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Research Article

The Effects of Green Roof on Heat Loss and Energy Consumption in the Buildings

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Keywords

Green Roof,
Heat Loss,
Energy Consumption,
Terrace Roof.

Abstract

Thanks to the developing technology and building material science, while the roof is an element that usually causes heat loss, with the sustainable use of green roofs, it has become an area that provides living spaces outside the building and can also be used as an activity. Green roofs are critical systems that improve the energy performance, air quality, and urban ecology without additional equipment, produce innovative solutions to the problems caused by rainwater and are located in sustainable buildings with these features. Green roofs are divided into two groups as intensive and extensive green roofs. These systems, which vary according to the thickness of the soil, may have a negligible effect in preventing the heat loss of the building. In this study, the impact of green roofs on energy performance and their role in preventing heat losses were analyzed through a sample social building. As a result, it was determined that green roofs avoid heat loss by 83% compared to the terrace roof.

1. Introduction

Energy resources are gradually decreasing, the population is increasing, and intense construction disrupts the balance of nature [1, 2]. Increasing energy use in construction has paved the way for ecological building designs that use energy efficiently in cities. Together with the developing technology, this situation the green roof has been brought to the agenda in the search for architecture, aesthetics, and ecology. Green roofs have provided people with an easy-to-reach green space and the opportunity to create a space that reduces the adverse effects of the external environment.

Thanks to the developing technology, the roof has ceased to be a building element that loses energy and has become a component that provides residues to the ecosystem. Thanks to sustainable use, green roofs have turned into a place that offers both a living space outside the building and a space for movement. With these features, the concept of the green roof have become ecologically, economically, and socially essential and its classical definition[3-5]. In short, green roofs increase the energy performance of the building, improve the air of the city, offer new solutions for rainwater, and develop the sustainable building concept with all these features [6].

According to research on green buildings, compared to roofs designed according to traditional methods in the design and construction of buildings with sustainability criteria, green roofs save between 24% and 50% [7, 8] in energy

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consumption, produce between 33% and 39% less carbon dioxide [9, 10], and provides 30-50% less water consumption [11, 12].

In addition, it has been observed that green roofs are 70% more efficient in the production of solid waste and 13% more efficient in maintenance and repair costs [13-15]. The American Green Building Council (USGBC) [16] stated that an average green building could save 32% [17].

Green and ecological roofs are covered with soil and plant layers in the upper layer. Between the roof sheet and the green part, there are layers such as drainage, root holding layer, moisture holding layer, water insulation, heat insulation [18-20]. Green roofs are divided into two as dense and widespread green roofs according to the depth of the layer carrying the plant and the type of vegetation. These two concepts were created by Dunnet and Kinsbury [21]. The depth of the intensive green roof plant carrier layer is between 20-60 cm roof type [22]. The extensive green roof is the type of roof planted less sparsely and whose soil thickness is in the range of 7-10 cm [23, 24], which does not require much maintenance, and even water needs are selected [25] for a longer life by choosing plants [26].

Sustainable systems have a significant role in protecting the natural balance [27], which is disrupted by climate change. Green roofs play an essential role in ensuring sustainability [28], especially in places where intense urbanization and green space are reduced. Green roofs offer a solution to protecting the natural balance in the face of rain and floods, high air temperature, air pollution, and even the noise of cities, reducing the adverse effects of climate change [29]. According to Green Roofs for Healthy Cities (GRHC) data [30], 75% of the surfaces of cities are covered with impervious surfaces, and roofs constitute a significant part of this. Against this situation in the cities, green roofs also provide aesthetic benefits. Thanks to the soil and plant layer on the green roofs [3, 31], vegetation forms a living space for birds and insects, reduces air pollution by reducing the rate of carbon dioxide in the air [32], cleans the air by producing oxygen, and plays an active role in reducing air temperature by contributing to evaporation.

