

The Impact of Optimum Insulation Thickness of External Walls to Energy Saving and Emissions of CO₂ and SO₂ for Turkey Different Climate Regions

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How to cite this paper: Dombayci, Ö.A., Ozturk, H.K., Atalay, Ö., Acar, Ş.G. and Ulu, E.Y. (2016) The Impact of Optimum Insulation Thickness of External Walls to Energy Saving and Emissions of CO₂ and SO₂ for Turkey Different Climate Regions. *Energy and Power Engineering*, 8, 327-348. <http://dx.doi.org/10.4236/epe.2016.811030>

Received: October 23, 2016

Accepted: November 20, 2016

Published: November 23, 2016

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Abstract

In this study, the optimum insulation thickness of the external walls of the housing and its energy saving and environmental impact in the provinces—Ardahan, Aydın, Eskişehir and Samsun—located in four different climate regions of Turkey was calculated for the expanded polystyrene and polyurethane insulation materials. Natural gas and coal were selected as fuels. Ardahan in the coldest climate region and Aydın in the hottest climate region, for the coal and optimum thickness of expanded polystyrene and polyurethane insulation materials, the reduction of CO₂ and SO₂ emissions. In the study, the relations between annual energy cost saving and insulation thickness are given. The value of energy cost saving increases up to optimum insulation thickness and beyond this level, the energy cost saving is decreased. For coal and optimum thickness of expanded polystyrene and polyurethane insulation materials, the energy cost savings was higher for the cold climate regions when it was compared with the hot climate regions.

Keywords

Optimum Insulation Thickness, Energy Saving, Environmental Impact

1. Introduction

Energy, because of the world's population and standard of living with constant increase, has become an important resource and power. Continuously and cheap supply of energy is insurance for the economic and social development [1]. The increment of the population, globalization of the world, improvement in technology and the increment of the welfare level causes to increase of energy use of goods and services. One of

the easiest ways to employ the growing demand was to utilize fossil fuel sources. However, due to the limited amount of fossil fuels, increase of the energy price, environmental problems and global warming, it is important to use energy efficiently [2] [3] [4].

The area of Turkey is 783,502 km². Turkey is located at the meeting point of three continents—Asia, Europe and Africa. Turkey can be considered a natural bridge between West and East or Europe and Asia [5] According to the data of Ministry of Energy and Natural Resources (MENR), total energy consumption in Turkey in 2013 was 120.3 Million Tons of Oil Equivalent (MTOE). The total energy demand in Turkey increased 127% from in 1990 to 2013. In 2013, imported primary energy supply was 75.5%. Currently, primary energy demand in Turkey is met by natural gas (31.3%), oil (28.2%), hard coal (14.7%) and lignite (11%). Turkey imports nearly 98% of the natural gas and 93% of the oil it consumes and coal import of Turkey increases steadily [6].

Generally, major energy end-use sectors are commercial, industrial transportation and residential. In many countries, the highest energy was consumed in residential sectors. Energy consumption for the space heating is about two times higher than domestic hot water, cooking, refrigeration, cooling etc. for residential sector. It is possible to significantly reduce the energy consumption with the insulation of the housing [7].

Insulation is the most important part of energy efficiency all over the world. The aim of the TS825 “Thermal Insulation Requirements for Buildings” is to decrease the energy consumption of space heating for the residential sector. This may help the energy saving and reducing CO₂ and SO₂ emissions [8] [9].

According to the International Energy Agency energy indicators in 2008, per capita primary energy consumption worldwide average of 1.83 of oil equivalent (toe/person) and the OECD average of 4.56 toe/person. In 2009, the energy-related greenhouse gas emission per person was 3.7 tons of carbon dioxide (CO₂) equivalent. In the same period, per capita emission was 10.6 tons of CO₂ equivalent/person for the OECD, 5.1 tons of CO₂ equivalent/person for non-OECD Europe and average of 4.4 tons of CO₂ equivalent/person for the world. Turkey’s total greenhouse gas emissions in 1990 amounted to about 187 million tons of CO₂ equivalent, while this value in 2009 amounted to about 370 million tons of CO₂ equivalent. Total sectoral distribution of emissions: energy 278.33 Mton CO₂ equivalent (75.3%), Waste 33.93 Mtoe of CO₂ equivalent (9.2%), industrial processes 31.69 Mtoe of CO₂ equivalent (8.6%) and agriculture 25.7 Mtoe of CO₂ equivalents (7%) [10].

Calculation of optimum insulation thickness of external walls of housing by using Life-Cycle Cost was discussed by Refs [11]-[33]. Çomaklı and Yüksel [34] selected Erzurum province of Turkey to analyze the optimum insulation thickness, fuel consumption and emission of CO₂. This analysis showed that CO₂ emissions amount decreased 50% by using optimum insulation thickness.

The purpose of this study is to determine the optimum insulation thickness of the external walls of the housing and its energy saving, fuel consumption and environmental impact in the provinces—Ardahan, Aydın, Eskişehir and Samsun—located in

four different climate regions of Turkey by using Life Cycle Cost Analysis (LCA) method. Expanded polystyrene and polyurethane were selected as insulation materials and natural gas and coal were selected as fuels. The geographic location of these provinces has been given in **Figure 1**.

2. Material and Methods

The amount of heat lost from the unit external wall surfaces of houses in selected provinces and the annual fuel consumption due to the heat loss for natural gas and coal as fuel were calculated. The optimum insulation thickness by using LCA method and the emissions of CO₂ and SO₂ from fuel combustion equations of chemical formulas were calculated for each province.

The external wall structure which is used in the calculations has been shown in **Figure 2**. As seen from the figure, the external wall also called as the “sandwich wall”, consists of 2 cm inner plaster, two 8.5 cm horizontal hollow bricks and 3 cm exterior plaster and insulation material.

The Life Cycle Cost Analysis (LCA) for a project or piece of equipment is the most

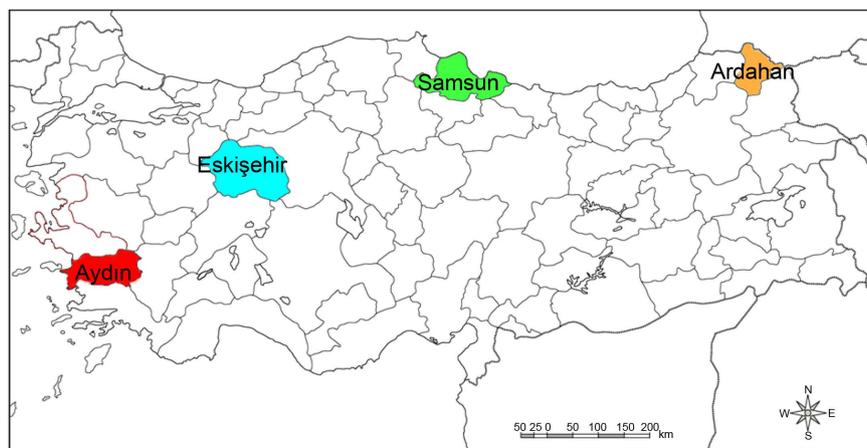


Figure 1. The geographic location of selected provinces.

