The Effect of Roof Insulation Applied on Cooling Energy Costs in Buildings in Mediterranean Climate

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ABSTRACT
In Turkey, the largest share in total energy consumption by sectors is in the residential and services sectors and has been increasing in recent years.(URL-1) The amount of energy consumption in buildings, heating or cooling needs vary according to climate zones. In this study, it is aimed to reduce the cooling energy need of a building in Antalya, which is located in the Mediterranean region, with roof insulation and to make cost analysis. Within the scope of the study, flat and pitched roof prototypes were modeled and analyzed separately. The roofs of the building prototypes modeled using the Design Builder energy simulation program were insulated at different levels and the cooling energy requirement values were determined. The initial investment cost, profitability and payback periods for different insulation alternatives were calculated, results were evaluated. It was found that 47.39% of the annual cooling energy requirement can be saved with roof insulation in a single-storey building in Antalya and the payback period is between 1.64 years and 8.23 years depending on the insulation thickness used. With this study, it was seen that there is a great potential to reduce the cooling energy need with roof insulation in buildings located in the Mediterranean.
Keywords: Cooling in the Mediterranean climate, energy consumption in buildings, cost effectiveness, roof insulation.

1. INTRODUCTION
The rapid increase in the world's population, global warming, international energy crisis, etc. have increased the need for energy on the one hand and caused energy prices to rise on the other. In addition, energy has become a globally strategic product. Today, it is extremely important to use energy effectively and efficiently in order to leave a sustainable and livable world to future generations due to the fact that the access and use of energy obtained from exhaustible resources is both environmentally negative and economically difficult. Using energy effectively reduces resource consumption, waste production and greenhouse gas emissions. As a result of this development, the world will be a livable and healthy place today and in the future by reducing environmental pollution, global warming and fossil fuel consumption. With the goal of a sustainable life, various solutions are being developed in many sectors to use energy effectively and efficiently. In buildings, which are known to have the highest share in energy consumption compared to sectors, 24.8% according to the data of the Republic of Turkey Ministry of Environment, Urbanization and Climate Change, it is obvious that the impact of the solutions developed will be great (URL-1). The building sector, which consumes high energy, needs to be supported and renewed with systems that use energy more effectively. (Savaşır and Kasul, 2020)

While the need for energy is increasing rapidly in developed and developing countries around the world, this situation is more important in Turkey. According to 2022 data, Turkey is approximately 74% dependent on foreign sources to meet its energy demand (URL-2). According to the Global Energy Statistical Yearbook, total energy consumption in Turkey was 51 Mtoe (million tons of oil equivalent) in 1990 and 147 Mtoe in 2019. Figure 1 shows that total energy consumption in Turkey has increased by 288% in the last 20 years, in other words, almost 3 times (URL-3). Reducing fossil fuel consumption, increases in energy prices, and environmental problems due to global warming necessitate the efficient use of energy in structures such as industry and transportation sectors (Yıldız et al., 2011).

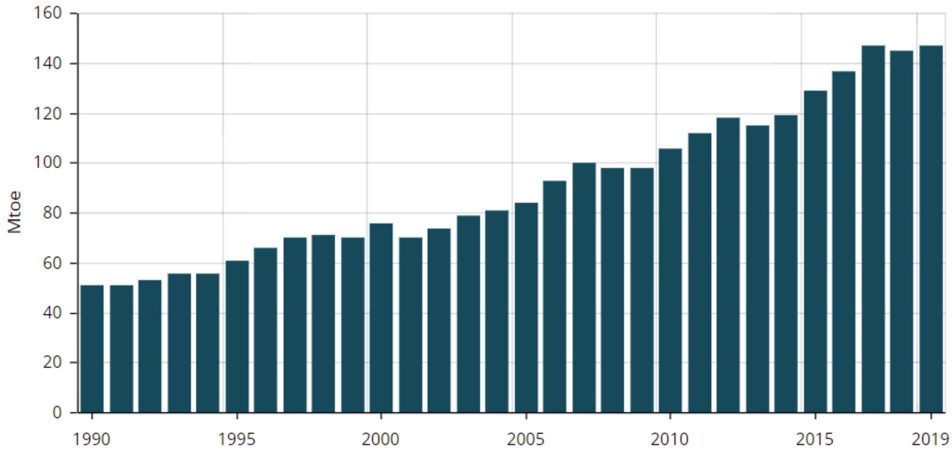


Figure 1- According to the Global Energy Statistical Yearbook, total energy consumption between the years 1990-2019 in Turkey (URL-3)

