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Effect of insulation thickness on energy saving in cold regions of Türkiye

Türkiye'nin soğuk bölgelerinde yalıtım kalınlığının enerji tasarrufuna etkisi

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Abstract
In the countries procuring a major amount of their energy from abroad, using of the energy effectively and ensuring the energy-saving become gradually more important. In this study, considering the climatic and meteorological conditions of Van province, optimum insulation thickness, payback period, and energy-saving values were analyzed for three insulation materials (rock wool, polyurethane, XPS) and five energy sources (imported coal, fuel oil, LPG, natural gas and electricity) on wall models built with pumice and aerated concrete. The optimum insulation thickness was calculated using the interest and inflation rates. The calculations were made by making use of the lifecycle cost analysis (LCCA). Insulation thickness that should be applied depending on the wall elements used in buildings can vary. Thus, examining the wall models, insulation materials and energy sources were examined, and the optimum insulation thicknesses, annual savings, and payback periods were found to be 3-15.6 mm, 30-63%, and 1.4-5.8 years, respectively, in the present study.

Keywords: Energy saving, Life Cost Analysis, Thermal insulation.

Öz
Enerji kullanımında dışa bağımlı ülkelerde enerjinin verimli olarak kullanılması ve bu sayede enerjiden tasarruf sağlanması gitgide daha önemli hale gelmektedir. Bu çalışmada, Van ili şartları ve meteorolojik değerleri göz önüne alınarak, bims ve gaz beton ile inşa edilen duvar modelleri üzerinde, üç farklı yalıtım malzemesi için (taş yünü, poliüretan, XPS) optimum yalıtım kalınlıkları, geri ödeme süreleri ve enerji tasarrufları, beş farklı enerji kaynağı (ithal kömür, fuel-oil, LPG, doğalgaz ve elektrik) dikkate alınarak incelenmiştir. Optimum yalıtım kalınlıkları; faiz ve enflasyon değerleri yardımıyla ömür maliyet analizine (lifecycle cost analysis) göre elde edilmiştir. Mimarilerde kullanılan duvar bileşenlerine göre uygulanması gereken yalıtım kalınlığının farklılık göstereceği bilinciyle, çalışmada incelenen duvar modelleri, yalıtım malzemeleri ve enerji kaynakları göz önüne alınarak, optimum yalıtım kalınlıkları, yıllık tasarruf miktarları ve geri ödeme sürelerinin sırasıyla; 3-15.6 mm, %30-63 ve 1.4-5.8 yıl aralıklarında olduğu elde edilmiştir.

***Anahtar kelimeler**: Enerji tasarrufu, Ömür Maliyet Analizi, Isı yalıtımı.*

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1. Introduction

1. Giriş

Today, especially because of the climate-related global problems, it is very important to have the energy and to use it efficiently. The need for energy constitutes one of the most important items in the budget for both governments and individuals. Moreover, in many countries, the need for energy increases with advancing technology and industry (Tolun 2010). In Türkiye, however, the energy requirement is met mainly using fossil fuels and renewable energy. A remarkable portion of these energy sources is imported. Approx. 35-40 of imported energy is used in heating the houses (Isık & Tugan 2017). Besides that, a large portion of the total energy is used in buildings in Türkiye and 80% of this energy is consumed in heating and cooling (Gurel & Cingiz 2011). As stated in the 2018 Energy Efficiency Development Report by the General Directorate of Renewable Energy – Ministry of Energy and Natural Resources, 20% of total energy and 22% of total electric energy are consumed in houses in Türkiye. Approx. 60% of this energy is consumed for heating purposes in buildings (ETKB 2018). When compared to the EU countries, the amount of energy used in houses is remarkably high (European Commission (EC) 2018). Previous studies reported that, if the amount of energy used in buildings having sufficient heat insulation is decreased to the level of EU, the energy-saving could reach 30-40% in Türkiye (CSB 2015).

Measures to be taken for energy efficiency in residences; insulation, preventing the formation of thermal bridges, preventing losses from windows, disconnecting the air-conditioned environment with the outside air, using canopies, using a double door system at building entrances. Thermal insulation in buildings has many other benefits besides energy and fuel savings. Human and environmental health is one of them. Because the amount of energy consumed with thermal insulation applications will decrease, the amount of harmful gases will decrease and their effects will be alleviated. Therefore, a healthier and more comfortable environment will be created (Bektas et al. 2017). The importance of the heat transfer from inner environment and outer environment becomes more remarkable considering saving the energy used for heating. Given the principles of thermodynamics, the heat transfer occurs between two media having different temperature values. This transmission occurs generally from a high-temperature medium to a low-temperature medium (Isık & Tugan 2017). The heat insulation becomes more important at this point. Heat insulation is the most efficient way to save energy in houses. From a general perspective, heat insulation can be defined as decreasing the heat transition between two media having different temperature levels (Karabey et al. 2012). Heat insulation in houses offers various advantages including a decrease in the fuel expenses, prolonged lifetime of building, a more livable and comfortable environment to be heated, and decreasing the harm to the environment by consuming less energy.

The type of material to be used in heat insulation and the optimum insulation thickness should be carefully calculated. The insulation process creates a cost at the beginning. This cost is compensated with the lower level of energy consumption in the process. When performed by using carefully selected parameters, 50% saving can be achieved and the payback period ranges between 3 and 5 years (Kaynakli & Yamankaradeniz 2007). Using a well-adjusted insulation thickness, heat loss (in case of low temperature) and heat gain (in case of high temperature) decrease. However, after a specific insulation thickness, the increasing thickness does not contribute to the energy-saving (Karabey et al. 2012). Hence, it is important to accurately determine the insulation thickness.

