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İçten Yalıtımlı Duvarlar İçin Enerji Maliyetine Dayalı Isı Yalıtım Kalınlığı Optimizasyonu

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Öne Çıkanlar

i. Ankara için optimum yalıtım kalınlığı 0,039 m olarak hesaplanmıştır.
ii. Optimum kalınlık için geri ödeme süresi 13,52 yıl olarak hesaplanmıştır.
iii. Optimum kalınlıkta tasarruf miktarı 5,97 USD/m^2 olarak hesaplanmıştır.

Anahtar Kelimeler
Isıl yalıtımı, İçten yalıtımlı duvar, Yaşam döngüsü maliyet analizi, Geri ödeme süresi, Enerji tasarrufu, Optimizasyon

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Amaç

Enerji, son yılların en stratejik unsuru haline gelmiştir. Tüm dünyada enerji verimliliği anlayışına uygun olarak geliştirilen politikaların en önemli adımlarından biri ısı yalıtımıdır. Türkiye'deki toplam enerji tüketiminin yaklaşık %30-35'inden konut ve yapı sektörü sorumlu olduğu için bu alanda büyük bir tasarruf potansiyeli bulunmaktadır.

Bu çalışmada, Ankara ilinde için içten yalıtımlı duvarlarda enerji maliyetini en aza indirmek için optimum ısı yalıtım kalınlığının tespiti amaçlanmıştır. Ankara, Türkiye'de derece-gün sınıflandırmasına göre üçüncü bölgede yer almaktadır. Yaşam döngüsü maliyet analizi kullanılarak optimum yalıtım kalınlığı, geri ödeme süresi ve tasarruf miktarı hesaplanmıştır.

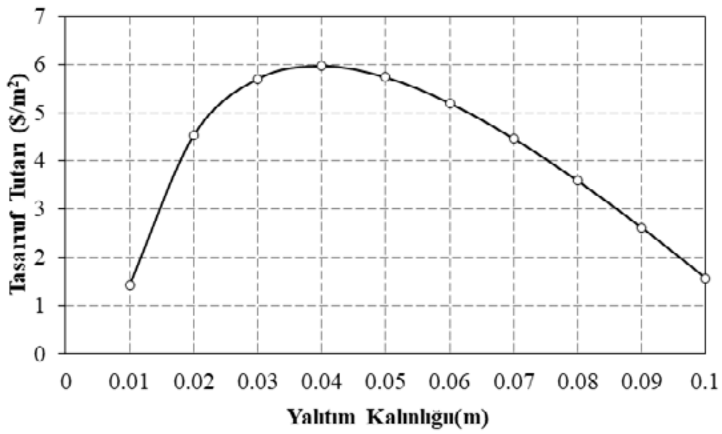
Materyal ve Yöntem

Derece gün (DD) yöntemi, herhangi bir lokasyonda bulunan bir binanın yıllık enerji ihtiyacını tahmin etmek için kullanılan en güvenilir yöntemlerden biridir. Bu çalışmada, yalıtım kalınlığını optimize etmek için, Türkiye'de üçüncü bölge için dış sıcaklık verilerinin derece-gün sınıflandırmasına göre değişimi ele alınarak içten yalıtımlı dış duvar uygulaması incelenmiştir. Belirli bir dönemde temel ve dış hava sıcaklığını dikkate alarak ısıtma enerji ihtiyacını tanımlayan ısıtma derecesi gün (HDD) değerleri hesaplanmıştır.

Tartışma ve Sonuçlar

Literatürde yalıtım kalınlığının optimizasyonu ve daha az enerji kullanımının çevreye etkileri ile ilgili birçok çalışma bulunmaktadır. Bu çalışmada Ankara için yalıtım kalınlığı optimize edilmiştir. Ayrıca, geri ödeme sürelerini ve tasarruf miktarını belirlemek için ömür maliyeti analizinden yararlanılmıştır. Elde edilen sonuçlar:

- ✓ Optimum yalıtım kalınlığı 0,039 m ve geri ödeme süresi 13,52 yıl olarak hesaplanmıştır.
- ✓ Ömür maliyeti analizi için optimum kalınlıkta tasarruf miktarı 5,97 USD/m^2 olarak belirlenmiştir.



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Thermal Insulation Thickness Optimization Based on Energy Cost for Internally Insulated Walls

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Highlights

i. The optimum thickness for Ankara was calculated as 0.039 m.
ii. The payback period for optimum thickness was calculated as 13.52 years.
iii. The optimum thickness savings amount was calculated as 5.97 USD/m^2.

