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DETERMINATION OF OPTIMUM INSULATION THICKNESS FOR DIFFERENT BUILDING WALLS IN TURKEY

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Summary

In this study, the influence of different wall types (stone, brick, concrete and bims - which are usually used in building construction in Turkey) on the optimum insulation thicknesses, energy savings, and payback periods was evaluated for six different energy types: LPG, electricity, fuel oil, coal, natural gas, and geothermal energy. Four cities from different climate zones (Aydın, Trabzon, Malatya, and Sivas) were selected for the analysis which was carried out with two different insulation materials. Results showed that 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 fuel and wall types.

Key words: *Optimum insulation, external wall, block pumice, life cycle cost*

1. Introduction

Energy requirements, especially of the residential building sector, are an important part of the total energy consumption in many countries [1]. For example, in Turkey, the building sector was the second largest consumer of energy with 25.793 million tons of equivalent energy (MTOE) in 2001, and its demand is estimated to reach 41.7 MTOE by 2020 [2]. This is the eventual result of the noteworthy increase in the demand for new buildings and apartment buildings. Another reason for the high energy consumption of the building sector may be related to inadequate energy conservation measures in some buildings due to uncontrolled urbanization and building construction activities [2].

It is clear from the above data that reducing the energy use for space heating in buildings is a key measure to energy conservation and environmental protection. Thermal insulation is applied for reducing heat loss in buildings through the envelope. In Turkey, the thickness of thermal insulation material that should be applied to buildings is determined according to Turkish Standard 825 (TS 825) “thermal insulation in building” [3]. Turkey is classified into four climatic zones considering only the heating energy requirement by using a degree-day concept in TS 825 [4].

Sallal K. [5] compared two types of roof insulation in warm and cold climates and found that the payback period in the cold climate is shorter than that is the warm climate. Bolattürk [6] calculated the optimum insulation thickness, energy savings and payback periods of various fuels for 16 selected cities from four climate zones. They found that energy savings vary between 22% and 79% and the optimum insulation thickness varies between 2cm and 17cm. Çomaklı and Yuksel [7] investigated the optimum insulation thickness for the coldest cities. The optimization is based on the life cycle cost analysis. Energy saving was obtained when the optimum insulation thickness is applied on the wall. Dombayıcı [8] found that in the city of Denizli, Turkey, when the optimum thickness of expanded polystyrene as the insulation material was used, energy consumption was decreased by 46.6%. Mahlia and Ikbal [9] determined potential cost savings by installing different insulation materials. Results showed that by having air gaps of 2 cm, 4 cm, and 6 cm energy consumption can be reduced by 65-77 %. Ozel and Pıhtılı [10] calculated the optimum thickness of insulation applied to external walls for Adana, Elazıg, Erzurum and Izmir provinces considering the heating and cooling degree day values. J. Yu et al. [11] investigated the optimum insulation thickness for four typical cities in a hot summer and a cold winter zone of China for five insulation materials including expanded polystyrene, extruded polystyrene, foamed polyurethane, perlite, foamed polyester chloride. Results show that the optimum insulation thickness range is 0.053-0.236 m, while payback periods range from 1.9 to 4.7 years. Uçar and Balo [12] 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.

In this study, four different cities of Turkey, Sivas, Malatya, Aydın and Trabzon are selected to represent the first, second, third, and fourth climatic zones, respectively. The annual heating degree-days of selected cites in this study are taken for a base temperature of 18 °C for heating as given in Table 1 [13]. The effect of four different wall structures is considered to determine the optimum insulation thickness for XPS and rock wool insulation materials. Also six fuels including geothermal energy, coal, natural gas, fuel oil, LPG, and electricity are chosen to determine the optimum insulation thickness, energy savings and payback period.

Table 1 Climate zones and certain data for the selected zci cities.

Zone	City	Altitude (m)	Longitude (°)	Latitude (°)	Degree-days(°C-days)
1st zone	Aydın	57	27°50′	37°51′	1213
2nd zone	Trabzon	30	39°43′	41°00′	1724
3rd zone	Malatya	998	38°18′	38°21′	2461
4th zone	Sivas	1285	37°01′	39°49′	3444

2. External wall structures in buildings

The four different types of wall in this study are: pumice blocks, autoclaved aerated concrete (AAC), walls with air gap, and brick walls. The structures of investigated walls are shown in Figure 1.