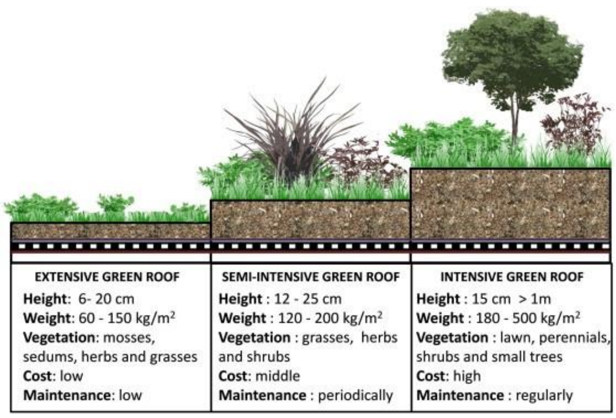


Figure 1. Summary of green roof types based on the International Green Roof Association (IGRA) classification [33]

In recent years, scientific studies have been carried out on ecological and energy-efficient building design and their contribution to building energy performance. Much research has been done on green roofs and their positive effects on energy sustainability. In the studies [34-38], the impact of green roofs on the heating and cooling loads of the building was investigated. The other research papers [39-46] refer to the analysis of the thermal and energy performance of the green roof. Further study about green roof systems installed in a nursery school building in Athens [47] energy performance evaluation showed a significant reduction in cooling load of the building during summer. However, these studies did not examine green roof types. This study aims to determine both the energy performance superiority of green roofs over traditional flat terrace roofs and the energy performance superiority of intensive and extensive green roofs over each other. So, the sample building will be simulated in 3 different ways as flat terrace roof (FTR), extensive green roof (EGR), and intensive green roof (IGR), and contribution to energy performance will be discussed. The study is expected to guide architects, practitioners, and designers in the roofing industry in choosing a roof type.

2. Case Study

The new campus of the Bartın University is located in Kutlubey Yazıcılar district, 13 km from the center of Bartın province. The Living Center (Figure 2), which has a floor session of 2387.95 m^2, is single-story, the floor height is 6 meters, and the maximum height is 8.5 meters with roof parapets and coating materials. The terrace roof is 2314 m^2.

The windows used in the building are Low-E double-glazed SC:0.2 specifications, together with an aluminum frame, while the doors are double-glazed with an aluminum frame. The thermo-optic properties of doors and windows are given in Table 1. The floor, wall, and roof components and properties of the building constructed with a reinforced concrete system are shown in Table 2.

Figure 2. Bartın University Life Center [48]

Table 1. U-R-SGHC values of doors and windows

Building Element	U (W/m^2K)	R (m^2/KW)	SGHC
Window	0.475	2.103	0.24
Door	4.116	0.242	-

In addition to the FTR of the building, two different alternatives were examined: an EGR and an IGR. The applied EGR (Table 3) is 16.8 cm high, while the IGR (Table 4) is 62.3 cm high. FLORAXX series of Delta® brand belonging to Dorken company was used for green roofs. The layers used in green roofs and their heights are shown in Table 3 and Table 4.

Table 2. Wall, floor and roof components and features of the building

	Components and Features			
	Thickness (m)	Conductivity (W/mK)	Intrinsic Heat (J /g°C)	Density (kg/m³)
Floor Covering				
Marble	0.02	2.9	0.8400	2750
Handle	0.03	0.720	0.9200	1650
Reinforced Concrete Paving.	0.15	1.046	0.6570	2300
Roofing				
Gravel	0.03	0.360	0.8400	1840
Polystyrene Foam Insulation	0.01	0.035	1.4700	23
Geotextile Felt	0.02	0.190	0.9500	960
Water isolation	0	1.150	0.8400	2330
Slope Concrete	0.02	0.720	0.9200	1650
Reinforced Concrete Paving.	0.15	1.046	0.6570	2300
Plaster	0.03	0.720	0.9200	1650
Wall				
Compact Container	0.05	0.106	1.4200	552
Rock Wool	0.02	0.034	0.7100	200
Exterior Plaster	0.03	0.720	0.9200	1650
Wall	30	0.540	0.8400	1550
Roughcast	0.02	0.720	0.9200	1650
Plaster	0.02	0.510	0.9600	1120

Table 3. Extensive Green Roof Layers (Adapted from [21, 26, 49-55])

Extensive Green Roof Layers	
Layer	Thickness (cm)
Plant Layer	3
Soil Layer	10
Filter Layer	0.2
Drainage	2.5
Moisture Retaining Layer	0.1
Root Holder Layer	0.5
Separator Felt	0.5
Water isolation	0

Table 4. Intensive Green Roof Layers [Adapted from [26, 56-59]]

Intensive Green Roof Layers	
Layer	Thickness (cm)
Plant Layer	20
Soil Layer	25
Filter Layer	0.2
Drainage	6
Moisture Retaining Layer	0.1
Root Holder Layer	0.5
Separator Felt	10
Water isolation	0.5
Plant Layer	0

The temperate marine climate (Black Sea Climate) prevails in Bartın, with hot summers and cool winters. Its proximity to the sea and the mountain ranges, which are not very high, are parallel to the coast generally cause a decrease in temperature differences on the coastline, increased humidity, and air masses coming from the Balkans [60]. The weather data of Bartın can be shown in Figure 3.