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Abstract

In this study, optimization of the thermal insulation thickness, which minimizes the energy cost of the internally insulated wall application, was carried out for the province of Ankara. Ankara is located in the third region according to the degree-day classification in Turkey. Optimum insulation thickness, payback period and saving amount were calculated by utilizing life cycle cost analysis. The optimum insulation thickness for the internally insulated wall application, in which XPS is used as the insulation material, was determined as 0.039 m. The payback period for the optimum insulation thickness determined was 13.52 years and the savings amount was approximately 5.97 USD/m^2.

Keywords: thermal insulation, internally insulated wall, life cycle cost analysis, payback period

1. Introduction

Today, the human population and consumption are increasing and the requirement for energy is increasing every day. As a result, energy has become the most strategic element in recent years. One of the most significant steps of the policies improved by the understanding of energy efficiency all over the world is thermal insulation. Since the housing and building sector is responsible for approximately 30-35% of the total energy consumption in Turkey, there is a major saving potential in this field and the interest in this sector is increasing day by day [1,2].

There are many studies in the literature on the optimization of insulation thickness and the effects of less energy use on the environment. Kaynakli et al. [3] presented a procedure for the optimization of the thermal insulation thickness applied on the external walls of buildings. In the study, a sample calculation was made by considering the heating and cooling degree-days (HDDs and CDDs) for the province of Istanbul and the most appropriate insulation thicknesses were found to be 4.0 cm and 2.6 cm, respectively.

Erdem and Tugan [4] calculated the optimum insulation thickness of 0.079 m, 0.082 m, and 0.1040 m in Tunceli, Hakkari and Kars regions with different insulation materials and variable HDD values, respectively. Also, the ideal insulation thickness for Turkey was determined between 0.028 m - 0.096 m.

Karakaya [5] determined the optimum insulation thickness for cooling and heating by utilizing various fuel types and insulation materials for different wall types. Moreover, the total cost, payback periods and energy savings were calculated and environmental analyzes were carried out in this study.

Kurekci [6] calculated optimum insulation thicknesses for 81 provincial centers of Turkey using various fuels (coal, LPG, natural gas, and fuel-oil) and various insulation materials (EPS, XPS, polyurethane, rock wool and glass wool).

Kaynakli and Kaynakli [7] determined the optimum insulation thickness taking into account the solar radiation effect, for different cities (Iskenderun, Istanbul, Ankara, Ardahan) in different DD regions in Turkey. Within the scope of the study, it was calculated that the optimum thickness varies between 3.9 cm - 7.5 cm with the effect of solar radiation.

Aydin and Biyikoglu [8] conducted a 30-year life cycle cost analysis for different DD regions of Turkey and calculated the optimum insulation thickness, fuel savings, net profit, and payback periods of ceilings, floors, and exterior walls. In this study, it was determined that the optimum thickness varies between 5.0 cm - 26.8 cm based on the different parameters.

Kaynaklı et al. [9] performed the optimization of thermal insulation thickness for various structural applications taking into account condensation. In this study, it was calculated the least thickness of insulation required to prevent condensation in the structural component.

Canbolat et al. [10] determined the optimum insulation thickness and its payback period by taking into account two cities characterizing the cold and hot climatic terms and performed detailed parametric analyzes. In addition, the order of importance of the studied parameters and the contribution rates to the optimum insulation thickness were determined utilizing the Taguchi method.

In this study, the optimum insulation thickness was determined for the internally insulated wall application utilizing the life cycle cost analysis. The method discussed in the study is based on the minimization of energy cost. First of all, HDD value was calculated for Ankara as 2697.8. The optimum insulation thickness was determined as 0.039 m for the application using XPS as the insulation material. The payback period for this insulation thickness is 13.52 years, and the amount of savings is calculated as 5.97 USD/m^2.

2. Mathematical Model

The degree day (*DD*) method is one of the used most reliable methods used to estimate the annual energy needs of a building located in any location. This method presumes that the variation between the base temperature (T_b) and the average outdoor temperature (T_o) is directly proportional to the energy requirement of the structure. Base temperature is defined as the temperature at which heat losses from the building are equal (in balance) with the heat sources (heating system, lighting, human, television, computer, solar radiation, etc.) in the structure.

The heating degree days (HDD) value defines the density of the cold by considering the base and outside air temperature in a given period. HDD values can be calculated as follow,

$$HDD = \sum_{1}^{365} (T_b - T_o)^+ \quad (1)$$

In this equation, T_o means the outside air temperature, and T_b means the base temperature. The plus sign above the parenthesis remarks that only positive values are to be considered, therefore, when $T_o > T_b$, the temperature variance should be taken as zero. In this study, T_b was taken at 18°C.