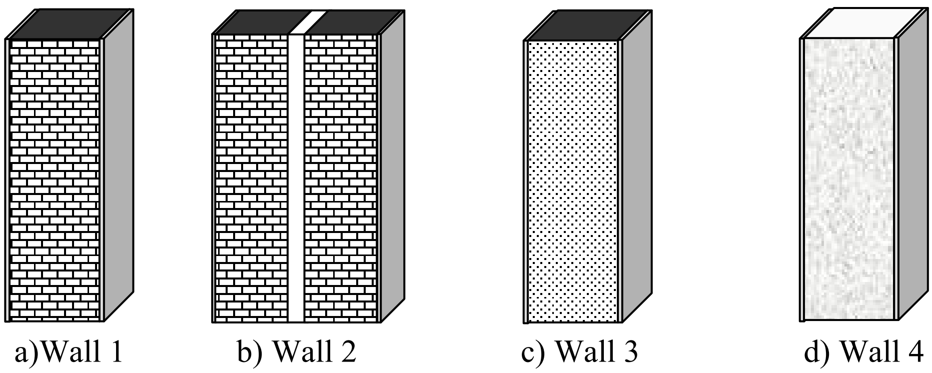

Fig. 1 Structures of the investigated external walls a) brick b) wall with air gap c) pumice block d) autoclaved aerated concrete (AAC)

Wall 1 consists of inner plaster, brick, insulation material and external plaster. On the other hand, Wall 2 is an example of a wall that is named as a sandwich wall which comprises a combination of inner plaster, air gap, brick and external plaster. The materials used in Wall 3 are inner plaster, block pumice (bims), insulation, and external plaster. The structure of Wall 4 is formed with inner plaster, autoclaved aerated concrete, and external plaster. The wall parameter values used in this study and their thermal properties are given in Table 2. These structures are used for calculation for all the cities considered here. In this study, extruded polystyrene and rock wool are used as insulation material. The values of the parameters used in the calculations for the insulated buildings are given in Table 2 and Table3. The optimum insulation thickness, payback periods and the net energy savings are calculated for all the walls, fuels and insulation materials. The conductivity and resistant values were taken from TS 825 Turkish Standard of Thermal Insulation in Buildings [3].

Table 2 The parameters used in calculations [3-19]

Parameter	Value	Parameter	Value
Degree-days, DD (°C-days)	See Table 1	*Insulation*	
Fuel	See Table 3	Extruded polystyrene	
		Conductivity, k	0.030 W/m K
External walls		*Cost, C_i*	142 \$/m^3
Brick			
Conductivity, k	0.523 W/m K	Rockwool	
		Conductivity, k	0.045 W/m K
Block pumice		*Cost, C_i*	234 \$/m^3
Conductivity, k	0.19 W/m K		
		Thermal resistances	
		$R_{w,1}$	0.645 m^2 K/W
Autoclaved aerated (AAC)		$R_{w,2}$	0.886 m^2 K/W
Conductivity, k	0.14 W/m K	$R_{w,3}$	1.223 m^2 K/W
		$R_{w,4}$	1.580 m^2 K/W
Wall with air gap		R_i	0.142 m^2 K/W
Conductivity, k	0.465 W/m K	R_o	0.0454 m^2 K/W
Interior plaster		*Interest rate*	11.5%
Conductivity, k	0.872 W/m K	*Inflation rate*	10.7%
		Lifetime,x	10 years
Exterior plaster			
Conductivity, k	1.4 W/m K		

Table 3 Properties and cost of fuels [20]

Fuel	Price	H_u	η_s
Coal	0.456 \$/kg	$29.294 \cdot 10^6$ J/kg	0.65
Natural Gas	0.476 \$/m^3	$34.525 \cdot 10^6$ J/m^3	0.93
Fuel-oil	1.601 \$/kg	$41.326 \cdot 10^6$ J/kg	0.80
LPG	2.757 \$/kg	$46.453 \cdot 10^6$ J/kg	0.92
Electricity	0.177 \$/kWh	$3.5990 \cdot 10^6$ J/kWh	0.99
Geothermal	0.444 \$/kg	$36.000 \cdot 10^6$ J/kg	0.98

