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Review

The Benefits of Green Roofs and Possibilities for Their Application in Antalya, Turkey

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Abstract: Rapid population growth, urbanization, and industrialization have many negative environmental effects. These adverse effects are felt more in urban areas than in rural areas. Considering the high rate of urban development, the idea that green roof structures can be used on rooftops is important in reducing the current negative effects. In addition, water retention on these roof areas can be helpful in the face of drought periods. In this study, the amount of water that can be retained on a 100 m^2 roof area in Antalya Province, Turkey was calculated. As a result, it was determined that August is the month when the least water can be retained due to rainfall. It was calculated that between 0.168 m^3 and 0.363 m^3 of water can be retained in August. Furthermore, the month in which the most water can be retained due to rainfall is December, and the amounts of water that can be retained are between 5.762 m^3 and 21.640 m^3. These calculated values are anticipated to be important in understanding how much water can be retained in the planned green roofs. In addition, it has been determined that the energy savings that can be made for heating purposes in a 100 m^2 green roof area can be between 3900 kWh and 11,250 kWh.

Keywords: green roof; rainfall; benefit; energy; sustainability

Academic Editors: Michael Loupis and Christos Spyrou

Received: 13 February 2025
Revised: 6 April 2025
Accepted: 23 April 2025
Published: 28 April 2025

Citation: Ertop, H.; Atılgan, A.; Jakubowski, T.; Kocięcka, J. The Benefits of Green Roofs and Possibilities for Their Application in Antalya, Turkey. *Sustainability* **2025**, *17*, 3949. https://doi.org/10.3390/su17093949

1. Introduction

The positive physiological and psychological contributions of green areas to the lives of individuals who form urban society are an indisputable fact. Therefore, apart from urban recreation areas, roof surfaces are one of the areas that gain importance among potential green area usage areas such as vertical building surfaces, courtyards, and balconies in cities [1]. Green roofs, which provide aesthetic value and sustainable function to unused empty spaces in urban areas and on building roofs, positively offset the loss of open space and land development. Nowadays, this approach is gaining increasing importance worldwide [2].

Moreover, with the opportunities offered by developing technology and building material science, roofs are moving away from energy-consuming building elements and evolving into building systems that contribute to urban ecosystems. With the sustainable use of green roofs, rooftops, mainly evaluated as building elements that heat the building and as unused areas, have begun to be actively used and transformed into alternative spaces that provide outdoor living space. At this point, beyond its simple definition, the concept of green roofs gains great importance in social and ecological terms. In this context, green roofs are sustainable, environmentally friendly, green building systems that contribute to the energy performance of the building, improve air quality and urban ecology, and produce innovative solutions in using rainwater without the need for any other equipment [3]. Today, structural architectural technologies, which are used for both ecological and aesthetic purposes, are bringing green roofs back into the agenda in living spaces. For this reason, green roofs are gaining importance as places that provide urban people with a green area that they can reach very close to them and also protect people from the negative conditions of the external environment [4].

Water is indispensable for life, and there is an increasing demand for it daily. Therefore, water resources should be protected and used sustainably [5,6]. Population growth, climate change, agriculture, animal husbandry, industrialization, and urbanization threaten water resources. Climate change can cause global temperature increases, which in turn cause heavy rainfall and floods in some places, and high evaporation and drought in other places [7]. In addition, it causes changes in the soil's moisture-holding capacity and the amount of surface runoff [8]. Climate change can disrupt the balance of the natural ecosystem, and water management in cities can also be affected [9]. With urbanization, wetlands and green areas are decreasing daily; precipitation events are increasing due to climate change, and rainwater runoff problems are observed in cities [10–12].

Correct land use is of great importance in reducing the impact of climate change, which is seen as the most important environmental problem nowadays in cities [13]. Incorrect land use, in which lands are not used according to their capabilities, also means that lands are not used according to their characteristics such as slope, aspect, hydrological and soil properties, and geology. This situation, which includes excessive use of natural ecosystems, has emerged due to the increase in population, uncontrolled expansion of city residential areas, and wrong decisions taken by industry and decision-makers [14].

Irregular and rapid urbanization movements cause problems and damage the natural structure without considering the above-mentioned characteristics of the land. When the increasing effects of climate change are also considered, these problems grow and become more difficult to solve. For example, a construction movement on agricultural land indicates wrong land use and destroys qualified agricultural land and potential services that can be obtained from the relevant agricultural ecosystem [13].

These can cause the capacity of water resources to decrease, and problems regarding the protection of water resources, especially in cities, are rapidly increasing [15]. For all these reasons, methods for the management and efficient use of rainwater need to be developed [16]. Therefore, it is essential for cities to be in harmony with the natural environment and to protect natural resources [17]. It is necessary to establish mechanisms and create management plans that will reorganize water resources according to the needs of nature and technology [5,6]. Urban sustainability can be presented as an approach that provides solutions to these problems but has not yet reached the point it deserves [18].

Sustainable buildings can be an alternative to adapt to this change and reduce the effects [9]. Moreover, sustainable buildings can compensate for the wetlands and permeable areas lost by cities with green infrastructure methods [19]. In sustainability, resource usage ensures people's health and comfort and minimizes negative effects such as waste and pollution. Looking at the role of residual waste in sustainable development, recycling material will minimize the effects of the damage that the deteriorated substances in the content of waste products will cause to the environment, thus yielding ecological and economic benefits. For this reason, reusing waste materials is very important for sustainability [20,21].

In Antalya Province, Turkey, where agricultural activities are intensive, reusing the water that falls to the surface as rainwater is beneficial for agricultural activities. In addition, green roof examples that can be applied to the roof surfaces of buildings in Antalya, where the urbanization rate is also high, can create positive effects for both water and energy saving. Considering the literature on green roofs, this study determined the water-holding capacities and energy saving values for a sample green roof area in Antalya Province, where agriculture is most intensive.

This study focused on the contributions of green roof applications to urban sustainability in Antalya Province, where the urbanization rate is high. The awareness of green space deficiencies in the city has led to green roof applications. In addition, the importance of both water and energy saving that can be achieved was stated. Although there are many studies on green roof applications, it is foreseen that this study will promote more studies on green roofs in the future because it includes both literature research and theoretical information.

2. Basic Definition of Green Roofs

The origin of green roofs dates back thousands of years. The most famous green roofs are the Hanging Gardens of Babylon. Many civilizations have used various types of green roofs for many beneficial purposes such as aesthetics, insulation, heating-cooling, noise reduction, and protection of the roof structure, depending on the geographical conditions they are located in. Green roof systems were created in Northern Europe in the early 19th century to provide thermal insulation by covering the roof with soil and applying herbaceous plants. Modern green roof technologies were created in Switzerland in the early 1960s. They were made of a layer system placed on the roof to support the soil environment and vegetation. This system has spread and started being used in many countries, especially Germany [22]. The concept of a green roof includes various planting applications on the roof surface. It refers to the surface area covered with a waterproof layer and soil and plant elements, specially designed to provide and balance local, social, and ecological benefits at the highest level [23].