In the building sector, which is known to have the highest energy consumption compared to other sectors, there are many architectural solutions developed to use energy efficiently. Energy efficient retrofitting in buildings can be done with passive techniques such as insulating different building elements at different levels, using shading elements, using double skin systems or active techniques such as photovoltaic panels. One of the most widely used passive techniques used to use energy effectively and efficiently in buildings is to insulate the building envelope. The building envelope is exposed to environmental influences such as sunlight, humidity, cold, heat and rain throughout the year. Insulating the building envelope at an appropriate level is of great importance in terms of energy efficiency while ensuring the continuity of indoor thermal comfort conditions. Building envelope insulation, which is easy to apply, widely preferable and known to have a great impact on energy consumption, is used at different levels according to the needs in buildings located in different climates.

In the literature; in a study where external wall insulation was used to investigate the effect of building envelope insulation on cooling consumption in summer, it was revealed that 23.5% less energy could be consumed according to the results obtained (Fang et al., 2014). In another study, the effect of the material configuration of the building walls on heating and cooling loads was investigated and it was emphasized that the insulation greatly affects the thermal performance (Kossecka and Kosny, 2002). In a study conducted in Tunisia, it was revealed that 71.33% energy savings could be achieved for cooling and heating with building insulation, the payback period was calculated over the useful life of the building, and cost effectiveness was investigated (Daouas, 2011). For Italy, which is located in the Mediterranean climate, the effect of roof insulation on thermal performance was investigated and the effect of insulation in different roof sections on consumption was revealed (D'Orazio et al., 2010). In a study conducted in Algeria, which is located in Mediterranean, it was emphasized that passive strategies such as natural ventilation and insulation have a significant potential for cooling energy savings (Imessad et al., 2014).

Nowadays, it has become a necessity to produce energy efficient solutions in buildings in order to reduce dependence on exhaustible fuel resources, to maintain indoor comfort conditions in summer months and to ensure economic sustainability. In this study, both the effect of different thicknesses of insulation in different roof structures on the cooling energy requirement and the cost effectiveness of a building located in the Mediterranean were investigated.

2. MATERIAL AND METHOD

This study, which investigates the effect of roof insulation on the cooling energy demand, efficiency and cost effectiveness of a building located in the Mediterranean climate, consists of four main parts. First, a building is designed to be used as a model in the study. Both pitched roof and flat roof alternatives are modeled for this building. Since the effect of different levels of insulation of the roof of the building was investigated, 8 different glass wool thicknesses between 6 and 20 cm were determined. The glass wool of the determined thickness was applied through the Design Builder simulation program with 24 different alternatives using between rafters and above the slab for pitched roof and only above the slab for flat roof. For each simulation, the annual cooling energy requirement values were obtained separately and compared with the cooling energy requirement under non-insulated conditions. Finally, in order to investigate the cost-effectiveness of the insulation, the initial investment costs of each alternative were calculated, cost-benefit analyses were performed and payback periods were determined.

