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CALCULATION OF INSULATION THICKNESS DEPENDING ON THE COOLEST AND HOTTEST CLIMATE CONDITIONS FOR DIFFERENT FLAT ROOF TYPES OF BUILDINGS

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Abstract: In this study, optimum insulation thicknesses are calculated for three different flat-surfaces which are navigable terrace roof; stone-covered and soil-covered un-navigable flat roof types. The outdoor temperature, the value of January, which is the coldest month in winter, and the value of July, which is the hottest month in summer, and solar radiation, are considered together. Flat roof surfaces are considered to be stone-covered and soil-covered black painted and marble. Firstly, solar-air temperatures were determined for the winter and summer periods. Then, optimum insulation thickness calculations are made using life cycle total cost analysis. Extruded polystyrene (XPS) is accepted as the insulation material. Natural gas is used in winter and electricity in summer as an energy sources. The optimum insulation thicknesses have been calculated for five climate zones and three different roof types based on the TS 825. Then the results are compared. As a result, the optimum insulation thickness calculated considering the hottest and coldest months of the year was determined as 0.128 m in the 5th climate zone in roof one with the highest value, and as the lowest value with the 0.052 m in the 1st climate zone for roof three.

Keywords: Flat roof, Green roof, Optimum insulation thickness, Solar-air temperature, TS 825 standard

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1. Introduction

Today, green roof applications are implemented all over the world. Green roofs contribute positively to climate change by reducing environmental pollution, especially in city centers, and green roofs are an important application in terms of energy consumption and saving. Green roofs, which are an ecological application, can reduce the heat island caused in city centers, also contribute to the retention of rainwater, especially in humid areas, and reduce the emission release (Tang and Zheng, 2019).

In the literature, green roofs are called vegetated roofs, bio-roofs or ecological roofs. Thanks to the green roof application, it makes a positive contribution to indoor air conditioning, especially in the summer period. It reduces the insulation thickness to be applied to the building envelope. In addition, biodiversity enrichment, air purification, acoustic isolation can be counted as positive effects (Lee and Jim, 2020).

Insulation of the building envelope is an important energy-saving application. Insulation material with a low heat conduction coefficient should be used in building envelope insulation. In addition, the insulation thickness value should be high. On the other hand, the cost of insulation should be below. In a certain life, the value that minimizes the energy consumption and the costs of the insulation material is important. This value is the optimum point. The insulation thickness at this point is the optimum insulation thickness (De Rosa et al., 2014). In the literature, when determining the optimum insulation value, the degree-day method, which is very simple and can be calculated quickly, is used. This method is based on the temperature difference between the outdoor and indoor environments. Depending on different climate parameters such as a lot of suns and relative humidity, degree-day values can be calculated for the both heating and cooling season. Thanks to this method, it provides convenience in the energy consumption estimation of long-term buildings (Daouas, 2016).