Another point to consider while calculating the optimum insulation thickness is the heating and cooling degree-day regions. It explains which parts of 24 hours of a day are cold for heating day-degrees. Similarly, the outer temperature should be considered for cooling day-degrees (Ucar 2010). In some of the studies carried out in Türkiye, 4 or 5 regions were reported. As stated by Bulut et al. (2007) in their study on determining the heating and cooling degree day regions, it was determined that there are five regions in Türkiye. The present study carried out in Van province is in the fourth region. Thus, heating is performed 7 months of a year. Taking the inner temperature to be t_h=20 °C and outer temperature to be approx. t_e<15 °C, the degree-day number would be DD=3988 °C days (Dagsoz & Bayraktar 1995).

Gustafsson (2000) carried out a study in Sweden on the insulation dimensions in order to reduce the costs. In that study, the costs and benefits of insulation and economic transformations were examined from various aspects. Golcu et al. (2006) examined the effects and results of optimum insulation thickness on the energy saving. In their study, they used coal as the energy source and the optimum insulation thickness was found to be 0.048 m, annual saving to be 42%, and payback period to be 2.4 years. Gulten and Aksoy (2007) investigated the energy expenses in outer wall system alternatives for different fuel types. In their study, they determined that, when applying the optimum insulation thickness to the wall, there was a reverse relationship between payback period and optimum insulation thickness.

Yu et al. (2009) carried out a study on the insulation thickness for an ideal and economical heating system. In their study, the authors stated that determining the insulation material is also important for insulation thickness and prices and thermal efficiencies should be considered while determining the material. Ucar and Balo (2010), in their study, selected cities from 4 different regions and calculated the payback periods of optimum insulation thickness with different insulation materials by 5 different fuel types. The longest payback period was found in Mersin province located in Mediterranean Region and the shortest one in Bitlis province located in the Eastern Anatolia region.

Karabey et al. (2012) investigated the optimum insulation thickness and conducted an energy-cost assessment for different fuel types and the brick-wall structure used in Van province. In their study, by using two different wall models in Van province, insulation thickness, energy-saving, and payback period values were calculated for five fuel types. In India, Mishra et al. (2012) calculated the optimum insulation thickness values for external walls and roof by using glass wool and expanded polystyrene. In their study, they used the degree-day method. The energy-saving and the payback period values were calculated. Conducting cost analysis for all the cities in Türkiye, Kurekci et al. (2012) computed the heat insulation thickness values. In their study, they used two fuel types (natural gas and coal). Moreover, analyzing five different insulation materials, they also calculated optimum insulation thickness and payback period values. Ashrafian et al. (2016), in their study, investigated different insulation materials for houses in three different regions of Türkiye. Isık and Tugan (2017) conducted calculations in order to minimize the heat losses and energy expenses by making use of optimum heat insulation thickness in Tunceli, Hakkari, and Kars provinces in Türkiye. As a result, the authors reported the optimum insulation thickness to be 7.9 cm for Tunceli, 8.2 cm for Hakkari, and 10.4 cm for Kars. In a postgraduate thesis, Erdogan (2018) computed optimum heat insulation thickness and payback periods and costs for different lifetimes of various insulation materials for Bursa province, which is located in the second degree-day region, for non-zero real interest rates. Dylewski and Adamczyk (2018) examined various characteristics of heating and conducted climatic and economic analyses for this purpose. They emphasized that the climate of location and the cost should be considered while calculating the optimum insulation thickness. In a previous study, Bektas (2018) used the TS825 standard and cost analysis method and determined the optimum insulation thickness for a building under the conditions of Ankara province. The calculations were performed for five different insulation materials and external-coating of two different wall models. It was determined that brick and aerated-concrete walls should not have the same thickness.

Rosti et al. (2020), in their study carried out in Iran, calculated the payback period and saving obtained from the optimum thickness on the outer wall for all the climate regions in Iran. Gelis and Yesildal (2020) investigated the classical and modern construction components. In their study, they used different wall components in 4 degree-day regions of Türkiye as sample. They reported that the minimum insulation thickness value should be 2-7cm in the 1st degree-day region, 2-8cm in the 2nd degree-day region, 3-10cm in the 3rd degree-day region, and 4-13cm in the 4th degree-day region. Gelis and Yesildal (2020), in another study, examined the insulation thicknesses for different materials for the climatic conditions of Gumushane province by using TS 825 standard. In their study, they reported that the minimum insulation thickness should be 4cm for the structures in Gumushane. Kalhor and Ememinejad (2020) conducted analyses on insulation materials by using heat resistance and other factors. Insulation materials were traditionally chosen, and suggestions were provided for those materials. In another study carried out by Unver et al. (2020), heat insulation practices were examined for houses considering their climate regions. At this point, optimum thickness and payback periods of different insulation materials were tested. Kizirgil (2021) determined the optimum insulation thickness and environmental effects for the cold regions of Türkiye. In that study, optimum insulation thickness, costs, and CO_2 emission analyses were performed for two fuel types and four materials for 15 provinces located in the cold climate region.

In the present study, considering the conditions and meteorological characteristics of Van province, optimum insulation thicknesses, payback periods, and energy savings were analyzed for three different insulation materials (rock wool, polyurethane, XPS) and five different energy sources (imported coal, fuel oil, LPG, natural gas, and electricity) on the wall models built using pumice and aerated concrete. The results were compared and presented in tables and graphs. In this way, it is aimed to enrich the existing studies in the literature by making a detailed analysis on insulation about Van province. At the same time, it is expected that this study will shed light on other studies related to thermal insulation, energy saving and environmental impact.

2. Material and method

2. Materyal ve metot

Even though they vary depending on the architectural project and status, the heat losses in multi-storey buildings arises generally from outer walls by 40% of total heat, windows by 30%, roof by 7%, basement floor by 6%, and air leaks by 17%. For a single-storey house, heat losses occur from outer walls by 35%, roof by 22%, windows by 20%, basement by 20%, and air leaks by 13%. As can be seen, the largest portion of heat loss in buildings arises from outer walls, windows, ceiling-roof, and floor (Altinisik 2006). For this reason, the outer walls causing the highest level of heat loss were examined in this study and the samples that are most widely preferred in Van province were used.