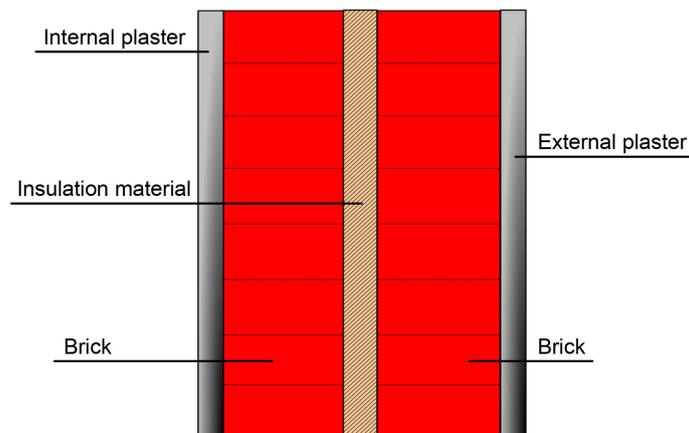


Figure 2. The model of external wall.

commonly method used to assess the economic benefits of energy conservation projects over their lifetime [39] [40]. The parameters of calculation are given in **Table 1**.

Heat loss from unit external wall surface,

$$q = U\Delta T \tag{1}$$

where, U is coefficient of heat transfer. In the heating season, the annual heat loss from unit external wall surface and the annual energy demand which is depends on this heat loss are calculated by using heating degree day numbers (HDD) [36],

$$q_A = 86.4HDDU \tag{2}$$

$$E_A = \frac{86.4HDDU}{\eta} \tag{3}$$

for the typically wall given by,

$$U = \frac{1}{R_i + R_w + R_{ins} + R_o} \tag{4}$$

where, R_i and R_o the thermal resistance of interior and exterior air film respectively and R_w , the thermal resistance of non-insulated wall layers.

The thermal resistance of insulation material given by,

$$R_{ins} = \frac{x}{k} \tag{5}$$

Table 1. Parameters used in calculations of optimum thickness.

Parameter	Unit	Value
Cost of insulation materials		
Expanded polystyrene [8]	\$/m ³	120
Polyurethane [8]	\$/m ³	260
Cost of fuel		
Natural gas [37]	\$/kg	0.55
Coal [8]	\$/kg	0.26
Heating value (Hu)		
Natural gas [8]	kJ/kg	48570
Coal [8]	kJ/kg	25122
Heating degree-days (HDD)		
Aydın [35]	°C days	1603
Ardahan [35]	°C days	5845
Eskişehir [35]	°C days	3649
Samsun [35]	°C days	2339
Conductivity of insulation material		
Expanded polystyrene [8]	W/mK	0.039
Polyurethane [8]	W/mK	0.024
PWF [8]		9.83

where and are the thickness and thermal conductivity of insulation materials respectively.

$$R_{wt} = R_i + R_w + R_o \tag{6}$$

The annual energy consumption (kJ/m²·year),

$$E_c = \frac{86.4HDD}{\left[R_{wt} + \left(\frac{x}{k} \right) \right] \eta} \tag{7}$$

Annual fuel consumption (kg/m²·year),

$$m_F = \frac{86.4HDD}{\left[R_{wt} + \left(\frac{x}{k} \right) \right] \eta H_u} \tag{8}$$

where, annual fuel consumption, *HDD*, heating degree day numbers, *R_{wb}*, thermal resistance of the external wall insulation material excluding and *H_{lb}*, the lower calorific value of the fuel. The total cost from LCA method [8] [36],

$$C_T = PWFC_F m_F + C_{ins} x \tag{9}$$

where, *PF* is the present worth factor, is the total cost, *C_{ins}* is the unit insulation material cost (\$/m³), is the unit fuel cost (\$/kg) and *x* is insulation thickness (m).

The total cost of the derivative based on insulation thickness by equalizing to zero, the optimum insulation thickness is calculated [41].

$$\frac{dC_T}{dx} = \frac{d}{dx} (PWFC_F + C_{ins} x) \tag{10}$$

and,

$$\frac{dC_T}{dx} = 0 \tag{11}$$

The optimum insulation thickness is obtained from (11) equation.

Energy cost saving (\$/m²·year) [36],

$$E_{costsaving} = (C_T)_{nins} - (C_T)_{ins} \tag{12}$$

where, *(C_T)_{nins}* and *(C_T)_{ins}*, the total energy costs for non-insulated and insulated walls respectively.

Assuming the complete combustion, the chemical reactions for annual *n* kmole fuel consumption and the parameters in **Table 2** by using.

For coal,

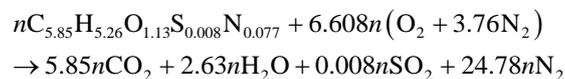


Table 2. Chemical formulas and boiler efficiency of fuels used in calculations.

	Natural gas	Coal
Chemical formula	<i>C_{1.05}H₄O_{0.034}N_{0.022}</i> [38]	<i>C_{5.85}H_{5.26}O_{1.13}S_{0.008}N_{0.077}</i> [9]
<i>η</i> [36]	0.93	0.65

For natural gas,



Mol number n ,

$$n = \frac{m_F}{M} \tag{13}$$

M is molecular mass of fuel. The molecular mass of coal and natural gas used in calculations 94.874 ve 17.452 kg/kmol respectively.

The annual emissions of CO₂ and SO₂ by combustion coal [9] [33],

$$m_{CO_2} = 5.85nM_{CO_2} \tag{14}$$

$$m_{SO_2} = 0.008nM_{SO_2} \tag{15}$$

There is no sulfur in the chemical composition of the natural gas, the emission of CO₂,

$$m_{CO_2} = 1.05nM_{CO_2} \tag{16}$$

and are emissions of CO₂ ve SO₂ (kg/m²-year), and are molecular mass of CO₂ ve SO₂ (44 ve 64 kg/kmol) respectively.

3. Results and Discussion

In this study, the optimum insulation thickness and its energy saving and environmental impact of the external wall of the housing in the provinces—Ardahan, Aydın, Eskişehir and Samsun—located in four different climate regions of Turkey was calculated for the expanded polystyrene and polyurethane insulation materials. Natural gas and coal were selected as fuels. Although reduced heat loss from walls in the houses with increasing thickness of the insulation material, the insulation cost is higher. As seen in Figures 3-18, total cost which is the sum of fuel cost and insulation cost decreases up to specific value of the insulation thickness and then the total cost is increased. The value of optimum insulation thickness that corresponding to the minimum total cost value. For coal and expanded polystyrene insulation material, optimal

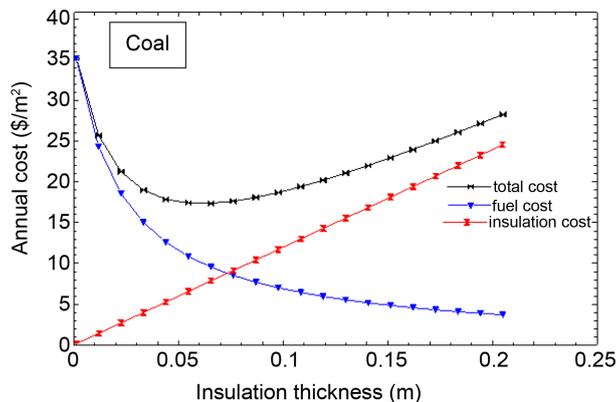


Figure 3. Annual cost versus insulation thickness for expanded polystyrene insulation material for Aydın.

