Turkish Journal of Science & Technology
Volume 13(2), 15-22, 2018

Calculation of Optimum Insulation Thickness and Energy Savings for Different Climatic Regions of Turkey

Ebru Kavak AKPINAR*, İbrahim Halil DEMİR
Firat University, Department of Mechanical Engineering, Elazig, Turkey
* ebruakpinar@firat.edu.tr

(Geliş/Received: 18.10.2017; Kabul/Accepted: 29.08.2018)

Abstract

In this study, the optimum insulation thickness, energy savings and payback periods were calculated based on life-cycle cost analysis for the cities of Balıkesir, Kayseri, Malatya, Mersin, Muğla, Şanlıurfa and Trabzon. These cities were selected from Turkey's four climate zones. The calculations were carried out for coal as energy source, expanded polystyrene (EPS) and extruded polystyrene (XPS) as insulation materials on two types of walls: (1) sandwich and (2) externally insulated. Results indicated that insulation thicknesses varied between 0.002–0.049 m, with the amount of life-cycle energy saving as 0.629–21.047 $\$/m^2$ and a payback period of 0.3–6.5 years depending on the type of fuel, insulation material and wall-type.

Key words: Degree-Day Method, Energy saving, Optimum insulation thickness, XPS, EPS, Coal, Turkey

Türkiye'nin Farklı İklim Bölgeleri İçin Enerji Tasarrufu ve Optimum Yalıtım Kalınlığının Hesaplanması

Özet

Bu çalışmada Balıkesir, Kayseri, Malatya, Mersin, Muğla, Şanlıurfa ve Trabzon illerinin optimum yalıtım kalınlığı, enerji tasarrufu ve geri ödeme süreleri yaşam döngüsü maliyet analizlerine göre hesaplanmıştır. Bu şehirler, Türkiye'nin dört iklim bölgesinden seçilmiştir. Hesaplamalar enerji kaynağı olarak kömür, iki tip duvar üzerinde: (1) sandviç ve (2) dıştan yalıtılmış, yalıtım malzemesi olarak genişletilmiş polistiren (EPS) ve ekstrüde polistiren (XPS) için yapılmıştır. Sonuçlar, yakıt türüne, yalıtım malzemesine ve duvar tipine bağlı olarak yaşam döngüsü enerji tasarrufu 0.629–21.047 $\$ / m^2$ ve 0.3-6.5 yıl geri ödeme süresi ile yalıtım kalınlıklarının 0.002-0.049 m arasında değiştiğini gösterdi.

Anahtar kelimeler: Derece-Gün Yöntemi, Enerji tasarrufu, Optimum yalıtım kalınlığı, XPS, EPS, Kömür, Türkiye

1. Introduction

Energy consumption is distributed among four main sectors such as industrial, building (residential/commercial), transportation, and agriculture. The building sector is the largest energy consumer following the industrial sector [1-2].

Thermal insulation is the first of the methods for decreasing the energy consumption. Reduction of the energy consumption to the minimum values for the buildings is compulsory according to national regulations. Most of the studies focus on the determination of optimum thickness of insulation for external walls in buildings based on cooling degree days (CDD) and heating degree days (HDD) [3-15].

In this study, seven different cities of Turkey (Balıkesir, Kayseri, Malatya, Mersin, Muğla, Şanlıurfa and Trabzon) were selected as to represent the first, second, third, and fourth climatic zones (Fig. 1). The effect of two different wall structures was considered to determine the optimum insulation thickness, energy savings and payback period for EPS and XPS insulation materials, using coal for fuel.

Figure 1. Four different degree-day regions of Turkey according to TS 825 Standard

2. Material and Methods

2.1.Calculation of degree days

According to Turkish Standard Number (TS 825), heat insulation rules for buildings, four different degree-day (*DD*) regions have been defined for Turkey, as shown in Fig. 1. Climatic conditions are the main factors affecting the thermal load requirements of buildings [16-18].