The overall heat transfer coefficient (U) of the internally insulated wall can be calculated with the following equations,

$$U = \frac{1}{1/h_i + x/k + R_w + 1/h_o} \quad (2)$$

$$U = \frac{1}{R_{t,w} + x/k} \quad (3)$$

In this equation, h_o and h_i mean the outside and inside heat-transfer coefficients respectively, k means the thermal conductivity of insulation material, R_w means the total thermal resistance of the composite wall materials without insulation, $R_{t,w}$ indicates the total wall thermal resistances excluding the insulation layer, and x indicates the thickness of insulation material.

The annual heating energy requirement can be calculated for per unit area as following equation,

$$q_{A,H} = \frac{86400.HDD.U}{\eta} \quad (4)$$

In this equation, η means the efficiency of the heating system. The efficiency of the system was presumed as 0.93 in this study [11, 12].

When the insulation thickness increases, the insulation cost increases, while the cost of heating decreases. Hence, these costs should be calculated simultaneously to determine the optimal thickness. The insulation cost (Ct,ins) can be expressed for the external wall as follow,

$$C_{t,ins} = x.C_{ins} + C_{inst} \quad (5)$$

In this equation, *Cins* means the insulation cost of material per unit volume and C_{inst} means the installation cost. For the unit surface area, the annual cost of heating (C_H) can be determined by the following equation

$$C_H = \frac{86400.HDD.C_f.PWF}{(R_{t,w} + x/k)Hu.\eta} \quad (6)$$

In this equation, PWF means the present worth factor, and *Hu* means the lower heating value of the fuel, and C_f means the cost of fuel. PWF is a coefficient used for life cycle cost analysis and calculated considering the lifetime of the insulation material or structure (*LT*) and the real interest rate (*r*). Based on the inflation rate (i) and the interest rate (g), The real interest rate can be determined as follow,

$$r = \frac{g-i}{1+i} \qquad (g > i) \quad (7)$$

$$r = \frac{i-g}{1+g} \qquad (i > g) \quad (8)$$

The PWF coefficient can be expressed as follow,

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

In this study, LT is presumed to be 20 years. The total heating cost can be stated as the following equation,

$$C_{total} = C_{t,ins} + \frac{86400.HDD.C_f.PWF}{(R_{t,w} + x/k).Hu.\eta} \quad (10)$$

Optimum insulation thickness (x_{opt}) can be stated in the following equation. As the derivative of the total heating cost (C_{total}) according to the insulation thickness (x) is taken and equalized to zero.

$$x_{opt} = 293.94 \left(\frac{HDD.C_f.k.PWF}{Hu.C_{ins}.\eta}\right)^{1/2} - k.R_{t,w} \quad (11)$$

Table 1. Data used in the optimization [9, 11, 12, 13, 14]

Parameters	Values
Wall Structure (Internally insulated)	
0.02 m Internal plaster	k = 0.87 W/mK
x m Insulation material	k = 0.034 W/mK
0.135 m Hollow brick	k = 0.45 W/mK
0.03 m External plaster	k = 1.40 W/mK
Outside heat-transfer coefficient	h_o = 34 W/m^{2}K
Inside heat-transfer coefficient	h_i = 8.3 W/m^{2}K
	$R_{t,w}$ = 0.4943 m^{2}K/W
	U = 2.023 W/m^{2}K
Fuel (Natural gas)	
Lower heating value (Hu)	34.526 x 10^6 J/m^3
Price (C_f)	0.258 USD/m^3
Efficiency of heating system (η)	0.93
Insulation material (XPS)	
Material cost (C_{ins})	140 USD/m^3
Installation cost (C_{inst})	7.0 USD/m^2
Thermal conductivity (k)	0.034 W/mK
Financial parameters	
Lifetime (LT)	20
Interest rate (g)	14%
Inflation rate (i)	30%
Present worth factor (PWF)	7.125 (with Eq. 9)

The saving amount (*SA*) provided by insulation can be determined as follow,

$$SA = C_{H(x=0)} - C_{H(x)} - C_{t,ins(x=0)} \quad (12)$$

3. Result and Discussion

In this study, the internally insulated exterior wall application in Ankara was examined and different parameters related to the study are shown in Table 1. In order to optimize insulation thickness, HDD values should be calculated taking into account the daily average temperature values of the region to be examined.