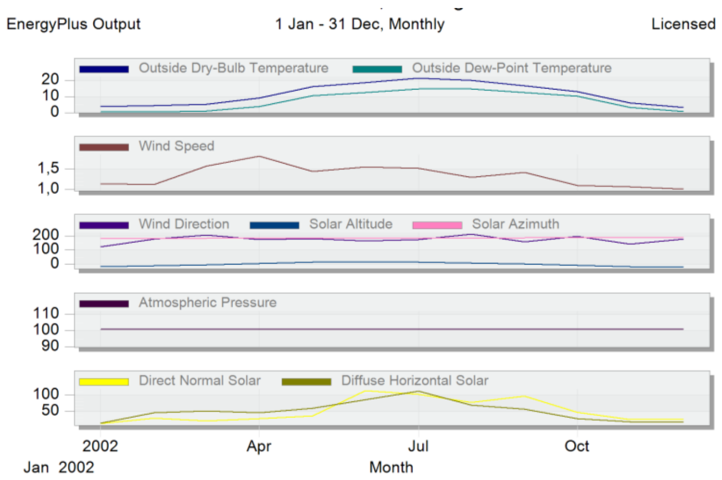


Figure 3. Weather data of Bartın exported from Design Builder software

Modeling and simulation of building energy have been done in Design Builder Software to perform the relevant analyses and observe the differences of the three models. Design Builder Software [61], which is one of the most advanced and up-to-date software in this field and simulating heating and cooling systems, has dynamically the ability to model different energy uses of the building, including heating, cooling, lighting, appliances, water consumption, etc. According to the use of the building, its working hours are from Monday to Saturday from 8:00 AM to 6:00 PM, and the operating time of HVAC is considered according to this time. The windows are closed in all seasons, and comfortable temperatures are set according to ASHRAE standards. The front outlooks of rendered models are shown in Figure 4.

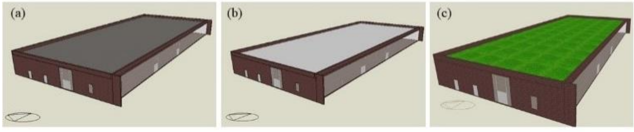


Figure 4. Rendered images modeled in Design Builder a)FTR b)EGR c) IGR

3. Results

In the energy simulations made for the Bartın University Life Center building, the heating load, cooling load, and energy consumption used for ventilation was considered within each roof type. Then the energy consumption ratio was calculated between the three roof types and was evaluated in terms of efficiency.

So, at first, it was made energy transfer calculations seen in Figures 5, 6, and 7 to determine the size of the heating and cooling loads.

