International Journal of Materials Science and Applications
2016; 5(6-1): 1-5
http://www.sciencepublishinggroup.com/j/ijmsa
doi: 10.11648/j.ijmsa.s.2016050601.11
ISSN: 2327-2635 (Print); ISSN: 2327-2643 (Online)

Insulation of Ceiling with Different Insulation Materials and its Effect on Energy Saving

Ö. Altan DOMBAYCI[1], Harun Kemal ÖZTÜRK[2, *]

[1]Department of Material Engineering and Science, Faculty of Technology, Pamukkale University, Kinikli, Denizli, Turkey

[2]Department of Mechanical Engineering, Engineering Faculty, Pamukkale University, Kinikli, Denizli, Turkey

Email address:

hkozturk@pau.edu.tr (H. K. ÖZTÜRK)

*Corresponding author

To cite this article:

Ö. Altan DOMBAYCI, Harun Kemal ÖZTÜRK. Insulation of Ceiling with Different Insulation Materials and its Effect on Energy Saving. *International Journal of Materials Science and Applications*. Special Issue: Energy and Materials. Vol. 5, No. 6-1, 2016, pp. 1-5. doi: 10.11648/j.ijmsa.s.2016050601.11

Received: June 9, 2016; **Accepted:** June 21, 2016; **Published:** July 9, 2016

Abstract: The aim of this paper is to investigate the effect of ceiling insulation with different insulation material on energy saving. The values of the optimum insulation thickness, the payback periods (PP), and the life-cycle savings (LCS) for three different types of insulation materials (expanded polystyrene, glass wool, and rock wool) were calculated. In calculations, life cycle cost analysis (LCCA) was applied. In the analysis, the present-worth factor (PWF) technique was used for evaluating systems and annual interest and inflation rates were taken 8% and 0%, respectively. The best solution was obtained when the expanded polystyrene was used. The optimum insulation thickness, PP, and LCS were computed as 0.0901m, 1.615years, and 9.643 $\$/m^2$, respectively.

Keywords: Insulation Thickness, Life Cycle Cost, Energy Saving, Insulation Materials

1. Introduction

Insulation has been always important for thermal engineers. It has also been important for the early development of heat transfer technologies [1]. Adding insulation in buildings decreases heat transfer and provides energy conservation. Pollution products (CO_2, CO, SO_2) and the dust particles also decrease with application of insulation [2]. Taylor et al [3] indicated that energy saving for high-income houses in winter heating period per year can be obtained as 3000 GWh. They also obtained a reduction of approximately 1950 MW in national peak demand in winter by installing ceiling insulation. Mathews et al [4] showed that peak demand could be reduced by more than 2000 MW by insulating ceilings.

The industry and building sectors are the most important energy consumption sectors. The total energy consumption in 1999 has been distributed between the sectors like; 37% industry, 32% buildings, 23% transportation, 5% agriculture and 3% the other sector [5]. Global energy demand for sectors in 2012 have been 28% industry, 34% buildings, 27% transportation, 11% agriculture and the other sectors [6]. Walls, windows, floors, ceilings and roofs are the most significant parts of a building that cause heat loss of the buildings, so heat insulation is considered very important [7]. It can be easily said that there is a very large technical potential to improve the energy efficiency in the residential sector and the buildings. It has been reported that the technical savings potential from the use of energy efficient equipment and appliances can range between 5-90%, depending on the end-use and using holistic retrofits at the building structure and using energy in the building sector will be increase an average annual rate of 0.4% between 2010 and 2035 [6]. Some countries like Turkey import most of the energy they need. As buildings in Turkey aren't generally insulated or well insulated, therefore, energy consumption for heating is too high and energy saving is very important.

Dombayci et al. [8] used two different insulation materials and five different energy sources to determine the optimum insulation thickness of the external walls. When the optimum insulation thickness is used, the result showed that the life cycle, saving and payback period occurs at 14.09 \$/m2, 1.43 years, respectively. Dilmac et al [9] showed that the mean consumption for heating exceeds 200kWh/m^2-year in buildings.

