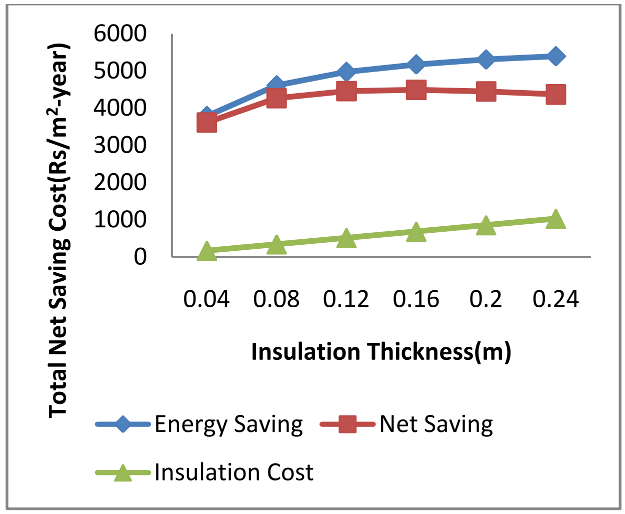


**Figure 5. Variation of Energy Saving, Insulation Cost and Net Saving for the insulated external walls versus insulation thickness**

Fig.5 show the variation of Net saving cost with respect to insulation thickness for the selected region (Dehradun), when External walls has insulated by Glass wool. From Fig.5, it can be concluded that there is a non-linear relation between energy saving and insulation thickness. The Optimum insulation thickness, Payback period and Energy saving for four different regions are given in table 2.for External walls. When insulation thickness is increased, then Net saving is gradually increased and reaches it maximum values at optimum insulation thickness, and after that Net saving decreases.

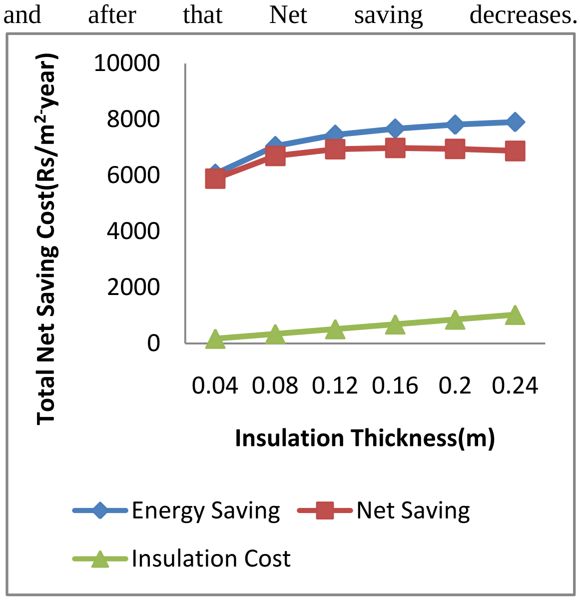

**Figure 6. Variation of Energy Saving, Insulation Cost and Net Saving for the insulated Roof versus insulation thickness**

Fig.6 show the effect of Insulation thickness on net energy saving for selected region (Dehradun), when Roof has insulated by Glass wool. The Optimum insulation thickness, Payback period and Energy saving for four different regions are given in table 3.for Roof. From Fig.6, it can be seen that more energy saving is achieved, when Roof is insulated as compared to External walls. Energy saving is mainly depend upon insulation cost, fuel type and climatic condition. Energy saving is more important for the expensive fuel.

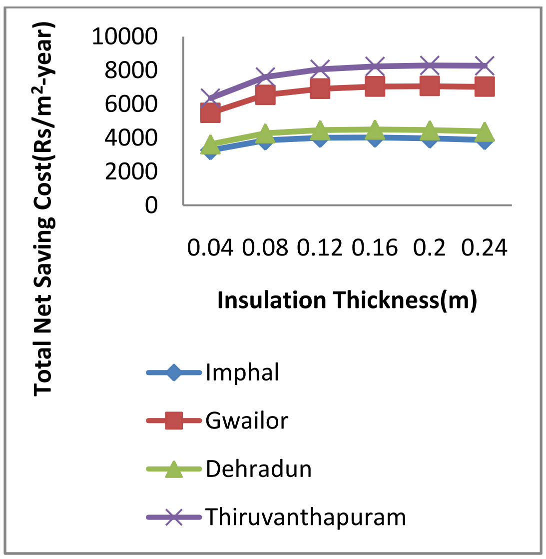


**Figure 7. Total Net Saving versus insulation thickness for different Degree-Days region**

The effect of insulation thickness on Total net saving cost for LPG heating source is shown in Fig.7 , for four different Degree-Days region. When insulation thickness is increased, then Net energy saving is gradually increased and reaches it maximum value at optimum insulation thickness and after that energy saving decreases. At a given value of insulation thickness, region having higher Degree-Days value will save more energy. Thiruvanthapuram having higher Degree-Days Value, so more energy is saving in this region. Insulation thickness is more beneficial in the higher Degree-Days value region. From Fig.7 , it is observed that for given value of insulation thickness, least energy saving region is Imphal and highest energy saving region is Thiruvanthapuram.

## 4. Conclusions

The optimum insulation thickness, Net energy saving and Payback periods are calculated for four different Degree-Days region and two different insulation materials. The optimum result has been obtained, when LPG is used as energy sources and Expended Polystyrene as the insulating material. Energy saving is maximum at optimum insulation thickness. As seen from Fig.5 , choosing a thickness value apart from optimum thickness will increase the total cost. Therefore, optimum insulation thickness must be applied to building for economic aspect. From Fig. 7, it is observed that Net saving is highest for Triruvanthapuram(DD : 4507) and lowest for Imphal (DD : 2372). Energy saving rate is proportional to climatic condition and fuel cost. In cold region, there is higher Degree-Days value so more energy saving can be achieved.

As a results, the Optimum insulation thickness varies between 0.1446m and 0.2077 m , Net energy saving varies between 500.03 Rs/$m^2$ and 1014.27 Rs/$m^2$, and Payback period varies between 0.87 to 1.2374 years for External walls.

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