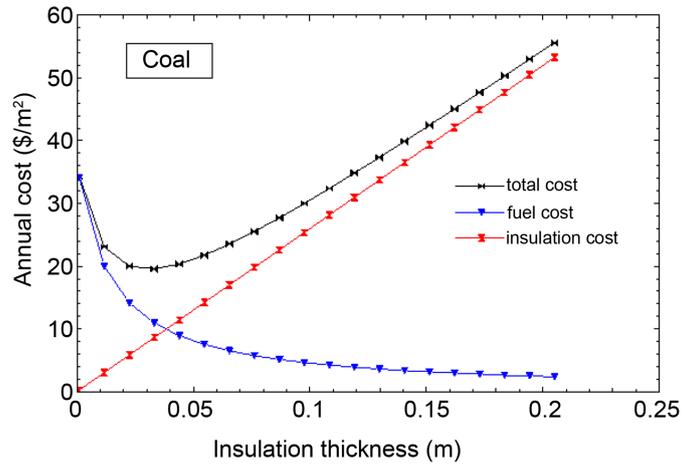


Figure 4. Annual cost versus insulation thickness for polyurethane insulation material for Aydın.

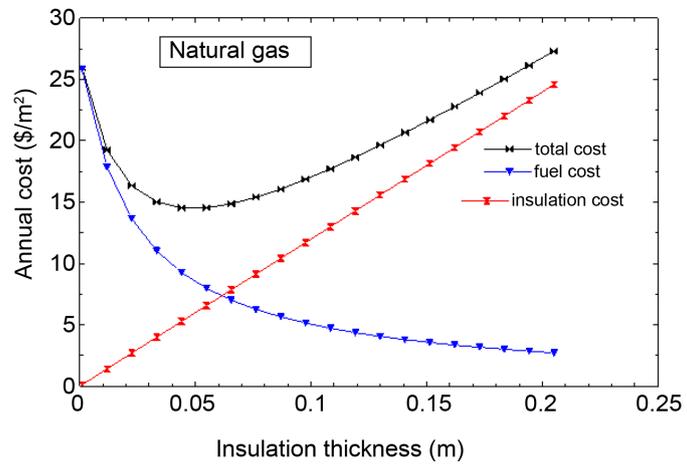


Figure 5. Annual cost versus insulation thickness for expanded polystyrene insulation material for Aydın.

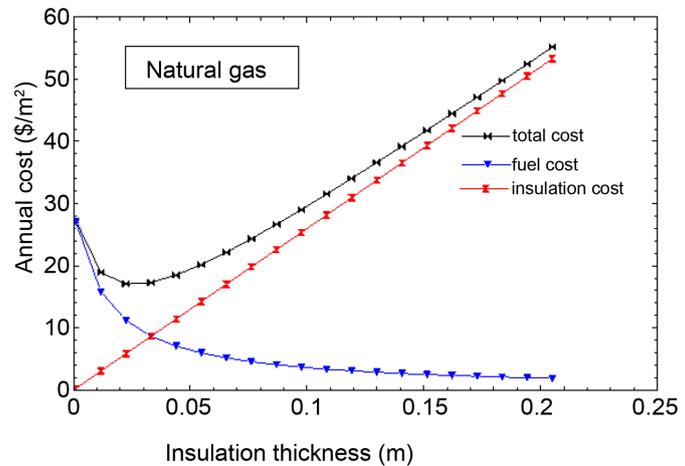


Figure 6. Annual cost versus insulation thickness for polyurethane insulation material for Aydın.

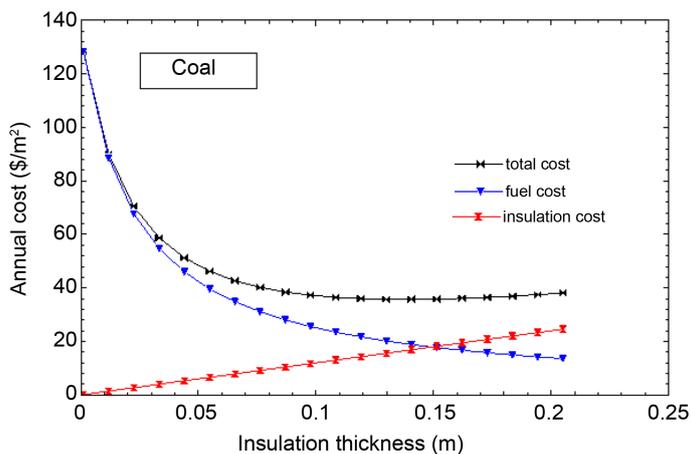


Figure 7. Annual cost versus insulation thickness for expanded polystyrene insulation material for Ardahan.

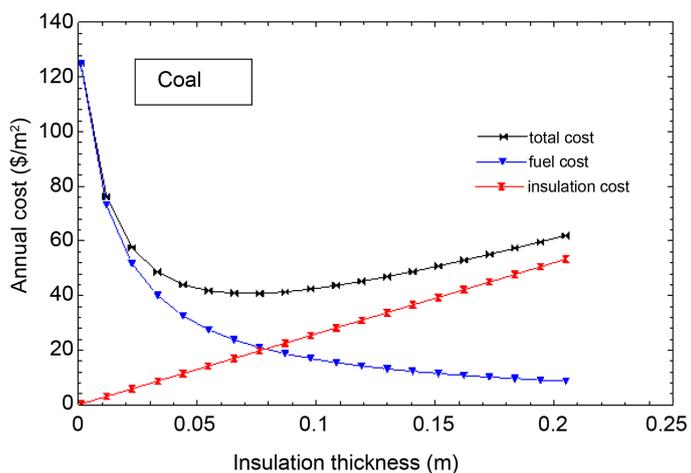


Figure 8. Annual cost versus insulation thickness for polyurethane insulation material for Ardahan.

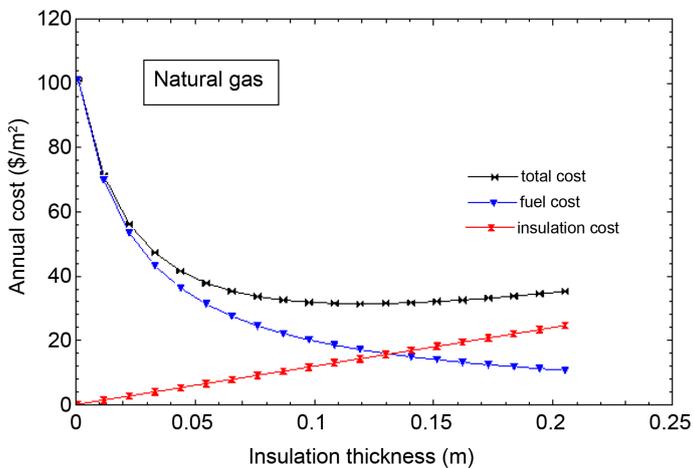


Figure 9. Annual cost versus insulation thickness for expanded polystyrene insulation material for Ardahan.

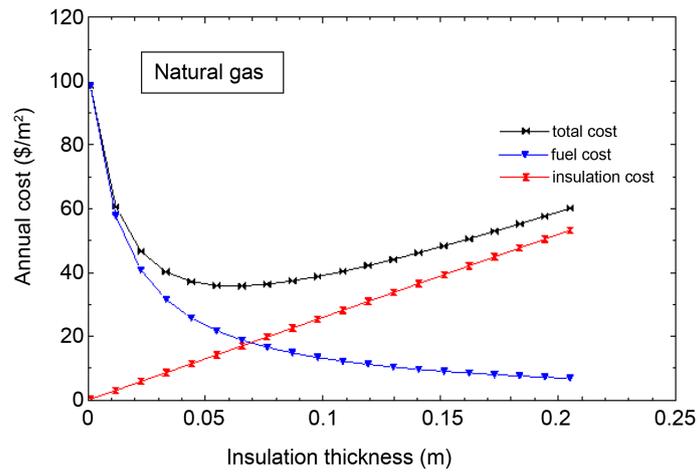


Figure 10. Annual cost versus insulation thickness for polyurethane insulation material for Ardahan.

