Optimum Insulation Thickness With Respect to Heating and Cooling Degree Days for Different Geographical Regions of Turkey

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Abstract

In this study, optimum insulation thicknesses of seven cities from every geographical region of Turkey for heating and cooling load have been calculated for external walls. Natural-gas was chosen as fuel for heating while electricity was chosen as energy source for cooling. Rock wool and expanded polystyrene (EPS) were chosen as insulation materials. Payback periods of insulations materials were calculated over 10 years. For heating, the highest value for optimum insulation thickness obtained for Erzurum as 0.1610 m when insulation material is EPS. For cooling, the highest insulation thickness is obtained as 0.0384 m for Mardin and EPS as insulation material. Energy savings obtained between 10.38- 104.24 $/m^2 for rock wool and 23.25-139.43 $/m^2 for EPS due to heating degree days while they are between 9.54- 48.24 $/m^2 for rock wool and 23.00-116.09 $/m^2 for EPS due to cooling degree days. Payback periods for rock wool vary between 5.13-7.69 years for rock wool and 7.67-12.86 years for EPS due to heating degree days. For cooling degree days, payback periods vary between 0.09-0.28 years for rock wool and 0.01-0.65 years for EPS.

Key words: Insulation thickness, energy saving, payback period, cooling degree days, heating degree days.

1. Introduction

Insulation is the most effective method of energy saving for buildings which have the highest pie of energy consumption in the world. Using optimum insulation thickness on external walls could be an appropriate solution to decrease insulation cost and to increase energy savings [1].

Degree-days method is stil the most advantageous and simplest method for the energy analysis of buildings. Many studies conducted on optimum insulation thickness due to heating load of external buildings [2-5]. On the other hand researchers have started to take into consideration

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both of heating and cooling loads of buildings in order to calculate optimum insulation thickness in recent years [6,7].

In this study, optimum insulation thicknesses for seven cities of Turkey have been calculated due to degree-day method including heating and cooling loads. Cities have been selected randomly from different geographical regions of Turkey. Rockwool and expanded polystyrene were used as insulation materials while natural gas was used as fuel for heating and electricity was used as energy source for cooling. Selected cities from different geographical regions are listed in Table 1 with heating and cooling degree days [8]. Energy savings due to cooling and heating loads and payback periods have been calculated beside optimum insulation thicknesses.

Table 1. Selected cities from different geographical regions of Turkey

City	Region	Heating DD	Cooling DD
Çanakkale	Marmara	1789	249
Denizli	Aegean	1627	469
Antalya	Mediterranean	1083	562
Kayseri	Central Anatolia	3113	38
Trabzon	Black Sea	1724	91
Erzurum	East Anatolia	4827	7
Mardin	South-East Anatolia	2004	755

2. Heating and Cooling Degree-Days

In this study, degree-day method has been used to calculate optimum insulation thickness. According to degree-day method, energy need of a building is based on the difference between air temperatures of indoor and a base temperature [9]. For heating degree days, base temperature is assessed as 15 °C while it is assessed as 22°C for cooling degree days.

Heating degree day (HDD) is calculated as

$$HDD = (18°C - T_m) \times d \qquad (1)$$

Where T_m mean daily temperature value and d is number of days.

İf $T_m > 15°C,\ then\ \ HDD = 0$

Cooling degree day (CDD) is calculated as below

$$CDD = (T_m - 22) \times d \qquad (2)$$

If $T_m > 22°C$, then $CDD = 0$

A detailed information about heating and cooling degree days are presented in Ref [6].

2.1. Annual Heating / Cooling Loads and Optimum Insulation Thickness

In this study, it is accepted that a big amount of heat loss occurs from external walls. Figure 1 presents the wall section.

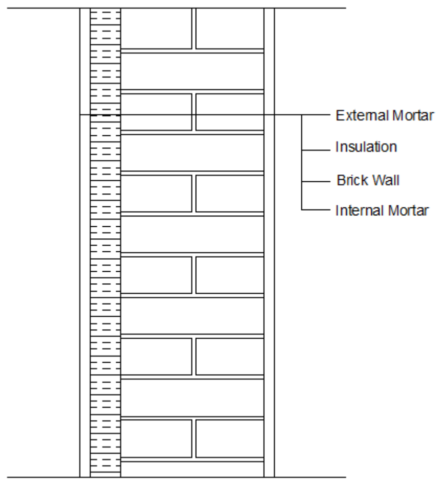

Figure 1. Wall section used in the study

The heat loss (q (W/m^2)) occurs in a unit of external wall is expressed as below

$$q = U.\Delta t \tag{3}$$

Where U (W/m^{2}K) is heat transmission coefficient and calculated by the equations with Ref [3], Δt (°C) is the difference of indoor and outdoor air temperature.