Green roof application is the process of making roof areas suitable for plant growth through various subsystems, layers, and equipment [24]. Over the years, as the damage caused by structures to the environment has become apparent, the production of 'green structures' that consider a more natural and sustainable environment has begun to be emphasized. While the number of options for roof products was limited in the early stages of creating green structures, today product options have increased with the development of technology. Previously, surfaces were generally covered with gravel, and waterproofing was done with tar- or asphalt-based materials. Today, many different coatings and waterproofing products can be used on roofs [25]. Although the word green is perceived as a color, it is used in the sense of planting or covering with plants. There are ongoing naming and conceptual differences in this regard worldwide and in our country. In Turkish studies, terms such as vegetated roof, green roof, roof garden, vegetated building envelope, terrace garden, eco-friendly roof, and living roof are used [26].

3. History of the Green Roof

The history of green roofs dates back to 400,000 BC. It is thought that the Terra Amata houses in Nice, France, were some of the first examples of houses during the human settlement process. Terra Amata houses, which were built with rotten wooden load-bearing elements and stones placed around them, are known as the oldest man-made spaces, according to today's data [27]. In Terra Amata houses, a roof cover was created using tree branches and animal skins to protect the inhabitants from environmental conditions [28].

First of all, green roofs were applied in Northern Europe to provide heat insulation. The concept of green roofs as a part of the law, which we see much later than their first appearance, is included in the Capitulare de Vilis, which consists of the administrative articles of King Charlemagne's country in the 790s [29]. The concept of the green roof later emerged in the 1800s in Scandinavia to support heat insulation in buildings to provide heat control. However, Northern European scientists used green roofs installed on buildings intensively. This approach later became widespread in Northern Europe [30].

Roof gardens, the forerunner of contemporary green roofs, have ancient roots [31]. The oldest documented rooftop gardens are the Grape Gardens of Babylon, considered one of the Seven Wonders of the Ancient World, built around 500 BC [32]. Like Babylon, the Roman and Greek empires also used these systems [33]. During the Middle Ages and Renaissance, roof gardens were specially designed for the wealthy [34]. More recently, people have covered their roofs with soil and grass for insulation from extreme climates. However, technological advances have made modern green roofs much more efficient, practical, and beneficial than their former applications [35].

There are also examples of green roofs in Europe. During the Roman Empire, green terrace roofs were used as resting areas in residences. In the northwest of Classical Rome and Pompeii, ruins of luxury villas with green terraces were found. One of these villas had a terrace overlooking three directions, and studies have shown that plants were grown directly in the soil on the terrace. During the Viking period in 800–1000, grass-covered sloping roofs began to be widely used along the North Atlantic. It is also possible to come across examples of walls and roofs covered with soil and grass in Canada to protect from wind, rain, and snow and to provide thermal insulation [36].

In Scandinavian countries and Northern Europe, grass-covered roofs are common because the climate is cold. Grass roofs have been used in Scandinavian countries for more than 300 years. In some countries with warm climates, grass roofs have been used to protect houses from the heat [37]. Green roofs create a natural insulation layer, helping to keep the building warm in cold weather and cool in hot weather. In this sense, green roof applications emerged in Scandinavian buildings in the 1800s to protect from the cold. Northern Europeans used green roofs intensively for this purpose, and green roof applications increased in the following years [31].

Roof gardens, which developed in the early 1900s, were perceived as a new and healthy outdoor opportunity and were accepted by all segments of society. The era of sustainable roof gardens began in the late 1900s. The idea of creating roof gardens on high-rise buildings created a new, interesting, and rapid trend in sustainable, horticultural, and ecological building design [2].

Modern green roofs began to be used in Germany at the beginning of the 20th century with the placement of vegetation on roofs to reduce the harmful effects of solar radiation [31]. Thanks to the initial initiatives of Germany and neighboring European countries, green roofs have become popular in other parts of the world [35]. In recent years, awareness of the numerous economic and social benefits of green roofs and their environmental advantages, such as rainwater management, has emerged in some developed countries such as the USA, Canada, Australia, Singapore, and Japan. Thus, green roofs have become common and even mandatory in cities in these countries [33].

4. Green Roof Layers

4.1. Vegetation Cover

Vegetation constitutes the living upper layer of the green roof. In the design of the green roof, plants that will extend the roof's life should be selected. In plant selection, geographical location, rainfall intensity, humidity, wind, sun exposure, and growing medium depth should be considered [32]. Considering the harsh environment on roofs, important features of extensive green roof plants are drought resistance, good ground cover, ability to survive in minimum nutrient conditions, short and thin roots, and low maintenance [35].

Intensive green roofs have a wider range of plant selection options, including grass, flowers, vegetables, shrubs, and even trees, as they include irrigation systems. Vegetation selection is of great interest due to its benefits, such as aesthetic appeal, habitat for biodiversity, and urban ecosystem support [38]. Plant selection on extensive green roofs is usually limited to native grass or sedum varieties. Sedums are the most popular choice for extensive green roofs. If sedum species are used for an extensive green roof, the plant can survive for more than 3 weeks without irrigation [39]. Native grasses are always preferred because their growth pattern is known. They adapt to the climatic conditions and resist the region's insects [35].

4.2. Growing Environment

The growing environment is a substructure formed by mixing soil or other special materials that meet the nutritional needs of the selected plant. It is a dense resource with all the basic physical, chemical, and biological properties required for plant growth. It must be stable to absorb leakage water, which is beneficial to the plants, and only allow excess water to pass to the drainage path. Even if it has reached its maximum water content, it must contain enough air for the plant species planted [40]. This layer is critical to the long-term success of a living roof. The growing medium is an extremely lightweight 'engineered' soil substrate with a high ratio of inorganic minerals to organic material [41]. It contains water and air in addition to inorganic and organic matter. Attempts at soilless growing media began in the late 1920s [42]. Inorganic components in the growing medium may include expanded slate and clayey slate, extruded clay, crushed recycled brick and concrete rubble, lava, rock wool, and perlite. Smaller amounts of organic matter, such as well-rotted humus material, can be added. This can be supplemented with organic fibrous material and small clay particles. This mixture retains and slowly releases essential trace elements necessary for the health of the soil community [41]. Compared to ground-level gardens, the planting environment requirements on green roofs are different. First of all, green roofs need good drainage. In order to prevent soil loss through the drainage layer, a rot-resistant filter layer should separate the growing medium from the drainage layer. Since the accumulation of excess water in the soil will cause plant roots to rot and add an additional load to the roof, the growing medium should be silt-free to prevent the filter layer from clogging [31].