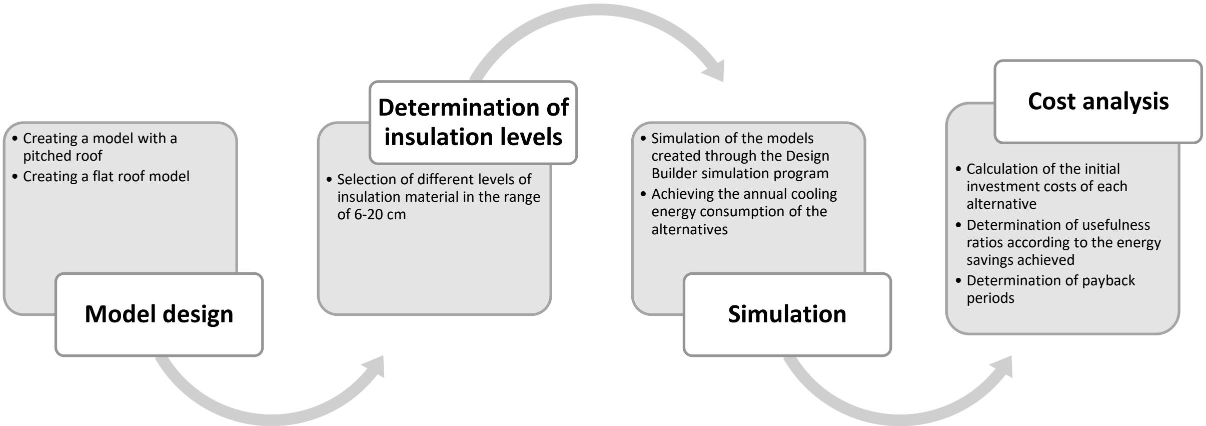


Figure 2- Flow diagram followed in the study

The path followed in the study is shown in stages in the flow diagram in Figure 2. In the continuation of the study, each step and findings will be explained in detail.

2.1 Model Design

The building simulated for the comparison of existing cooling energy consumption and cooling energy consumption values after different levels of roof insulation is located in Belek district of Antalya province in the 1st degree climate zone in the south of Turkey.

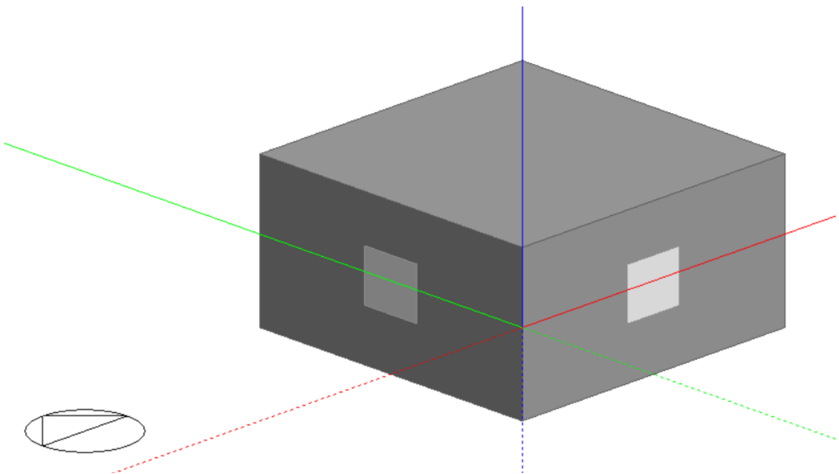


Figure 3- Version of the model with flat roof

The latitude of the model created is 36°51'56" and longitude is 31°03'20". The single-storey 49 m.^{2} model has a 700x700 cm. square plan. There are 120x150 cm. windows on the east, west and south facades of the model created and a 90x210 cm. door on the north facade.

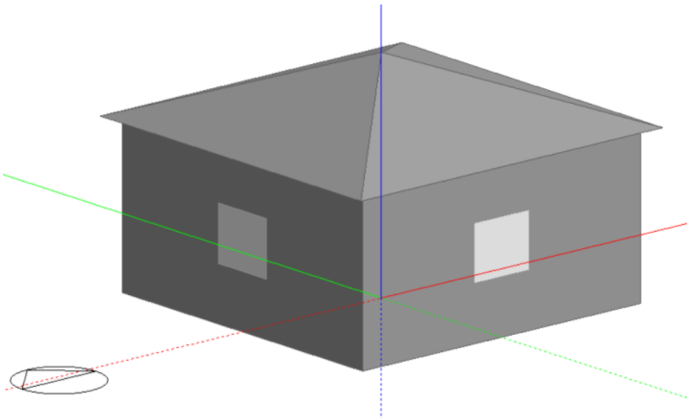


Figure 4- Version of the model with pitched roof

Since both pitched roofs and flat roofs are common in buildings located in the Mediterranean, the model was created for both roof types and energy and cost analyses were performed for both types of buildings. (Figure 3, Figure 4)