3. Heat losses at the external wall

In buildings, heat losses mostly occur through external walls, floor, ceiling, windows, and air infiltrations [12]. In this study, the optimum insulation thickness was calculated by considering heat loss through external walls. The heat loss from per unit area of external wall [12] is

$$q = U \cdot (T_b - T_0) \tag{1}$$

U is the overall heat transfer coefficient, T_h is the base temperature and T_0 is the mean daily temperature. The annual heat loss occurring on the per unit area according to the degree-day method [14] is expressed as:

$$q_A = 86400 \cdot \mathrm{DD} \cdot U \tag{2}$$

where DD is the degree-day sum. The annual energy requirement can be calculated by dividing the annual heat loss by the efficiency of the heating system η_s [15]

$$E_A = \frac{86400 \cdot DD \cdot U}{\eta_s} \tag{3}$$

The overall heat transfer coefficient U for a typical wall that includes a layer of insulation is defined in Eq. (4) as:

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

Here, R_i and R_o are the inner and the outer air film thermal resistances, respectively, R_w is the total thermal resistance of the wall materials without the insulation, and R_{ins} is the thermal resistance of the insulation layer [15] , which can be written as

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

where x and k are the thickness and the thermal conductivity of the insulation material, respectively. If R_{tw} is the total thermal resistance of the wall without the insulation material, Eq. (4) can be rewritten as [16]

$$U = \frac{1}{R_{tw} + R_{ins}} \tag{6}$$

As a result, the annual heating load is then given by [16]

$$E_A = \frac{86400 \cdot DD}{\left(R_{tw} + \frac{x}{k}\right) \cdot \eta_s} \tag{7}$$

and the annual fuel consumption is [6]

$$m_{fA} = \frac{86400 \cdot DD}{\left(R_{tw} + \frac{x}{k}\right) \cdot LHV \cdot \eta_s} \tag{8}$$

where LHV is the lower heating value of the fuel given usually in J/kg, J/m^3 or J/kW h, depending on the fuel type [16].

4. Life-cycle analysis and optimization of insulation thickness

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 (PW). The present worth factor is calculated based upon the inflation and interest rate as follows [6]:

The interest rate adapted for an inflation rate r is given by:

if $i > g$, then

$$r = \frac{i-g}{1+g}$$

if $i<g$, then

$$r = \frac{g-i}{1+i}$$

and

$$PW = \frac{(1+r)^N - 1}{r(1+r)^N} \tag{9}$$

where N is the lifetime, which is taken to be 10 years. If $i=g$, then

$$PW = \frac{N}{1+i} \tag{10}$$

The annual heating cost per unit area may be determined from [17] as

$$C_A = \frac{86400 \cdot DD \cdot C_f}{\left(R_{tw} + \frac{x}{k}\right) \cdot LHV \cdot \eta_s} \tag{11}$$

where C_f is the fuel cost in \$/kg, \$/m^3, or \$/kWh, depending on the fuel type. The cost of insulation is given by [17] as

$$C_{ins} = C_l \cdot x \tag{12}$$

where C_l is the cost of insulation material in \$/m^3 and x is the insulation thickness in m.

The total cost of heating the insulated building in present dollars is given by [18] as

$$C_t = C_A \cdot PW + C_l \cdot x \tag{13}$$

or

$$C_t = \frac{86400 \cdot DD \cdot C_f \cdot PW}{\left(R_{tw} + \frac{x}{k}\right) \cdot LHV \cdot \eta_s} + C_l \cdot x \tag{14}$$

The optimum insulation thickness is obtained by minimizing Eq.14. Hence, the derivation of C_t to x is determined and equalized to zero and the optimum insulation thickness (x_{opt}) is obtained as follows [17]:

$$x_{opt} = 293.94 \cdot \left(\frac{DD \cdot C_f \cdot k \cdot PW}{LHV \cdot C_1 \cdot \eta_s}\right) - kR_{tw} \tag{15}$$

From Equation 15, it can be seen that the optimum insulation thickness depends on degree-days, price of fuel and insulation material, PW value and properties of wall, and insulation material. The parameters used in these calculations and their corresponding values are given in Table 2 and Table 3.