4.3. Waterproofing Layer

Protecting structures from water and its effects is called waterproofing. Waterproofing is of great importance, especially on the roofs of buildings. One of the most important elements of green roofs is waterproofing [43]. The waterproofing layer in green roof systems must have high elasticity, resistance to plant roots, high tensile strength, and adhesion strength properties [38]. The waterproofing layer is used to prevent water from reaching the building, hold water for flow control, and ensure that the growth medium layer is moist [44]. Waterproofing is an application layer with various chemicals to protect against water leaks and moisture. The main purpose of waterproofing is to keep unwanted moisture, rain, snow, hail, and condensation away from the structure. Unlike traditional roof systems, waterproofing is the lowest layer of the standard green roof system, being the primary protective element of the flooring and the structure underneath. However, since the membrane is an organic asphalt product and a food source for microorganisms, these membranes must be covered with a high-density polyethylene (HDPE) membrane to prevent root penetration [38]. Selection, installation, and protection of the waterproofing membrane are very important for the success and longevity of any additional component or system on the structure. Failure of a waterproofing membrane can lead to the failure of the entire green roof or landscape structure [45].

4.4. Thermal Insulation Layer

A thermal insulation layer can be laid under the root-holding layer to increase thermal insulation on roofs. This layer should be light and resistant to pressure effects. This feature prevents the layer from being crushed due to the weight of the upper material [46]. In buildings, people are healthier and happier and can work more efficiently when thermal comfort is provided, which is one of the most important conditions required for human life. Thermal comfort provides people with environmental conditions to live healthily, happily, and productively by keeping the ambient temperature balanced. Thermal comfort in a space can be provided by building elements, various electronic and mechanical systems, and thermal insulation products that increase thermal comfort in the space. These products can also be used on the interior and exterior facades of buildings [47]. It is known that green roofs provide high-level thermal insulation. The depth of the soil, which is the growth environment of the plants on green roofs, serves as natural thermal insulation on green roofs. In addition, other thermal insulation and separator layers in the green roof system also contribute to thermal insulation [45]. Green roofs generally use EPS, XPS, or rock wool boards as thermal insulation layers. Thermal insulation layers are generally applied on the roofs of heated volumes. Apart from this, thermal insulation boards are generally not used on the green roofs of spaces that do not require thermal comfort, such as parking lots [43].

Moreover, this layer reduces heat transfer between two regions with different temperatures. Heat transfer always occurs from hot to cold. For this reason, cold never enters the structure; rather, the heat inside the structure leaves the structure. Insulation is used between layers with different temperatures to prevent heat transfer. Failure to use a heat insulation layer may cause deterioration in materials with high expansion coefficients that form the vegetated roof system due to fatigue during temperature increases and decreases. Due to the heat flow that occurs because of temperature differences between the interior and exterior, the cooling energy needs inside the building increase in hot seasons, and the heating energy needs inside the building increase in cold seasons. In order to control heat flow on the roof, a thermal resistance factor should be created that prevents heat transfer at a certain level, provides the desired indoor temperature, and thus contributes to the reduction of heating-cooling energies used in the building. Thermal insulation can be achieved through the low coefficient of thermal conductivity of the materials used and the heat storage property of the plant carrier layer [48].

4.5. Drainage Layer

The drainage layer removes excess water and provides aeration of the growing medium. The two main classes of drainage layers are granular materials and modular panels. Examples of granular material drainage layers include lightweight expanded clay aggregate (LECA), expanded shale, crushed brick, and coarse gravel [35]. The modular panel drainage layer contains compartments to store water and is made of high-strength plastic materials (polyethene or polystyrene). Modular panels have higher performance due to their thinness, low weight, higher water storage, and durability [49].

4.6. Filter Layer

This layer separates the growing medium from the drainage layer to prevent small particles from entering and clogging the drainage layer. This filter layer should have high tensile strength to withstand its load. The filter layer should have at least 10 times higher water permeability than the growing medium [49]. The filter layer is used to prevent particles in the upper layers from being filtered by the water flow and to prevent clogging of the drainage layer. The function of this layer is to prevent the growth medium material from leaking into the lower layers after rainfall or irrigation. In addition, the filter layer protects the integrity of the growth medium and vegetation [44].

4.7. Protective/Separating and Moisture Retaining Layer

The protective layer provides additional protection for the moisture-proof lining/root barrier on the roof and is a permanent component of the roof. The roof membrane requires protection against movement of the building structure, diurnal temperature changes, damage during the green roof installation process, and fertilizer. This protective layer is usually made of water-resistant and non-degradable materials [42]. It can also be used as a separating layer if supported by suitable materials [40]. The separating layer keeps chemically incompatible materials separate from each other. It also acts as a permeable layer that protects the insulation layers against mechanical effects or allows the passage of water vapor. In this way, it prevents condensation [50]. From the perspective of moisture-proofing and protection, the sealing of a roof surface divided into several sub-areas should be carried out as a whole. Root penetration protection measures should not be limited to areas where vegetation is planted. Any joints, borders, areas where features pass through the roof, and structural joints should be protected against root penetration [40].

4.8. Root-Retaining Layer

The root-retention layer is the layer that prevents plant roots from reaching the waterproofing layer [48]. It aims to prevent the waterproofing membrane from being penetrated or damaged by roots (Figure 1). This includes permanent resistance of the waterproofing membrane to invasion by plant roots and plant rhizomes (underground shoots), especially at membrane joints and perimeter and wall connections, where the waterproofing membranes are most susceptible to deterioration and subsequent leakage [45]. Like the waterproofing layers, the root-retention layer must have a certificate showing that it is resistant to plant roots. The use of waterproofing membranes without an FLL certificate (plant resistance certificate) is not recommended in any type of system. Such membranes should not be used, especially on intensive green roofs [51].

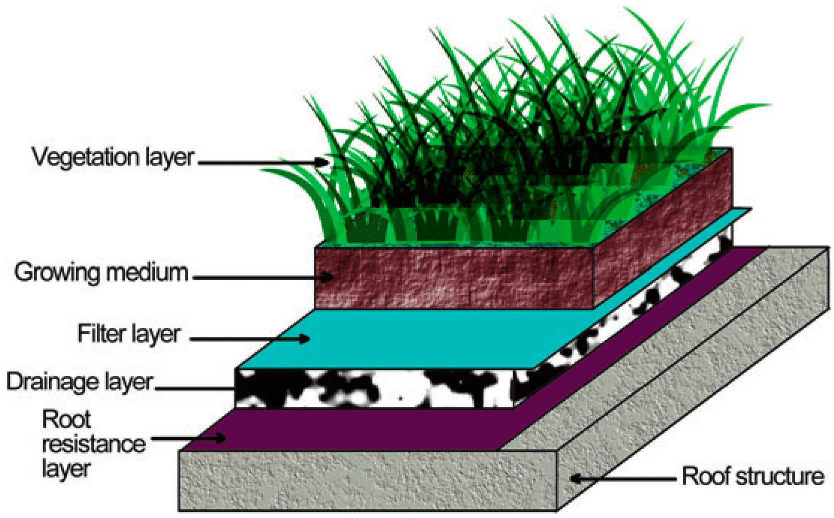

Figure 1. Scheme of a typical green roof [52].