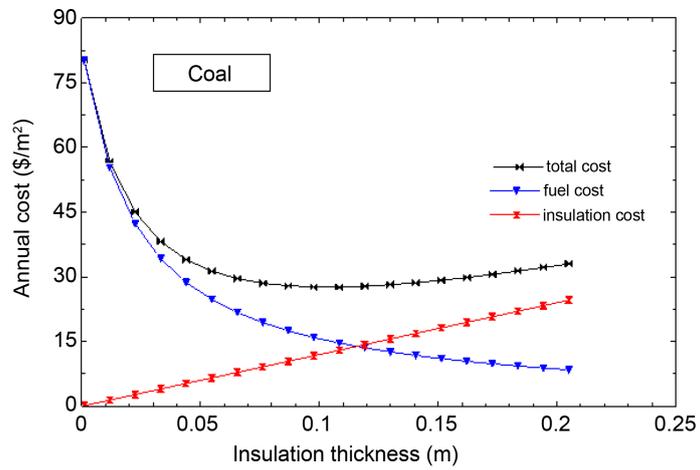


Figure 11. Annual cost versus insulation thickness for expanded polystyrene insulation material for Eskişehir.

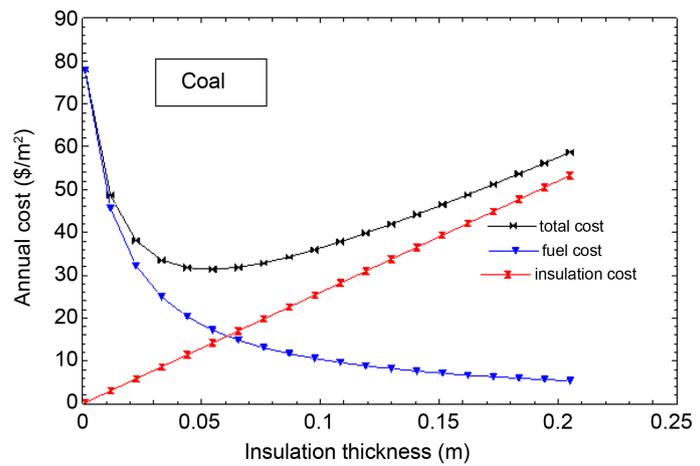


Figure 12. Annual cost versus insulation thickness for polyurethane insulation material for Eskişehir.

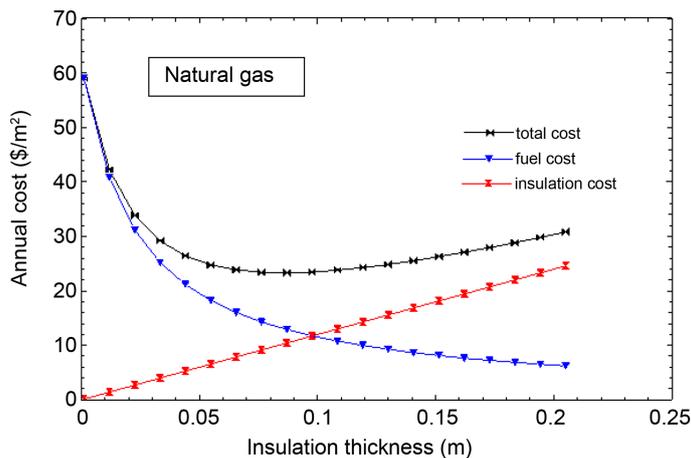


Figure 13. Annual cost versus insulation thickness for expanded polystyrene insulation material for Eskişehir.

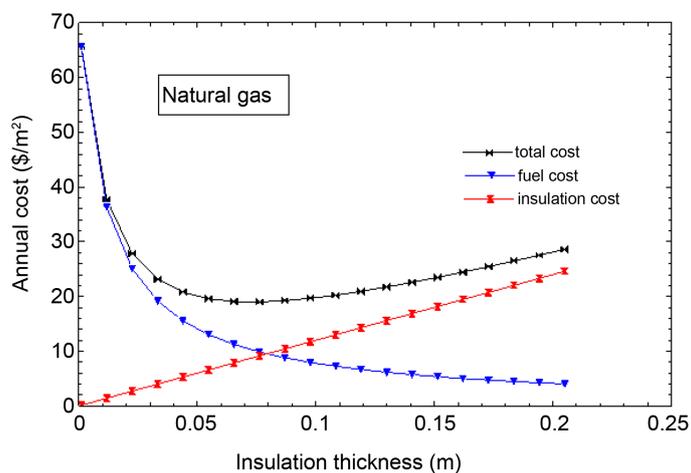


Figure 14. Annual cost versus insulation thickness for polyurethane insulation material for Eskişehir.

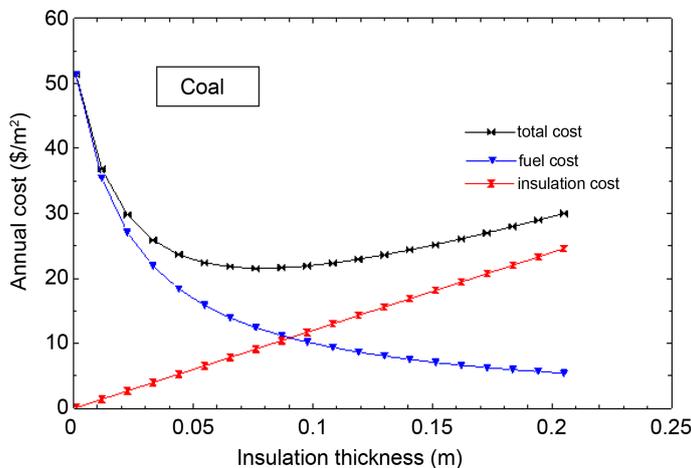


Figure 15. Annual cost versus insulation thickness for expanded polystyrene insulation material for Samsun.

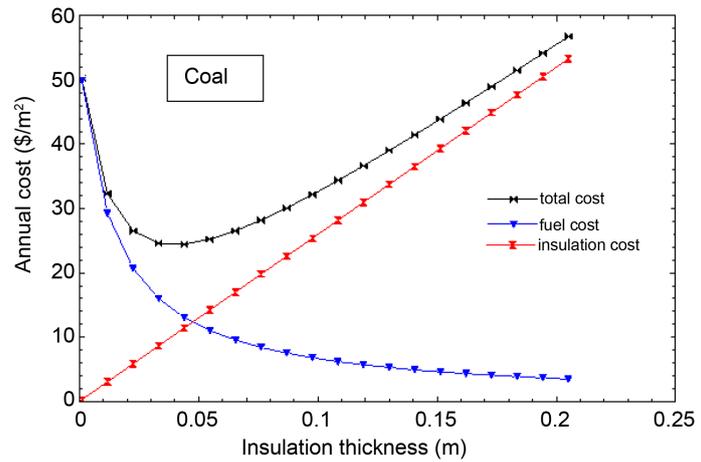


Figure 16. Annual cost versus insulation thickness for polyurethane insulation material for Samsun.

