ENVIRONMENTAL AND ECONOMIC ANALYSIS OF OPTIMUM HEAT INSULATION THICKNESS IN ENERGY SAVING

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Received: 1 November 2016; Accepted: 25 December 2016

Developing technology and increasing population cause the natural energy resources rapidly. This has compulsorily forced the countries such as Turkey, which import almost all energy needs and use great deal of it in home heating, to save energy. It will provide benefits for users, indirectly the economy of the country, with saving obtained from insulation. One of the most effective methods attaining gain of energy is heat insulation. While heat insulation is carried out, by determining the optimum efficiency point, the amount of fuel used decreases, which leads to cost reduction and highest efficiency level. Therefore, it is possible to tolerate harmful emissions. In this study, optimum insulation thickness, total cost, energy saving, duration of pay-back and environmental analysis for heating were conducted in Diyarbakır by utilizing different fuel and insulation types. When extruded polystyrene (XPS) was used, average optimum thickness was 0,0675 (m), annual return was 62,165%, duration of pay back was 1,83 (years) and CO_2 *and* SO_2 *emissions were 76% lesser. When expanded polystyrene (EPS) was used, the parameters such as average optimum thickness 0,0825 (m), annual return 73,06%, duration of pay back 1,245 (years) and* CO_2 *and* SO_2 *emissions 85% lesser.*

Key words: Insulation, environmental analysis, energy saving, Diyarbakır

1. Introduction

Turkey is a foreign dependent country in terms of energy sources; therefore, any kinds of energy efficiency investigation present great importance for our country. The fact that the insulation materials are used properly and in sufficient amount will lead to saving in materials, energy and costs.

Energy saving, due to increasing population and urbanization, has become compulsory in respect to raise in energy consumption and efficient utilization of existing energy sources. The construction sector has a major share in energy consumption in the world with heating and cooling energy needs in buildings. Increasing the thickness of the insulation materials implemented in the buildings can be shown the simple and effective solution. However, the applications where thicker insulation than a certain level increases insulation costs rather than decreasing heating and cooling needs, hence this increases the total cost to the maximum level. For this reason, measuring the optimum insulation thicknesses possibly applicable to buildings gained importance, so that both energy saving and total cost can be optimized (Gülten, Ekici, 2015; Hasan, A.1999).

The previous studies to determine the optimum thickness in buildings was as follows: In their study, Özel and Şengür determined optimum outdoor insulation thicknesses using different fuel types and insulation materials for Antalya and Kars (Özel, Şengür, 2013). At the end of the investigation, it was determined that optimum insulation thicknesses for Antalya and Kars were 0.031 m and 0.068 m, respectively if rock wool was used as insulation and natural gas was used as fuel. Kaynaklı et al attempted to calculate insulation thickness for heating temperature-day (HTD) number and cooling temperature-day (CTD) number and outer walls for İstanbul; and they found out insulation thicknesses decreasing total cost minimum both for heating and cooling seasons. Optimum insulation thicknesses were determined as 4 cm and 2.6 cm for heating and cooling seasons, respectively. Thus, total saving rates of 40% and 28% for heating and cooling were obtained respectively (Kaynaklı, Kılıç, Yamankaradeniz, 2010). Ertürk made calculations such as optimum insulation thickness, total cost, energy saving, pay-back period making use of air space with insulation material for Ankara. According to his analysis, he used natural gas and coal as fuel, extrude polystyrene foam (XPS), rock wool and expand polystyrene for the outer walls, and together with these, four different air space. When natural gas as fuel and XPS as insulating material and 4mm air space were used, it was observed that optimum insulation thickness decreased from 9,2 cm to 3,4 cm and payback period decreased from 1.509 years to 1.320 years and total cost decreased 28% and annual earnings increased 94% (Ertürk, M. 2016). Gürel and Cingiz took the outer wall of a building insulated with different construction materials and insulation forms as a model. According to life cycle cost analysis, optimum heating insulation thicknesses, payback periods and energy saving were determined. The thicknesses of the insulation materials were determined as 0.05-0.132 m for stone outer wall, 0.038-0119m for aerated concrete and 0.033-0.114m for sandwich wall. The annual earning total for outer walls was calculated between 189.7 TL/m^2 and payback periods between 1.31-4.5 years (Gürel, Cingiz, 2011).