Annual energy cost for heating is calculated as

$$E_{A,H} = \frac{C_f.U}{LHV.\eta_s} HDD \tag{4}$$

Where C_f is cost of fuel (\$/m^3), LHV is heating value of fuel (J/m^3) and η_s is system efficiency.

Annual energy cost for cooling is expressed as

$$E_{A,C} = \frac{C_{elct}\,U}{COP} CDD \quad (5)$$

Where C_{elct} is cost of electricity (\$/kWh) and performance coefficient of cooling system (COP) has been accepted as 2.5 in this study [6].

Total heating cost, energy cost and insulation cost of buildings are calculated over a life time (N) by a parameter called Present Worth Factor (PWF). It depends on inflation (i) and interest rates (g) of countries and it is calculated as

If $i>g$ then $r=\frac{i-g}{1+g}$ and $i<g$ then $r=\frac{g-i}{1+i}$

$$PWF = \frac{(1+r)^N-1}{r(1+r)^N} \quad (6)$$

Cost of insulation is calculated as

$$C_I = C_{ins}x \quad (7)$$

Where C_{ins} is unit price of insulation material (\$/m^3), x (m) is insulation thickness. Total heating annual cost ($S_{ann,H}$) of an insulated building can be written as cost net energy savings for heating for a lifetime is expressed as [6]

$$S_{ann,H} = \frac{PWF\,C_f\,U}{LHV\,\eta_s} HDD - C_{ins}x \quad (8)$$

Optimum insulation thickness is obtained by minimizing total annual heating cost. Accordingly optimum insulation thickness for heating a unit area ($x_{opt,H}$) is calculated as

$$x_{opt,H} = 293.94\left(\frac{PWF C_f k HDD}{C_{ins} LHV \eta_s}\right)^{1/2} - R_w k \quad (9)$$

Where R_w is total thermal resistant of wall layers without insulation (m^{2}K/W) and k is thermal conductivity of insulation material (W/mK).

Similarly total cooling annual energy cost ($S_{ann,C}$) and optimum insulation thickness for cooling ($x_{opt,C}$) also could be calculated as below [6]

$$S_{ann,C} = \frac{PWF\,C_{elct}\,U}{COP} CDD - C_{ins}x \quad (10)$$

$$x_{opt,C} = 293.94\left(\frac{PWFC_{elct}kCDD}{C_{ins}COP}\right)^{1/2} - R_w k \quad (11)$$

Table 2 presents the parameters used in the calculations [4].

Table 2. Parameters used in the calculations

Parameter	Value	Parameter	Value
Fuel (Heating)	Natural Gas	Energy (Cooling)	Electricity
LHV	34.542×10^6 (J/kg)	Unit Price	0.1620 ($/KWh)
η_s	0.93	COP	2.5
Unit Price	0.8714$	R_w	0.642
Insulation	Expanded Polystyrene	Insulation	Rock wool
k	0.031 (W/mK)	k	0.040(W/mK)
C_{ins}	107$	C_{ins}	364$
i	11.3	g	9.2

3. Results

Optimum insulation thicknesses calculated for two different insulation materials are presented in Table 3 for heating degree days. According to results, optimum insulation thickness values vary between 0.0271 m for Antalya and 0.0858 m for Erzurum choosing rock wool as insulation material. On the other hand for EPS, values increases and varies between 0.0658 for Antalya and 0.1610 m for Erzurum. Coldest region and city presents the highest values for insulation and in relation to this, maximum energy savings for Erzurum as 139.43 $/m^2 for EPS and 104.24 $/m^2 are obtained.

For cooling degree days calculation results for optimum insulation thickness, energy savings and payback periods of insulation materials listed in Table 4. Especially cities in cold regions like Kayseri and Erzurum do not need any insulation for cooling. On the other hand warmest cities like Antalya and Denizli presented thinner insulation thicknesses with higher energy savings when insulation material is EPS. Energy savings for Antalya are obtained as 78.85 $/m^2 for EPS and 21.30 $/m^2 for rock wool.