5. Green Roof Systems

Green roof systems are examined in two groups according to the characteristics of the growing medium layers used on the roof surface and the preferred plant species. Looking at the type of planting methods, they are classified as roof gardens (intensive) and green roofs (simple/extensive) [16].

5.1. Intensive (Dense) Vegetated Roof Systems

When installing a green roof system, the static structure of the building must be designed to withstand the additional load of around 300–400 kg·m^{-2} that the green roof will cause. This roof system has functional effects both in terms of functionality and recreation [53]. Since the soil depth increases on these roofs, small trees and shrub species are generally preferred in plant selection. Therefore, high costs are generally required for fertilization and maintenance [35]. The concept of intensive roofs is a system that allows for a large and diverse range of plant species and has a wider soil depth and substrate than other systems [45]. Intensive green roofs are more resistant to high temperatures and have a higher rainwater storage capacity than other green roof systems [54].

From a functional perspective, intensive green roofs are preferred for recreational purposes [55]. Intensive roofs with high architectural and aesthetic features are primarily preferred in newly constructed buildings, and the design can be shaped by determining the additional loads they impose on the building during the design phase [56].

The advantages of roof gardens can be listed as follows:

- They are quite suitable for plant diversity [57].
- They have excellent insulation properties [57].
- The system appears as if it were the ground (soil analogy) [57].
- From a visual perspective, they create tremendous appeal [57].
- They allow the roof to be used for various purposes [38].
- They retain more rainwater [58].
- They allow the roof membrane to have a long life [54].

5.2. Vegetated Roof Systems (Extensive)

The plant species used for the sparsely (extensive) vegetated green roof type are preferred to be maintenance-free, self-sustaining, and reproducing plants in their natural life cycle. In this type of roofs, the thickness of the plant carrier layer varies between 2 and 15 cm. The total load it will give the roof is an average of 100 kg·m^{-2}. A common misconception is that the roof on which the green roof environment will be provided must be flat. However, since drainage problems will occur on flat roofs, a gentle slope of 1.5–2% will provide natural drainage on these roofs. Extensive roof systems are used for visual and functional purposes rather than for recreational use [41].

Extensive green roofs are generally created to preserve the roof's life, providing environmental vitality and economic benefits rather than aesthetics. This system, which has a considerably lower maintenance cost than roof gardens, also has a lower installation cost and load per unit area [2].

The advantages of extensive roof gardens can be listed as follows:

- They are preferred for large areas [57].
- They are preferred for roofs with 0–45 degrees slopes. Roofs with a slope up to 45 degrees can be planted with the standard system. Roofs with a greater angle can also be planted, but the design and application must match [57].
- They require low maintenance and are less expensive than intensive roofs [57].
- Because they are lightweight, they require little structural support and little maintenance after installation [59].
- These roofs, which are usually created for aesthetic and ecological reasons, are often self-sufficient and require less maintenance, as they require less water and fertilizer [60].
- Another feature of extensive green roofs is that they reduce the effect of radiation by forming a protective layer against sun rays and extend the roof's life by protecting it against damage that may occur due to expansion and contraction [42].

- Suitable for renovation projects [3].

6. Effects of Green Roofs

6.1. Effects on Energy Efficiency

Green roofs provide energy savings in buildings in many ways. They reduce the heat gain and loss of the building. In hot climates, when the air temperature reaches 35 °C in the summer, the roof surface temperature reaches 65 °C. These high temperatures directly affect both the interior and exterior of the building. When the roof is protected by a layer of soil and shaded by plants, the surface temperature generally does not exceed the ambient air temperature. In addition, there are effects such as the evaporation of water by plants and soil, which creates a cooling effect, humidifies the air, and naturally cools the building [61].

These systems, with the heat storage feature of the plant carrier layer, transfer less heat load, which is reduced thanks to the plant layer on the surface, to the interior environment in the summer months and reduce heat transfer from the interior to the exterior environment in the winter months, thus decreasing the cooling and heating energy consumed in buildings. In recent years, scientific studies have been carried out to analyze the effect of green roofs on heating and cooling loads for buildings with different functions and areas [62]. A study in China observed that roof garden application significantly reduced heating and cooling loads even in buildings with poor insulation. Within the scope of this research, it was noticed that the indoor temperature of the buildings was reduced by 7 °C during the cooling season [63]. In a study conducted in Canada, a 72 m^2 roof area was created and divided into two equal parts, half of which was converted to a sparsely vegetated roof system and the other half to a traditional roof system. In light of the data obtained from the traditional roof and the reference roof converted to a green roof, the average daily energy required for heating and cooling the interior space under the roofs was measured as 6–7.5 $kWh \cdot day^{-1}$ for the traditional roof. This value was 1.5 $kWh \cdot day^{-1}$ for the greened roof. The vegetated roof consumed seventy-five percent less energy per day than the reference roof. Furthermore, the greened roof provided 75% energy savings compared to the reference roof [64].

6.2. Effects on the Life of Roofing Material

Green roofs protect building elements from mechanical damage caused by the sun. In contrast to the temperature fluctuations of –20 °C to 80 °C on classical roof surfaces, green roof systems with a soil thickness of 10 cm keep the temperature fluctuations between 10 °C and 30 °C and do not create heat stress on the roof surface, preventing structural fatigue or breakage. This increases the functional life of the elements, creating economic savings and cost reductions [65].

One feature of green roofs is protection of the roof membrane. The waterproofness of the roof is damaged by the effects of the sun, temperature changes, and loss of elasticity. Green roofs protect the membrane from UV rays and high temperature changes, extending its life. This saves material, energy, and money and ensures less waste. This is also an ecological approach [3].

6.3. Creating Employment

Green roof systems involve many requirements, from design to installation and maintenance, due to the technological and structural elements they contain. In addition, green roof systems offer new employment opportunities when the planted area is used rationally. A park or bar or even a bowling alley can be located on the roof, as well as many other businesses that require additional people to work [3].

6.4. Urban Agriculture

The pressure of over-density in cities and towns confronts us with the demand for green space at ground level. Garden areas are quite limited due to the over-density of buildings in urban areas. Therefore, green roofs offer safe and important opportunities for city dwellers to love gardens and produce food [66]. Any green roof that will be designed for this purpose will be suitable for agricultural issues and therefore will allow the cultivation of vegetables and fruits, and people will be able to sell these foods to markets and restaurants. On the other hand, a smaller roof system will enable an apartment to produce enough for itself. The advantages of food grown on the roof are quite high. The transport costs of the products grown here will be none or very low [67]. Urban agriculture is also important regarding its potential to contribute to urban areas' sustainability and the urban fabric's positive change. Urban agriculture is perceived as a solution to some of the negative effects of urban growth and development [68].