2.2 Determining Insulation Levels

Regulation on Energy Performance in Buildings in Turkey, previously constructed buildings are mostly buildings where energy is not used efficiently. It is seen that improvements such as insulation to be made in existing buildings will have a rapid and large impact on energy consumption throughout the country. (Aşıkoğlu et al., 2021)

According to TS 825, there are 4 degree day regions in Turkey. According to TS 825, Antalya province, which is included in the study, is among the 1st region degree day provinces. For the 1st degree day zone provinces, the ceiling U-value recommended to be accepted as the maximum value is 0.45 W/m2K. (TS 825, 2013) In this study, insulation thicknesses with U-values between 0.5 W/m2K and 0.18 W/m2K were used to determine the insulation level.

Glass wool, which is widely used in Turkey, was used as insulation material. Glass wool was chosen for its ease of application and low thermal conductivity (U-value). The thickness of the materials used and the roof U-values obtained in 3 different models are shown in Table 1.

Table 1- U-values according to glass wool thicknesses and roof types

	U-value (W/m²K)								
Insulation thickness (cm.)	**Uninsulated**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
Flat roof	2,437	0,523	0,415	0,344	0,293	0,256	0,227	0,204	0,185
Pitched roof (between the rafters)	2,93	0,543	0,427	0,352	0,299	0,26	0,23	0,207	0,187
Pitched roof (on th slab)	2,93	0,567	0,442	0,362	0,362	0,266	0,235	0,21	0,19

2.3 Simulation

Design Builder used in this study is an EnergyPlus interface program designed to determine energy performance, comfort and lighting performances in buildings. EnergyPlus is a 3rd generation simulation program used for heating, cooling, ventilation, lighting and comfort criteria in buildings (Fotopoulou et al., 2018).

Using the Design Builder simulation program, the building prototype is modeled as a building that is used in all periods of the year, where comfort conditions are kept constant in summer and winter periods, heating is provided by natural gas and cooling is provided by electricity.

In order to determine the effect of roof insulation on cooling consumption, 3 different types of insulation were used in the study. The first of the models with the same plan is a building with a flat roof. In the flat roof version, different levels of thermal insulation were placed on the reinforced concrete slab. Gravel was placed on the top layer and a non-walkable roof was designed. A partial section of the insulation in the flat roof model is shown in Figure 5.