Table 3. Optimum insulation thickness, energy savings and payback periods calculated for heating degree days due to optimum insulation thickness

	Optimum Ins. Thick. (m)		Energy Savings ($/m^2)		Payback Period (year)	
	Rockwool	EPS	Rockwool	EPS	Rockwool	EPS
Çanakkale	0.0422	0.0903	25.19	43.79	6.21	8.19
Denizli	0.0390	0.0852	21.59	38.99	6.02	8.10
Antalya	0.0271	0.0658	10.38	23.25	5.13	7.67
Kayseri	0.0638	0.1254	57.68	84.52	7.12	8.62
Trabzon	0.0409	0.0882	23.70	41.82	6.14	8.15
Erzurum	0.0858	0.1610	104.24	139.43	7.69	8.89
Mardin	0.0461	0.0967	30.20	54.74	6.42	12.86

Table 4. Optimum insulation thickness, energy savings and payback periods calculated for cooling degree days due to optimum insulation thickness

	Optimum Ins. Thick. (m)		Energy Savings ($/m^2)		Payback Period (year)	
	Rockwool	EPS	Rockwool	EPS	Rockwool	EPS
Çanakkale	0	0.0136	0	23.00	0	0.40
Denizli	0.0026	0.0260	9.54	61.49	0.09	0.56
Antalya	0.0053	0.0304	21.30	78.85	0.17	0.60
Kayseri	0	0	0	0	0	0
Trabzon	0	0.0003	0	0.31	0	0.01
Erzurum	0	0	0	0	0	0
Mardin	0.0102	0.0384	48.24	116.09	0.28	0.65