The degree day method is one the simplest methods used in the heating, ventilating and air-conditioning industry to estimate heating and cooling energy requirements [19]. Degrees days are a specialized type of weather data, calculated from the readings of the outside air temperature. Many approaches and techniques to calculating HDDs can be found in the literature [20-22]. In this study, calculations of optimum insulation thickness, payback period and energy savings were performed using T_b =25°C base temperature. The HDDs were calculated (Table 2, 2002–2012) based on the daily data of the maximum and minimum air temperatures collected from the 7 main stations of the Turkey climate network (Fig. 1) for the colder eight months (October–May).

The calculation of HDDs was carried out by means of different equations, depending on the relationship between the base temperature T_b and the mean T_m, minimum T_{min} and the maximum T_{max} daily air temperatures. The total number of heating degree-days for the whole heating season can be expressed as [23],

$$(T_m \leq T_b) \quad (1)$$

$$(T_m > T_b) \quad (2)$$

where, T_i is the constantly adopted indoor design air temperature, T_b is the base temperature and T_m is the daily mean outdoor temperature, N is total number of heating days.

The daily mean outdoor temperature is determined by the average of the measured maximum and minimum temperature during the day.

$$T_m = \frac{(T_{m,min} + T_{m,max})}{2} \quad (3)$$

Here, $T_{m,min}$ ve $T_{m,max}$ is the average of the measured lowest and highest temperatures during the day, respectively [23].

In this study, the seven cities from seven different regions in Turkey, Balıkesir, Kayseri, Malatya, Mersin, Izmir, Sanliurfa and Trabzon were selected to determine the optimum insulation thickness. Table 1 shows the climate characteristic and degree days values of each city. Data are mean values of ten years, was taken in 2012 from The State Meteorological Affairs General Directorate (DMI).

2.2. External wall structures in buildings

External wall insulation is immensely important in terms of energy saving [2-3]. In Turkey generally, the external walls have a composite structure called sandwich wall or externally insulated wall. The structures of investigated walls (sandwich wall and externally insulated wall) are shown in Fig. 2. The sandwich wall is formed from 2 cm internal plaster, two pieces of 13 cm horizontal hollow brick, insulation material between horizontal hollow brick and 3 cm external plaster. Externally insulated wall is consisted from 2 cm internal plaster, 29 cm horizontal hollow brick, insulation and 3 cm external plaster. In the calculations, as the insulation material, *expanded polystyrene* (EPS) (k = 0.032 W/mK) and *extruded polystyrene* (XPS) (k = 0.040 W/mK) were used.

Table 1. Climate zones, heating degree days and certain data for the selected cities

City-Region	Zone	Longitude(°)	Latitude (°)	Elevation (m)	Heating degree days
Balıkesir-Marmara	2	27.52	39.39	147	1914
Trabzon-Black Sea	2	39.43	41.00	30	1724
Kayseri-Central Anatolia	4	35.29	38.43	1068	3113
Muğla-Aegean	1	28.21	37.12	646	1879
Mersin-Mediterranean Sea	1	34.36	36.49	5	852
Şanlıurfa Southeastern Anatolia	2	38.46	37.08	547	1503
Malatya-East Anatolia	3	38.18	38.21	998	2996

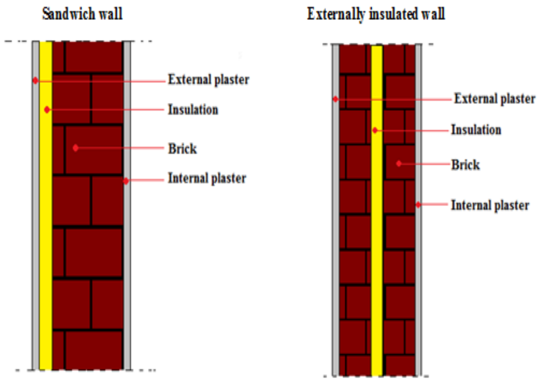

Figure 2. Wall models

The heat conduction and resistant values for sandwich and externally insulated wall are given in Table 2. Thermal resistances of the walls are calculated using these coefficients. Thermal resistances of the walls were calculated without taking into account the insulation material. The conductivity and resistant values were determined from TS 825 (Turkish Standard of Thermal Insulation in Buildings) [16].