When we examined the literature, Daouas (2016) investigated a dynamic model for multi-layered roofs subjected to constant climate conditions in Tunis by using the incoming solar radiation. A life cycle cost analysis was conducted to determine the optimum insulation thicknesses (Yin et al., 2019). Ozel (2013) numerically investigated the thermal, economic and environmental effects of insulated external walls for different wall layers. In the province of Kars, which is one of the coldest cities in Türkiye, investigations were made for different wall orientations during the winter period. For this purpose, a computer model based on finite differences under various stable periodic conditions is used in the study (De Rosa et al., 2014). Wang et al. (2022) determined the roof thermal insulation type and optimum insulation thickness. They presented an optimization design method based on an integrated economic and environmental consideration for the best insulation design on building roofs. A double-layered ventilated roof heat transfer model has been developed in a low-temperature granary in Changsha, China. Extruded polystyrene, mineral wool and polyurethane were used as insulation materials. Yin et al. (2019) evaluated the green roof at three heights (30, 60 and 120 cm) during the summer in Nanjing, China. Among the outdoor scenarios, sunny days had the highest effect on the thermal performance of the large green roof, while cloudy and rainy days had less effect (Peng et al., 2019). De Rosa et al. (2014) proposed a model to simulate the energy consumption in buildings. The model has some temporary energy balance equation for walls and indoor air and is implemented using Matlab/Simulink. The results showed that the cooling energy demand on days with low cooling degrees and solar radiation play an important role in this case (Daouas, 2016). Tang and Zheng (2019) examined the thermal properties of green roof using a real data. Equivalent thermal resistance and reduction factor of a green roof compared to a bare roof. Peng et al. (2019) evaluated and compared the long-term energy performance of large-scale green roofs in a humid subtropical climate region of China. Based on the outdoor temperature, roof surface temperature, roof heat flux, and cooling/heating energy load, seasonally, hourly, daily and year-round analyzes were made for green roof and bare roof. Wahba et al. (2019) compared the electricity consumption and savings potential of green roofs and green walls when applied in arid climatic conditions for different latitudes in Cairo, Egypt. The study investigated the effect of green roof and walls on indoor thermal comfort in the arid climate region. These studies were done with the energy simulation DesignBuilder. Huang and Ma (2019) performed a cost analysis of large green roofs containing light expanded clay aggregate (LECA) and Ipomoea batata, both measuring the change in surface temperature and heat amplitude, as well as reducing energy. Kaboré et al. (2020) investigated the performance of heat flows using energy simulation to research the performance of passive cooling technique. In the building models, both a green roof and a wet roof are used. For wet roofs, heat transferred to the environment was found to be higher for a Mediterranean climate. Family et al. (2020) investigated reinforced concrete panels and three different types of plant-covered roofs for passive cooling applications. Combined radiation and conduction heat transfer analyses were performed to evaluate their insulation potential. Mahmoud and Ismaeel (2019) conducted simulation studies to examine the usage of three different roof design principles on the energy consumption in Egypt. Rosti et al. (2019) calculated the optimum insulation configuration in buildings based on the theory of delay and decay factor. In the study, they made investigations for different multilayer wall configurations using the transient heat conduction equation. Saydam et al. (2021) investigated the effect of green roof application on heating requirement, environmental emissions and fuel cost in two different cities located in different degree day regions. Investigations were made for two different indoor temperatures of 19 ^{0}C and 21 ^{0}C. Heating requirement, monthly fuel cost and emission values were determined for the non-heat insulated, thermally insulated and green roof conditions of the building. Ragab and Abdelrady (2020) examined the green roof application to reduce the energy need different climate zones. The energy consumption of various types of green roofs with different thermal properties to cool school buildings in Egypt has been studied. As a result, green roofs have been found to be effective to reduce the energy demand compared to traditional roof. Lee and Jim (2020) studied the effect of temperature and solar radiation on the microclimate, by comparing a bare roof with an intense green roof. Microclimatic studies were conducted in subtropical Hong Kong during the winter season. Sunny, cloudy and rainy conditions were adopted for analyzes of interactions between factors such as temperature and solar radiation. Kurekci (2016) determined the optimum insulation thicknesses needed in 81 provincial centers of Türkiye. Calculations were made for four different fuels and insulation materials. Three different situations are considered. Optimum insulation thicknesses were calculated according to these three conditions. Dombayci et al. (2017) examined the usage of energy sources and insulation materials for Denizli on energy consumption. Optimization was made based on life cycle cost analysis. Ulaş (2010) investigated the schools, which are the most widespread institutions in our country, are insulated and uninsulated; Heat loss, fuel consumption and the amount of carbon dioxide released to the atmosphere as a result of the combustion of the consumed fuel for four different thermal insulation zones and three different fuel types. Different insulations were compared with each other by making economic analysis according to the life cycle cost analysis method. Then, optimum insulation thicknesses were calculated in the thermal insulation zones. Lewandowski and Lewandowska-Iwaniak (2014) studied building envelopes depending on their ability to transmit the solar energy flows and investigate the energy-saving building materials. Kon et al. (2021) calculated optimum insulation thicknesses for exterior walls of a hospital building in Balıkesir, taking into account the combustion properties of glass wool, stone wool and polyurethane insulation materials. Based on the non-insulated and optimally insulated external wall, life cycle savings and life cycle total cost values were calculated for energy consumption. Hao et al. (2022) conducted experiments in Hunan, China, using a comparative test platform consisting of two experimental chambers equipped with greenery systems and the other without greenery systems during the transition seasons. They investigated the effects of Greenery systems on the thermal comfort of indoor environments and saw that energy savings were achieved in the operating times of the air conditioner with this system. Ayın (2021) examined the properties of building materials to be used in the design of roof gardens and offered different solutions for the problems that may occur in roof gardens and gave an information about the situation of roof gardens in Türkiye. Also, he researched emerging building materials in the design of roof gardens. El-Zoklah and Refaat (2021) simulated the effect of Green Facades Systems on energy efficiency in a residence with 12 cm wall thickness in New Cairo, Egypt. They used the Design Builder program. They made calculations for the south, east, and west directions and different thicknesses of the wall. Juras (2022) analyzed the experimental measurements taken on two different large green roofs in Central Europe and compared the results with a single-ply roof with PVC membrane. Vermaa and Asafo-Adjeib (2021) determined the optimum thickness of walls and ceilings according to cities in order to reduce the energy needs of buildings in the housing sector of the country in Ghana. For this, a mathematical model has been developed to determine the threshold values for cooling and heating degree days. Dominguez-Torres et al. (2021) optimized a solution that combines thermal insulation and a cold roof for the renovation of residential roofs in Seville, Spain. Various combinations of solar reflective coatings and insulation layer thickness were considered in the optimization analysis. Mahapatra et al. (2022) investigated how the optimum insulation thickness will change when cellulose, corn-based insulation, polyurethane and polystyrene insulation materials are used together with brick materials with different outer surface absorptivity for the Indian cities of Delhi, Jodhpur, Mangalore and Pune.