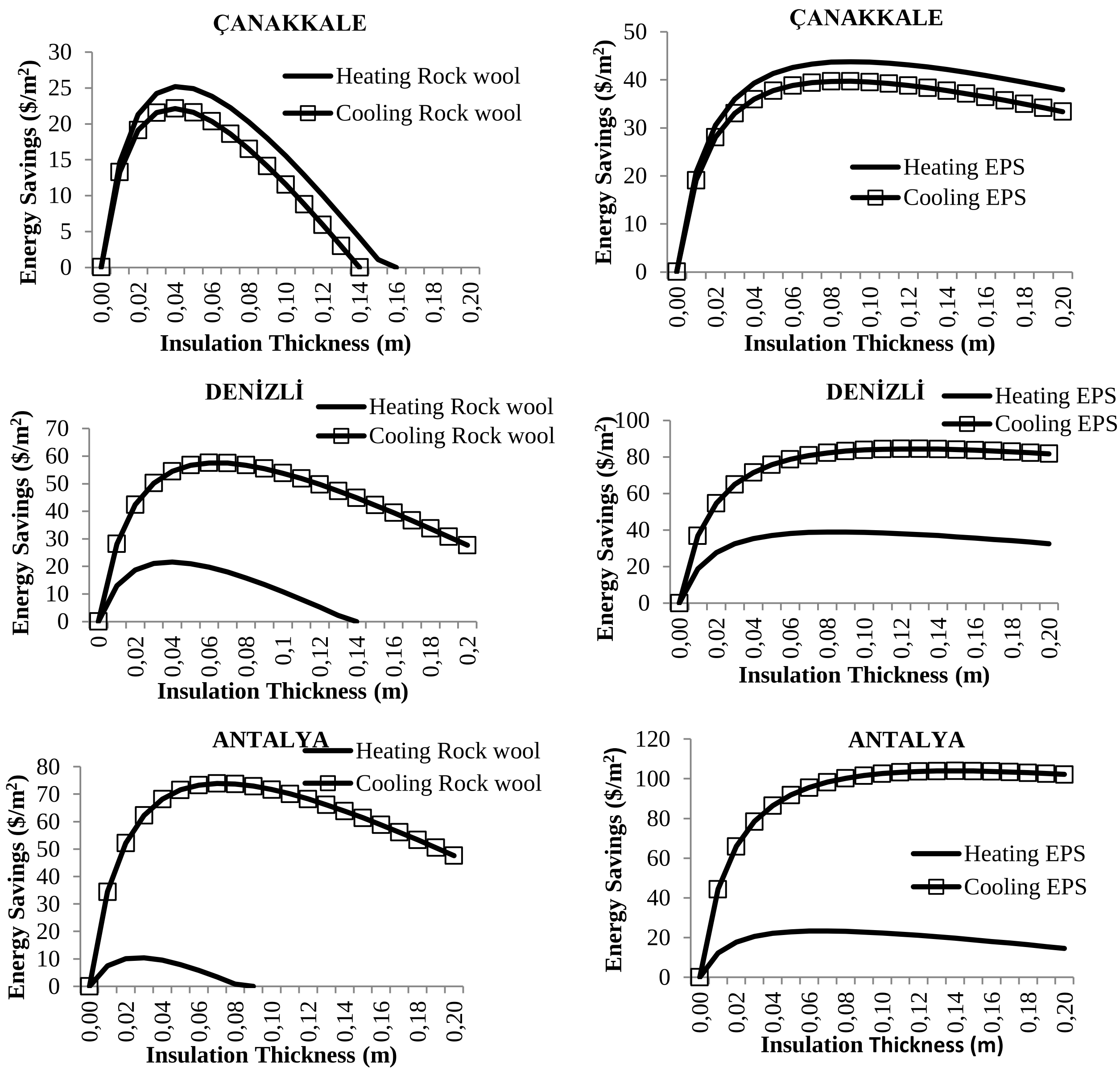

Figure 2. Energy savings versus insulation thickness for Çanakkale, Denizli Antalya.

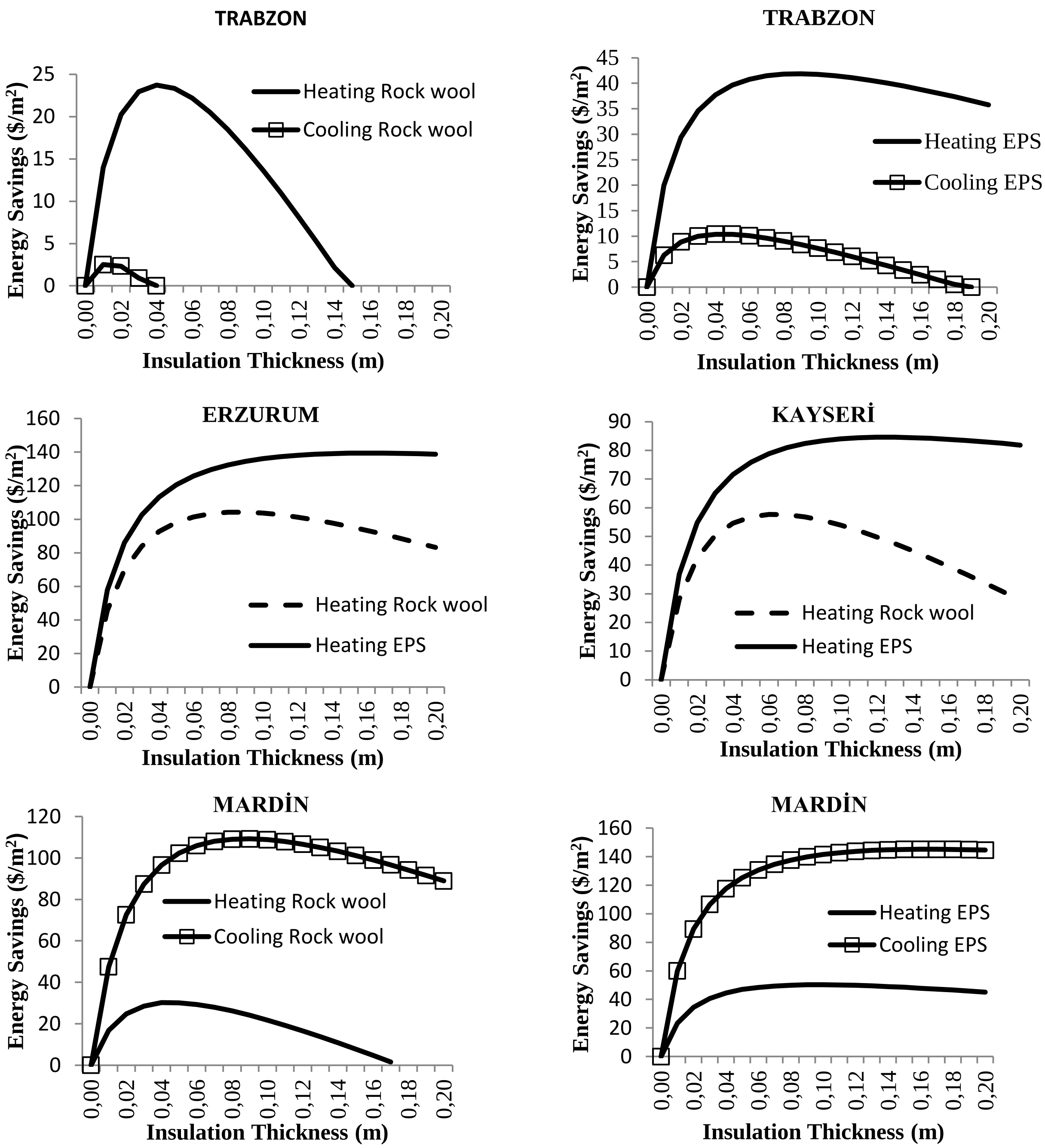

Figure 3. Energy Savings versus insulation thickness for Trabzon, Erzurum, Kayseri and Mardin.