Table 2. The physical properties of the external wall materials

	Sandwich wall			Externally insulated wall		
Material	**thickness (m)**	**k (W/mK)**	**R (m^2K/W)**	**thickness (m)**	**k (W/mK)**	**R (m^2K/W)**
interior plaster (lime based)	0.02	0.87	0.02	0.02	0.87	0.02
horizontal hollow brick	0.13	0.45	0.28	0.26	0.45	0.64
exterior plaster (cement based)	0.03	1.4	0.02	0.03	1.4	0.02
R_i	0.13			0.13		
R_o	0.04			0.04		
R_{wt}(wall layers without the insulation material)	0.77			0.85		

2.3. Heating load for external walls

The heat loss and the annual heat loss from the unit surface of the external wall are calculated respectively by [3, 6]:

$$q = U.\Delta t \tag{4}$$

$$q_A = 86400.DD.U \tag{5}$$

The yearly energy requirement is determined by:

$$E_A = \frac{86400.DD.U}{\eta} \tag{6}$$

Overall heat transfer coefficient for wall is given as,

$$U = \frac{1}{R_i + R_w + R_{ins} + R_o} \tag{7}$$

The thermal resistance of the insulation layer is,

$$R_{ins} = \frac{x}{k} \quad (8)$$

If R_{wt} is the total wall resistance excluding the insulation layer resistance, Eq. (7) can be written as,

$$U = \frac{1}{(R_{wt} + R_{ins})} \quad (9)$$

The annual amount of the energy expended for heating can be obtained as the following,

$$E_A = \frac{86400.DD}{(R_{wt} + (x/k))\eta} \quad (10)$$

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

$$C_A = \frac{86400.DD.C_f}{(R_{wt} + (x/k)).H_u.\eta} \quad (11)$$

The life-cycle cost analysis (*LCCA*) is one of the methods to calculate the optimum insulation thickness. The total heating costs over a period of time of *N* years is evaluated in the present value using the present worth factor (*PWF*). The present worth factor is calculated based upon the inflation (*g*) and interest rate (*i*) as follows [3, 6].

If $i > g$ then

$$r = \frac{i - g}{1 + g} \quad (12)$$

If $i < g$ then

$$r = \frac{g - i}{1 + i} \quad (13)$$

and

$$PWF = \frac{(1 + r)^N - 1}{r.(1 + r)^N} \quad (14)$$

If $i = g$, then

$$PWF = \frac{1}{1 + i} \quad (15)$$

The cost of insulation is given by Eq. (16)

$$C_{ins} = C_i.x \quad (16)$$

The total heating cost of the insulated building is given by

$$C_t = C_A.PWF + C_i.x \quad (17)$$

or

$$C_t = \frac{86400.DD.C_f.PWF}{(R_{wt} + (x/k)).H_u.\eta} + C_i.x \quad (18)$$

The optimum insulation thickness is obtained as the following,

$$x_{op} = 293.94\left(\frac{DD.C_f.PWF.k}{H_u.C_i.\eta}\right) - k.R_{wt} \quad (19)$$

The values of the parameters used in the calculations of the optimum insulation thickness, payback period and life cycle savings for the insulated buildings in selected cities are given in Table 3. The payback period is described as the ratio of the energy cost of the uninsulated building to the energy savings [3, 6, 10].