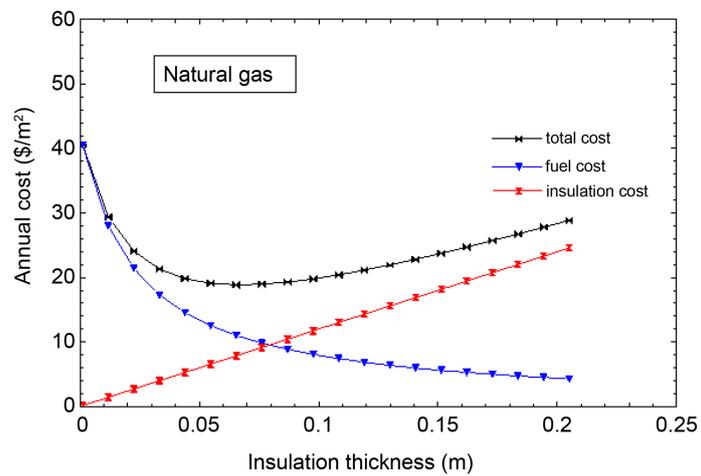


Figure 17. Annual cost versus insulation thickness for expanded polystyrene insulation material for Samsun.

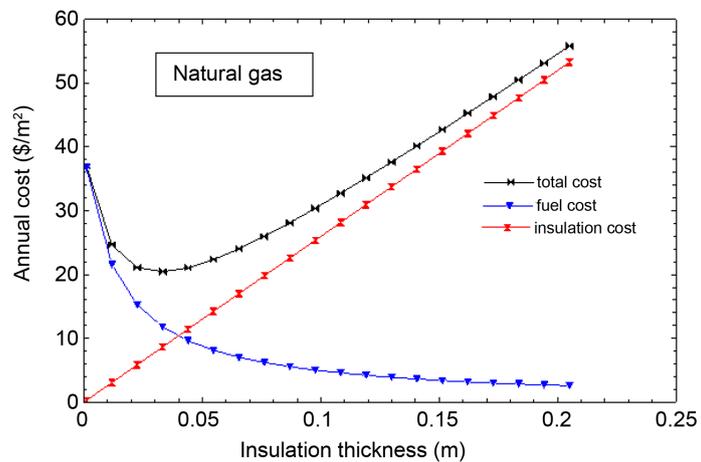


Figure 18. Annual cost versus insulation thickness for polyurethane insulation material for Samsun.

insulation thickness values of Aydın, Ardahan, Eskişehir and Samsun provinces 0.0608 m, 0.137 m, 0.103 m and 0.078 m respectively, for coal and polyurethane insulation material, 0.0304 m, 0.071 m, 0.0532 m and 0.0398 m respectively. For natural gas and expanded polystyrene insulation material, optimum insulation thickness values of Aydın, Ardahan, Eskişehir and Samsun provinces 0.0514 m, 0.1193 m, 0.0895 m and 0.067 m respectively, for natural gas and polyurethane insulation material 0.0255 m, 0.0617 m, 0.0476 m and 0.0338 m respectively.

For the 4 provinces, the changes of CO₂ and SO₂ emissions depending on insulation thickness are shown in **Figures 19-30**. As seen from the figures, while the insulation thickness increases, emission values decrease logarithmically. When compared the provinces of Ardahan in the cold climate region and Aydın in the hottest climate region, for the coal and optimum thickness of expanded polystyrene and polyurethane insulation materials, the reduction of CO₂ and SO₂ emissions of Aydın 72.5% and 68%

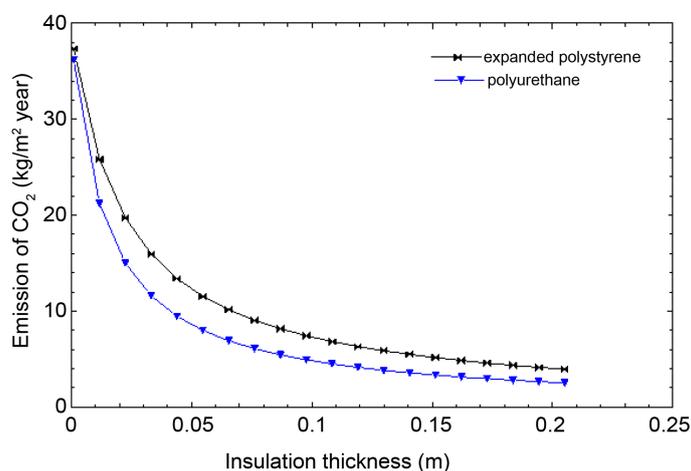


Figure 19. Variation of CO₂ emission with insulation thickness for coal for Aydın.

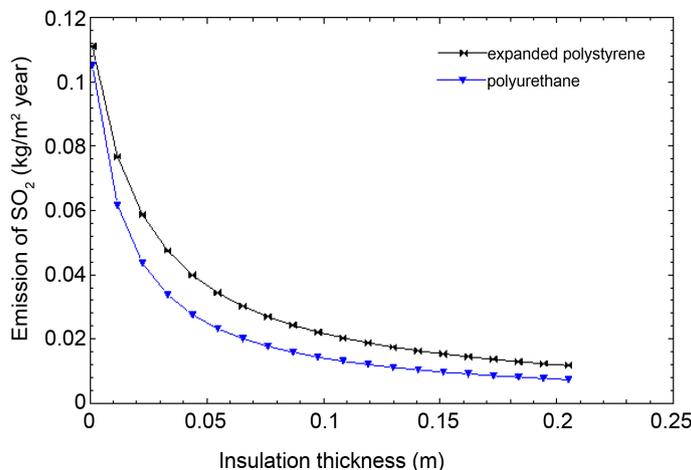


Figure 20. Variation of SO₂ emission with insulation thickness for coal for Aydın.

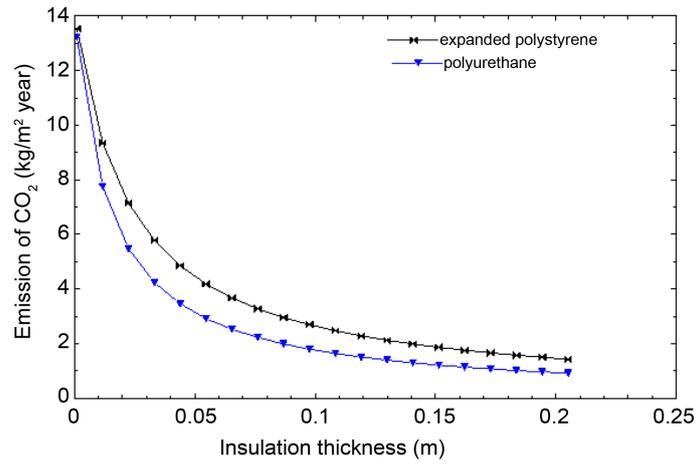


Figure 21. Variation of CO₂ emission with insulation thickness for natural gas for Aydın.