. It is also more advantageous for Denizli and Mardin to use EPS due to cooling degree days with an energy saving of 61.49 and 116.09 \$/m^2 respectively. For cooling degree days, EPS generally provides better energy savings than rock wool and it's more preferable.

Payback periods of insulation materials depend on the ratio between insulation cost and annual savings. So increasing insulation thicknesses also causes an increasing for insulation cost and payback periods. EPS presented higher optimum insulation thicknesses in comparison to rock wool in general. This is the main reason for shorter payback periods of rock wool. Payback periods vary between 5.13-7.69 years for rock wool and 7.67-12.86 years for EPS due to heating degree days. For cooling, as a result of decreasing insulation thicknesses, payback periods are generally less than 1 year.

Fig. 2 and Fig. 3 show the energy savings versus insulation thickness for two insulation materials due to cooling and heating degree days. It is obtained that energy savings provided by applying insulation on external walls for heating do not always gives the best results. It is preferable for the cities Çanakkale, Trabzon, Erzurum Kayseri to apply insulation thickness assessed for heating. Especially for Erzurum and Kayseri there is no need to insulation for cooling. Therefore, comparison of two insulation materials for heating is presented in the graphics of Kayseri and Erzurum. Cities of Antalya, Denizli and Mardin present better energy savings for cooling especially when EPS is insulation material and applying insulation according to cooling degree days is more economical. For the cities of Çanakkale, Trabzon, Erzurum and Kayseri insulation thicknesses should be assessed due to heating degree days.

1. Conclusion

In this study, optimum insulation thickness, energy savings and payback periods of insulation materials (rock wool and expanded polystyrene) over 10 years were calculated for chosen seven cities from every geographical region of Turkey due to cooling and heating degree days method. According to obtained energy savings, insulation should be applied due to cooling degree days for the cities existed in warmest zone of Turkey. In this respect Antalya (1st Region), Mardin and Denizli (2nd Region) represents the warmest zone due to Degree-Days Regions of Turkey. On the other hand Erzurum and Kayseri represents the coldest zone defined as 4th region, and highest insulation thicknesses for heating were obtained while they need no insulation for cooling. EPS showed longer payback periods in comparison with rock wool. But also it provided better energy savings and could be evaluated as a more economical insulation material.

These results demonstrate the importance of thermal insulation for energy savings. Application of optimum insulation thickness is important in order to ensure energy savings while it is avoiding environmental pollution at the design stage.

References

[1] Hasan, A., "Optimazing Insulation Thickness For Buildings Using Life Cycle Cost" Applied Energy,1999, 63; 115-124.
[2] Dombaycı ÖA, Gölcü M, Pancar Y. Optimization of insulation thickness for external walls using different energy-sources. Appl Energy 2006; 83:921–8
[3] Aytac A, Aksoy UT. "The relation between optimum insulation thickness and heating cost on external walls for energy saving", Gazi Univ. Müh. Journal of Faculty of Engineering and Architecture, 2006;21(4):753–8.
[4]BektaşEkici,B.,Gülten A.,Aksoy U.T.,"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 2012, 92;211-217.
[5] Uçar A, Balo F. Effect of fuel type on the optimum thickness of selected insulation materials for the four different climatic regions of Turkey. Appl Energy 2009;86(5):730–6.
[6] Bolattürk, A., "Optimum Insulation Thickness For Building Walls with Respect to Cooling and Heating Degree-Hours in the Warmest Zone of Turkey. Building and Environment 2008; 43:1055-1064.
[7]Daouas N., "A study on optimum insulation thickness in walls and energy savings in Tunisian buildings based on analytical calculation of cooling and heating transmission loads", Applied Energy,2011;88-1, p:156-164.
[8] Buyukalaca O, Bulut H, Yılmaz T. Analysis of variable-base heating and cooling degree-days for Turkey. Applied Energy 2001;69:269–83
[9] www.mgm.gov.tr (07.04.2105)