Table 3. Parameters and values used in the calculation of insulation-thickness

Parameters	Value
Fuel (Coal)	
H_u	25.122x10^6(J/kg)
η	0.65
Insulation (Expanded polystyrene (EPS))	
k	0.032(W/mK)
Insulation (Extruded polystyrene (XPS))	
k	0.040 (W/mK)
C_i	23.88 \$/m^3
i	16 (%)
g	10 (%)
N	10 year
PWF	1.8

3. Results and Discussion

The optimum insulation thicknesses for the two different wall type were obtained by Eq. (19) and the results for coal fuel and insulation materials (*EPS* and *XPS*) are given in Table 4. Optimum insulation thickness varied between 0.011 and 0.046 for EPS, 0.014 and 0.049 m for

XPS in sandwich wall, whereas the optimum insulation thickness varied between 0.002 and 0.036 m for EPS, 0.006 and 0.039 m for XPS in case of external insulated wall, respectively. The optimum thickness for sandwich wall was higher than that required for external insulated wall. The optimum insulation thickness for *EPS* was less when compared to *XPS*.

Table 4. Optimum insulation-thickness of selected cities for different wall types and insulation materials

City	Sandwich wall		External insulated wall	
	EPS (m)	**XPS (m)**	**EPS (m)**	**XPS (m)**
Balıkesir	0.030	0.033	0.021	0.024
Kayseri	0.046	0.049	0.036	0.039
Malatya	0.045	0.047	0.034	0.038
Mersin	0.011	0.014	0.002	0.006
Muğla	0.030	0.032	0.020	0.023
Şanlıurfa	0.024	0.026	0.014	0.018
Trabzon	0.027	0.030	0.018	0.021

The curves of insulation and fuel costs, and total cost versus the insulation thickness for the selected cities are illustrated for sandwich wall and external insulated wall in Fig.3, respectively. It was seen that the fuel cost decreased with increasing insulation thickness. The total cost decreased until a certain value of the insulation thickness was reached, after which it began to increase again.

On the other hand, the insulation cost increased linearly with insulation thickness. The insulation thickness at the minimum total cost was taken as the optimum insulation thickness.

The payback period is reduced with increasing degree days. The optimum insulation thickness is increased with increasing degree days. Larger insulation thickness is required in colder climates with higher degree days, but less insulation in warmer climates with lower degree days. Therefore, the optimum insulation thickness for Mersin became lower, since it has more hot days. The optimum insulation thickness for Kayseri became higher, since it has less hot days.

Table 5 displays life cycle energy savings over 10 years and the payback periods for insulated buildings in selected cities for coal. The results according to selected cities showed that life cycle savings varied between 0.629 $/m^2 and 21.047 $/m^2, and payback periods varied between 0.3 and 6.5 years according to insulation materials (*EPS* and *XPS*) and wall types (*SW* and *EIW*) and the fuel type (coal). Fertelli [14] evaluated the influence of different wall types (stone, brick, concrete and bims) on the optimum insulation thicknesses, energy savings, and payback periods for six different energy types (LPG, electricity, fuel oil, coal, natural gas, and geothermal energy), and four cities from different climate zones (Aydın, Trabzon, Malatya, and Sivas). Insulation thicknesses were determined between 0 – 0.179 m, with the amount of 0 – 235.053 $/m^2 of energy saving, and 0 – 11.53 years of payback period, depending on various fuels and wall types. Uçar and Balo [15] calculated the optimum insulation thickness of different wall structures for four different insulation materials and for four climatic zones of Turkey and different fuel types. Their results show that the energy cost savings vary between 4.2 $/m^2 and 9.5 $/m^2, depending on the city and insulation materials.