The aim of the study is to calculate the optimum insulation thicknesses of three different roof types, such as a navigable flat roof, a non-navigable stone-covered roof, and a green roof. While calculating the optimum insulation thickness, the degree-day method and life cycle total cost analysis were used. Firstly, the sol-air air temperatures calculated depending on the solar radiation value for the coldest month of the year, January, and the hottest month of July, was used. Heat transfer calculations are used for outdoor and indoor environments. Secondly, the optimum insulation thickness calculated based on the recommended values for indoor and outdoor environments according to TSE (2013). The results of the two insulation thicknesses were compared. This study shows the importance of green roof application in buildings in terms of energy saving. Finding the optimum insulation thickness values for roofs depending on the coldest and hottest months of the year and changing them with different roof types provides a new contribution to the studies in the literature.

2. Materials and Methods

2.1. The Interior-Surface Combined Heat Transfer Coefficient

Convection heat transfer coefficient for horizontal direction; $h_{c,i}$ = 3.08 W/m² K for upward direction of heat flow, $h_{c,i}$ = 4.04 W/m² K for downward direction of heat flow were taken. Based on the indoor emissivity (ε_i =0.9) radiation heat transfer coefficient was taken as in Equation 1 (Çengel and Boles, 2002; Lewandowski and Lewandowska-Iwaniak, 2014; Daouas, 2016);

$$h_{ri}=5.72\ \varepsilon_i \tag{1}$$

2.2. The Exterior-Surface Combined Heat Transfer Coefficient

The convection heat transfer coefficient based on the outdoor air speed (V taken as 6 m/s) (Equation 2);

$$h_{co}=2.28\ V+8.18 \tag{2}$$

The radiation heat transfer coefficient based on the exterior surface emissivity (ε_{os}) and surroundings temperature (T_{sur}) can be calculated in Equation 3 (Çengel and Boles, 2002; Lewandowski and Lewandowska-Iwaniak, 2014);

$$h_{ro}=\sigma.\varepsilon_{os}.(T_o+T_{sur.}).(T_o^2+T_{sur}^2) \tag{3}$$

here, the exterior surface emissivity for roof 1 with marble surface was taken as 0.88, and for roof 2 and roof 3 which accepted as black painted, exterior surface emissivity were taken as 0.98. σ is Stefan Boltzmann constant (Çengel and Boles, 2002; Daouas, 2016). The surroundings temperature temperature (T_{sur}) (Equation 4) based on the outside temperature (T_o);

$$T_{sur}=0.0552\ T_o^{1.5} \tag{4}$$

According to TS 825, interior surface combine heat transfer coefficient is 7.69 W/m².K and outer surface heat transfer coefficient is 25 W/m².K. The equation for combined heat transfer coefficient (h_{comb}) for the interior and exterior surfaces (Equation 5) (Çengel and Boles, 2002; TSE, 2013);

$$h_{comb}=h_c+h_r \tag{5}$$

2.3. Calculation of Sol-Air Temperature

Sol-air temperature is given in Equation 6;

$$T_{sol\text{-}air}=T_o+\frac{\alpha_{abs}I_{sol}}{h_{comb}}-\frac{\varepsilon_{os}\sigma.(T_o^4-T_{sur}^4)}{h_{comb}} \tag{6}$$

here, α_s is surface absorbty, I_{sol} is the solar radiation value and T_o is outdoor temperature. For roof 1 with marble surface, α_s (absorbty) is taken as 0.40, and for roof 2 and roof 3 as a black painted surface, α_{abs}

(absorbty) are taken as 0.98. I_{sol} is the solar radiation value. For January which is the coldest month of the year, the solar radiation on the horizontal surface is taken as 72 W/m² and for the July which is the hottest month of the year is taken as 93 W/m² (Çengel and Boles, 2002; Ozel, 2013; TSE, 2013).