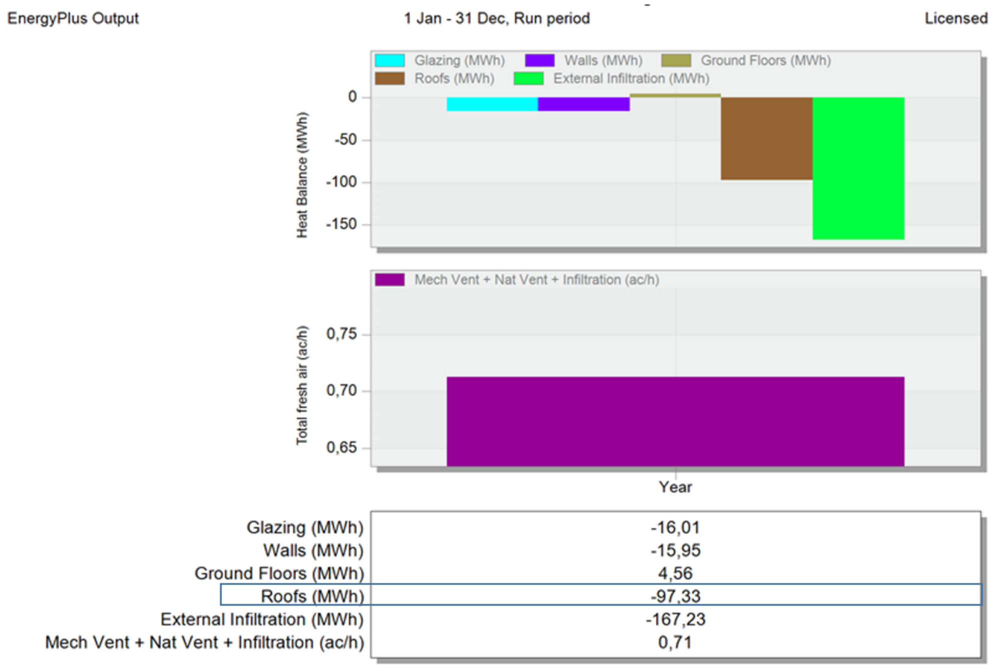


Figure 5. FTR heating design and the amount of roof heat loss compared to other exterior surfaces

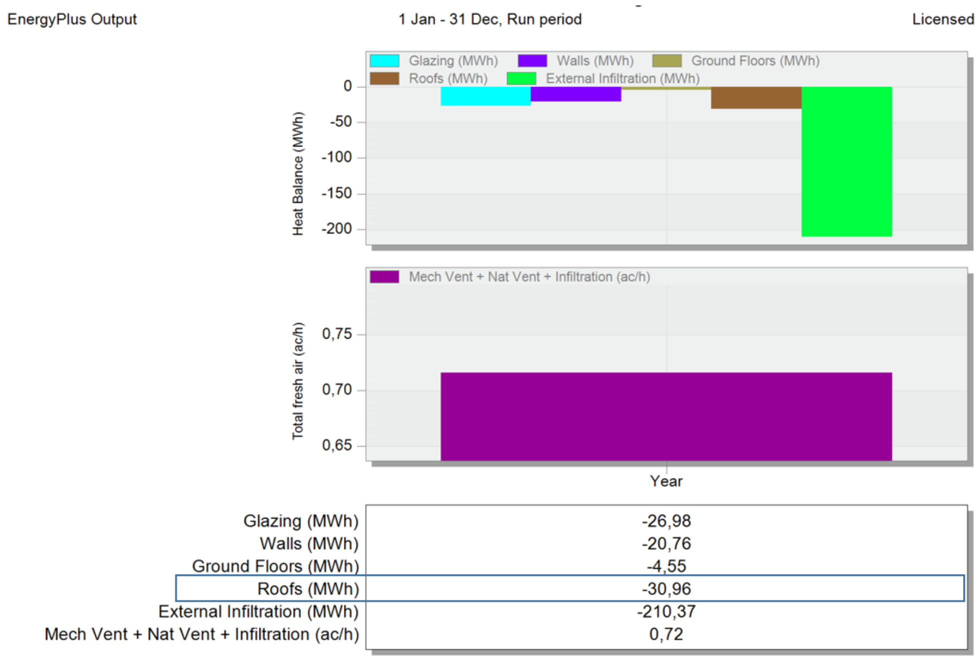
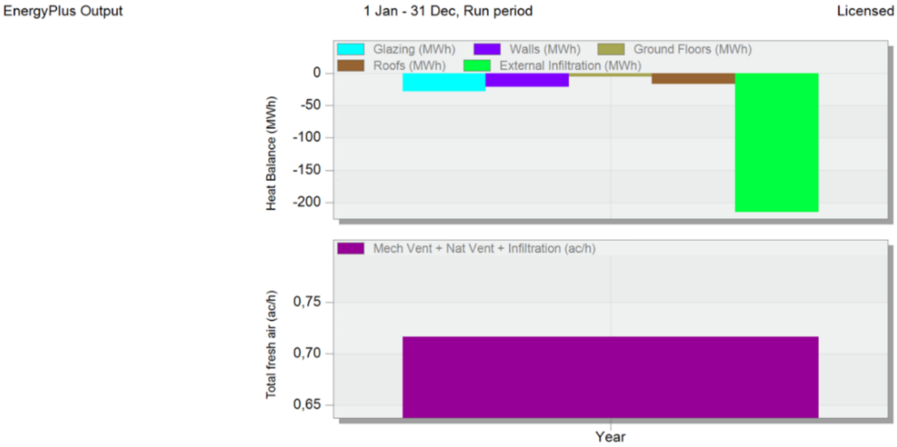


Figure 6. EGR heating design and the amount of roof heat loss compared to other exterior surfaces

According to Figures 5-7, the energy loss by the roof in the terrace roof model is 97.33 kWh, and in the EGR and IGR roofs are 30.96 and 16.65 kWh, respectively which is a significant reduction. According to the decrease in the amount of energy lost from the roof, there is a decrease in the heating and cooling load of the building. The energy consumption of the building can be seen in Figure 8.