The energy-saving in buildings mainly depends on accurate details, use of high-quality materials, and performing a perfect application with skillful craftsmanship. Heat insulation should be a specialty. Thus, it should be performed by expert professionals; energy saving should be achieved using heat insulation and the individuals living in the place should be provided with comfortable conditions.

In Van, the fuels such as natural gas, domestic and imported lignite, liquid fuels, oil-derivative waste oils, wood, etc. are used for heating. Old automobile tires are crumbled and combusted in industrial zones (Cinar & Kocu 1999).

In Van province, the use of fossil fuels in heating the constructions is at a much higher level in winter. This is because no sufficiently effective insulation materials have been used especially in old structures. Heat Insulation Principles have not been implemented in buildings. Thus, too much energy is consumed in heating the non-insulated buildings in the winter season and the use of fossil fuels increases. This causes environmental pollution. Because of the harmful gases and particles, important air pollution and environmental problems have been experienced in Van, especially in the winter season.

In a well-insulated medium, a large portion of the energy to be obtained by making use of an appropriate combustion method can be used as useful heating energy and the environment-polluting effect of fuel being combusted can be minimized.

Assessing the insulation materials in terms of applicability, price, procurement, fire safety, and environment and public health, it should be considered that they also should comply with the standard that the industry has set for future advancements. These purposes should be analyzed together with their combined effects within the scope of regulations, market, and safety (Gelis & Yesildal 2020). In the present study, by using maximum heat transfer coefficient (U) values recommended for four degree-day regions, the minimum insulation thickness, in which the heat transfer coefficient is a parameter, was calculated.

Because different wall structure components are used in buildings and there are different practices, pumice and aerated concrete that are among the most widely used wall structure components in Van province were used as standard structure components. The minimum insulation thickness recommendations were calculated for the type and thickness of these components (10 cm for pumice concrete and 20 cm for aerated concrete).

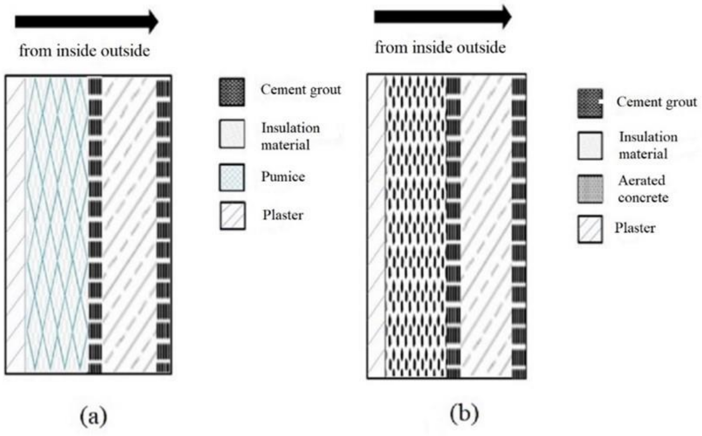

Figure 1. Cross-section of outer-wall components.
Şekil 1. *Dış duvar bileşenlerinin kesit görünüşü.*

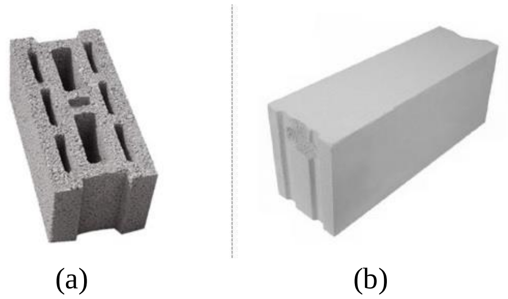

Figure 2. Construction components used in outer wall.
Şekil 2. *Dış duvarda kullanılan yapı elemanları.*

2.1. Calculations
2.1. Hesaplamalar

Building envelope plays an important role in heat gains and losses in buildings. Heat losses in buildings generally occur through outer walls, windows, ceilings, basements, and air leakages. It suggests the necessity of heat insulation. In the present study, optimum insulation thickness was calculated considering only the losses occurring on the outer walls and ignoring the heat bridges. Heat loss on the unit surface of outer wall is calculated using the formula below

$$q = U.\Delta T \quad (1)$$

where, q refers to the heat loss on the unit surface of outer wall, U to heat transfer coefficient of outer wall, and ΔT to temperature difference between two sides.

Annual heat loss on the unit surface is

$$q_A = 86400.DD.U \quad (2)$$

where, q_Y refers to annual heat loss on the unit surface of outer wall and DD to the degree-day number.

The annual amount (E_A) of energy needed for heating due to the heat loss on the unit surface of outer wall is calculated by dividing the annual heat loss by the efficiency of system (Açıkkalp & Kandemir 2019).

$$E_A = 86400 \cdot DD \cdot U/\eta \quad (3)$$

Total heat transfer of wall U is

$$U = \frac{1}{R_i + R_w + R_{ins} + R_o} \quad (4)$$

where, R_i refers to heat resistance of inner surface, R_w to heat resistance of non-insulated wall layers, R_{ins} to heat resistance of insulation material, and R_o to heat resistance of outer surface.

Heat resistance of insulation material (R_{ins}) is

$$R_{ins} = \frac{x}{\lambda} \quad (5)$$

where, x refers to insulation material thickness and λ to insulation material's heat transfer coefficient (Kandemir et al. 2019).

Total heat resistance of non-insulated wall layer is

$$R_{wt} = R_i + R_w + R_o \quad (6)$$

Total heat transfer is

$$U = \frac{1}{R_{wt} + R_{ins}} \quad (7)$$

In conclusion, annual amount of energy consumed E_A is

$$E_A = \frac{86400 \cdot DD}{(R_{wt}+R_{ins}) \cdot \eta} \quad (8)$$

The lifecycle energy cost analysis of a system or a component of a system was conducted using the Lifecycle Cost Analysis method. The annual cost of energy for heating the unit area (insulated or non-insulated) (C_E) is

$$C_E = \frac{86400 \cdot DD \cdot C_F}{(R_{wt}+R_{ins}) \cdot H_u \cdot \eta} \quad (9)$$

Where, C_F refers to the cost of the energy source and H_u to the lower calorific value of the energy source (Kurekci et al. 2012).