2.4. Calculation of Degree-Day

The degree-day values based on the coldest and hottest month temperature can be calculated as in Equation 7 and 8;

$$HDD = M_h.30.(T_i - T_{sol\text{-}airmin}) \tag{7}$$

$$CDD = M_c.30.(T_{sol\text{-}airmax} - T_i) \tag{8}$$

Here, M_h is the number of months with heating which outdoor air temperatures are below 19 ⁰C. M_c is the number of months with cooling which outdoor air temperatures are above 22 ⁰C. $T_{sol\text{-}airmin}$ is the sol-air temperature belongs to the lowest outdoor air temperature of the January which is the coldest month of the year and $T_{sol\text{-}airmax}$ is the sol-air temperature belongs to the highest outdoor air temperature of July which is the hottest month of the year. Each month is accepted as 30 days. Degree-day calculation based on the TS 825 (Equation 9 and 10)(Ulaş, 2010; TSE, 2013).

$$HDD = 30\sum_{1}^{12}(T_i - T_o) \tag{9}$$

$$CDD = 30\sum_{1}^{12}(T_o - T_i) \tag{10}$$

here, T_o is outdoor temperature and T_i indoor air temperature. In the study, the heating temperature is taken as 19 ⁰C and cooling temperature is taken as 22 ⁰C (Ulaş, 2010; TSE, 2013).

2.5. Optimum Insulation Calculation

The heat loss from unit area of roof (Equation 11) (Ozel, 2013; TSE, 2013; Kurekci, 2016; Dombayci et al., 2017; Kon et al., 2021);

$$q = U.\Delta T \tag{11}$$

The heat loss for heating season (Equation 12);

$$q_H = 86400.HDD.U \tag{12}$$

The heat loss from unit area for cooling season (Equation 13);

$$q_C = 86400.CDD.U \tag{13}$$

Roof total heat transfer coefficient can be calculated with Equation 14;

$$U = \frac{1}{\left(R_{t,roof} + \left(\frac{x_{opt}}{\lambda_{ins}}\right)\right)} \tag{14}$$

Optimum insulation thickness for both season with Equation 15;

$$x_{opt,H,C} = \left(\frac{86400.HDD.a.\,C_{ng}.\lambda_{ins}.PWF}{H_u.C_{ins}.\eta} + \frac{86400.CDD.a.\,C_e.\lambda_{ins}.PWF}{C_{ins}.COP}\right) - \lambda_{ins}.R_{t,roof} \tag{15}$$

where, HDD is heating degree-day, CDD is cooling degree-day, $R_{t,roof}$ is thermal resistance of uninsulated roof, C_{ng} is natural gas price for the heating period (0.385 \$/m³), H_u (34.485 10⁶ J/m³) is the fuels' lower heating value, η (93%) is the heating system efficiency, C_e is the electricity price for cooling period (0.107 \$/kWh) (Topçuoğlu, 2017; Limak, 2021), COP (2.5) is the cooling system performance coefficient, λ_{ins} is insulation materials conduction heat transfer coefficient (0.031 W/m.K), C_{ins} is insulation price (180 \$/m³) and a is adjustment coefficient and it is taken as 1.0 for ceilings open to the external environment and 0.8 for ceilings covered with roofs.

If i>g ; real interest rate (Equation 16);

$$r = \frac{i-g}{1+g} \tag{16}$$

If i<g ; real interest rate (Equation 17);

$$r = \frac{g-i}{1+i} \tag{17}$$

Present Worth Factor (Equation 18);

$$PWF = \frac{(1+r)^N - 1}{r.(1+r)^N} \tag{18}$$

where, i is the inflation rate (7.91%), g is the interest rate (8.25%), and N is life (10 year) (Dombaycı et al., 2006; Kurekci, 2016).

2.6. The Values Used in Calculations

In the study, firstly, the outdoor bulb temperature dependent surroundings (sky) temperature value was calculated. Surroundings temperature outdoor radiation heat transfer coefficient was found. The outdoor convection heat transfer coefficient was determined depending on the outdoor air wind speed. The outdoor combine heat transfer coefficient, which is the sum of the outdoor radiation and convection heat transfer coefficient, was found. Likewise, indoor radiation heat transfer coefficient and convection heat transfer coefficient were calculated separately. Then, the combined heat transfer coefficient, which is the sum of the indoor radiation and convection heat transfer coefficient, was determined. Depending on the surroundings (sky) temperature, the maximum and minimum values of the left-air temperature were calculated. Then, heating and cooling degree days were found depending on these values and indoor temperature. Financial values and present worth factors were calculated to use in the optimization process. Optimum insulation thickness values were determined for three different roof types by using other cost values and the conduction heat transfer coefficient of the coatings forming the roof layer. These are given in Figure 1.