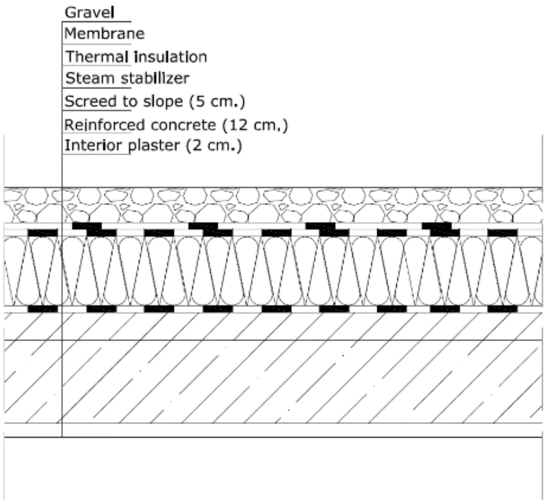


Figure 5- Partial section with thermal insulation for flat roof version

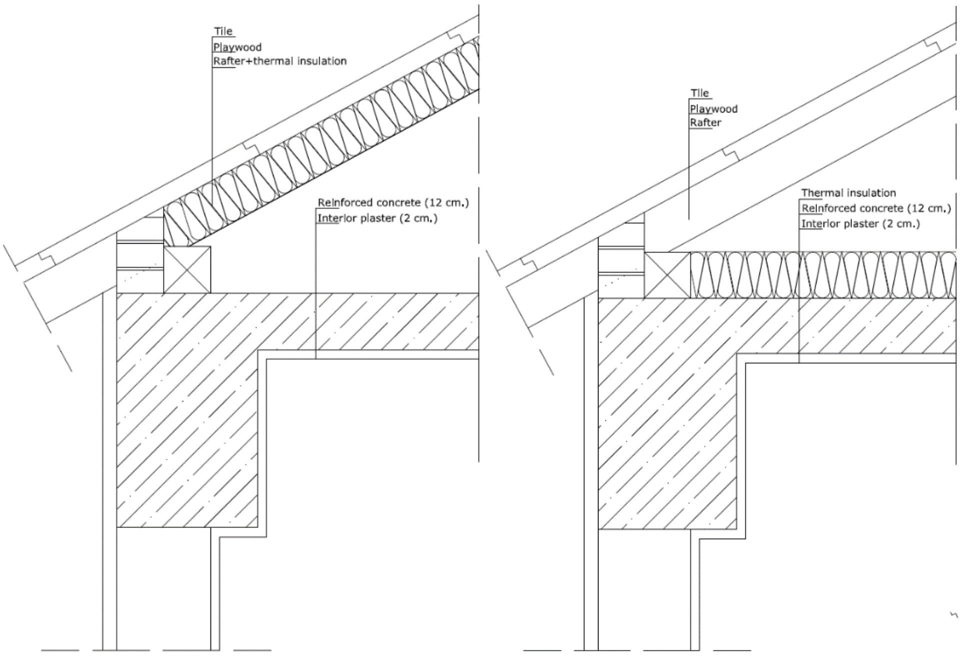


Figure 6- Partial section with thermal insulation for pitched roof models

The second model is a pitched roof building and for this model, both insulation alternatives between rafters and insulation alternatives above the slab were made. In the first alternative, glass wool was placed on the reinforced concrete slab under the pitched roof, and in the other alternative, glass wool was placed between the rafters on the pitched roof. (Figure 6)

A total of 8 insulation levels were simulated for insulation in 3 different alternatives: above slab in flat roof, above slab in pitched roof and between rafters in pitched roof.

Table 2- Cooling demand values obtained as a result of insulation of roof types with different thicknesses of glass wool

	Cooling demand (kWh/m²)								
Insulation thickness (cm.)	**Uninsulated**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
Flat roof	1262,732	756,3325	726,1642	706,8522	693,1938	682,7712	675,2677	669,186	664,1164
Pitched roof (between the rafters)	828,4576	661,8308	645,6774	635,0212	627,4179	621,6122	617,2114	613,7245	611,0919
Pitched roof (on th slab)	828,4576	675,3646	664,3719	660,323	653,7953	648,7404	644,6564	641,4315	638,6538

The insulation thicknesses applied to different building components in the Figure 7 and the cooling energy demand values obtained are shown in Table 2. When the cooling consumption values obtained as a result of the simulations are compared with the models without insulation, it is seen that the highest savings are made on the flat roof. It was determined that 47.39% savings could be made with insulation on the flat roof. In pitched roof models, 26.20% savings were achieved with insulation between rafters and 22.94% savings were achieved with insulation on the slab. The cooling consumption values obtained as a result of insulation with different thicknesses of glass wool for roof types are shown graphically in Figure 7.