Lifecycle cost analysis (LCCA) was used in calculating the optimum insulation thickness. Total heating cost was calculated by combining lifecycle (N) and real value factor (PWF). Real value factor is related with inflation rate (g) and interest rate (i). Real interest rate (r) and PWF are calculated using interest rate and inflation rate (Acıkkalp & Kandemir 2019).

$$r = \frac{i-g}{1+g} \quad (10)$$

$$PWF = \frac{(1+r)^N - 1}{r \cdot (1+r)^N} \quad (11)$$

In Equation 11, N refers to lifecycle and was taken as 10 years. Investment cost C_{ins} (\$/m^2) is calculated as follows.

$$C_{ins} = C_i \cdot x \quad (12)$$

Where, C_i refers to the cost of insulation material (\$/m^3) and x to the insulation material thickness (Kandemir et al. 2019).

In conclusion, the total heating cost of an insulated building was calculated using lifecycle cost analysis (LCCA)

$$C_t = (C_{ins} \cdot PWF) + C_i \cdot x \quad (13)$$

or

$$C_t = \frac{86400 \cdot DD \cdot C_F}{(R_{wt}+R_{ins}) \cdot H_U \cdot \eta} + C_i \cdot x \quad (14)$$

Optimum insulation thickness is calculated in order to minimize the total heating expenses or maximize the annual savings. Optimum insulation thickness is calculated by taking the derivative of total heating expenses (Equation 14) by the insulation thickness (x). In conclusion, the optimum insulation thickness, where the investment cost and fuel expenses are at optimum, is

$$x_{opt} = 293{,}94\left(\frac{DD \cdot C_F \cdot PWF \cdot \lambda}{H_U \cdot C_i \cdot \eta}\right)^{\frac{1}{2}} - \lambda \cdot R_{wt} \quad (15)$$

Payback of investment is an important parameter. It requires the calculation of the payback period. This period is calculated by proportioning the annual heating expenses of non-insulated condition to the annual total heating cost different calculated for insulated and non-insulated conditions. The payback period was calculated using the formulas below (Işık & Tugan 2017).

Total heating expense of non-insulated building is;

$$C = \frac{86400 \cdot DD \cdot C_F \cdot PWF}{(R_{wt}) \cdot H_U \cdot \eta} \quad (16)$$

Payback period is

$$PP = \frac{C}{(C - C_{ins})} \quad (17)$$

As seen in Equation 15, optimum insulation thickness varies depending on the parameters such as energy source costs, insulation material costs, wall and insulation material characteristics, and PWF. For Van province, the parameters used in the calculation of optimum insulation thickness, annual savings, and payback periods are presented in Table 1(AKSA Naturel Gas 2022; Hepsiburada 2022; Bulut et al. 2007; TS 825 2008; TUIK 2022).

Table 1. Parameters used in calculations.
Tablo 1. *Hesaplamalarda kullanılan parametreler.*

Parameters			
R_{wt} (pumice all model)	1.16 W/m^{2}K	H_u (natural gas)	34542750 j/kg
R_{wt} (aerated concrete wall model)	1.21 W/m^{2}K	H_u (electricity)	3600820 j/kg
PWF	9.81	H_{coal}	0.65
DD (°C day)	3476	$\eta_{fuel-oil}$	0.80
λ (rock wool)	0.040 W/mK	η_{LPG}	0.92
λ (polyurethane)	0.035 W/mK	$H_{n.gas}$	0.93
λ (XPS)	0.031 W/mK	$H_{electricity}$	0.99
c_i (rock wool)	65.4 $/m^3	C_F (imported coal)	0.18 $/kg
c_i (polyurethane)	115.4 $/m^3	C_F (Fuel-oil, No:4)	0.6 $/kg
c_i (XPS)	61.5 $/m^3	C_F (LPG)	0.97 $/kg
H_u (imported coal)	29309000 j/kg	C_F (natural gas)	0.19 $/m^3
H_u (Fuel-oil, No:4)	41346625 j/kg	C_F (electricity)	0.07 $/kg
H_u (LPG)	46475700 j/kg	i=14 (mean value for December 2021), g=13.6 (December 2021), N=10 years	

3. Results and discussion
3. Bulgular ve tartışma

The investment expenses increase with increasing thickness of insulation used in building walls but heating costs and fuel expenses decrease. The effect of insulation thickness on the fuel and investment costs increases after a specific value. The value yielding the minimum total cost yields the optimum insulation thickness. Using rock wool, polyurethane, and XPS as insulation materials for the wall models widely preferred in Van province, optimum insulation thickness was calculated for five different energy sources by making use of Equation 15. The results obtained for pumice and aerated concrete walls are presented in Table 2.

Table 2. Optimum insulation thicknesses for wall models by different energy sources.
Tablo 2. *Farklı enerji kaynaklarına göre duvar modelleri için optimum yalıtım kalınlıkları.*

Energy Source	**Optimum Insulation Thickness (m)**					
	Pumice concrete wall model			**Aerated concrete wall model**		
	rock wool	**polyurethane**	**XPS**	**rock wool**	**polyurethane**	**XPS**
Imported Coal	0.084	0.051	0.082	0.082	0.049	0.081
Fuel-oil	0.134	0.087	0.128	0.132	0.085	0.126
LPG	0.156	0.102	0.147	0.154	0.1	0.146
Natural Gas	0.057	0.032	0.058	0.055	0.030	0.056
Electricity	0.142	0.092	0.135	0.140	0.09	0.133

Total annual heating expenses were calculated for an insulated building under the conditions of Van province by five different energy sources and two different wall models by making use of Equation 14. Then, the relationship between annual total cost and optimum insulation thickness was illustrated in diagrams for energy sources and wall types; the relationships for the pumice concrete wall are illustrated in Figures 3-5 and those for the aerated concrete wall in Figures 6-8. The values used in calculations are presented in Table 3.