2. Method

In this study, heating temperature day value, 18ºC, for Diyarbakır province was taken as 2142 and heat loses in the outer walls and energy needs in regard to this were determined (Büyükalaca, Bulut, Yılmaz, 2001). In calculations, life cycle cost analysis (LLCA) was used and according to two different fuel types and insulation materials, the results were analyzed.

2.1. Building Wall Model

The highest heat lose in houses occurs in structural elements such as walls, floors, roofs, windows and heat bridges. The heat loses occurring in these areas exhibit differences according to architecture of the construction, its location, heat isolation and properties of the materials used. In general, the biggest proportion energy loses occur in the outer walls of the buildings. Therefore, that the outer walls are insulated makes a significant factor in alterations of heat lose calculation results. Today, the walls can be handled as construction elements which can be made of not only one layer, but also more than one layer including insulating material in its body.

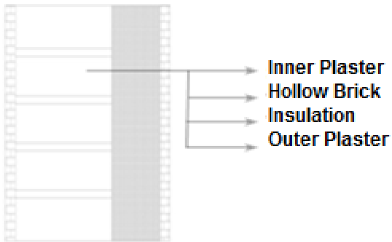

Figure 1.Wall Model

In this study, calculation of optimum insulating thickness is carried out with the assumption that heat lose occurs only in the outer walls. The wall components used in the study are inner mortar, tile, insulating material and outer mortar as shown in Figure 1. The properties belonging to the components of this wall are demonstrated in Table 1.

Table 1.Wall Structure Used in the Study

Tile Wall	Thickness (m)	k (W/m.K)	R (m^2K/W)	RWall (m^2K/W)
Inner Mortar with Cement	0,02	0,85	0,0235	
Hollow Brick	0,19	0,45	0,4222	0,4692
Outer Mortar with Cement	0,02	0,85	0,0235	

For a typical Wall, U(W/m^2K)expressing total heat transfer coefficient is calculated by Equation 1.

$$U = \frac{1}{R_i + R_w + R_{izo} + R_o} \qquad (1)$$

R_i and R_o in Equation 1 show inner and outer surface heat resistance, respectively, and $R_w$states the heat resistance of uninsulated layer of wall, while R_{izo}demonstrates heat resistance of insulation material. These are calculated by means of Equation 2. x in this equation represents the thickness of insulation material, while k is the heat transmission of insulation material. The properties of insulation materials used in this study are given in Table 2

$$R_{izo} = \frac{x}{k} \qquad (2)$$

Table 2.Properties of Insulation Materials

Insulation Materials	k (W/mK)	Cost ($\$/m^2$)
Extruded polystyrene (XPS)	0,039	102
Expanded polystyrene (EPS)	0,030	63

2.2. Heating Load for Building Walls

The heat loses in buildings usually occur from outer walls, windows, roof and floors and with the help of air infiltration. In this study, however, calculations were carried out supposing that losses occurred only in the outer walls. The heat loses occurring in the unit surface of outer wall are calculated using Equation 3 written below (Liu et al.2015)

$$q = U.\Delta T \qquad (3)$$

U(W/m^2K) in Equation 3 is the total heat transfer coefficient. Annual heat lose occurring from unit surface is calculated with the help of Equation 4 using U and temperature heat day numbers (HDD).

$$q_A = 86400.HDD.U \qquad (4)$$

Annual energy need, EA (J/m^2-year), necessary for heating is obtained with Equation 5 by dividing annual unit heat lose by system efficiency.

$$E_A = \frac{86400.DGS.U}{\eta} = \frac{86400.HDD}{(R_{TW} + R_{izo}).\eta} \qquad (5)$$

Annual fuel amount consumed, m_{fA}(kg/m^2-year) is calculated with the help of Equation 6.

$$m_{fA} = \frac{86400.HDS}{\left(R_{izo} + x_y/k_y\right).H_{u.}.\eta} \qquad (6)$$