5. Results and Discussions

In this study, the effects of wall type and degree-day values on the optimum insulation thickness for different fuels and insulation materials are investigated. The calculations were conducted on four different cities in four different climatic zones in terms of TS 825. In addition, XPS and rockwool were applied as insulation materials.

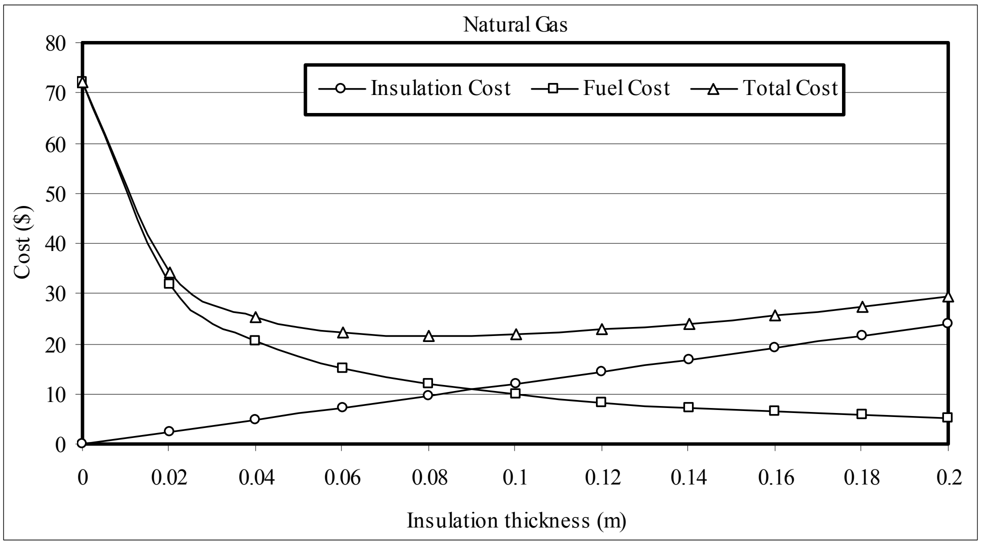

Fig. 2 Effects of insulation thickness on the insulation cost, energy cost for heating and total cost

Figure 2 shows the effect of the insulation thickness on the heating, insulation, and the total cost of a brick wall in Sivas. The aim is to reduce heat losses by increasing the insulation thickness in buildings. In this way, heating load and fuel cost of the building will decrease as the insulation thickness increases. However, the negative side-effect of thicker insulation is that the insulation price will increase. The sum of the cost of fuel and insulation material is the total cost, which decreases until a certain value of the insulation thickness is reached, after which it begins to increase again.

The energy savings at wall area are calculated from the difference between the energy need of an insulated and a non-insulated condition. Energy savings depend on types of fuel, efficiency of the heating system, the cost and insulation thickness of insulation material, etc [1]. The amount of energy savings as a function of the insulation thickness for different structural materials is shown in Figure 3 for two different insulation materials in the selected cities. When insulation thickness increases, energy savings rises and reaches its max. value at the optimum insulation thickness. When the maximum energy saving is obtained with XPS insulation, the minimum is obtained with Rockwool insulation. It is seen from Figure 3 that lowest value of energy saving is obtained for wall with autoclaved aerated concrete (Wall 4), while the higher energy savings are obtained for wall made brick. Similar results can be drawn for all cities. However, the magnitude of savings depends on the degree day of cities. The maximum energy savings of the optimum insulation thickness is about 170 $/m^2 (wall 1-XPS) for Sivas, and about 48 $/m^2 (wall 1-XPS) for Aydın.