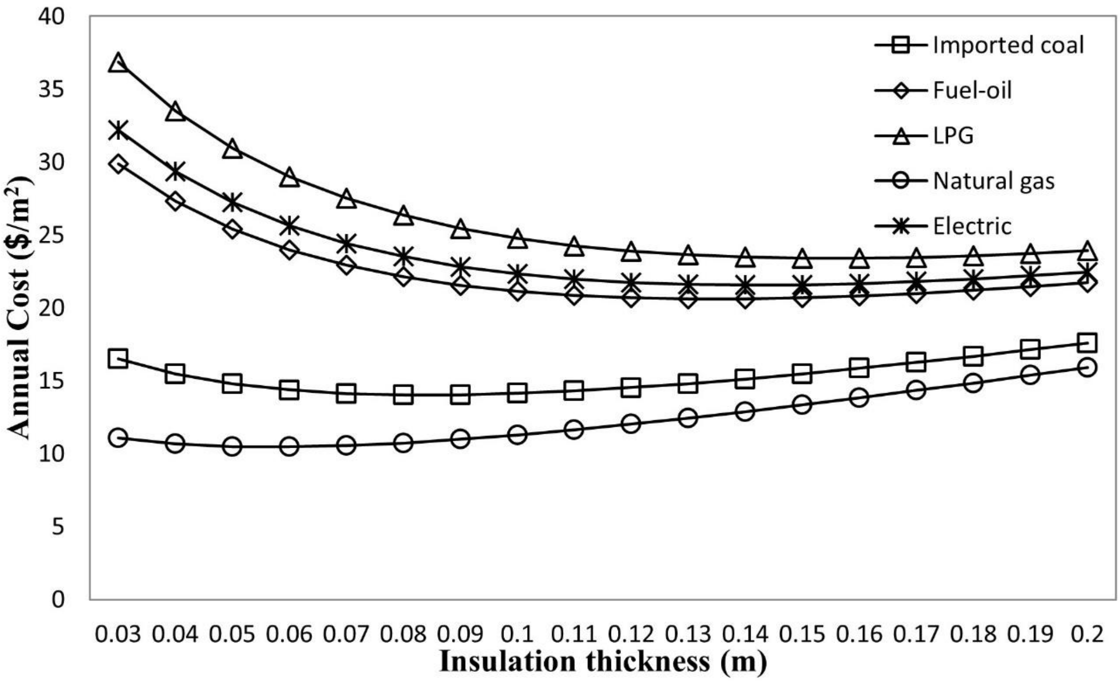

Figure 3. Effect of the insulation thickness on the annual total expenses for rock wool and pumice concrete wall model.
Şekil 3. *Bims ile yapılan duvar modelinde taş yünü kullanılan durum için yalıtım kalınlığının yıllık toplam maliyet üzerine etkisi.*

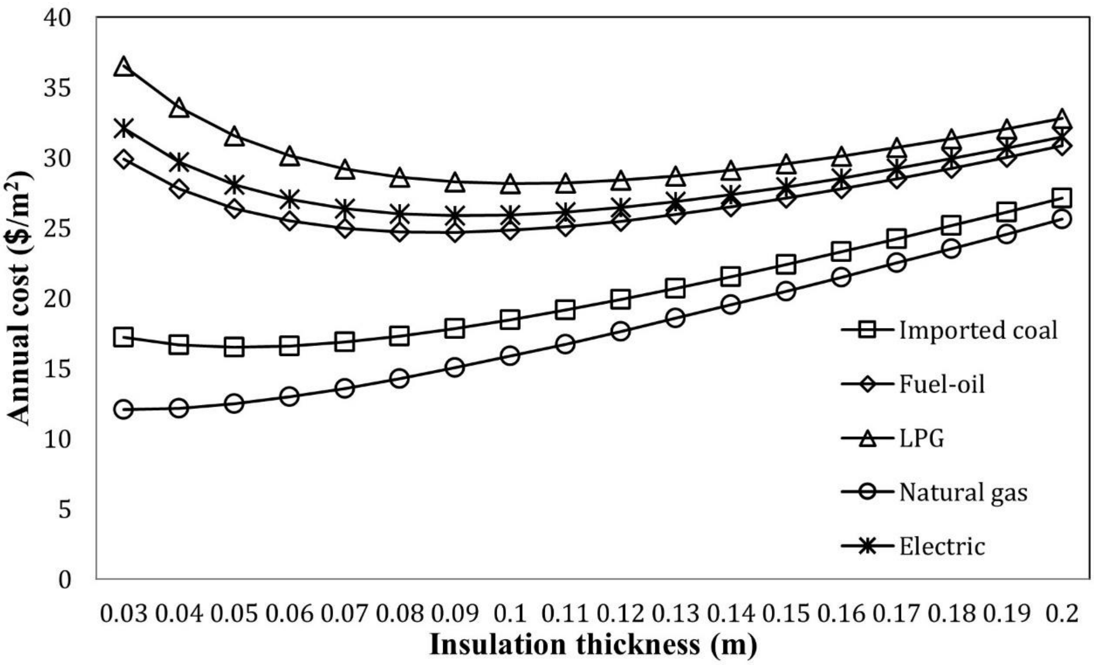

Figure 4. Effect of the insulation thickness on the annual total expenses for polyurethane and pumice concrete wall model.
Şekil 4. *Bims ile yapılan duvar modelinde poliüretan kullanılan durum için yalıtım kalınlığının yıllık toplam maliyet üzerine etkisi.*