Annual energy cost, CA (\$/m^2-year), used for heating unit area is calculated using Equation 7. Here, the sub thermal value of fuel, $H_{u.}$ (J/kg; J/m^3), fuel efficiency, η the price of fuel, Cf (\$/kg; \$/m^3) are shown in Table 3.

$$C_A = \frac{86400.HDS.C_f}{(R_{TW} + R_{izo}).\eta.H_{u.}} \qquad (7)$$

Table 3.Characteristics of Fuel Used in Study

Fuel	*Cf*	H_u	η	Chemical Formula
Coal (Soma)	0,2084 \$/kg	21,113 x 10^6	0,65	$C_{5.85}H_{5.26}O_{1.13}S_{0.008}N_{0.077}$
Natural gas	0,3356 \$/m^3	34,526 x 10^6	0,93	$C_{1.05}H_4O_{0.034}N_{0.022}$

2.3. Optimum Insulation Calculation

In determining the optimum insulation thickness the building needs, it is aimed to keep insulation cost at minimum level. There are several methods for establishing the cost of the system; however, life cycle cost analysis method is used in this study. The total heating, energy, insulation- if there is, a parameter (PWF) called as present worth factor costs of the building are calculated according to a time period (N) previously determined. Depending on real interest rate (r), inflation rate (g) and interest rate (i) used in calculation of PWF value, it is calculated via Equation 8 according to two separated cases (Liu et.al 2015; Shekarchian et al. 2012)

$$\text{if } i>g \text{ is } r = \frac{i-g}{1+g} \text{ ; if } g>i \text{ is } r = \frac{g-i}{1+i} \quad (8)$$

In this study, the calculations were made with the values of a decade to be time period, the latest updated interest rate to be 8,18% and inflation rate to be 8,07% and PWF factor was calculated via Equation 9.

$$PWF = \frac{(1+r)^N}{r.(1+r)^N} \quad (9)$$

The total cost of a completed building, C_T ($), is calculated via Equation 10. Here, C_i is the unit price of insulation material; and ($/m^3) and x (m) is the thickness of the insulation.

$$C_T = C_A.PWF + C_i.x \quad (10)$$

In calculating the optimum thickness, it is necessary that the total cost be at minimum level. Calculating the derivative of Equation 10, which gives the total cost, insulation thickness (x) is calculated via Equation 11.

$$x_{op} = 293.94.\left(\frac{HDS.C_f.PWF.k}{H_U.C_i.\eta}\right)^{1/2} - k.R_{TD} \quad (11)$$

In calculating the payback period after gain obtained from the investment, Equation 12 is used. S_A in this equation is annual saving and it is the annual energy difference between insulated and uninsulated walls (Çomaklı, Yüksel 2003).

$$p_b = \frac{In\left[1-\left(\frac{1-g}{1+g}\right).\left(\frac{C_i.x}{S_A}\right)\right]}{In\left(\frac{1+g}{1+i}\right)} \quad (12)$$

2.4. Environmental Analysis

The ever increasing population of the world is increasing the energy need of every passing day. This increasing energy need is mostly used in domestic heating. In meeting this demand, the fossil fuels have been used since they were both common and inexpensive; however, the amount of greenhouse gases and harmful emissions has increased, which has led to air pollution. Increasing insulation thickness in houses might partly bring a solution to this problem, which will also cause the heating costs to decrease. General formula for burning is shown in Equation 13 (Ertürk 2016).

$$C_x + H_z + O_w + S_y + N_t + \alpha.A(O_2 + 3.76N_2) \rightarrow xCO_2 + \left(\frac{z}{2}\right)H_2O + ySO_2 + B.O_2 + E.N_2 \quad (13)$$

A, B and E constants in oxygen balance condition are calculated via Equations 14, 15 and 16.

$$A = \left(x + \frac{z}{4} + y - \frac{w}{2}\right) \qquad (14)$$

$$B = (\alpha - 1).\left(x + \frac{z}{4} + y - \frac{w}{2}\right) \qquad (15)$$

$$E = 3.76\alpha\left(x + \frac{z}{4} + y - \frac{w}{4}\right) + \frac{t}{2} \qquad (16)$$