The heating load on the FTR in January and December are the maximum total of 40868 and 34976 kWh. This value in the same month (January) in EGR and IGR are 33772 and 31876 kWh, respectively. The cooling load is the maximum in July, and its amount is 11822, 5708, and 5548 kWh in FTR, EGR, and IGR, respectively. The gas and electricity consumption of the building without considering the lighting energy is shown in Figure 9.



Glazing (MWh)	-28,25
Walls (MWh)	-21,46
Ground Floors (MWh)	-5,52
Roofs (MWh)	-16,65
External Infiltration (MWh)	-213,93
Mech Vent + Nat Vent + Infiltration (ac/h)	0,72

Figure 7. IGR heating design and the amount of roof heat loss compared to other exterior surfaces

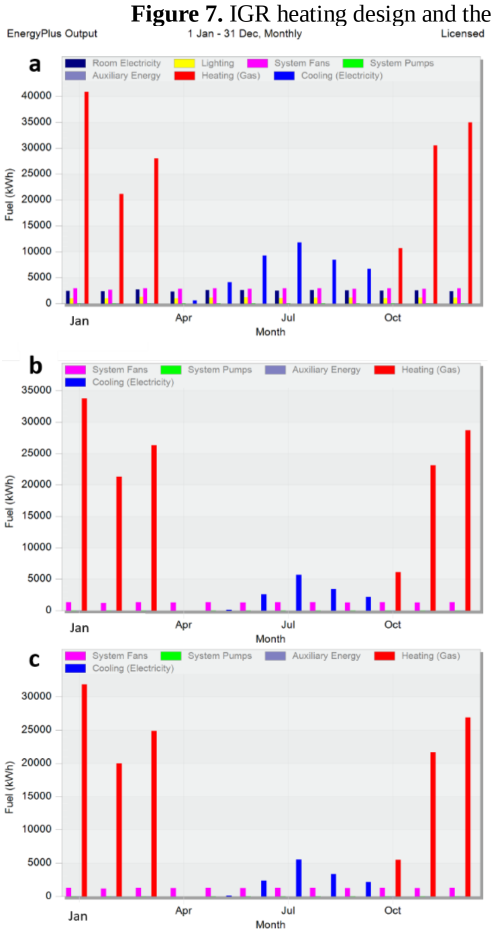


Figure 8. The energy consumption of the building. a) FTR, b) EGR, c) IGR

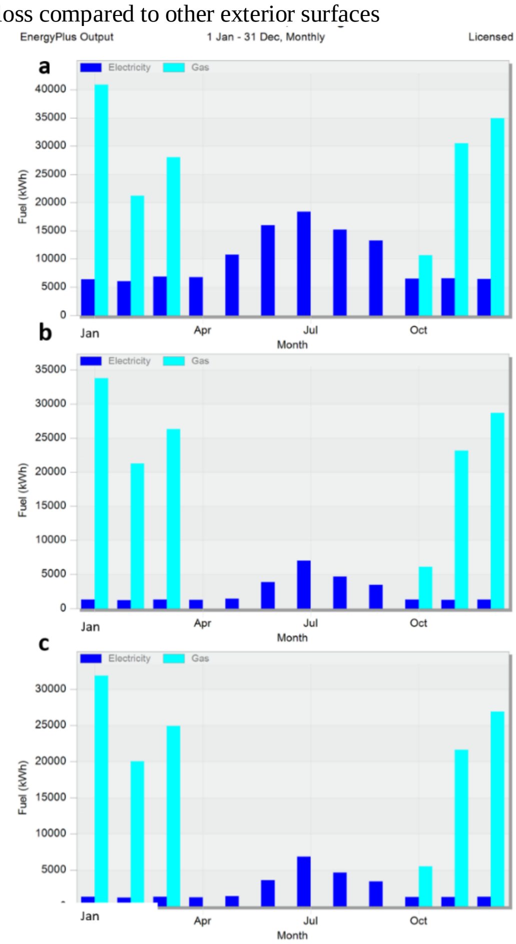


Figure 9. Total Monthly Energy Consumption. a) FTR, b) EGR, c) IGR

Total energy consumption is like graphs, ignoring the lighting data. There is a decrease of 8000 kWh in gas consumption in January and approximately 6000 kWh in electricity consumption in August. CO_2 emission from energy consumption is like the graphs below.