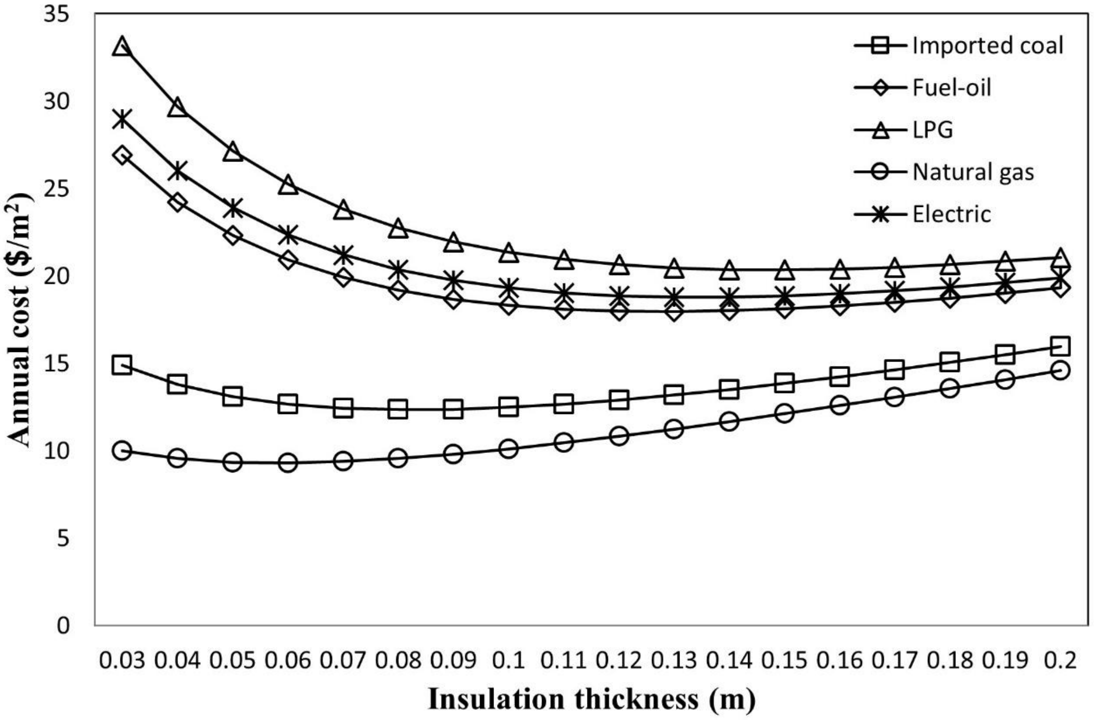

Figure 5. Effect of the insulation thickness on the annual total expenses for XPS and pumice concrete wall model.
Şekil 5. *Bims ile yapılan duvar modelinde XPS kullanılan durum için yalıtım kalınlığının yıllık toplam maliyet üzerine etkisi.*

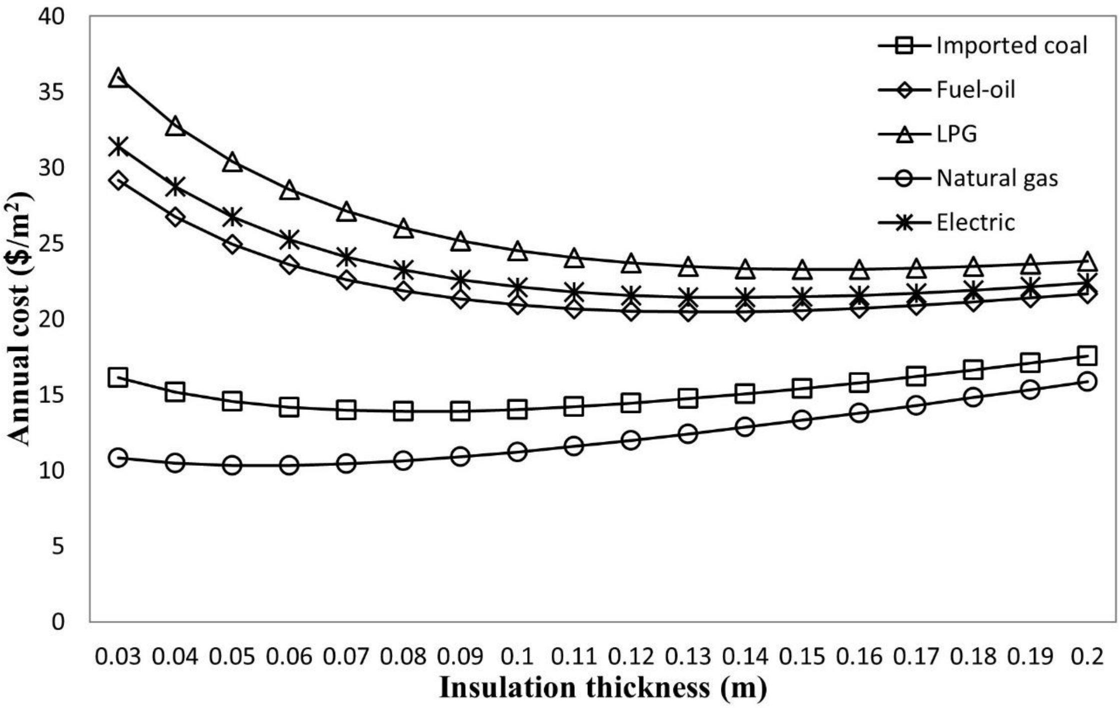

Figure 6. Effect of the insulation thickness on the annual total expenses for rock wool and aerated concrete wall model.
Şekil 6. *Gaz beton ile yapılan duvar modelinde taş yünü kullanılan durum için yalıtım kalınlığının yıllık toplam maliyet üzerine etkisi.*