SO_2 and CO_2 emissions in Equation are neglected. Emission values can be calculated via Equation 17 and 18 with regard to annual fuel consumption.

$$mCO_2 = \frac{44.x}{M} m_{fA} \qquad (17)$$

$$mSO_2 = \frac{64.x}{M} m_{fA} \qquad (18)$$

M is the weight of mole in Equation 17 and 18, and it is calculated with the help of Equation 19.

$$M = 12x + z + 16w + 32y + 14t \qquad (19)$$

3. Results and Discussions

In this study, calculated optimum insulation thickness displays variations in terms of different fuel and insulation materials and economic properties. Increasing insulation thickness applied to the outer walls of the buildings decreases heat loss of the buildings; and, in connection with this, the heating load is lessened. This decreases not only fuel costs and consumptions but also indirectly the emissions. Nevertheless, the fact that the thickness of the insulation material increases will increase the insulation cost, as a result it is natural to observe increases in total costs. This increase continues until the thickness of the insulation material reaches to the optimum level. After this value, with regard to the unnecessary increasing insulation thickness, the insulation costs and naturally total cost increase. Total cost, a total of fuel and insulation expenses, decreases until it reaches a certain level; whereas it increases after this level. The value which gives the minimum cost will submit the most convenient insulation thickness. For Diyarbakır, total cost of insulation material, fuel cost and the effect of these on insulation cost are shown in Figure 3 and 4 according to outer insulated wall applications. For various fuel types and insulation materials, optimum insulation thickness is calculated by using Equation 11. The results found in outer insulated walls are shown in Table 4.

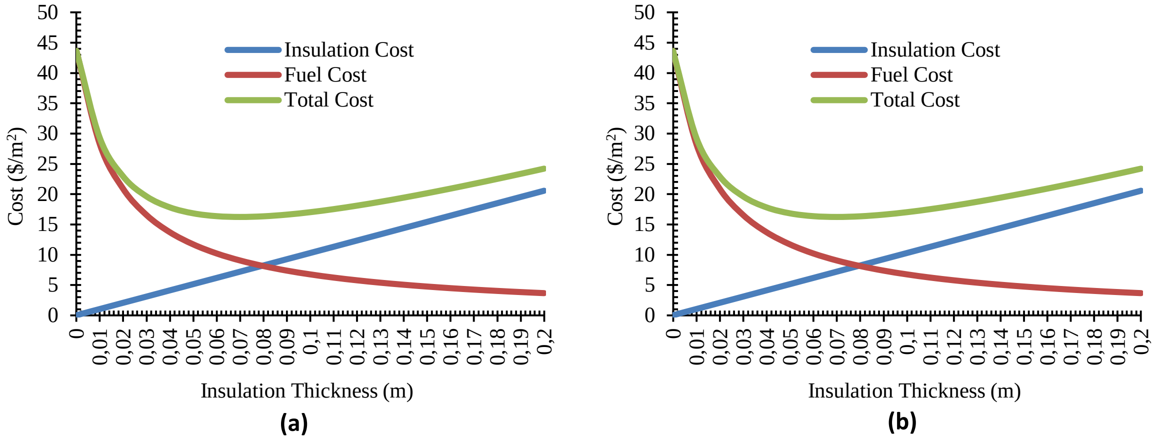

Figure 3. Cost-thickness relation in using XPS insulation material a) Natural gas b) Coal