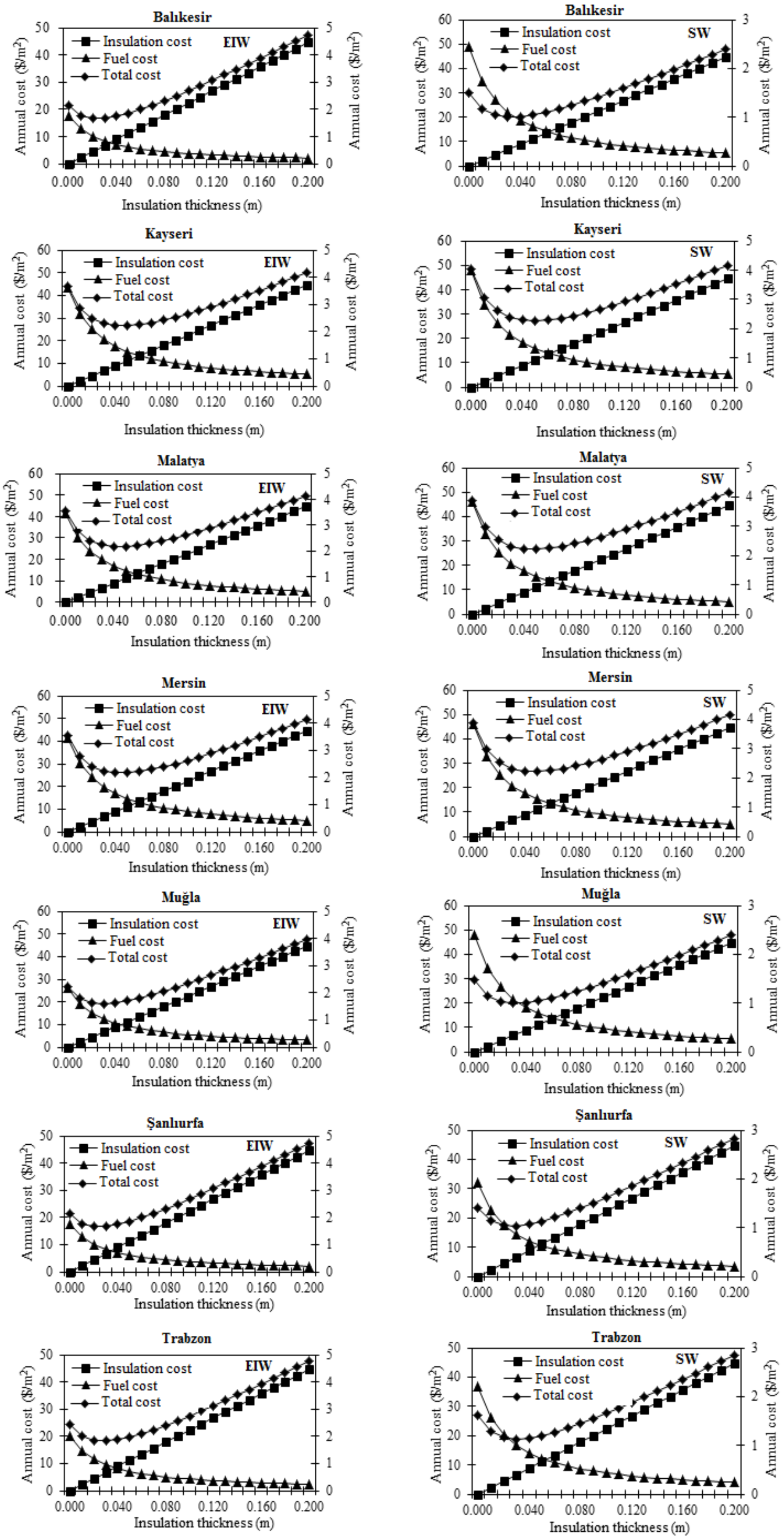

Fig. 3. Effect of insulation thickness on costs for sandwich wall and external insulated wall at selected cities