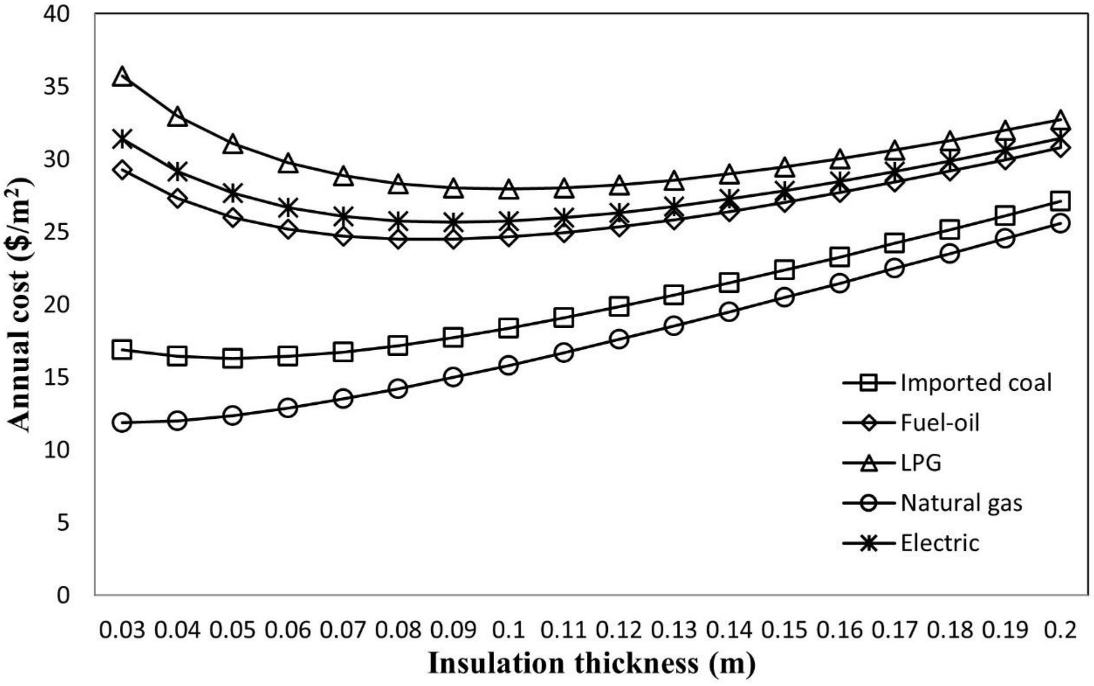

Figure 7. Effect of the insulation thickness on the annual total expenses for polyurethane and aerated concrete wall model.
Şekil 7. *Gaz beton ile yapılan duvar modelinde poliüretan kullanılan durum için yalıtım kalınlığının yıllık toplam maliyet üzerine etkisi.*

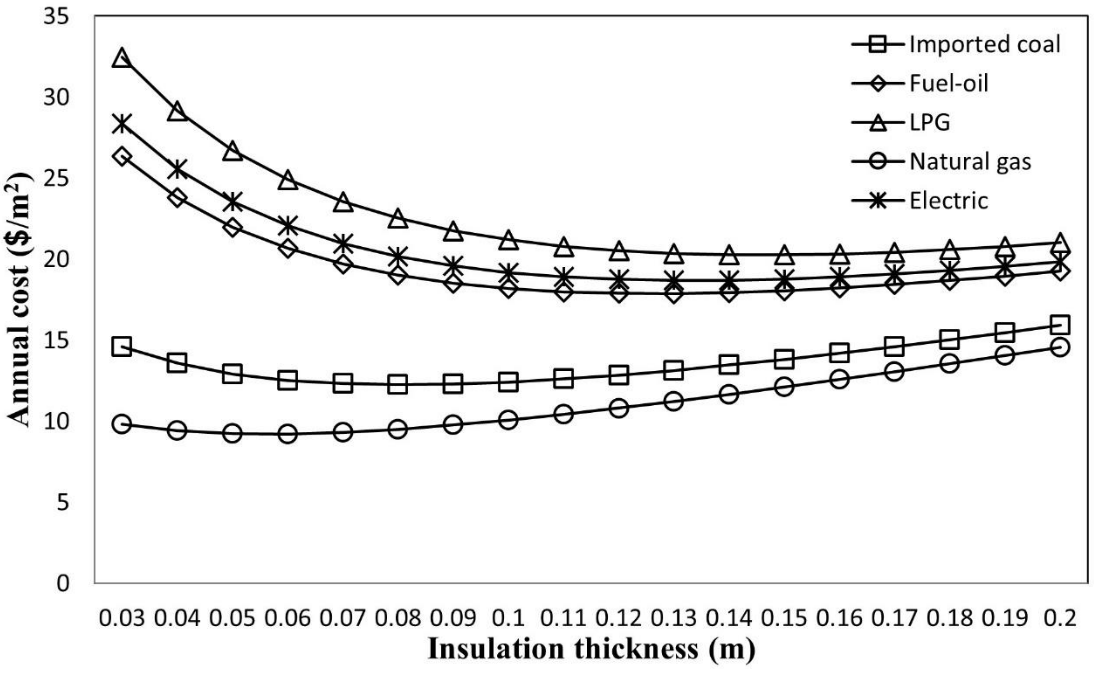

Figure 8. Effect of the insulation thickness on the annual total expenses for XPS and aerated concrete wall model.
Şekil 8. *Gaz beton ile yapılan duvar modelinde XPS kullanılan durum için yalıtım kalınlığının yıllık toplam maliyet üzerine etkisi.*

Table 3. Relationship with annual total expenses by different wall models and energy sources.
Tablo 3. *Farklı duvar modelleri ve enerji kaynaklarına göre yıllık toplam maliyet ilişkisi.*

Energy Source	Annual Total Expenses ($/m^2)					
	Pumice concrete wall model			Aerated concrete wall model		
	Total Annual Cost for Rock Wool ($/m^2)	Total Annual Cost for Polyurethane ($/m^2)	Total Annual Cost for XPS ($/m^2)	Total Annual Cost for Rock Wool ($/m^2)	Total Annual Cost for Polyurethane ($/m^2)	Total Annual Cost for XPS ($/m^2)
Imported Coal	14.02	16.50	12.35	13.89	16.30	12.25
Fuel-oil	20.6	24.68	17.97	20.47	24.48	17.87
LPG	23.4	28.16	20.36	23.27	27.95	20.26
Natural Gas	10.46	12.07	9.31	10.33	11.87	9.21
Electricity	21.56	25.87	18.78	21.43	25.67	18.69

Payback period is calculated by dividing the annual heating expenses by the annual difference between insulated and non-insulated buildings. Similar to the effect of PWF on optimum insulation thickness, with increasing degree-day value, optimum insulation thickness increases but the payback period decreases. Thus, since Van is in a cold region, the results obtained were similar to optimum insulation thickness values obtained for Erzurum, Kars, and Erzincan.