Urban agriculture practices are carried out on a smaller scale than agricultural activities in rural areas, such as gardens belonging houses, gardens belonging to institutional structures such as schools, hospitals, and factories, and gardens created on the roofs of buildings [69]. Problems such as food safety due to pesticide use in agriculture, energy loss during the supply phase, and opening agricultural areas to construction have led to the importance of urban agriculture practices. It is thought that including planted building roofs in agricultural activities in the urban ecology will also reduce dependence on the energy-driven global food economy to some extent [70].

6.5. Reducing Noise Impact

The amount of sound reflected by surfaces covered with greenery is 3 dB lower than other roof surfaces. In addition, noise penetrating into the building from the roof can be reduced by up to 8 dB. This significantly benefits structures near noisy areas such as airports and highways [71]. One study mentioned that green roofs contribute to sound insulation: 'Green roofs absorb the noise reflected from buildings and pavement surfaces in cities thanks to the grass cover, and instead of reflecting the sounds, they provide a sound-reducing effect' [72]. The soil and material used for plant arrangement in roof gardens have sound-absorbing properties. Therefore, green roofs reduce the noise occurring both inside the building and in the immediate surroundings of the building [73].

6.6. Improved Air Quality

While using trees on the ground to control air pollution is tempting, green roofs are considered equally effective solutions for achieving desirable urban air quality in densely populated cities with limited planting space. Green roofs, especially those with dense designs that allow for the use of trees and shrubs, can significantly reduce carbon emissions in cities. A study in Chicago found that a 19.8 hectare green roof area removed 1675 kg of air pollutants per year. Of these pollutants, 52% was ozone, 27% was nitrogen dioxide, 14% was particulate matter $\leq$10 µm, and 7% was sulfur dioxide [74]. In experiments with green roofs, it has been demonstrated that 2000 m^2 of uncut grass area can remove 4000 kg of dust particles [35]. Another study explained this potential in a way that any city dweller can easily understand by showing that just 1 m^2 of green roof area can offset the particle emissions of a vehicle [75].

6.7. Carbon Dioxide and Oxygen Exchange

Photosynthesis is a process that converts carbon dioxide, water, and solar radiation into oxygen and glucose. It occurs within green plants. While humans and animals produce carbon dioxide, plants need this carbon dioxide to survive [76]. The O_2 produced by a green area consisting of an average of 25 m^2 of plant leaf surfaces equals the 27 g of O_2 a young person uses for one hour. If a surface covered with 1 m^2 of green is provided in the area, the O_2 needs of exactly four people during the hot summer season can be met. When factors such as cold, heat, light, and darkness are also considered, an average value of 1.5 m^2 of green area can meet one person's average annual O_2 needs [62]. Plants in green roof systems carry out photosynthesis, just like other plant species, which reduces CO_2 and increases O_2 levels, at least to some extent reducing the damage caused by pollution [77].

6.8. Effect on Air Temperature

Plant carrier and soil layers provide extra insulation in roof areas during winter. Roof types with deep soil layers can reduce the amount of energy the structure needs for heating and reduce heat and energy losses caused by breezes to a certain extent [77]. Field measurements from grass gardens in Japan during the summer months recorded a decrease in surface roof slab temperature from 60 °C to 30 °C, confirming the importance of evaporative cooling in reducing heat gain [78]. Other simulation studies of city-scale implementation of green roofs indicate potential temperature reductions of 0.3 to 3 °C [79]. Another study conducted in Singapore found that green roof systems reduced roof-ground temperatures by 18 °C, demonstrating how green roof systems play a role in air temperatures [80].

Green roofs absorb the sun's rays in the summer months with the vegetation used and keep the humidity level under control. In winter and when there is no sun, heat energy is released from the plants and green roof elements into the atmosphere. In this case, thanks to the ability of green roofs to keep hot weather cool and cold weather warm, urban heat island effects are reduced in cities [18]. In addition, green roofs slow runoff and reduce the amount of runoff to a certain extent, especially after low-intensity and short-term rainfall [81,82].

6.9. Effect on Heat Island

Urbanization and industrialization affect the heat and water cycle in the atmosphere's boundary layer and differentiate urban climates from rural areas, creating the urban heat island effect, one of the best-known forms of local anthropogenic climate change [58]. In Canada, a 2005 study determined that the surface and air temperatures in urban areas of Toronto were 2–3 °C higher in summer than in rural areas. A study conducted in Berlin observed that the air temperature in Berlin was 4–5 °C higher in the evening hours in summer than in the surrounding rural areas [34]. Green roofs replace damaged vegetation in urban areas and prevent increased air and surface temperature. Plants contribute to the prevention of temperature increase through evapotranspiration, shading, and the heat storage properties of the plant carrier layer. Evapotranspiration means that the plant releases water vapor to the atmosphere through evaporation and transpiration. The amount of heat required for the evaporation of water in plant leaves and the plant carrier layer is provided by shortwave infrared rays coming directly or indirectly from the sun to the surfaces. In this way, these rays are prevented from increasing the surface temperature [83].

6.10. Impact on Social Life

With the inevitable increase in urban density, sustainable recreational areas must be encouraged [76]. Green roofs provide recreational areas for the city and its surroundings. This role is especially seen in regions with high density and limited green areas. Many activities, such as barbecue, eating, sunbathing, exercising, and golf, occur in these green areas [42]. The environment can be arranged according to these functions. The advantage of having a green area on the roof depends on the height of the building and its surroundings. If the building is high, it can be exposed to more sunlight than green areas on the ground.

If there are tall buildings in and around a dense urban structure, it is shaded by these buildings [66].

6.11. Impact on Habitat and Biodiversity

Urban development harms the environment. However, in the case of green roofs, these systems provide new habitats for endangered species, birds, green plants, and insects [84]. Ecological systems are increased through green roofs. People can access a garden even on the tops of their buildings, which creates environmental awareness [78]. Regarding biodiversity, green roofs have been found to host many species, including native plants, birds, reptiles, bees, butterflies, spiders, beetles, grasshoppers, flies, and bats [85]. Moreover, green roofs provide effective and important variety for animal and plant biodiversity [86]. The results obtained from a study conducted in Basel, Switzerland, prove that green roof systems create a wildlife and natural development environment. In these studies conducted over 3 years, it was observed that 254 insect and 78 spider species started to live in the green roof environment after planting 17 different green roof surfaces [87].