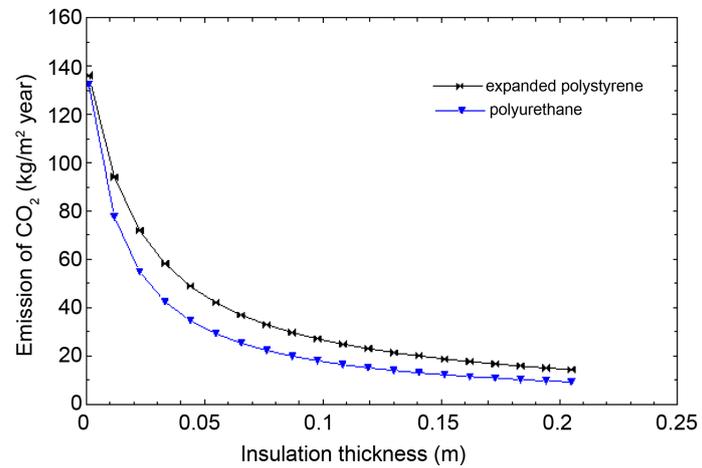


Figure 22. Variation of CO₂ emission with insulation thickness for coal for Ardahan.

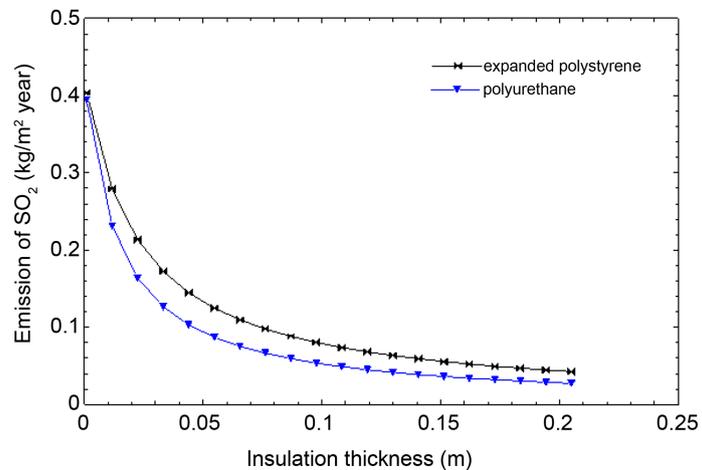


Figure 23. Variation of SO₂ emission with insulation thickness for coal for Ardahan.

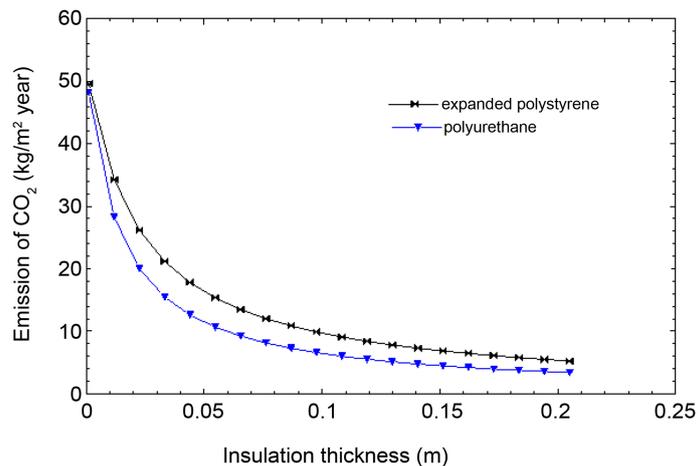


Figure 24. Variation of CO₂ emission with insulation thickness for natural gas for Ardahan.

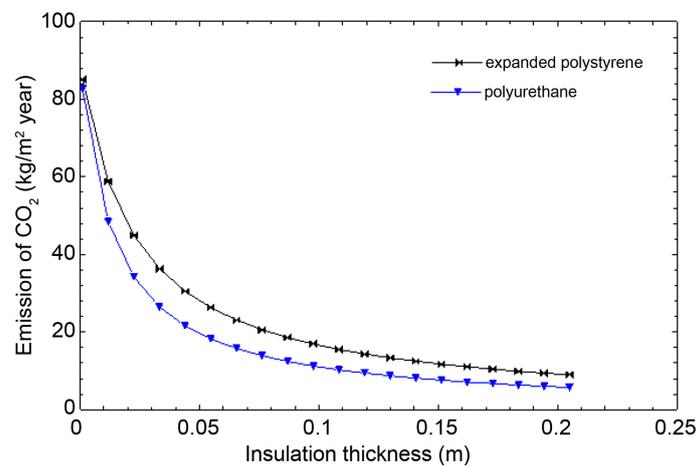


Figure 25. Variation of CO₂ emission with insulation thickness for coal for Eskişehir.

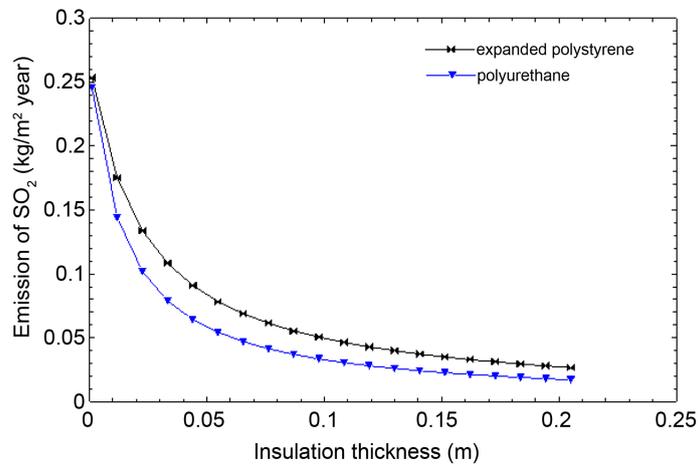


Figure 26. Variation of SO₂ emission with insulation thickness for coal for Eskişehir.

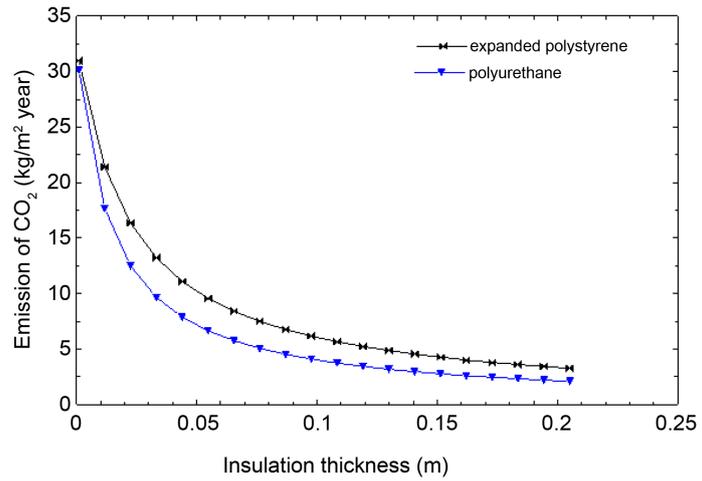


Figure 27. Variation of CO₂ emission with insulation thickness for natural gas for Eskişehir.

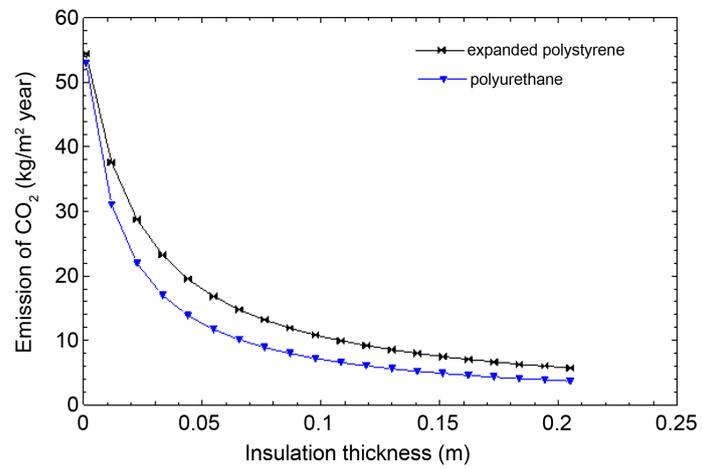


Figure 28. Variation of CO₂ emission with insulation thickness for coal for Samsun.