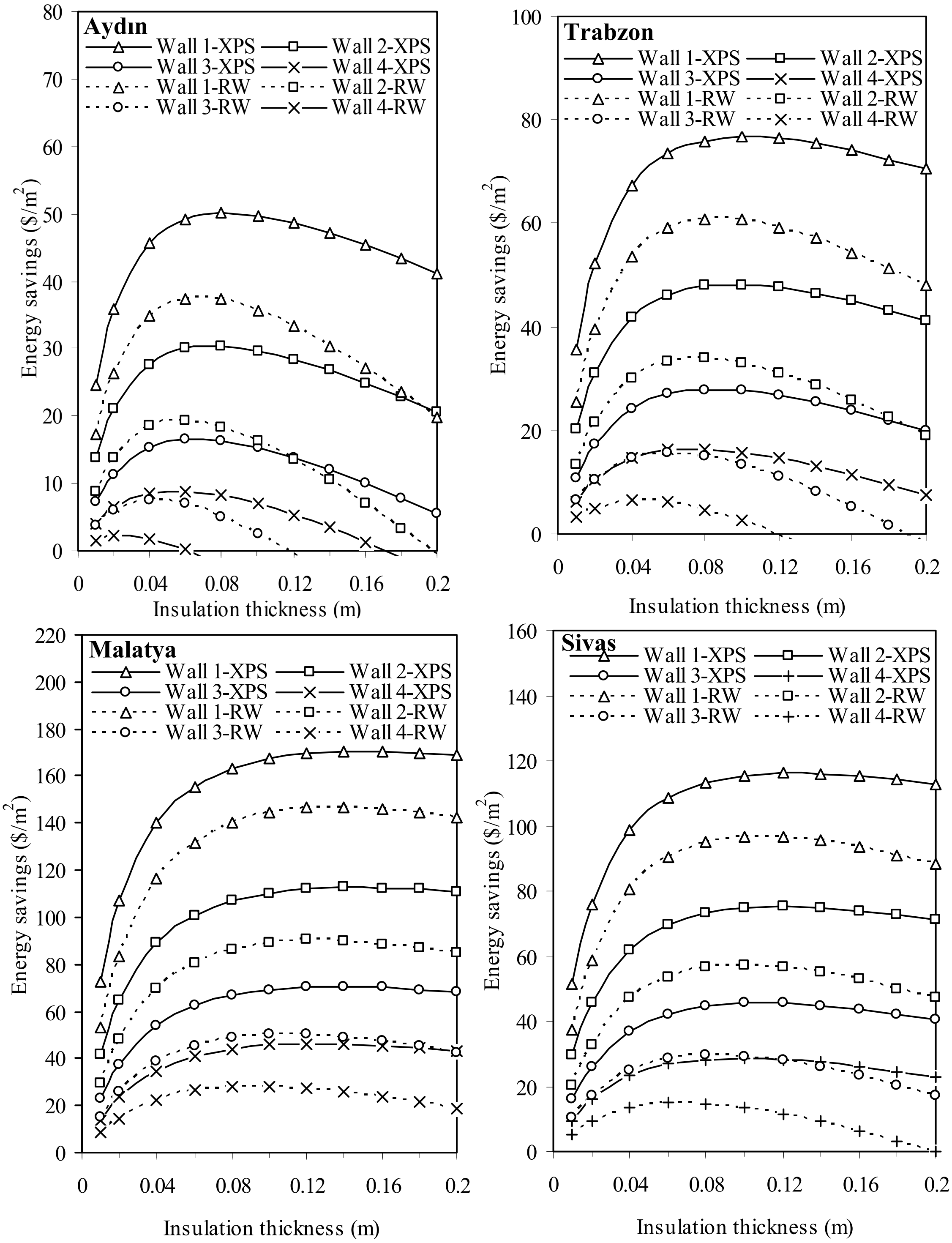

Fig. 3 Energy saving versus insulation thickness for different wall structures and insulation materials in the selected cities (for using fuel-oil as energy source)

Optimum insulation thickness given in Table 4 is for different wall types, fuels and insulation materials in the selected cities. For natural gas in Sivas, the optimum insulation thickness values for Wall 1-Wall 4 are 8.2 cm, 6.9 cm, 5.8 cm, and 4.8 cm, respectively, whereas the optimum insulation thickness values for Aydın are 3.7 cm, 3 cm, 2 cm, and 0.9 cm. It can be seen that the lowest optimum insulation thickness values are obtained for Aydın and rockwool insulation, while the highest values are obtained for XPS and Sivas. The results show that the optimum insulation thickness depend greatly on the wall structure, degree-days, and insulation material. Insulation thickness increases with both degree-days and energy cost for heating. Insulation thickness decreases with higher values of the thermal resistance for a given value of degree-days.