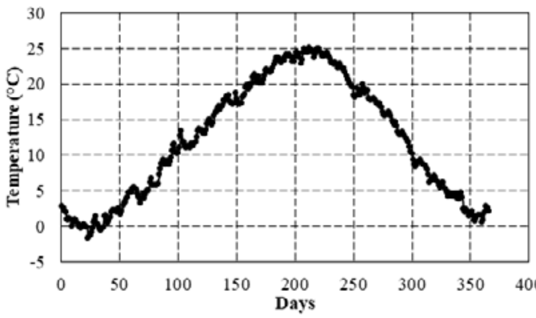

Figure 1. The change of the outdoor air temperature

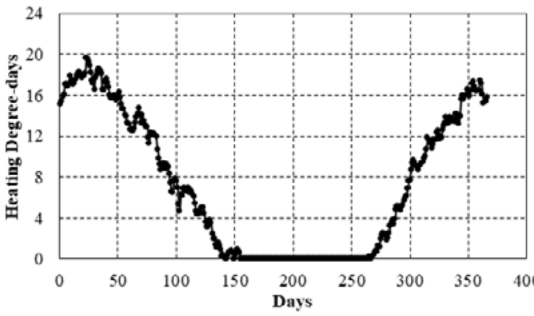

Figure 2. The change of the HDD for the Ankara province

The change of the outdoor temperature data of the province of Ankara, which is in the third region according to the degree-day classification in Turkey, is given in Fig 1. The change of the HDD values for Ankara is given in Fig 2. As Fig 2 is examined, it is seen that HDD values raise in the first and last days of the year. The cause of this situation is that the amount of energy needed for heating is greater due to the fact that the outdoor temperature is low on these days of the year. The total HDD value was calculated as 2697.8 for Ankara province.

The change of heating, insulation and total costs with increasing insulation thickness is given in Fig. 3. When the insulation thickness applied to the wall rises, the total thermal resistance (R_t) increases and the heat loss from the structure to air decreases. As seen in Figure 3, the annual cost of heating (C_H) decreases with the reduction of heat loss. However, the cost of insulation ($C_{t,ins}$) increases depending on the increase in insulation thickness. When these costs are assessed simultaneously, based on the insulation thickness, first the total cost (C_{total}) decreases and then increases. The reason for this situation is that the energy cost loses its effectiveness in the total cost due to the impact of the increased insulation cost. The insulation thickness, which ensures that the total cost is minimal, is determined as the optimum thickness. Using life cycle cost analysis methods, the optimum insulation thickness was calculated as 0.039 m (Fig. 3). The payback period was determined as 13.52 years for the optimum insulation thickness.

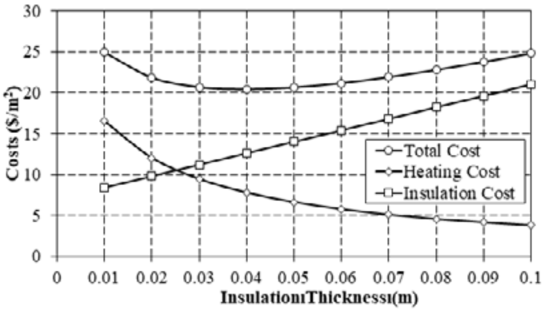

Figure 3. The change of costs based on insulation thickness

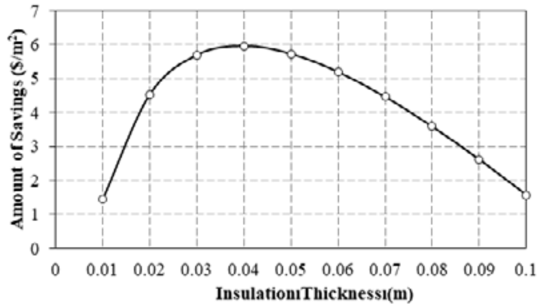

Figure 4. The change of saving amount with the insulation thickness

The change in the amount of saving amount with the applied insulation thickness is given in Fig 4, for life cycle cost analysis. The insulation thickness corresponding to the peak of the curve refers to the optimum thickness. The amount of saving at the optimum thickness was determined as 5.97 USD/m^2 for the life cycle cost analysis.

4. Conclusion

The insulation thickness was optimized for Ankara, the capital of Turkey by utilizing the HDD method. Moreover, the life cost analysis was utilized to determine the payback periods and saving amount. The results obtained are as follows:

- The optimum insulation thickness was calculated as 0.039 m and the payback period for this thickness was determined as 13.52 years by utilizing the life cost analysis.
- The amount of saving at the optimum thickness was determined as 5.97 USD/m^2 for the life cost analysis.

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