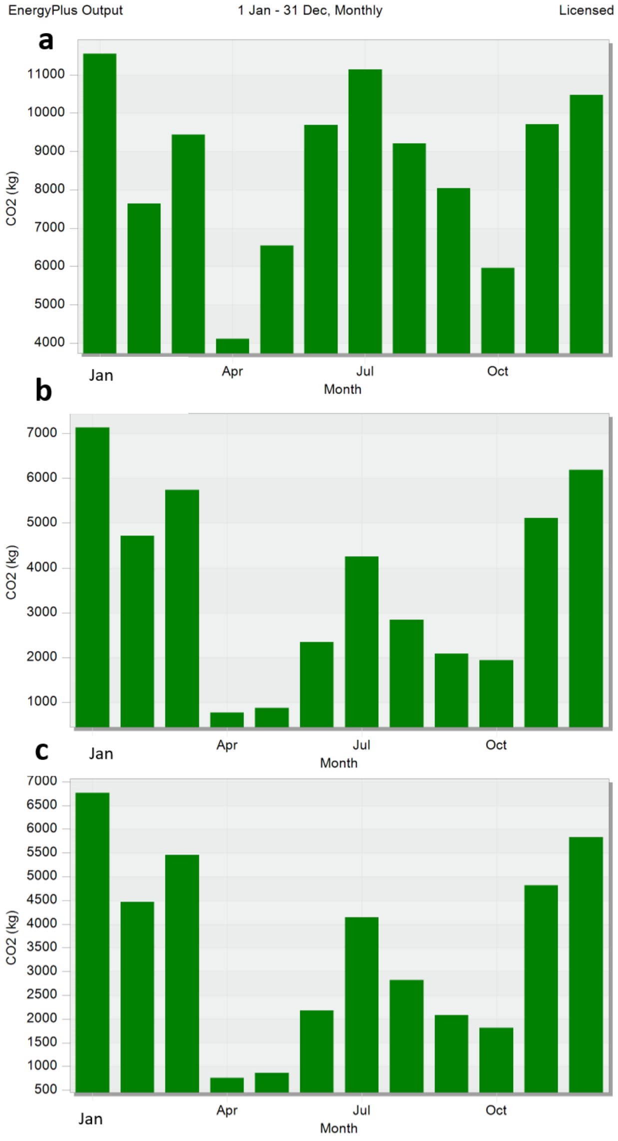


Figure 10. CO_2 emission from energy consumption a) FTR b) EGR c) IGR

4. Conclusions

Thanks to the sustainable use of green roofs, it has turned into a space that provides both a living room outside the building and a movement area. Thanks to these features, the concepts of the green roof have become ecologically, economically, and socially significant and its classical definition.

The results for green roofs show less heat transfer than terrace roof, which is due to the use of conductive materials such as filter layers. It should be noted that the conductivity of the culture medium (plant) and drainage layer is higher in the wet state.

In the two types intended for green roofs (extensive and intensive), the main difference is the thickness of the soil and, consequently, water insulation. Therefore, heat transfer from the roof in the intensive type is relatively reduced compared to the extensive type. Considering the contribution of green roofs to energy consumption, the Bartın University Life Center building, which was built with a flat terrace roof, was modeled with extensive and intensive green roofs, and energy consumption rates were discussed. According to the results obtained by comparing the energy simulation graphics in the EGR and IGR applications, the green roof type cooling loads are reduced by up to 57% compared to the terrace type, and the total carbon dioxide production is reduced by 82% by reducing the heating load of the building by up to 20%. There was no significant difference between the intensive and the extensive types, but the intensive type showed better results than the extensive type.

The increase in energy performance in buildings with green roof, is due to the isolation effect of the soil on the roof. Roof and floor slabs are the building elements where the heat loss of the building occurs the most. The heated air rises and forces it to come out from the roof floor, and heat losses occur in the structure. If there is no thermal insulation on the roof, these losses become more evident. For this reason, green roofs increase energy gain by preventing losses from the roof in buildings. Replacing the polystyrene foam used in the structure selected within the scope of the study with another thermal insulation material or increasing its thickness may lead to a further improvement in energy performance with green roofs. In future studies, scenarios for the integration of green roof types with different thermal insulation materials will be able to answer these questions. In addition, the economy and longevity of both roof types will be discussed in future research, and a double-confirmed decision can be made about these two roof types according to the results.

Conflict of Interest Statement

The authors declare no conflict of interest.

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