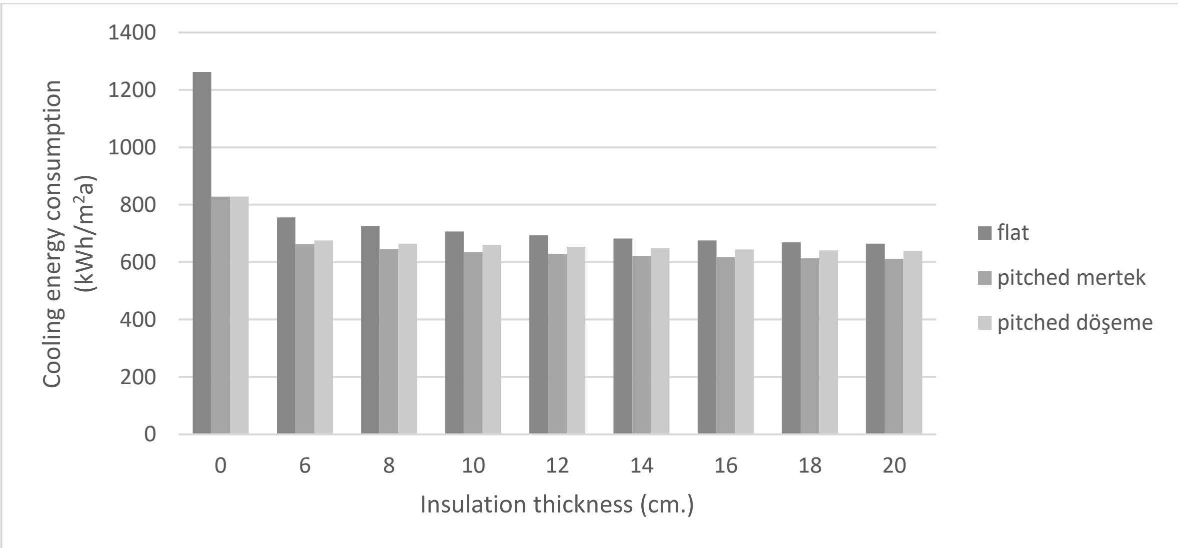


Figure 7- Graphical representation of the cooling consumption values obtained as a result of insulation with different thicknesses of glass wool on roof types

2.4 Cost Analysis

Each of the selected retrofit alternatives has different initial investment costs, payback period or profitability ratio. For this reason, cost-effectiveness is as important as the energy savings achieved during energy-efficient retrofitting of buildings. In EPBD-recast 2010, it is emphasized to develop cost-effective solutions while improving energy performance in buildings (EPBD, 2010).

In the study, initial investment costs were calculated for each roof insulation alternative in order to investigate cost-effectiveness and benefit analyses were conducted. While calculating the initial investment costs; the list of "Construction and Installation Unit Prices" for the year 2022 published by the Ministry of Environment, Urbanization and Climate Change of the Republic of Turkey was used. (URL-4)

It allows an evaluation according to the ratio of the average annual profit to the investment amount, in other words the profitability that will be provided during the useful life of the investment. With this method, when the insulation levels to be made on the roof are seen as an investment and the energy savings obtained as a profit, it is possible to quantitatively express the relationship between the first investment and profitability.

The ratio of the average annual profit to the investment amount can be calculated using the following formula (Büker et al., 2018):

$$Investment\ Average\ Profitability\ Rate = \frac{\sum_{t=1}^{n} \ \frac{K_t}{\mathrm{n}}}{\mathrm{S+(C-H)}}$$

K: Annual profits
n: Useful life of the investment
S: Working capital
C: Fixed investment amount
H: Scrap value of the investment at the end of its useful life
t : Year

The payback period is the time period until the "annual net cash inflows" of the investment become equal to the initial investment amount (Aşıkoğlu et al., 2011). In this study, the value accepted as "annual net cash inflow" is the monetary value of the annual cooling energy savings obtained as a result of the roof insulation. Since the increase in energy prices is not at a certain rate and the rate of increase in future years cannot be predicted, the payback period within the scope of the study was calculated using static methods. For this reason, it is assumed that the revenues from the investment do not change over the years.