Turkey is split up into four climatic regions. Denizli province is located in the 3rd region in which mean heating degree-days value is 2055 [10, 11]. In this study, in order to show the effect of insulation material on the energy saving, three different types of insulation materials are used for insulation of the ceilings; expanded polystyrene, glass wool and rock wool. The main objective of this study is to calculate the values of the optimum insulation thickness, the Payback Period (PP), and the Life-Cycle Saving (LCS) for the different types of insulation materials by using LCCA method for minimizing the energy loss.

2. The Heat Loss from the Ceiling

Heat losses from buildings occur via external walls, windows, ceilings and floor, and also via air infiltration. The range of the heating degree-days varies significantly from one region to another for different climate regions in Turkey. For example, the annual heating degree-days for Mersin (located in the east of the Mediterranean) is 1118, while it is 3063 for Isparta (Southwest Turkey, located in the middle of the Mediterranean), it is 2055 for Denizli (Ege region, located in the west of Turkey), 5049 for Kars (located in the northeast of Turkey), at a base temperature of 15°C [11]. This means that a building in Kars requires 4.5 times (2.45 times in Denizli) more heating energy than a building located in Mersin, for the same characteristics. Since the sunshine duration in Denizli is very short in heating session, the heating degree-days was considered in the calculations, however, the effect of solar radiation was ignored. In the present study, only the heat losses from the ceilings was considered to calculate the optimum insulation-thickness. The ceiling structure of the buildings consists of plaster, reinforced concrete and the insulation material.

The heat loss from unit surface of ceiling calculated from following equation:

$$q = K \cdot \Delta T , \qquad (1)$$

Where K is the total heat-transfer coefficient. The annual heat loss from unit surface q_A, can be calculated using the Heating Degree Days (DD) and K [2]:

$$q_A = 86{,}400 \cdot DD \cdot K , \qquad (2)$$

Where DD is the heating degree-days. K for a typical surface is given by,

$$K = \frac{1}{R_{wt} + R_{ins}} \qquad (3)$$

R_{wt} is the sum of R_i, R_0, and R_w. Where R_i, R_0, and R_w are respectively the inner, outer air film thermal resistance, and total thermal resistance of the surface without insulation. The thermal resistance of the insulation layer R_{ins} is also given by,

$$R_{ins} = \frac{x}{\lambda} , \qquad (4)$$

Where x and λ are respectively the thickness and thermal conductivity of the insulation.

The annual energy requirement, E_A, is calculated by dividing the heat loss per year by the system efficiency:

$$E_A = 86{,}400 \cdot DD \cdot K / \eta , \qquad (5)$$

3. Calculation of Total Heating Cost and Optimum Insulation Thickness

The annual energy cost of heating per unit area, C_A, can be defined as

$$C_A = 86{,}400 \cdot DD \cdot C_c \cdot K / H_u \cdot \eta , \qquad (6)$$

where C_c in \$/kg is the cost of the coal, and H_u in J/kg is the heating value of it.

LCCA may be applied when calculating the optimum insulating-thickness. Total heating cost is evaluated in present value of dollar by using the PWF for the lifetime of N years. The PWF depends on the inflation rate (g), and the interest rate (i). In this paper, because of the interest rate is bigger than inflation rate, real interest rate (r) and the PWF is defined as below, respectively [1]

$$r = (i - g)/(1 + g) \qquad (7)$$

$$PWF = \frac{(1+r)^N - 1}{r \cdot (1+r)^N} , \qquad (8)$$

where N is the lifetime, and it is assumed to be 10 years. Cost of insulation, C_{ins}, in \$/m^2, is given by

$$C_{ins} = C_i \cdot x , \qquad (9)$$

where C_i in \$/m^3 is the cost of insulation material and x is the insulation thickness. As a result, the total heating cost C_t of the insulated building is given by

$$C_t = \frac{86{,}400 \cdot DD \cdot C_c \cdot K \cdot PWF}{H_u \cdot \eta} + C_{ins} \qquad (10)$$