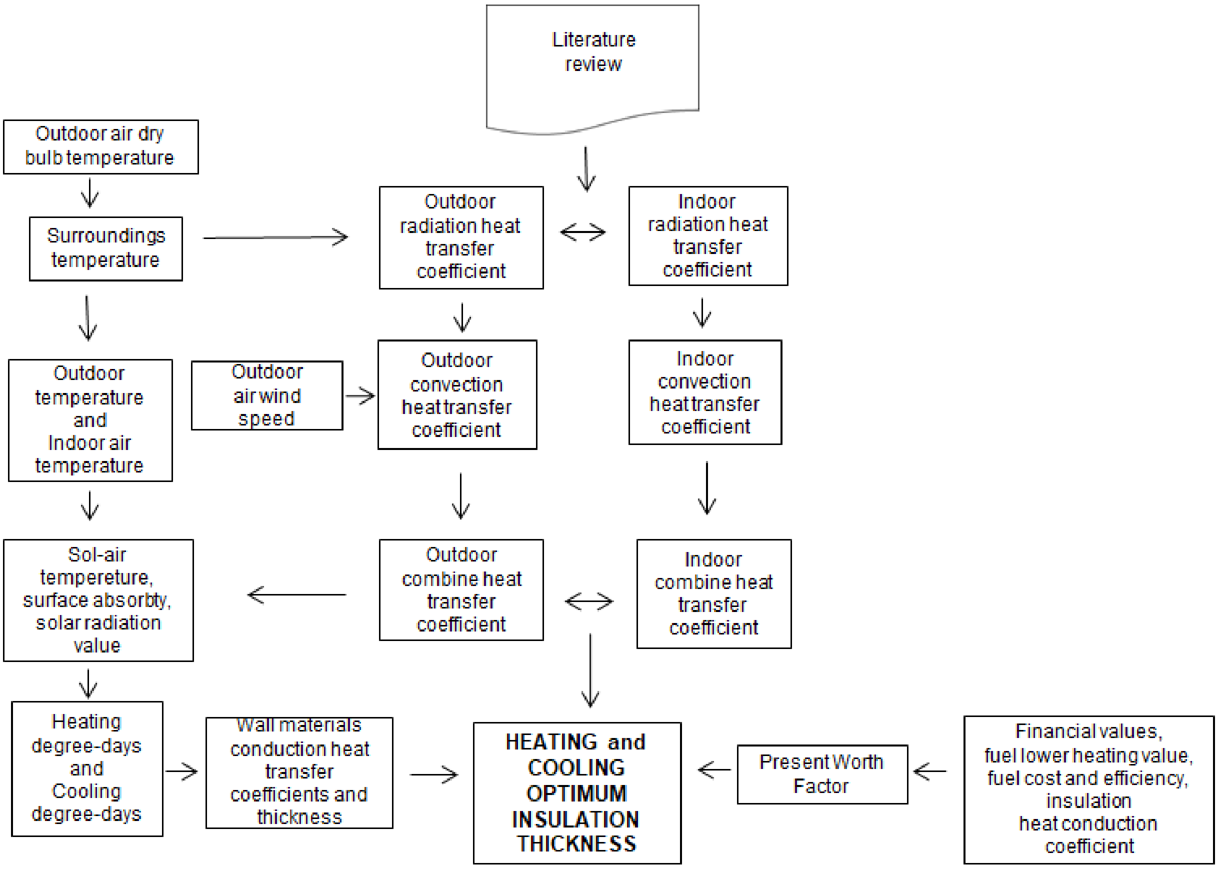
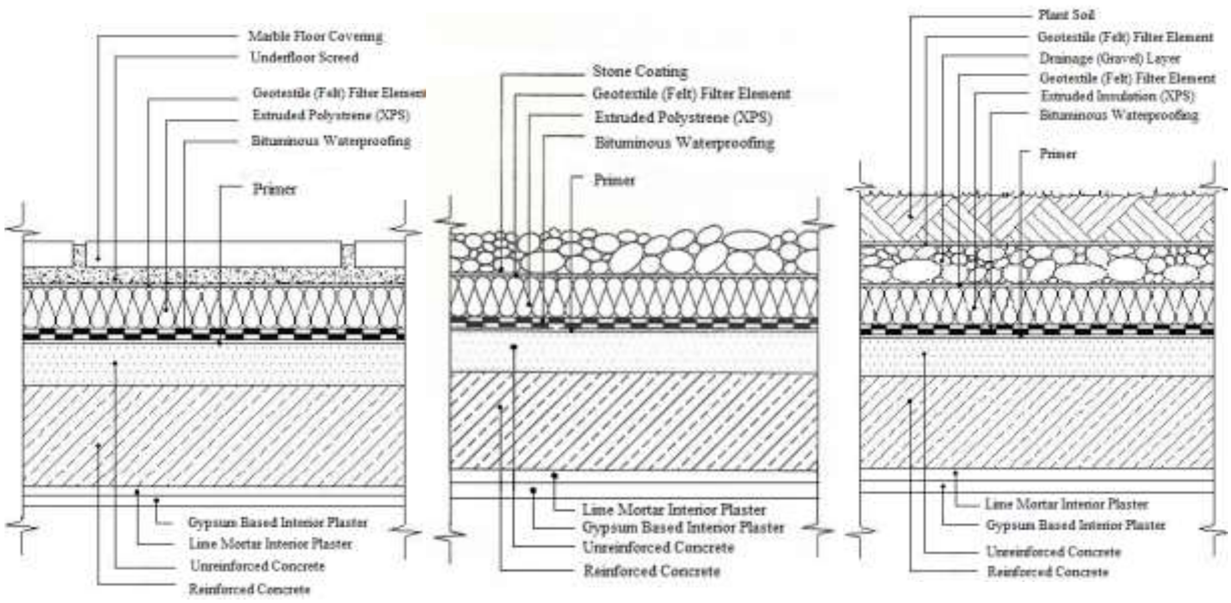