Table 4 Optimum insulation thickness

Wall type	***Optimum Insulation Thickness (m)***											
	XPS						Rockwool					
	LPG	Electricity	Fuel-oil	Coal	Natural Gas	Geo-thermal	LPG	Electricity	Fuel-oil	Coal	Natural gas	Geo-thermal
							Aydın					
Wall 1	0.098	0.084	0.083	0.052	0.037	0.033	0.083	0.069	0.068	0.039	0.025	0.021
Wall 2	0.091	0.077	0.075	0.045	0.030	0.025	0.072	0.059	0.057	0.029	0.014	0.010
Wall 3	0.081	0.067	0.065	0.035	0.020	0.015	0.057	0.043	0.042	0.013	0.000	0.000
Wall 4	0.070	0.056	0.055	0.024	0.009	0.005	0.041	0.027	0.026	0.003	0.000	0.000
							Trabzon					
Wall 1	0.121	0.104	0.102	0.066	0.048	0.043	0.105	0.088	0.087	0.053	0.035	0.030
Wall 2	0.114	0.096	0.095	0.059	0.041	0.035	0.094	0.078	0.076	0.042	0.024	0.019
Wall 3	0.104	0.086	0.085	0.049	0.031	0.025	0.079	0.062	0.061	0.027	0.009	0.004
Wall 4	0.093	0.076	0.074	0.038	0.020	0.015	0.063	0.046	0.045	0.010	0.000	0.000
							Malatya					
Wall 1	0.148	0.128	0.126	0.083	0.061	0.055	0.131	0.111	0.110	0.068	0.048	0.042
Wall 2	0.141	0.120	0.119	0.076	0.054	0.047	0.120	0.100	0.099	0.058	0.037	0.031
Wall 3	0.131	0.110	0.109	0.065	0.044	0.037	0.105	0.085	0.084	0.042	0.022	0.016
Wall 4	0.120	0.100	0.098	0.055	0.033	0.027	0.089	0.069	0.067	0.026	0.006	0.000
							Sivas					
Wall 1	0.179	0.155	0.152	0.101	0.082	0.068	0.160	0.137	0.135	0.086	0.062	0.055
Wall 2	0.172	0.147	0.145	0.094	0.069	0.061	0.149	0.126	0.124	0.075	0.051	0.044
Wall 3	0.162	0.137	0.135	0.084	0.058	0.051	0.134	0.111	0.109	0.060	0.036	0.029
Wall 4	0.151	0.126	0.124	0.073	0.048	0.040	0.118	0.095	0.093	0.044	0.020	0.012

Table 5 Energy savings

Wall type	***Energy Savings ($/m²)***											
	XPS						Rockwool					
	LPG	Electricity	Fuel-oil	Coal	Natural Gas	Geo thermal	LPG	Electricity	Fuel-oil	Coal	Natural gas	Geo-thermal
							Aydın					
Wall 1	71.003	51.618	50.090	20.104	10.098	7.826	55.918	38.889	37.564	12.498	4.970	3.418
Wall 2	44.370	31.378	30.362	10.872	4.765	3.454	30.796	20.159	19.347	4.777	1.148	0.558
Wall 3	25.408	17.130	16.492	4.741	1.510	0.908	13.947	8.024	7.590	0.759	0.000	0.000
Wall 4	14.811	9.334	8.920	1.768	0.245	0.064	5.589	2.467	2.256	0.024	0.000	0.000
							Trabzon					
Wall 1	107.416	78.921	76.668	32.081	16.867	13.348	88.655	62.969	60.958	22.236	9.976	7.317
Wall 2	69.131	49.722	48.197	18.526	8.855	6.702	51.881	35.280	33.997	10.192	3.475	2.182
Wall 3	42.576	28.867	27.879	9.208	3.625	2.479	26.438	16.538	15.792	2.988	0.357	0.072
Wall 4	25.874	17.146	16.477	4.341	1.185	0.639	12.976	7.056	6.629	0.359	0.000	0.000
							Malatya					
Wall 1	161.362	119.562	116.248	50.244	27.336	21.966	138.165	99.719	96.695	37.697	18.318	13.975
Wall 2	106.295	77.459	75.184	30.464	15.465	12.044	84.608	59.127	57.142	19.428	7.957	5.564
Wall 3	66.362	47.088	45.579	16.556	7.389	5.405	46.788	30.869	29.650	7.633	1.994	1.038
Wall 4	43.308	29.714	28.660	8.962	3.259	2.129	25.973	15.733	14.969	2.277	0.103	0.000
							Sivas					
Wall 1	235.053	175.280	170.533	75.569	50.851	34.200	206.869	151.065	146.66	59.918	30.696	24.006
Wall 2	157.571	115.943	112.649	47.408	25.080	19.903	130.898	93.238	90.288	33.335	15.181	11.220
Wall 3	101.107	72.861	70.641	27.368	13.203	10.038	76.547	52.270	50.392	15.409	5.417	3.468
Wall 4	68.234	47.938	46.354	16.132	6.815	4.845	45.913	29.585	28.343	6.411	1.268	0.514