The optimum insulation thickness can be calculated either by maximizing the annual revenue or minimizing the annual total heating cost. Both of the ways of calculations give same results. When the total heating cost is derivated according to insulation thickness (x), optimum insulation thickness can be obtained.

$$\frac{dC_t(x)}{dx} = 0 \quad \Rightarrow \quad x = x_{op} \qquad (11)$$

The optimum insulation thickness which makes total cost minimum can be calculated as

$$x_{op} = 293.94 \cdot \sqrt{\frac{DD \cdot C_c \cdot PWF \cdot \lambda}{H_u \cdot C_i \cdot \eta}} - \lambda \cdot R_{wt}. \qquad (12)$$

From Eq. (12), it can be seen that the optimum insulation-thickness depends on parameters such as, the price of fuel, price of the insulation material, properties of the ceiling and insulation material and the PWF. The values of the parameters used in the calculations of the optimum insulation thickness are given in Table 1. The payback period is defined as the ratio of the energy cost of the uninsulated building to the energy savings.

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

Parameter	Value
DD	2055
Fuel	Coal
H_u	25.122x10^6 J/kg
C_c	0.19 \$/kg
η	0.65
Insulation	Expanded polystyrene
k	0.032 W/mK
C_i	29 \$/m^3
Insulation	Rock wool
k	0.040 W/mK
C_i	107 \$/m^3
Insulation	Glass wool
k	0.052 W/mK
C_i	25.25 \$/m^3
R_{wt}	0.763 m^{2}K/W
i	8(%)
g	0(%)
N	10
PWF	6.71

4. Results

Heat losses decrease by increasing the insulation thickness in buildings. When the different types of insulation materials are applied, the one which has the lowest annual cost is optimum insulation material [12]. The annual cost curves for the thickness of three different types of insulation materials for Denizli are shown in Fig. 1. As shown in this figure, optimum insulation material is expanded polystyrene.

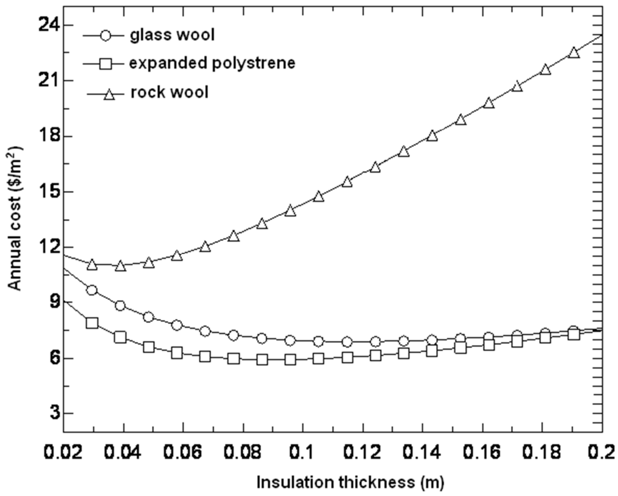

Fig. 1. *Variation of annual cost versus insulation thickness for different insulation materials.*

The optimum insulation-thicknesses of the different insulation materials were calculated. For a ceiling surface of 1m^2, annual energy saving is calculated with the difference between insulated and non-insulated energy costs. The values of the optimum insulation thickness, the payback period (PP), and the life-cycle savings (LCS) for different types of insulation materials (expanded polystyrene, glass wool, and rock wool) are shown in Table 2. As shown in Table 2, optimum insulation thicknesses of expanded polystyrene, glass wool, and rock wool have been calculated as 0.0901m, 0.1168m, and 0.0361m, respectively. Similarly, PP for these insulation materials have been obtained as 1.615, 1.795, and 3.403 years, respectively.

In change of inflation and interest rates, the value of present-worth factor (PWF) and depending on this, the optimum insulation thickness also changes (Fig. 2). When the inflation and interest rates increase, the values of PWF and optimum insulation thickness increase.