If the income from the investment does not change over the years, the payback period of the investment is found by dividing the investment amount by the annual investment income and the following formula is used (Büker et al., 2018);

$$n = \frac{I}{NNG}$$

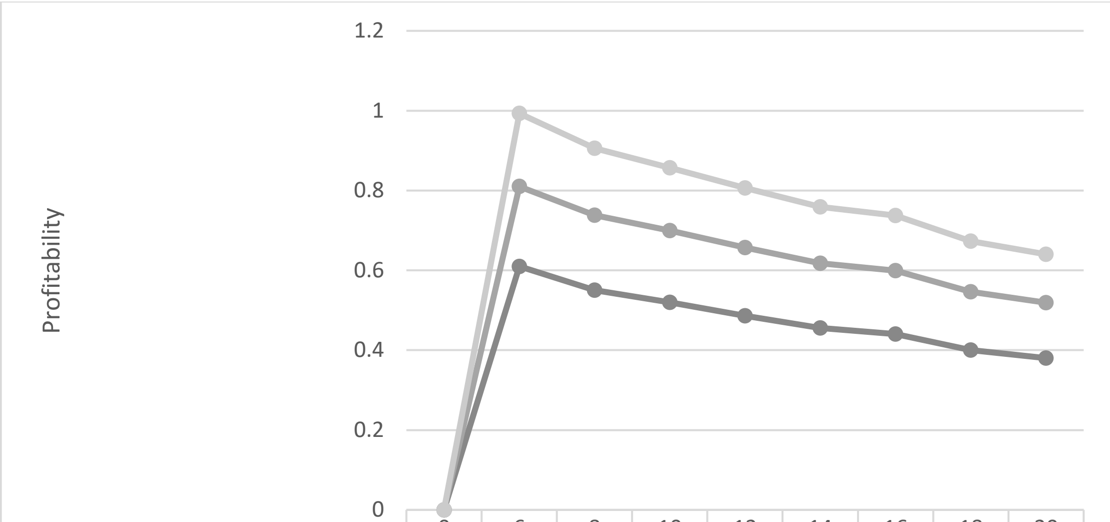
n = Payback period of investment,
I = Investment amount,
NNG = Annual net cash inflow of the investment.

Table 3- Energy consumption, savings and cost analysis values according to the insulation used in roof types

Scenario	Alternatives	Results						
	Model Type	**Insulation thickness (cm.)**	**Cooling demand (kWh/m²)**	**Cooling energy saving (%)**	**Investment amount (TL)**	**Annual profit (TL)**	**Profit (%)**	**Payback period (year)**
1	Flat roof	0	1262,732	-	-	-	-	-
2	Flat roof	6	756,3325	40,06	1441	876,07	0,61	1,644
3	Flat roof	8	726,1642	42,44	1681,1	928,26	0,55	1,81
4	Flat roof	10	706,8522	43,98	1852,6	961,67	0,52	1,92
5	Flat roof	12	693,1938	45,07	2024,1	985,3	0,486	2,05
6	Flat roof	14	682,7712	45,89	2200,5	1003,33	0,456	2,19
7	Flat roof	16	675,2677	46,49	2293,6	1016,31	0,44	2,25
8	Flat roof	18	669,186	46,97	2533,7	1026,83	0,4	2,46
9	Flat roof	20	664,1164	47,37	2705,2	1035,6	0,38	2,61
10	Pitched roof (between the rafters)	0	2184,526	-	-	-	-	-
11	Pitched roof (between the rafters)	6	661,8308	20,06	1441	288,26	0,2	4,99
12	Pitched roof (between the rafters)	8	645,6774	22,02	1681,1	316,21	0,188	5,31
13	Pitched roof (between the rafters)	10	635,0212	23,3	1852,6	334,64	0,18	5,53
14	Pitched roof (between the rafters)	12	627,4179	24,22	2024,1	347,8	0,171	5,81
15	Pitched roof (between the rafters)	14	621,6122	24,92	2200,5	357,84	0,162	6,14
16	Pitched roof (between the rafters)	16	617,2114	25,57	2293,6	365,46	0,159	6,27
17	Pitched roof (between the rafters)	18	613,7245	25,87	2533,7	371,49	0,146	6,82
18	Pitched roof (between the rafters)	20	611,0919	26,19	2705,2	376,04	0,139	7,19
19	Pitched roof (on the slab)	6	675,3646	18,43	1441	264,85	0,183	5,44
20	Pitched roof (on the slab)	8	664,3719	19,76	1681,1	283,87	0,168	5,92
21	Pitched roof (on the slab)	10	660,323	20,25	1852,6	290,87	0,157	6,36
22	Pitched roof (on the slab)	12	653,7953	21,03	2024,1	302,17	0,149	6,69
23	Pitched roof (on the slab)	14	648,7404	21,64	2200,5	310,91	0,141	7,07
24	Pitched roof (on the slab)	16	644,6564	22,14	2293,6	317,98	0,138	7,21
25	Pitched roof (on the slab)	18	641,4315	22,53	2533,7	323,56	0,127	7,83
26	Pitched roof (on the slab)	20	638,6538	22,86	2705,2	328,36	0,121	8,23