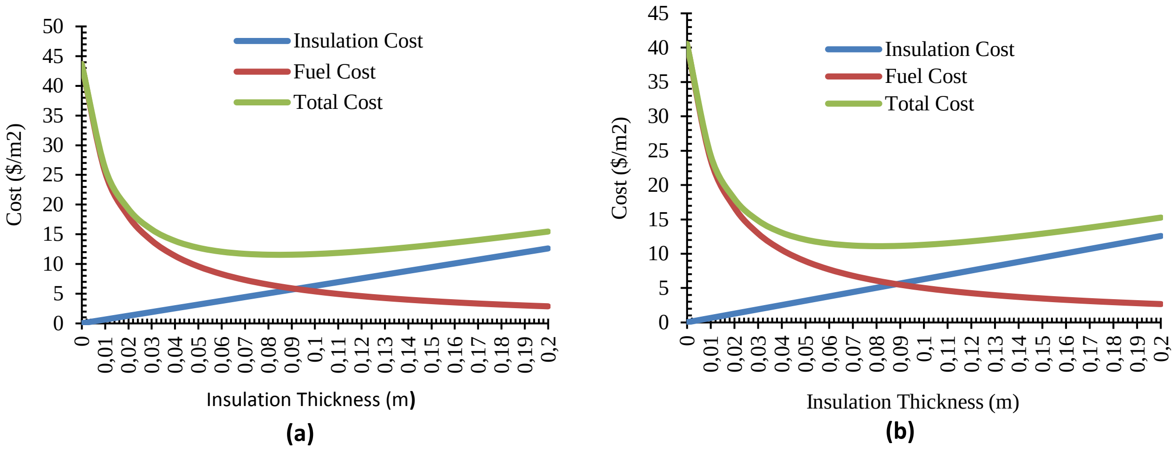

Figure 4. Cost-thickness relation in using EPS insulation material a) Natural gas b) Coal

Table 4.Values calculated for different insulation materials and fuels

	Extruded polystyrene (XPS)				Expanded polystyrene (EPS)			
	X_{opt}(m)	Annual Saving ($/m²)	Annual Saving Rate (%)	Payback Periods (years)	X_{opt}(m)	Annual Saving ($/m²)	Annual Saving Rate (%)	Payback Periods (years)
Natural Gas	0,069	27,42	62,79	2,06	0,084	32,11	73,52	1,41
Coal	0,066	24,94	61,54	1,60	0,081	29,42	72,60	1,08

When Table 4 was examined, it was determined that the optimum insulation thickness showed differences for two different fuels and insulation material. In heating the building, when natural gas was used, 73,52% of the energy used for heating was regained for Expanded polystyrene (EPS) material and for insulation thickness of 0,084 (m). When coal was used in the process, the thickness of the same insulation material is 0,081 (m) and regained energy amount is around 72,60%. Although the optimum thickness of Extruded polystyrene (XPS) was lower than the other material, since its unit prices were expensive, this increased payback period, which led it to be a disadvantageous case. When the process was examined in terms of two different fuels used for heating, coal with its 1,08 (year) payback period is more advantageous. The fundamental reason why two different insulations used in heating showed different performances can be expressed as interest and inflation rates and price per unit of insulation material.

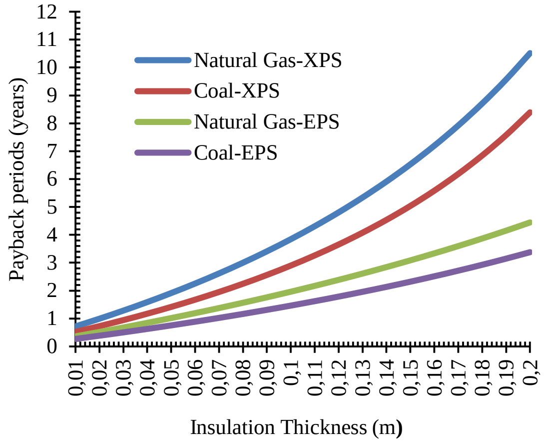

Figure 5. Relation between payback period and insulation thickness

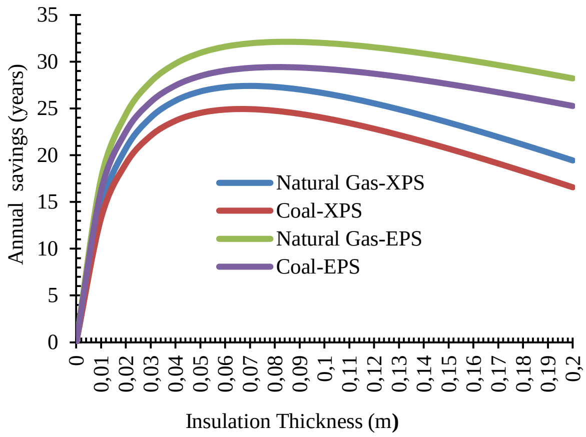

Figure 6. Relation between annual gain and insualtion thickness

According to optimum insulation thickness values obtained at the end of the calculations, payback period increases directly proportional to increasing thickness of insulation material. The redemption period of Extruded polystyrene (XPS), as can be seen in Figure 5, is longer for all fuels. In payback period, usage of Expanded polystyrene (EPS) insulation material and coal for heating will be the most profitable preference.