6.12. Job Opportunities in New Sectors

With the increasing demand for green roof systems in our country, companies that will design, implement, and maintain these systems and produce and market the materials that make up the systems will begin to provide services. As the systems become widespread, the employment rates provided by these companies will also increase. People working in various sectors, from architects to engineers, marketing managers to technicians and workers, will have new alternatives in using their professions thanks to vegetated roof systems [62].

6.13. Creating Open Areas for Public Use

With the increasing use of concrete in urban areas, public areas where people can gather in a common space is decreasing. At this point, green roof applications can provide an alternative to these decreasing common areas. With the greening of traditional conventional roofs, new spaces where city dwellers can carry out their social activities and breathe in the city can be provided by these roof areas. In areas where urbanization is irregular and excessive, some activities that can no longer be carried out at ground level will be able possible thanks to green roof systems [3]. Green roofs should be used:

- for comfortable private areas that can be shared by working people during their breaks.
- in creating areas that allow public use for plant food production or gardening.
- to create commercial areas for businesses such as cafes and restaurants.
- to create recreational areas where social activities can be carried out.
- as alternative agricultural areas for food production.

6.14. Effects on Human Health

While looking at trees and plants reduces stress, it also positively affects psychology. According to the findings of a study measuring the effects of green roofs on human health, patients who received treatment in rooms with a green-based view of nature entered the recovery process more quickly than patients who received treatment in rooms with a concrete view of buildings, etc.; that is, they responded to their treatments much more quickly [48]. Many studies have yielded similar results. In other words, there is a significant relationship between individuals' mental and physical health and the surrounding landscape (greenery, concrete, etc.). A study conducted in 1988 also found that participants working in a workplace with a green-based natural landscape got sick less and recovered faster when they did, thus reducing sick days and the stress and headaches caused by work life. Another study investigated whether natural landscapes or concrete landscapes were effective in patients' recovery periods and found that patients receiving treatment in buildings with natural landscapes recovered faster and had more positive relationships with the nurses in charge. In addition, it was recorded that they used less medication during treatment. All these studies and research show us that using green roof areas as gardens or parks can to increase both psychological and physical health [18].

7. Challenges Associated with Green Roofs

Despite the many benefits of green roofs, there are also some challenges. Green roofs are not like regular gardens. Unlike natural landscapes, they are not equivalent to nature. They are manufactured or produced systems requiring design and fabrication. Green roof access problems are among the problems green roof landscapers face. If a green roof is 20 stories above ground and has limited access, all materials must be transported to the site, including the growing medium and plants. This usually adds costs not related to landscaping. Using an elevator or renting a crane will be safe for transporting materials to the site. The behavior of plants in certain conditions affects their selection and maintenance methods. Correct plant selection is one of the most important issues to consider in green roof planting. For example, the possibility of sustaining different plant species is poor on roofs in North America without irrigation and with organic growth medium less than 20 cm in thickness. Another disadvantage of green roof planting is the high installation cost and the long return on investment [88]. The high installation cost limits the widespread use of green roofs, as does the extra structural load requirements and their unsuitability for roof slopes with high angles [89]. The costs of green roofs vary from project to project, depending on whether the system is simple or complex. If one wants to have a composite green roof, it can generally be seen that the cost of a green roof tends to increase [43].

The following criteria affect the cost of a green roof: roof area, roof height, roof slope, the type of green roof requested, initial maintenance and installation costs, water insulation and heat insulation used, and the types of plants to be grown [42,90]. The high costs of green roof applications are a problem. The high construction costs of these fixed cost amounts can be amortized with the water and energy savings made with green roofs. It is thought that these systems can form a financial module within themselves based on amortization periods.

Other problems with green roofs include climatic and weather restrictions, negative views for users (not wanting habitat area created by flying and moving creatures), fire safety issues, and the difficulty of constructing complex drainage systems [42].

8. Calculation on the Amount of Water That Can Be Obtained from a Green Roof in Antalya Province

Antalya is located in the west of the Mediterranean Region. The land structure of Antalya consists of two parts: the mountainous area known as the Western Taurus Mountains and the coastal areas on its edge. In the west, the Eşen, Elmalı, and Korkuteli Plains, the Teke Plateau, and the Bey Mountains and Akdağlar, which have varying elevations between the coast and the mountainous areas, present a topographic appearance fragmented by streams. The Korkuteli Plain is 7–8 km long and 2–3 km wide and is a fertile plain among the mountains. The central and eastern parts of Antalya are the Antalya Plain, where greenhouses are abundant, and the Western Taurus Mountains, which rise on the eastern and western sides of the inner parts of this plain, forming the general morphological structure. Antalya Province is under the influence of the Mediterranean climate [91].

Antalya Province was selected as the study area due to its high agricultural activities and urbanization rate. In calculating the amount of water that can be obtained with a green roof, the long-term precipitation values of Antalya Province for the years 1930–2023 were used (Table 1) [92].

Table 1. Long-term monthly total rainfall average in Antalya Province.

Months	Rainfall (mm)
January	234.5
February	150.2
March	92.1
April	49.0
May	34.3
June	11.0
July	4.4
August	4.3
September	16.9
October	70.9
November	129.7
December	256.1
Annual	1503.4

Considering the long-term average total monthly rainfall in Antalya Province, the amount of water was calculated considering a 100 m^2 roof area designed to hold water, based on different literature values of water retention capacities on green roofs.

Researchers have examined annual and monthly precipitation data recorded in Antalya and Isparta Provinces between 1971–2018 [93]. The trend analysis methods applied to Antalya precipitation were Mann–Kendall Trend Analysis, Trend Slope Estimator, and Innovative Trend Analysis [94]. When these three methods were applied, the results were generally different. In the Mann–Kendall test, no trend was found in annual and monthly precipitation in Antalya, while Şen's [94] Trend Slope Estimator reported a decrease in annual precipitation in February, March, November, and December in Antalya, while increasing trends were calculated for other months [93]. Şen's [94] Innovative Trend Analysis method indicated a decrease in precipitation in February, March, June, July, and November in Antalya, while increasing trends were calculated for other months and for annual precipitation [93]. The authors of this study stated that it is necessary to conduct more studies with more methods on hydro-meteorological parameters that directly affect water resources such as precipitation [93]. Therefore, it can said that the precipitation in Antalya Province has changed over many years despite the calculations, according to different trend analyses, on a monthly and annual basis.

The 5 year precipitation data in Table 2 cover the years 2019–2023, while the 10 year precipitation data belong to the years 2014–2023. When Table 2 is examined, it is seen that the total 10-year monthly precipitation amounts in Antalya province are more than the 5-year monthly precipitation amounts. In addition, the water savings that can be achieved with a green roof are based on the data for the years 1930–2023 in Table 1.

Table 2. Average precipitation values for Antalya Province for 5 and 10 years.