Table 5. Payback periods and life-cycle energy savings

City	SW			
	EPS (m)		XPS (m)	
	Payback period (years)	Life-cycle energy savings ($/m^2)	Payback period (years)	Life-cycle energy savings ($/m^2)
Balıkesir	3.6	10.822	2.9	14.175
Kayseri	5.6	14.430	4.3	21.047
Malatya	5.5	14.117	4.2	20.188
Mersin	1.3	3.978	1.2	6.013
Muğla	3.6	10.822	2.8	13.745
Şanlıurfa	2.9	8.658	2.3	11.167
Trabzon	3.3	9.740	2.6	12.885
	EIW			
	EPS (m)		XPS (m)	
	Payback period (years)	Life-cycle energy savings ($/m^2)	Payback period (years)	Life-cycle energy savings ($/m^2)
Balıkesir	3.7	6.610	2.7	10.332
Kayseri	6.5	11.332	4.4	16.789
Malatya	6.1	10.703	4.6	16.359
Mersin	0.3	0.629	0.7	2.583
Muğla	3.5	6.295	2.6	9.901
Şanlıurfa	2.4	4.407	2.1	7.750
Trabzon	3.1	5.666	2.4	9.040

4. Conclusion

In this study, the optimum insulation thickness of external walls, the energy savings over a lifetime of 10 years, and the payback periods were calculated for two different wall types, coal as energy source, and two different insulation materials in cities from four different climatic zones of Turkey. The calculations were carried out to TS 825. The results showed that the optimum insulation thickness varied between 0.002 and 0.049 m, energy savings varied between 0.629 $/m^2 and 21.047 $/m^2, and payback periods varied between 0.3 and 6.5 years depending on the cities, the type of wall, the insulation material and the cost of coal fuel. Energy saving was bigger, insulation was more effective, and the payback period was shorter for higher degree-day cities. The highest value of the optimum insulation thickness was reached for Kayseri city by using sandwich wall, *XPS* as insulation material; whereas the lowest optimum insulation thickness was obtained for Mersin city by using external insulation wall, *EPS* as insulation material, coal as energy source.

5. References

1. Kurt, H. (2011). The Usage of Air Gap in the Composite Wall For Energy Saving and Air Pollution. *Environmental Progress and Sustainable Energy*, **30**, 450–458.
2. Bolatturk, A. (2006). Determination of Optimum Insulation Thickness For Building Walls With Respect to Various Fuels And Climate Zones in Turkey. *Applied Thermal Energy*, **26**, 1301–1309.
3. Çay, Y, Gürel, A.T. (2013). Determination of Optimum Insulation Thickness, Energy Savings, And Environmental Impact For Different Climatic Regions Of Turkey. *Environmental Progress & Sustainable Energy*, **32** (2), 365-372.
4. Kaynaklı, O. (2012). A review of the Economical And Optimum Thermal Insulation Thickness for Building Applications. *Renewable and Sustainable Energy Reviews*, 16, 415– 425.
5. Ekici, B.B., Gulten, A.A., and Aksoy, U.T. (2012). A study on the Optimum Insulation Thicknesses of Various Types of External Walls with Respect To Different Materials, Fuels and Climate Zones in Turkey. *Applied Energy*, **92**, 211–217.
6. Comakli, K., Yuksel, B. (2003). Optimum Insulation Thickness of External Walls for Energy Saving. *Applied Thermal Engineering*, **23**(4), 473–479.
7. Comakli, K, Yuksel, B. (2004). Environmental impact of Thermal Insulation Thickness in Buildings. *Applied Thermal Engineering*, **24** (2), 933–940.
8. Dombayci, O.A. (2007). The environmental impact of Optimum Insulation Thickness for External Walls of Buildings. *Building and Environment*, **42** (11), 3855–3859.
9. Durmayaz, A., Kadioglu, M., and Sen, Z. (2000). An Application of the Degree-Hours Method to Estimate the Residential Heating Energy Requirement and Fuel Consumption in Istanbul. *Energy*, **25** (12): 1245–1256.
10. Hasan, A. (1999). Optimizing Insulation Thickness for Buildings Using Life Cycle Cost. *Applied Energy*, **63**, 115–124.
11. Ozkan, D.B., Onan, C. (2011). Optimization of Insulation Thickness for Different Glazing Areas in Buildings for Various Climatic Regions in Turkey. *Applied Energy*, **88** (4), 1331–1342.
12. Sundarama, S., Bhaskaranb, A. (2014). Optimum Insulation Thickness of Walls for Energy-Saving in Hot Regions of India. *International Journal of Sustainable Energy*, **33** (1), 213–226.