The energy saving is especially important in cold areas and in the use of expensive fuels, such as fuel oil and LPG, as the cost required for heating the building cold areas becomes considerably higher [16]. Depending on the type of energy and insulation material, the calculated energy savings for different wall structures and for all the cities are given in Table 5. Energy saving for Sivas is higher than for the cities in the other regions. In all cities, the energy saving value increases for costly fuels. When XPS is used in Wall 1 for Sivas and LPG as a fuel, the maximum value of energy saving was found as 235 $/m^2, whereas this value for Wall 4 is 68.234 $/m^2.

Table 6 Payback periods

Wall type	***Payback periods (years)***											
	XPS						Rockwool					
	LPG	Electri-city	Fuel-oil	Coal	Natural Gas	Geo-thermal	LPG	Electri-city	Fuel-oil	Coal	Natural gas	Geo-thermal
Aydın												
Wall 1	1.432	1.515	1.523	1.876	2.315	2.536	1.818	2.010	2.031	3.018	4.705	5.806
Wall 2	1.668	1.814	1.829	2.526	3.572	4.184	2.404	2.823	2.871	5.748	Neglect	Neglect
Wall 3	2.111	2.407	2.440	4.195	8.164	11.530	3.845	5.139	5.302	Neglect	0.000	0.000
Wall 4	2.803	3.419	3.492	8.711	Neglect	Neglect	7.428	Neglect	Neglect	Neglect	0.000	0.000
Trabzon												
Wall 1	1.345	1.408	1.414	1.671	1.970	2.113	1.630	1.765	1.779	2.411	3.331	3.855
Wall 2	1.522	1627	1.638	2.106	2.732	3.064	2.028	2.293	2.322	3.829	6.962	9.411
Wall 3	1.833	2.030	2.051	3.071	4.835	6.001	2.883	3.544	3.622	9.463	Neglect	Neglect
Wall 4	2.280	2.646	2.687	5.041	11.443	Neglect	4.547	6.429	6.678	Neglect	0.000	0.000
Malatya												
Wall 1	1.278	1.326	1.331	1.522	1.735	1.832	1.493	1.590	1.600	2.029	2.589	2.880
Wall 2	1.412	1.490	1.498	1.828	2.232	2.433	1.774	1.952	1.971	2.866	4.338	5.267
Wall 3	1.639	1.776	1.790	2.437	3.385	3.928	2.325	2.709	2.752	5.285	Neglect	Neglect
Wall 4	1.944	2.178	2.204	3.484	5.939	7.717	3.241	4.114	4.220	Neglect	Neglect	0.000
Sivas												
Wall 1	1.228	1.266	1.270	1.418	1.422	1.647	1.395	1.469	1.477	1.787	2.162	2.347
Wall 2	1.333	1.393	1.400	1.644	1.926	2.061	1.605	1.733	1.746	2.338	3.182	3.655
Wall 3	1.506	1.606	1.617	2.063	2.651	2.960	1.989	2.239	2.267	3.664	6.461	8.568
Wall 4	1.727	1.890	1.907	2.709	3.975	4.746	2.566	3.062	3.119	6.817	Neglect	Neglect