Figure 1. Study conceptual framework.

In Table 1, the structural components of three different roof types are given. The details of roof types are given in Figure 2. The details of plant density that can be applied on a soil covered roof for a green roof are given in Figure 3. Outdoor temperature values calculated in the study and recommended in TS 825 are shown in Table 2. In Table 3, the heating and cooling degree-day values calculated in the study and determined depending on the temperatures recommended in TSE (2013) are given.

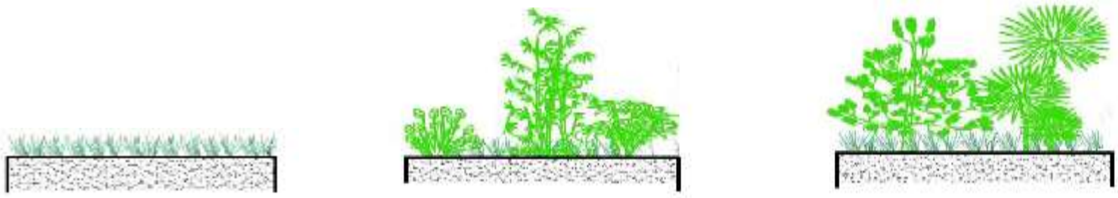
Table 1. Building components of three different roof types (TSE, 2013; Topçuoğlu, 2017)

Roof components	Thickness (m)	Heat transmission coefficient (W/m.K)
Roof 1 (navigable terrace roof)		
Marble Floor Covering	0.01	3.50
Underfloor Screed	0.02	1.40
Geotextile (Felt) Filter Element	0.005	0.06
Extruded Polystrene(XPS)	x_{opt}	0.031
Bituminous Waterproofing	0.01	0.19
Unreinforced Concrete	0.05	1.65
Reinforced Concrete	0.15	2.20
Lime Mortar Interior Plaster	0.02	1.00
Gypsum Based Interior Plaster	0.01	0.70
Roof 2 (un-navigable stone-covered terrace roof)		
Stone Coating	0.15	2.00
Geotextile (Felt) Filter Element	0.005	0.06
Extruded Polystrene (XPS)	x_{opt}	0.031
Bituminous Waterproofing	0.01	0.19
Unreinforced Concrete	0.05	1.65
Reinforced Concrete	0.15	2.20
Lime Mortar Interior Plaster	0.02	1.00
Gypsum Based Interior Plaster	0.01	0.70
Gypsum Based Interior Plaster	0.01	0.70
Roof 3 (un-navigable soil-covered green roof)		
Plant Soil	0.15	0.60
Geotextile (Felt) Filter Element	0.005	0.06
Drainage (Gravel) Layer	0.10	2.00
Geotextile (Felt) Filter Element	0.005	0.06
Extruded Insulation (XPS)	x_{opt}	0.031
Bituminous Waterproofing	0.01	0.19
Unreinforced Concrete	0.05	1.65
Reinforced Concrete	0.15	2.20
Lime Mortar Interior Plaster	0.02	1.00
Gypsum Based Interior Plaster	0.01	0.70



(a) (b) (c)

Figure 2. Details of the roof types used in the study; a) Navigable terrace roof (Roof 1) b) Un-navigable stone-covered terrace roof (Roof 2) c) un-navigable soil-covered green roof (Roof 3) (Gel, 2010).