Table 2. *Optimum insulation thickness, payback period, and life cycle savings for different insulation materials.*

	Expanded polystyrene	Glass wool	Rock wool
x_{op} (m)	0.0901	0.1168	0.0361
PP (years)	1.615	1.795	3.403
LCS (\$/m^2)	9.643	8.678	4.578

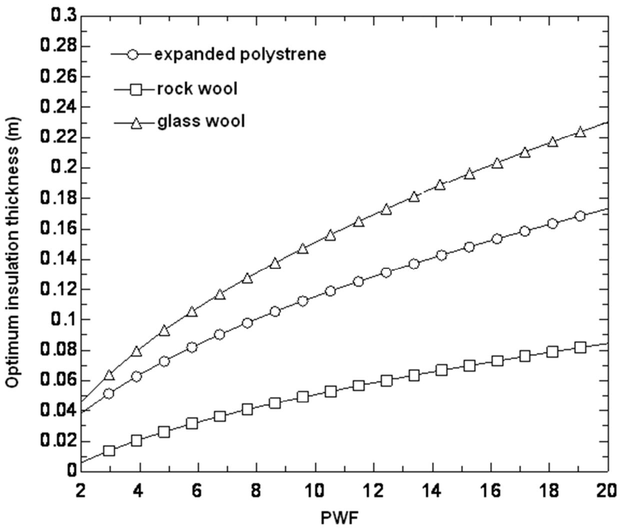

Fig. 2. Optimum insulation thickness versus present worth factor for different insulation materials.

The effect of degree-days (DD) on payback period is shown in Fig. 3. With the increase of DD, the payback period decreases. The effect of the thickness of different insulation materials on the annual saving is shown in Fig. 4. When the optimum insulation thickness of the expanded polystyrene is applied to ceiling surface, energy savings up to 9.643$/m^2 is obtained and this value is a major energy savings. As a result, energy savings become more important in regions where fuel (coal) costs much.

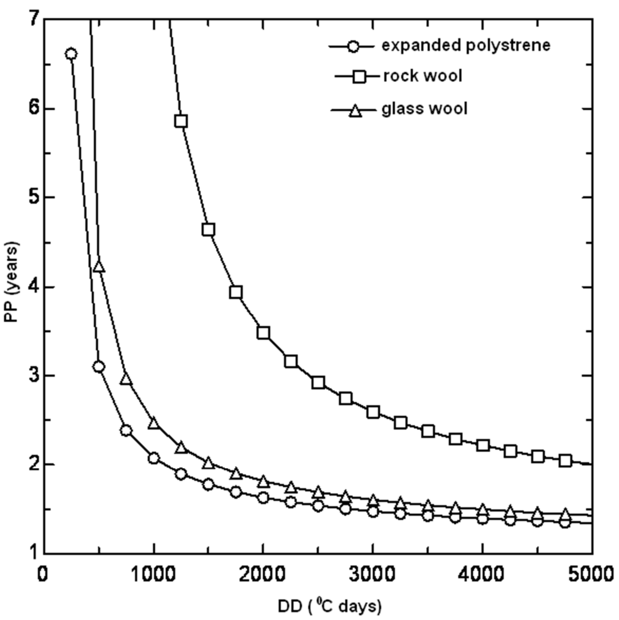

Fig. 3. Effect of degree-days on payback period for different insulation materials.