Profitability ratios were calculated separately for a total of 26 scenario alternatives created for three different models. During the calculation, the initial investment costs including labor were calculated for glass wool in different thicknesses between 6-20 cm for different thicknesses in accordance with the prices specified in the "Construction and Installation Unit Prices" list. The cooling energy requirement obtained as a result of the simulations was compared with the current situation and energy savings were determined for each scenario.

Profitability ratios were calculated with the investment costs and cooling demand savings data obtained and shown in Figure 8. Since there is no savings in the absence of insulation, the rate of return is assumed to be 0. As a result; profitability ratios ranging between 0.61 and 0.121 were obtained.



	0	6	8	10	12	14	16	18	20
pitched (on the slab)	0	0.183	0.168	0.157	0.149	0.141	0.138	0.127	0.121
pitched (between the rafters)	0	0.2	0.188	0.18	0.171	0.162	0.159	0.146	0.139
flat roof	0	0.61	0.55	0.52	0.486	0.456	0.44	0.4	0.38

Figure 8- Profitability ratios determined for insulation alternatives according to roof types

Payback periods have been calculated for each alternative, taking into account the initial investment costs and the cooling energy savings achieved. Payback periods between 1.64 years and 8.23 years were obtained for the different alternatives and are above all the values reached in Table 3.

4. DISCUSSION AND CONCLUSION

Within the scope of the study, the following findings were obtained depending on the roof insulation, roof type and insulation thickness in a building located in the Mediterranean climate;

- It was determined that savings between 47.39% and 22.94% could be made in cooling energy consumption. In this climate zone, where heat gain from sunlight is high in summer, it is seen that the potential for cooling energy savings is high with only roof insulation.
- It was found that the highest cooling energy saving was realized in the flat roof with 47.39%, while in the pitched roof, the rates were 26.19% in the insulation between the rafters and 22.86% in the insulation above the slab.
- With the same material and initial investment cost, it is seen that the cooling energy savings of the thermal insulation made between the rafters is greater than the thermal insulation made on the slab in buildings with pitched roofs.
- It is seen that the highest benefit of thermal insulation on the roof in reducing the cooling energy requirement is in the alternative where 6 cm. glass wool is used for each roof and application type.
- In cost calculations, the roof types with the highest profitability ratio and the lowest payback period were the roof types using 6 cm. glass wool.
- Payback periods increase with increasing insulation thickness for all 3 applications and the shortest payback period is 1.64 years for the flat roof model with 6 cm. glass wool. The longest payback period was found to be 8.23 years for the pitched roof model with 20 cm. glass wool on the slab.
- Although the alternative using 6 cm. glass wool seems to be more suitable than the other alternatives in terms of tolerating the initial investment cost of the insulation, high insulation may be preferred as a more sustainable solution since it is sustainable in the long term and keeps the annual energy consumption values low throughout the useful life of the building.

As seen in this study, it is possible to make architectural solutions to reduce the need for heating energy in cold climates and cooling energy in hot climates with building envelope insulation suitable for the climate zone. It is obvious that with the widespread use of need-oriented architectural solutions, building-based energy consumption can be reduced throughout the country and as a result, we can live in a more sustainable world.

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