(a) (b) (c)

Figure 3. a) Superficially planted green roof b) Semi-densely planted green roof c) Densely planted green roof section (Seçkin and Seçkin, 2016).

Table 2. Outdoor temperature values calculated in the study and recommended in TS 825 (2013)

Zone	This study						TS 825	
	Heating Solar-air Temperature (^{0}C)			Cooling Solar-air Temperature (^{0}C)			Heating Outdoor Temperature (January) (^{0}C)	Cooling Outdoor Temperature (July) (^{0}C)
	Roof 1	Roof 2	Roof 3	Roof 1	Roof 2	Roof 3		
Zone 1	6.35	7.58	7.58	27.72	29.43	29.43	8.40	28.70
Zone 2	0.72	2.00	2.00	23.72	25.44	25.44	2.90	24.90
Zone 3	-2.53	-1.25	-1.25	21.70	21.70	21.70	-0.30	21.70
Zone 4	-7.67	-6.38	-6.38	21.40	21.40	21.40	-5.40	21.40
Zone 5	-12.76	-11.47	-11.47	18.60	18.60	18.60	-10.50	18.60

Table 3. The heating and cooling degree-day values calculated in the study and determined depending on the temperatures recommended in TS 825 (2013)

Zone	This study			TS 825
	Roof 1	Roof 2	Roof 3	Roof
	Heating Degree-Day (HDD)			
Zone 1	2657	2398	2398	1430
Zone 2	4387	4080	4080	2573
Zone 3	6459	6075	6075	3248
Zone 4	8001	7610	7610	4074
Zone 5	11434	10969	10696	5052
	Cooling Degree-Day (CDD)			
Zone 1	687	892	892	556
Zone 2	207	413	413	176
Zone 3	---	---	---	---
Zone 4	---	---	---	---
Zone 5	---	---	---	---

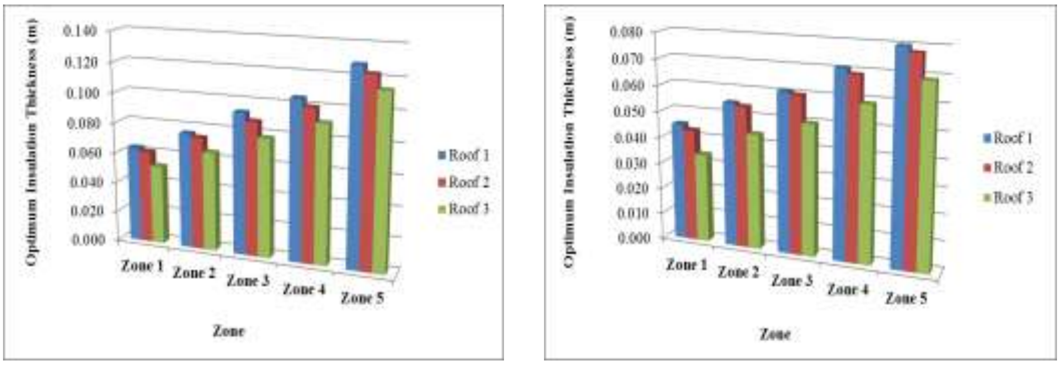
3. Results and Discussion

In the study, detailed heat transfer calculations and the values of the coldest and hottest months of the year used in degree day calculations, which are based on the recommended outdoor temperature values in the Turkish insulation standard TS 825, are given. Accordingly, the values calculated based on the solar air temperature for January, the coldest month of the year, are from the first to the fifth climate zone, between 6.35 to (-12.76) for roof 1, 7.58 to (-11.47) for roof 2 and 7.58 to (-11.47) ^{0}C for roof 3. On the other hand, depending on the outdoor temperature data in TS 825, the temperature values for January were found between 8.40 to (-10.50) ^{0}C. The values calculated based on the solar air temperature for July, the hottest month of the year, were calculated between 27.72 to18.60 ^{0}C for roof 1, 29.43 to 18.60 ^{0}C for roof 2 and 29.43 to 18.60 ^{0}C for roof 3. On the other hand, depending on the outdoor temperature data in TS 825, the temperature values for July were found to be between 28.70 to 18.60 °C.