Months	5 Years' Rainfall (mm)	10 Years' Rainfall (mm)
January	102.98	164.27
February	64.4	87.04
March	63.42	81.74
April	8.8	18.94
May	36.24	32.26
June	5.76	13.88

Table 2. *Cont.*

Months	5 Years' Rainfall (mm)	10 Years' Rainfall (mm)
July	2.92	2.28
August	1.96	1.18
September	5.3	16.73
October	18.36	27.96
November	85.52	89.58
December	167.94	149.25
Annual	563.6	685.11

Literature on Water Holding Capacity

- Literature Source 1

Kob [95] reported that green roofs' annual water retention rate is between 45% and 70%. Therefore, for literature source 1, the average water retention capacity was 57.5% for a green roof area of 100 m^2.

- Literature Source 2

Sims et al. [96] stated that green roofs retain 16–29% of precipitation over 45 mm. From this, the water retention capacity of a 100 m^2 green roof area for literature source 2 was calculated as 22.5% on average.

- Literature Source 3

Zaremba et al. [97] found that the water retention capacity of green roofs is between 34% and 4%. From this, the average water retention capacity of a 100 m^2 green roof area for literature source 3 was taken as 39%.

- Literature Source 4

Fioretti et al. [98] reported that green roofs reduce the annual water retention rate by 40–80%. For literature source 4, the water retention capacity in a 100 m^2 green roof area was taken as 60% on average.

- Literature Source 5

Intensive systems have higher water retention capacities than extensive systems due to the dense structure of the growing environments and vegetation. The water retention capacity, which is between 40% and 92% for extensive systems, varies between 70% and 99% for intensive green roof systems (roof gardens) [99]. It has been stated that the amount of water that can be retained on a green roof differs based on whether it is an intensive or extensive roof system. For literature source 5, the water retention capacity in a 100 m^2 green roof area was taken as 66% for an extensive roof and 84.5% for an intensive roof.

Calculations were made to determine the water that can be retained in an area of 100 m^2 for different percentage values suggested in the literature. Then, the calculations made based on these different percentage values were compared. Calculations were made based on average values to determine the water savings that can be obtained from green roofs, considering the literature values' minimum and maximum variability ranges. The amounts of water that can be retained in a 100 m^2 green roof area according to different literature sources are shown in Table 3. The graph of the total annual water amounts that can be retained according to different literature values is shown in Figure 2.

Table 3. The amount of water that can be retained in a 100 m^2 green roof area according to different literature sources (m^3).

Antalya	Literature Source 1	Literature Source 2	Literature Source 3	Literature Source 4	Literature Source 5 (Extensive)	Literature Source 5 (Intensive)
	Water Retention Capacity (57.5%)	**Water Retention Capacity (22.5%)**	**Water Retention Capacity (39%)**	**Water Retention Capacity (60%)**	**Water Retention Capacity (66%)**	**Water Retention Capacity (84.5%)**
January	13.484	5.276	9.146	14.070	15.477	19.816
February	8.637	3.380	5.858	9.012	9.913	12.691
March	5.296	2.073	3.592	5.526	6.079	7.782
April	2.818	1.103	1.911	2.940	3.234	4.141
May	1.972	-	1.338	2.058	2.264	2.898
June	0.633	-	0.429	0.660	0.726	0.930
July	0.253	-	0.172	0.264	0.290	0.372
August	0.247	-	0.168	0.258	0.284	0.363
September	0.972	0.380	0.659	1.014	1.115	1.428
October	4.077	1.595	2.765	4.254	4.679	5.991
November	7.458	2.918	5.058	7.782	8.560	10.960
December	14.726	5.762	9.988	15.366	16.903	21.640
Annual	60.571	17.210	41.083	63.204	69.524	77.590

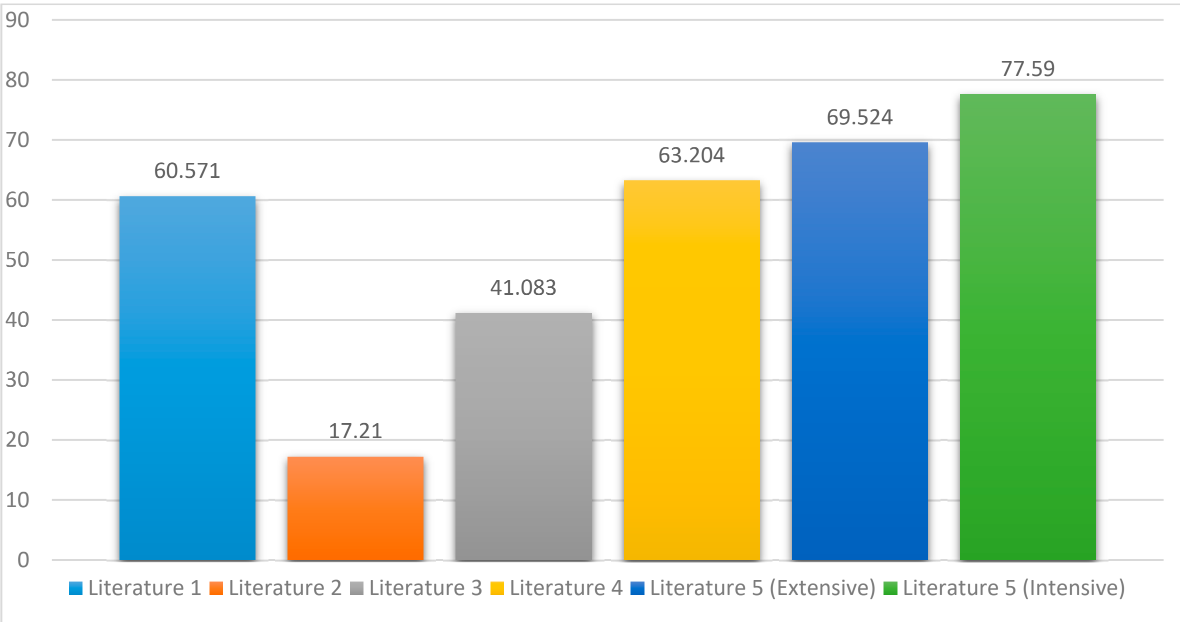

Figure 2. Total annual water amounts that can be retained according to different literature values (m^3).

Ekşi and Uzun [100] examined the effects of growing medium depth on surface runoff in green roof systems and stated that the amount of moisture in the growing medium varied according to the depth and type of growing medium, and that this situation affected plant development. In green roof applications, the increase in depth positively affected the amount of moisture in the growing medium, and it was stated that the type of growing medium also affected the moisture content. It was reported that a 10 cm depth had the highest water holding capacity in the growing medium, while the lowest value was reported for growing medium at a depth of 4 cm. The water retention properties of growing media have been stated by the authors as a factor directly affecting plant growth [100]. Therefore, it can be said that the values obtained in Table 3 are directly related to the water holding capacity of the layer thickness and content of the growing medium.