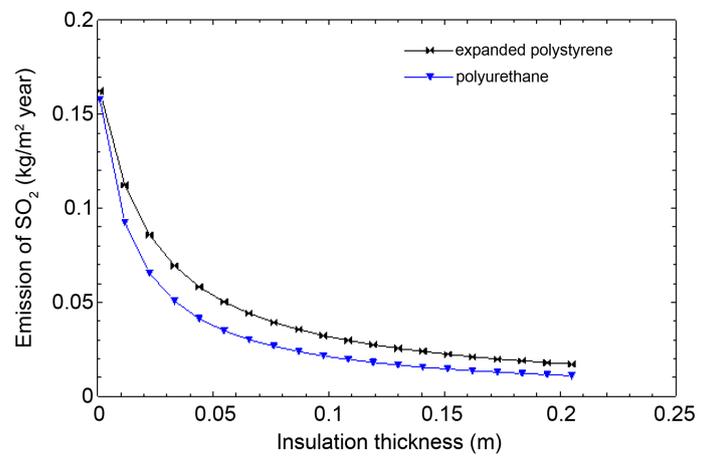


Figure 29. Variation of SO₂ emission with insulation thickness for coal for Samsun.

respectively, for natural gas and optimum thickness of expanded polystyrene and polyurethane insulation materials, the reduction of CO₂ emission of Aydın 69% and 64.2% respectively. For coal and optimum thickness of expanded polystyrene and polyurethane insulation materials, the reduction of CO₂ and SO₂ emissions of Ardahan 85.6% and 83.3% respectively, for natural gas and optimum thickness of expanded polystyrene and polyurethane insulation materials, the reduction of CO₂ emission of Ardahan 69% and 64.2% respectively.

The relations between annual energy cost saving and insulation thickness are shown in **Figures 31-38**. The values of energy cost saving increases up to optimum insulation thickness and beyond this level, the energy cost saving is decreased. For coal and optimum thickness of expanded polystyrene and polyurethane insulation materials, the energy cost savings of Aydın 19 \$/m²-year and 16 \$/m²-year respectively, for natural gas and optimum thickness of expanded polystyrene and polyurethane insulation materials, the energy saving of Aydın 13.9 \$/m²-year and 11.8 \$/m²-year respectively. For coal and

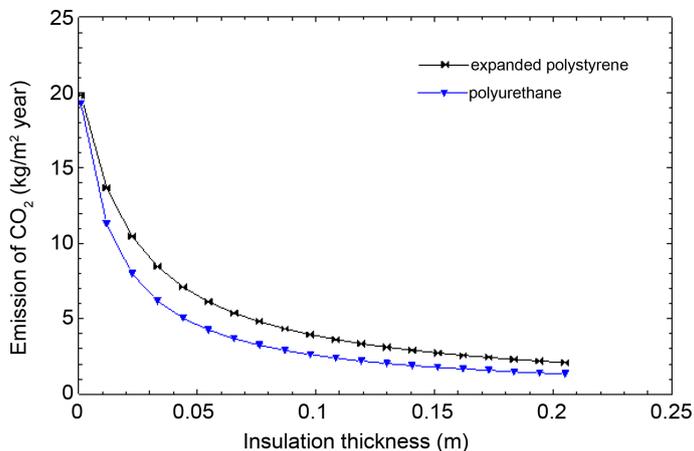


Figure 30. Variation of CO₂ emission with insulation thickness for natural gas for Samsun.

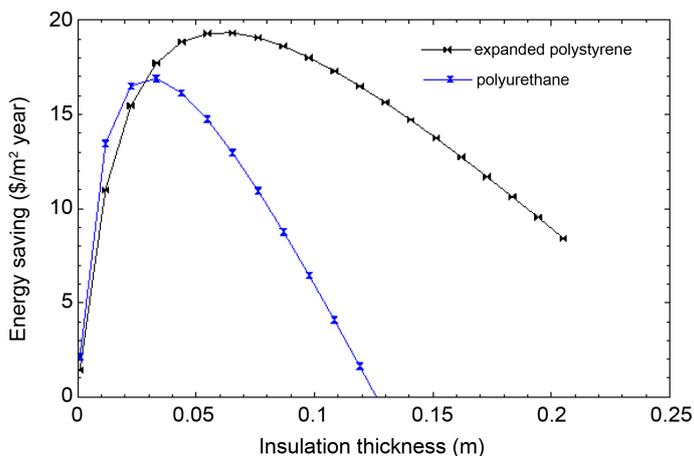


Figure 31. Variation of energy saving with insulation thickness for coal for Aydın.

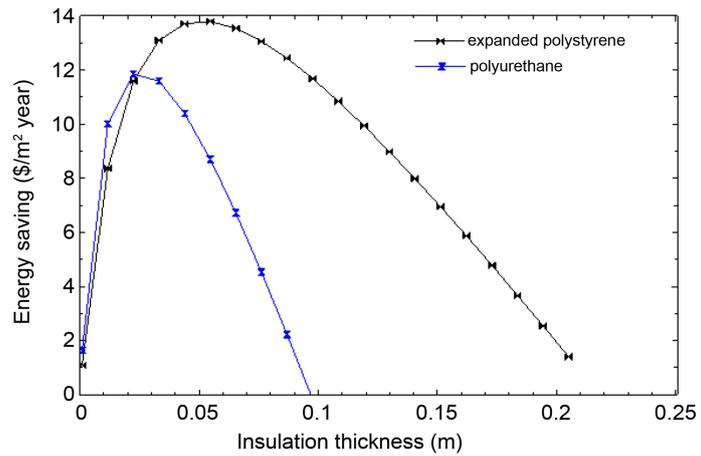


Figure 32. Variation of energy saving with insulation thickness for natural gas for Aydın.

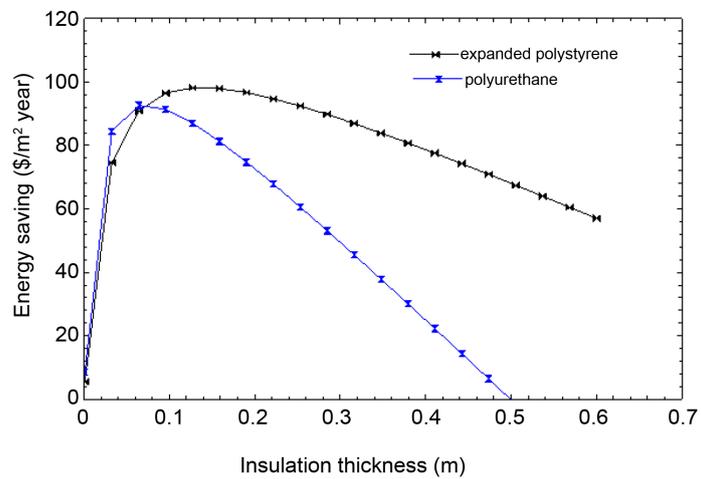


Figure 33. Variation of energy saving with insulation thickness for coal for Ardahan.