Payback periods and annual savings for a 10-year lifecycle by optimum insulation thickness values of different energy sources in pumice and aerated concrete wall models are presented in Table 4. The difference between heating expenses calculated for insulated and non-insulated forms of preferred wall models refers to the annual amount of saving for the unit area. Annual savings vary in parallel with fuel costs and PWF.

Table 4. Payback period - annual saving relationship by different wall types and energy sources.
Tablo 4. *Farklı duvar tipleri ve enerji kaynaklarına göre geri ödeme süresi, yıllık tasarruf ilişkisi.*

Energy Source	Payback period (Years) / Annual saving ($/m^2)					
	Pumice concrete wall model			Aerated concrete wall model		
	Rock Wool	Polyurethane	XPS	Rock Wool	Polyurethane	XPS
Imported Coal	2.4 / 9.88	3.2 / 7.40	2.1 / 11.55	1.7 / 9.03	1.4 / 6.62	1.9 / 10.67
Fuel-oil	1.8 / 25.29	2.2 / 21.21	1.6 / 27.92	1.9 / 23.53	2.3 / 19.52	1.7 / 26.13
LPG	1.7 / 34.00	2.0 / 29.24	1.6 / 37.04	1.7 / 31.76	2.0 / 27.08	1.6 / 34.77
Natural Gas	3.3 / 4.51	5.2 / 2.89	2.7 / 5.66	3.6 / 4.02	5.8 / 2.47	2.8 / 5.14
Electricity	1.8 / 28.12	2.1 / 23.81	1.6 / 30.90	1.8 / 26.21	2.2 / 21.97	1.7 / 28.95

4. Conclusion
4. Sonuçlar

Nowadays, because of the problems such as gradually decreasing energy sources, increasing heating expenses, gases released to the atmosphere and creating a greenhouse effect, and release of fossil fuel residuals, it is important to follow the heat insulation principles set in the standards and to use energy efficiently. Optimum insulation thickness was calculated for five energy sources by using two different wall models preferred in Van province and making use of rock wool, polyurethane, and XPS as insulation materials. Moreover, in the present study, the efficiencies of energy sources were analyzed for total insulation costs and payback periods and different wall models. Given the wall models used in this study, it was determined that the minimum values of optimum insulation thickness were obtained for natural gas and imported coal used as energy sources. It also reduced the annual total expenses. When using polyurethane as insulation material, optimum insulation thickness values were found to be 0.032 m for natural gas and 0.057 m for imported coal in pumice concrete wall model and 0.030 m for natural gas and 0.055 m for imported coal in aerated concrete wall model. Similarly, when using polyurethane as insulation material, the annual amount of saving was found to be 2.89 $/m^2 for natural gas and 7.40 $/m^2 for imported coal in pumice concrete wall model and 2.47 $/m^2 for natural gas and 6.62 $/m^2 for imported coal in aerated concrete wall model. Building insulation can directly contribute to the efficient and less consumption of energy resources by reducing the thermal energy demand. As building insulation reduces the amount of energy consumed, it also contributes to reducing the negative environmental effects of greenhouse gases emitted by buildings. Considering both its economic and environmental benefits, the selection of the exterior wall construction material and the determination of the thickness and type of the thermal insulation material at the end are interrelated and important issues.

Nomenclature
Terminoloji

C_A : Annual energy expense of heating ($/m^2-year)
C_F : Unit price of energy sources being used ($/kg, $/m^3, $/kWh)
C_{ins} : Total heating costs of insulated building ($/m^2- year)
C : Total heating costs of non-insulated building ($/m^2- year)
C_{ins} : Insulation material cost ($/m^3)
DD : Degree-day number (°C-day)
E_A : Annual amount of energy needed for heating (j/m^2- year)
g : Inflation rate
H_u : Calorific value (j/kg)
i : Interest rate
U : Total heat transfer coefficient (W/m^{2}K)
LCCA : Lifecycle cost analysis
N : Lifecycle (year)
PWF : Real value factor
q_A : Annual heat loss (W/m^2)
r : Real interest rate
R_o : Heat resistance coefficient of outer environment air (m^{2}K/W)
R_i : Heat resistance coefficient of inner environment air (m^{2}K/W)
R_{ins} : Heat resistance coefficient of insulation material (m^{2}K/W)
R_w : Heat resistance coefficient of non-insulated wall model (m^{2}K/W)
R_{wt} : Total heat resistance coefficient of non-insulated wall model (m^{2}K/W)
x : Insulation thickness (m)
x_{opt} : Optimum insulation thickness (m)
λ : Heat transfer coefficient of insulation material (W/mK)
η : Efficiency of the combustion system

Author contribution
Yazar katkısı

The author provided the literature review of the article, the preparation of the model, the preparation of all figures and tables, the evaluation of the results and the preparation of the references.

Declaration of ethical code
Etik beyanı

The author of this article declares that the materials and methods used in this study do not require ethical committee approval and/or legal-specific permission.

Conflicts of interest
Çıkar çatışması beyanı

The author declares that there is no conflict of interest.

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