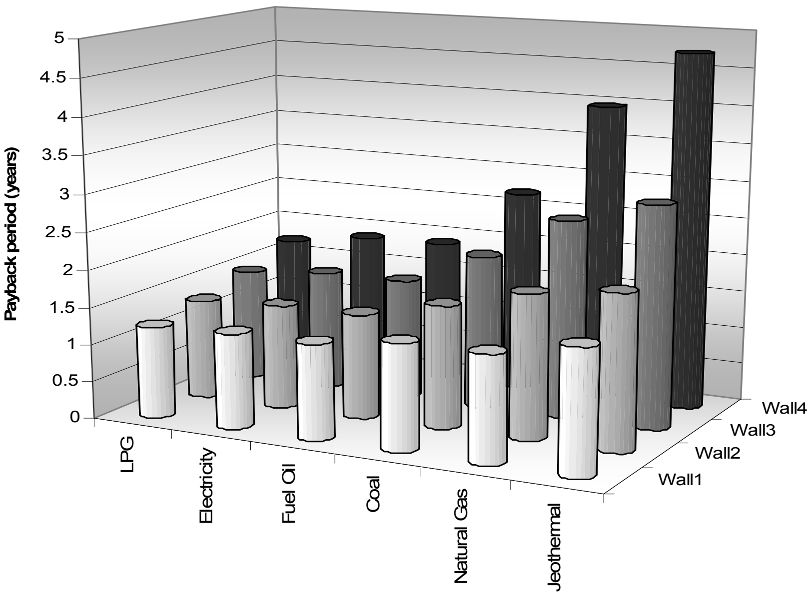

Fig. 4 Effects of wall structures on the payback period for different fuels

Table 6 gives the payback period of the optimum insulation thickness for each structure depending on the insulation materials and the energy types used. The payback period becomes more significant with an increase in degree-day. Naturally, the shortest payback periods occur in the components in which the maximum total annual savings are obtained. For example, the payback period for a brick wall with XPS insulation in Sivas is by 62.7% shorter than in the same situation in Aydın with natural gas energy. The payback periods over 12 years are not considered since they are not examined. As it can be seen from the table, while the payback period is 1.72 for applying the optimum insulation thickness with XPS for Sivas (Wall 4-LPG), it is 2.56 for applying the optimum insulation thickness with rockwool.

Payback periods of the insulation are shown in Figure 4 for different energy types and wall structures. The payback periods range between 1.3 – 4.6 years, depending on wall structures and fuel type. They increase with increasing resistance of the wall and with decreasing fuel price.

6. Conclusion

An important part of energy consumed in buildings is used as the heating energy in Turkey. Using insulation materials on buildings is the most significant application to reduce the level of losing heat energy. In this study, the optimum insulation thickness, annual energy saving, and payback periods are investigated for four different types of external walls, with XPS and rockwool as insulation materials, and six different fuel types. The calculations were carried out for different cities in four different climatic zones according to TS 825. The results show that the energy saving is bigger, insulation is more effective, and the payback period is shorter for higher degree-day cities.

As a result of the study, 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. The highest value of the optimum insulation thickness is reached by using Wall 1, XPS as insulation material, and LPG as energy source, whereas the lowest optimum insulation thickness is obtained by using Wall 4, rockwool as insulation material and geothermal energy as energy source.

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Nomenclature

C	cost(\$/kg, \$/m^3, \$/kWh)	x	insulation thickness (m)
DD	degree-days (^{o}C-days)		
E_A	annual heating energy (J/m^{2}year)	*Greek letter*	
g	inflation rate	η_s	efficiency of the heating system
i	interest rate		
LCCA	life-cycle cost analysis	*Subscripts*	
LHV	lower heating value (J/kg, J/m^3, J/kWh)	A	annual
k	thermal conductivity (W/mK)	f	fuel
m_{fA}	annual fuel consumption(kg/m^{2}year, m^3/m^{2}year kWh/m^{2}year)	I	insulation material
N	lifetime (years)	i	inside
PW	present worth factor	o	outside
R	thermal resistance (m^{2}K/W)	opt	optimum
q	heat loss (MJ/ m^{2}year)	s	system
T_b	base temperature(^{o}C)	t	total
T_o	mean daily temperature(^{o}C)	tw	total wall excluding insulation material
U	overall heat transfer coefficient(W/ m^{2}K)	w	wall material

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