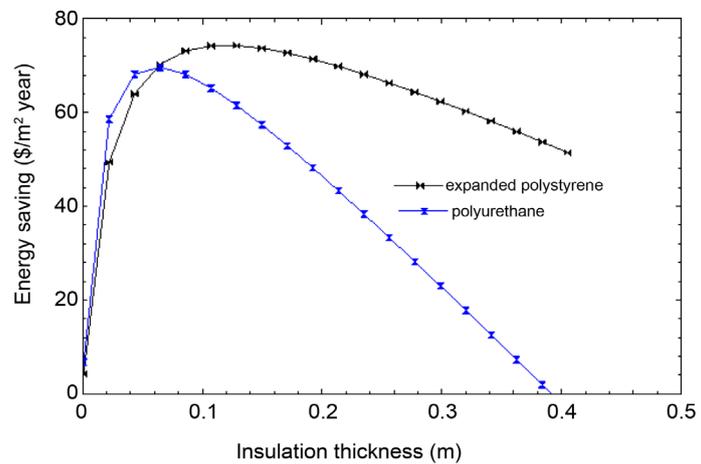


Figure 34. Variation of energy saving with insulation thickness for natural gas for Ardahan.

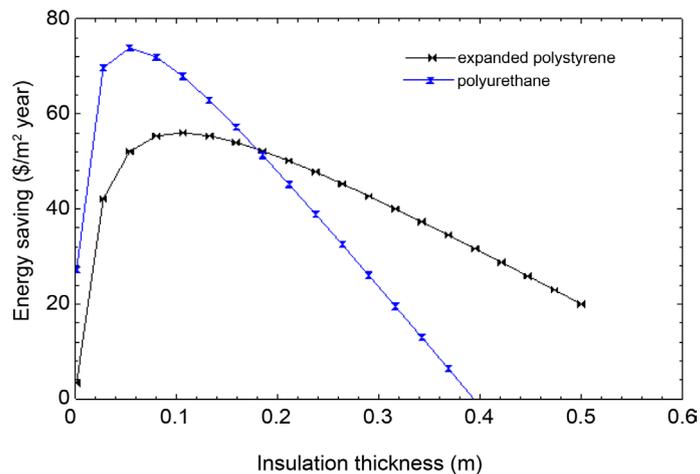


Figure 35. Variation of energy saving with insulation thickness for coal for Eskişehir.

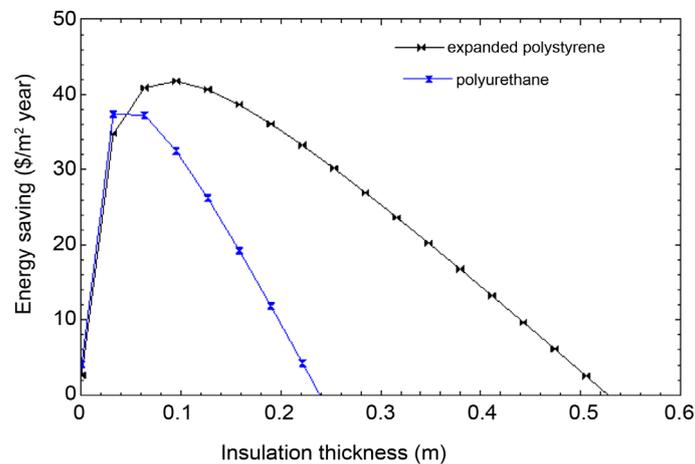


Figure 36. Variation of energy saving with insulation thickness for natural gas for Eskişehir.

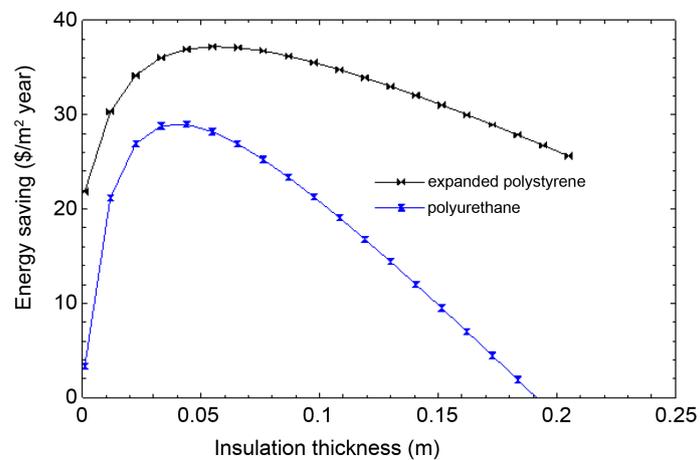


Figure 37. Variation of energy saving with insulation thickness for coal for Samsun.

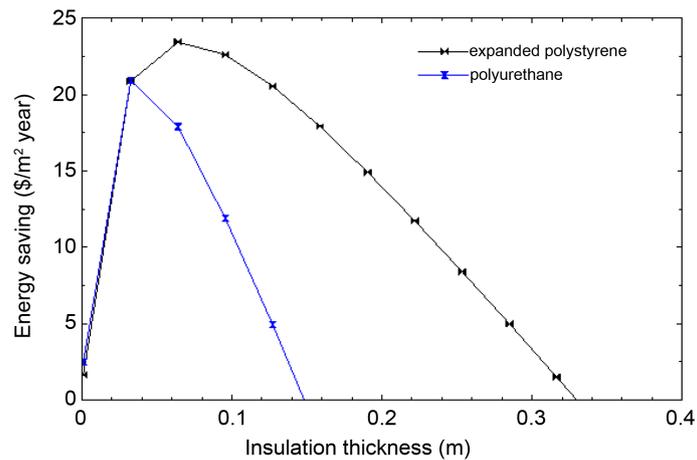


Figure 38. Variation of energy saving with insulation thickness for natural gas for Samsun.

optimum thickness of expanded polystyrene and polyurethane insulation materials, the energy saving of Ardahan 96 \$/m²-year and 88 \$/m²-year respectively, for natural gas and optimum thickness of expanded polystyrene and polyurethane insulation materials, the energy saving of Ardahan 73.35 \$/m²-year and 69.5 \$/m²-year respectively.

4. Conclusion

It has been calculated that Ardahan is located in the coldest climate region and Aydın is located in the hottest climate region. Thickness of the insulation material reduces the CO₂ and SO₂ emissions. It has been indicated that the reduction of CO₂ and SO₂ emissions for expanded polystyrene was higher than the polyurethane for the different climate regions. It can be concluded that the energy cost savings for coal is higher than the natural gas for the different regions. Also the energy cost savings for the expanded polystyrene was higher than the polyurethane insulation materials.

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Nomenclature

C	cost (\$)
C_f	unit cost of fuel (\$/kg)
C_t	total heating cost at present value (\$)
C_{ins}	unit cost of insulation material
HDD	heating degree-days
PWF	present worth factor
k	thermal conductivity coefficient (W/m·K)
q_A	annual heat loss (kJ/m ²)
U	heat transfer coefficient (W/m ² ·K)
m	mass (kg)
$M(m)$	molecular mass (kg/kmol)
n	mole(kmol)
E_A	annual energy needs(kJ/m ² -year)
E_C	annual energy consumption (kJ/m ² -year)
$E_{costsaving}$	annual energy cost saving (\$/m ² -year)
R	thermal resistance (m ² ·K/W)
x	insulation thickness (m)
η	efficiency of the heating system
<i>Subscripts</i>	
Q_{loss}	losses due to heat transfer
$F(f)$	fuel
Ins	insulation
$nins$	non-insulation
opt	optimum
t	total



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