9. Calculation of Energy Savings from a Green Roof

Considering the research on traditional roofs, it was stated that the annual energy usage for heating purposes varies between 100 and 200 kWh/m^2 [101]. The annual energy usage for heating purposes was taken as 150 kWh/m^2 on average, and this value was calculated as 15,000 kWh for a 100 m^2 green roof area. Based on different literature values, an attempt was made to calculate the energy savings that could be achieved due to a green roof application planned on a 100 m^2 roof, assuming the entire area was designed as a green roof.

Literature on Energy Saving

- Literature Source 1

  Reported that 75% savings can be achieved with green roof applications [64].
- Literature Source 2

  Reported that 50% savings can be achieved with green roof applications [65].
- Literature Source 3

  Reported that 60% savings can be achieved with green roof applications [102].
- Literature Source 4

  Reported that 37% savings can be achieved with green roof applications [103].
- Literature Source 5

  Reported that 26% savings can be achieved with green roof applications [104].

Calculations were made for different percentage values suggested in the literature to determine the energy savings that can be obtained in a 100 m^2 floor area. Then, the calculations made based on these percentage values were compared. The annual energy use for heating purposes was calculated based on an average of 150 kWh/m^2, taking into account the range of variability.

According to different literature sources, the values of energy savings that can be achieved for heating purposes based on a 100 m^2 green roof area are shown in Table 4.

Table 4. According to different literature sources, energy savings for heating purposes based on a 100 m^2 green roof area.

Traditional Roof Application Energy Use for Heating Purposes (kWh)	Savings in Heating Energy Use with Green Roof Application (kWh)				
	Literature Source 1	Literature Source 2	Literature Source 3	Literature Source 4	Literature Source 5
15,000	11,250	7500	9000	5550	3900

10. Conclusions

A significant portion of rainwater can be stored with a green roof. In addition, green roofs have many positive effects on the environment. Among these are valuable effects on many areas, such as economics, social life, and habitat. The importance of green roof applications is again emerging worldwide, where global warming and drought are felt. Green roof applications have been encountered in many civilizations and societies throughout history. With today's technological developments, green roof applications can be modernized, and the highest benefit can be obtained from roof areas. Making green roofs or green area applications mandatory in newly constructed buildings, especially in large cities with a lot of construction, will have many benefits in the coming years. In addition, green roof applications can provide all or part of the water needs for agricultural activities in rural areas. Also, they can serve as a supporting water source in landscaping and domestic uses in cities.

In order to create awareness among the public regarding green roof applications, educational activities should be planned, awareness studies should be carried out, and public service announcements should be created to adopt environmental awareness at a young age. In this study, considering the long-term monthly total rainfall average data of Antalya Province, the amount of water that can be retained as a result of a planned green roof application was calculated based on different literature values of water retention capacities in green roofs, considering that the entire area is designed to hold water in a 100 m^2 roof area.

According to literature source 1, the lowest water retention amount was 0.247 m^3 in August, and the highest water retention capacity was 14.726 m^3 in December. In line with literature source 2, the annual rainfall in May, June, July, August, and September was below 45 mm, so the water retention capacity of the green roof for these months was not calculated. According to literature source 3, the lowest water retention capacity was 0.168 m^3, and the highest was 9.988 m^3. In line with literature source 4, the lowest water retention amount was 0.258 m^3 in August, and the highest was 15.366 m^3 in December. According to literature source 5, the water retention capacities of extensive and intensive roofs were evaluated differently. In August, when the lowest water retention amount occurred, this amount was determined as 0.284 m^3 for the extensive roof and 0.363 m^3 for the intensive roof. In December, when the highest amount of water could be retained, this amount was determined as 16.903 m^3 for the extensive roof and 21.640 m^3 for the intensive roof.

It has been determined that water retention rates vary based on the literature sources examined. In this context, it has been determined that different water retention values were obtained for the same rainfall periods for a 100 m^2 area. In green roof applications, since there is an effect of the type of plant used, the water permeability of the building materials, and many different external factors, it can be said that a fixed water retention value cannot be determined, and that a special green roof application project should be designed for each structure.

In addition, the importance of energy saving in green roof applications is also revealed. A green roof application that complies with standards can provide energy savings. In a period when the threat of global warming is increasing daily, energy saving can be very important in reducing the carbon footprint. In addition, energy saving on green roofs will also result in economic gain for the individuals living under this roof.

In this study, the energy savings that can be achieved from a planned green roof application, considering that the entire area is designed as a green roof on a 100 m^2 roof area, were calculated based on different literature values. According to literature source 1, the energy savings that can be made for heating purposes based on a 100 m^2 green roof area is 11,250 kWh, according to literature source 27,500 kWh, according to literature source 39,000 kWh, according to literature source 45,550 kWh, and according to literature source 53,900 kWh. It was determined that the energy savings that can be achieved vary depending on the literature source.

Considering the amount of water that can be saved according to the literature values, using this water in different areas such as irrigation, vehicle washing, and ornamental pools may be important in today's world where there is a water shortage, and water supply leads to great costs. In addition, the energy saving amounts that can be achieved as a result of green roof applications will be applied to the roofs of newly designed buildings in addition to existing roofs, thus providing economic gain by providing energy savings and temperature reduction in the study area.

In order to ensure that the studies carried out are more permanent, some political steps need to be taken. The increasing world population and the urbanization rate with the increasing population are reducing green areas. Therefore, it can be said that these green areas should be made mandatory by laws and specifications rather than being left to the initiatives of architects, engineers, and building planners. In this context, with green roofs under the guarantee of public institutions, both water and energy savings can be made, and meeting the need for green areas can be ensured. If authorized bodies make green roof applications a state policy with laws, this can increase the effectiveness of public institutions in the fight against global warming and drought. Giving state incentives for small-scale agricultural activities that can be carried out on green roofs can also contribute to the spread of agricultural supports such as organic farming and good agricultural practices. It would be an important step to make it mandatory to use water obtained from green roofs in landscape irrigation of green areas, especially in areas where public buildings are located, and to make it a policy.

Author Contributions: Conceptualization, H.E., A.A., T.J. and J.K.; methodology, H.E. and T.J.; formal analysis, H.E., A.A. and T.J.; investigation, H.E. and T.J.; resources, H.E., A.A. and T.J.; writing—original draft preparation, H.E., A.A., T.J. and J.K.; writing—review and editing, H.E., T.J. and J.K.; supervision, A.A. and T.J.; funding acquisition, T.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Acknowledgments: The publication was prepared as part of Tomasz Jakubowski's internship carried out as part of the project "Raising qualifications and competences of teaching staff and doctoral students in order to Enhancing the quality of teaching at the University of Agriculture in Kraków" co-financed by the European Union as part of the European Funds for Social Development program.

Conflicts of Interest: The authors declare no conflicts of interest.

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