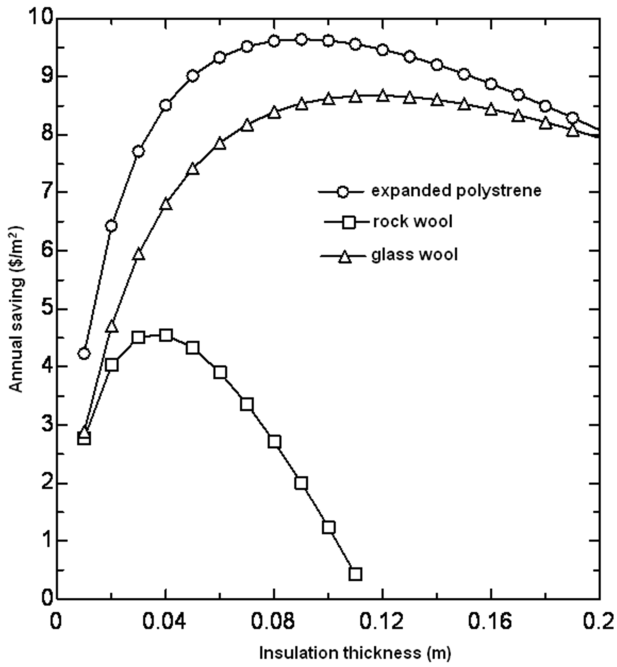

Fig. 4. Effect of insulation thickness on annual saving for different insulation materials.

5. Conclusions

For the different types of insulation materials, optimum insulation thickness of ceilings and LCS and PP based on a lifetime of ten years were computed by using coal. In calculations, LCCA is used. It is seen that the most economical insulation material is expanded polystyrene. When the optimum insulation thickness of expanded polystyrene is used, LCS and PP are 9.643$/m^2 and 1.615 years, respectively.

Nomenclature

C_A	Annual heating cost ($/m^2-year)
C_c	Cost of the coal ($/kg)
C_i	Insulation material cost ($/m^3)
C_{ins}	Insulation cost ($/m^2)
C_t	Total heating cost of the insulated building ($)
DD	Heating degree days (°C-days)
E_A	Required annual heating energy (J/m^2 -year)
g	Inflation rate
q_A	Annual heat loss from unit area (J/m^2)
H_u	Heating value (J/kg)
i	Interest rate
K	Total heat transfer coefficient (W/m^{2}K)
LCCA	Life-cycle cost analysis
N	Lifetime (years)
PWF	Present-worth factor
r	Real interest rate
R_{ins}	Insulation thermal resistance (m^{2}K/W)
R_{wt}	Total thermal resistance of the surface without insulation (m^{2}K/W)
x	Insulation thickness (m)
x_{op}	Optimum insulation-thickness (m)

λ Thermal conductivity of the insulation (W/mK)
η Efficiency of space-heating system (%)

References

[1] M. Spinnler, E. R. F. Winter, R. Viskanta “Studies on high-temperature multilayer thermal insulations”, International Journal of Heat and Mass Transfer 2004, 47: 1305-1312.

[2] H. T. Ozkahraman, A. Bolatturk, “The use of tuff stone cladding in buildings for energy conservation”, Construction and Buildings Materials 2006, 20: 435-440.

[3] P. P. Taylor, E. H. Mathews, M. Kleingeld, G.W. Taljaard, “The effect of ceiling insulation on indoor comfort”, Building and Environment 2000, 35: 339-346.

[4] E. H. Mathews, M. Kleingeld, P.B. Taylor, “Estimating the electricity savings effect of ceiling insulation”, Building and Environment 1999, 34: 505-514.

[5] A. K. Dagsöz, “Isı yalıtımı ve kalorifer tesisatı standartları üzerine görüşleri. MMO Tesisat Mühendisliği”, 2001.

[6] WEO, World Energy Outlook 2012, International Energy Agency, 2012.

[7] A. Bolatturk, “The calculations of optimum insulation thickness and the role of energy saving in buildings. Proceedings 14th The Congress of National Heat Science and Technical”, Isparta, 2003.

[8] Ö. A Dombaycı, M. Gölcü, Y.Pancar, “Optimization of insulation thickness for externall walls using different energy sources” Applied Energy 2006, 83: 921-928.

[9] S. Dilmac, N.A. Kesen, “Comparision of new Turkish thermal insulation standart (TS 825), ISO 9164, EN 832 and German regulation” Energy and Buildings 2003, 35: 161-174.

[10] Turkish Standarts (TS 825) The rule of thermal insulation in buildings Formal Newspaper 23725, 1999.

[11] A. K. Dagsöz, The Degree Days in Turkey, İzocam A-61995.

[12] Y. A. Cengel, “Heat Transfer a Practical Approach”, McGraw-Hill, New York, 2001.