13. Büyükalaca, O., Bulut, H., Yılmaz, T. (2001). Analysis of Variable-Base Heating And Cooling Degree-Days for Turkey. *Applied Energy*, **69**, 269–283.

14. Fertelli, A. (2013). Determination of Optimum Insulation Thickness for Different Building Walls in Turkey. *Transactions of Famena*, XXXVII-2, ISSN 1333-1124, 103-113.

15. Ucar A., Balo F. (2010). Determination of the Energy Savings and the Optimum Insulation Thickness in the Four Different Insulated Exterior Walls. *Renewable Energy*, **35**, 88-94.

16. TSE (Turkish Standards Institution). (1998). TS 825: Thermal Insulation in Buildings.

17. Dagsoz, A.K. (1995). Degree Day Values in Turkey, National Energy Saving Policy. Heat Insulation in Buildings. Izocam, Istanbul (in Turkish).

18. Sisman, N., Kahyab, E., Aras, N., Aras, H. (2007). Determination of Optimum Insulation Thicknesses of The External Walls And Roof (Ceiling) for Turkey's Different Degree-Day Regions. *Energy Policy*, **35**, 5151–5155.

19. Baskerville, G.L., Emin, P. (1969). Rapid Estimation of Heat Accumulation from Maximum and Minimum Temperatures. *Ecology*; **50**, 514–517.

20. Floyd, R.B., Braddock, R.D. (1984). A Simple Method for Fitting Averaging Diurnal Temperature Curves. *Agricultural and Forest Meteorology*, **32**, 107–119.

21. Yang, S., Logan, J., Coffey D.L. (1995). Mathematical Formulae for Calculating the Based Temperature for Growing Degree Days. *Agricultural and Forest Meteorology*, **74**, 61–74.

22. Matzarakis, A., Balafoutis, C. (2004). Heating Degree-Days Over Greece As an Index of Energy Consumption. *Int. J. Climatol.*, **24**, 1817–1828.

23. Demir, I.H. (2014). Determination of Optimum Insulation Thickness for Building Exterior Walls and Cost Analysis (Bina dış duvarları için optimum yalıtım kalınlığının belirlenmesi ve maliyet analizi). MSc Thesis, Firat University, (in Turkish).

Nomenclature

C_A	annual heating cost ($/m^{2}year)
C_f	energy cost of fuel ($/kg, $/m^3, $/kWh)
C_i	insulation material cost ($/m^3)
C_{ins}	insulation cost ($/m^2)
C_t	total heating cost at present value ($)
CDD	cooling degree days (ºC.days)
DD	degree days (ºC.days)
E_A	annual heating energy (J/m^{2}year)
g	inflation rate
H_u	heating value (J/kg, J/m^3, J/kWh)
HDD	heating degree days (ºC.days)
i	interest rate
k	thermal conductivity (W/mK)
LCCA	life cycle cost analysis
N	lifetime (years)
PWF	present worth factor
R_i	thermal resistance (inside air) (m^{2}K/W)
R_{ins}	insulation thermal resistance (m^{2}K/W)
R_o	thermal resistance (outside air) (m^{2}K/W)
R_w	total thermal resistance of uninsulated wall plates (m^{2}K/W)
R_{wt}	total of R_i, R_w, R_o (m^{2}K/W)
q	heat loss (W/m^2)
U	overall heat transfer coefficient (W/m^{2}K)
T	temperature (ºC)
T_b	base temperature (ºC)
T_i	indoor design air temperature (ºC)
T_m	daily mean outdoor temperature (ºC)
T_{min}	minimum daily air temperature (ºC)
T_{max}	maximum daily air temperature (ºC)
x	insulation thickness (m)
x_{op}	optimum insulation thickness (m)
η	efficiency of the heating system