In the study, the heating degree days calculated based on the solar air temperature were calculated from the first to the fifth climate zone, from 2657 to 11434 for roof 1, 2398 to 10969 for roof 2 and 2398 to 10696 for roof 3. On the other hand, depending on the temperature data in TS 825, heating degree days were determined from 1430 to 5052. Since cooling will be done for the first and second climate zones with cooling degree days, the solar air temperature has been calculated as between 687 to 207 on roof 1, 892 to 413 on roof 2 and 892 to 413 on roof 3. According to the temperature given in TS 825, the cooling degree days were determined from 556 to 176. This is due to both heating and cooling degree days and when detailed heat transfer calculations are used, it is seen that optimum insulation thicknesses are much higher. This is an important situation in terms of energy saving in buildings. Thus, much more energy savings can be achieved on the ceilings of buildings

In the study, the coldest month of the year is January and the hottest month of the year is July. For the values calculated depending on the outdoor temperature, solar radiation value, and heat transfer; the optimum insulation thicknesses on roof 1 are calculated as 0.063-0.128 m for zone1 and zone 5, 0.061-0.123 m for roof 2, and 0.052-0.114 m on roof 3. The optimum insulation thickness values determined by considering the recommended values in TS 825 (2013) are 0.045-0.080 for roof 1, 0.043-0.078 m for roof 2 and 0.034-0.069 m for roof 3. In the insulation thicknesses calculated according to the data recommended in TS 825 (2013), it is stated by the engineers working in the market that the residents of the buildings experience heating or cooling problems during the hottest and coldest periods throughout the year in some meteorological conditions. For this reason, such special cases should be taken into account when calculating optimum insulation thicknesses. In Figure 4, the optimum insulation thickness values determined based on a) the values calculated in the study and b) the recommended values in TS 825 (2013) are given.

Wang H. et al. (2022) calculated the optimum insulation thickness of expanded polystyrene, polyurethane and mineral wool for a single-layered roof with a solar radiation reflection coefficient of 0.55 as 0.148 m, 0.082 m and 0.122 m, respectively. The optimum insulation thickness for a single-layered roof with a solar radiation reflection coefficient of 0.25, thicknesses are 0.171 m, 0.095 m and 0.142 m, respectively. The optimum insulation thickness is 0.128 m, 0.068 m and 0.104 m, respectively, for a double-skin roof with a solar radiation reflection coefficient of 0.55. The optimum insulation thickness for a double skin roof with a solar radiation reflection coefficient of 0.25 is 0.153 m, 0.081 m and 0.127 m, respectively. In this study, the optimum insulation thicknesses determined by using detailed heat transfer calculations are in accordance with the studies in the literature. However, the optimum insulation thickness values determined based on TS 825 was found to be much lower than the studies in the literature. For this reason, the calculation techniques and values in TS 825 should be updated again.



(a) (b)

Figure 4. a) The optimum insulation thickness values calculated in the study, b) The optimum insulation thickness values determined based on the values recommended in TS 825 (2013).

4. Conclusion

In this study, the highest optimum insulation thickness for five climate zones was determined between 0.063-0.128 m on Roof 1. Based on TS 825 data, the highest insulation thickness in roof 1 was calculated between 0.045-0.080 m for five climate zones. The optimum insulation thickness calculated for the roof is higher than the optimum insulation thickness values found in TS 825 for all regions. Thus, with the higher optimum insulation thickness in this study, less heat loss will occur when the thickness of the roof insulation is compared to TS 825 and a lower heat transfer coefficient will be obtained.

As the climate zone increases, the optimum insulation thickness value also increases. In the optimum insulation thickness values calculated in this study and the optimum insulation thickness values calculated with the recommended values in TS 825, 65.4-71.4% for the 1st climate zone, 67.7-73.0% for the 2nd climate zone, 64.1-68.2% for the 3rd climate zone, 64.8%-69.0% in the 4th climate zone and 60.5-63.4% in the 5th climatic zone.

In future studies, the effect of covering the exterior walls of buildings with plants and materials with different properties will be evaluated in terms of heat transfer. Accordingly, the energy saving potential and environmental impacts will be investigated for summer, winter and transition periods connected to external walls.

Author Contributions

Percentages of the author(s) contributions is present below. All authors reviewed and approved final version of the manuscript.

%	O.K.	İ.C.
C	50	50
D	50	50
S	50	50
DCP	50	50
DAI	50	50
L	50	50
W	50	50
CR	50	50
SR	50	50
PM	50	50
FA	50	50

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

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