While amount of annual gain, when Figure 6 is examined, shows increase up to optimum level for different insulation and fuel types, it exhibits a tendency towards decrease as the insulation thickness increases. The main reason for this is that increasing insulation thickness is more than necessary, thus this creates a negative case for relation of gain needed for heating. Annual gain obtained from natural gas is more advantageous than coal for all insulation materials. The only reason for this is that per unit price of natural gas used for heating is more than coal.

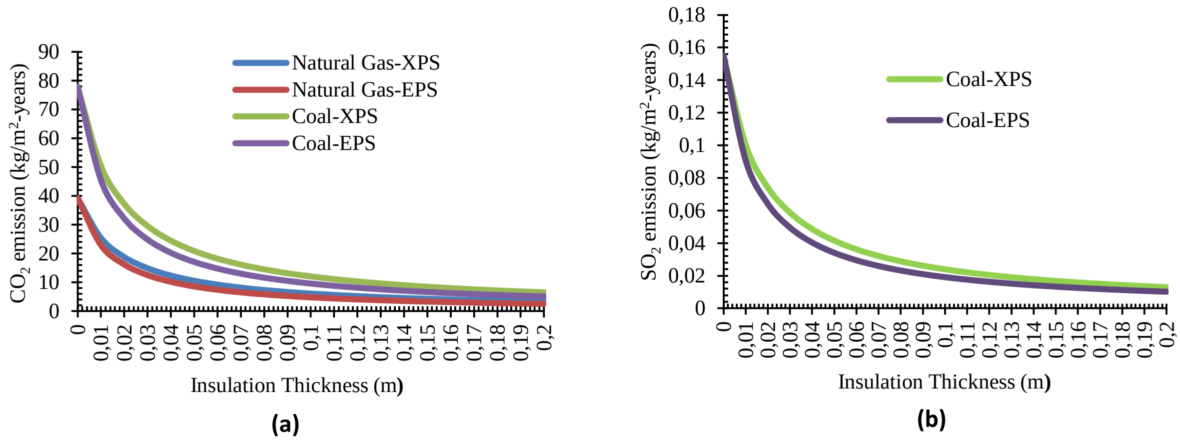

Figure 7. Relation of insulation thickness and chimney emmision a)CO_2 b)SO_2

Variations of annual CO_2 and SO_2 gases in respect to insulation thickness are shown in Figure 7a and Figure 7b Annual fuel consumption decreases in regard with increasing insulation thickness, hence drops are observed in emitted emission values. In Diyarbakır province, 76% and 85% decrease in CO_2 and SO_2 were obtained at optimum point of Extruded polystyrene (XPS) and in using of Expanded polystyrene (EPS), respectively

4. Conclusion and Suggestions

In the study conducted, values for optimum insulation thickness were calculated for building heating in the Diyarbakır province with different insulation materials and fuel types. When Extruded polystyrene (XPS) was used as insulation material, parameters such as mean optimum insulation thickness, annual gain, payback period and emission were found as 0,0675 (m), 62,165%, 1,83 (years) and less than 76%, respectively. When Expanded polystyrene (EPS) was used as insulation material, parameters such as mean optimum insulation thickness, annual gain, payback period and emission were found as 0,0825 (m), 73,06%, 1,245 (years) and less than 85%, respectively.

The fact that energy need in the global economy is increasing and that saving measures are not taken sufficiently puts the users into difficulty and interrupts country's economy. Moreover, tendency to fossil origin energy sources have caused serious changes in the world atmosphere and climate. For these reasons, human beings owe to save energy in order to prevent the present situation to go worse. For us, all these will come true when the applications and systems become widespread and per unit prices of insulation materials are cheaper and humanity protects the nature. As long as societies are not persistent, the energy exporting countries will not give up financial gain.

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