NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF ARCHITECTURE

GREEN ROOFS, VEGETATION TYPES, IMPACT ON THE THERMAL EFFECTIVENESS: AN EXPERIMENTAL STUDY IN NICOSIA, CYPRUS

PhD. THESIS

Sinem YILDIRIM

Nicosia

February, 2023

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Thesis advisor
Prof. Dr. Özge ÖZDEN

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Approval

The thesis titled **"Green roofs, vegetation types, impact on the thermal effect: An experimental study in Nicosia, Cyprus"** prepared by Sinem YILDIRIM was accepted as a Doctoral Thesis in the Department of Architecture on February, 2023 on its compliance with quality standards in terms of scope and quality.

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Declaration

I have obtained the data, information and documents I have presented in this thesis within the framework of academic and ethical rules; I present all information, documents, evaluations and results in accordance with scientific ethics and morals; I declare that I have made full reference to all data, thoughts, results and information that do not belong to me in this study, in accordance with scientific ethical rules, and that I have cited them as sources.

Sinem YILDIRIM

27/02/2023

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Abstract

Green Roofs, Vegetation Types, Impact on the Thermal Effectiveness: An Experimental Study in Nicosia, Cyprus

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Cities are facing rapid growth of environmental issues as a result of the combined effects of urbanization and climate change. Climate change has the most conspicuous impact on environmental issues. Nowadays, energy conservation is a very crucial subject for the city planners, and the greenroofs can provide environmental benefits which include building insulation and mitigating urban heat island effect within the cities. Various studies indicated that green roofs help regulate the roof temperature and they have conducive effect on indoor temperature of the buildings. This research provides an experimental investigation on usage of different types of green roof vegetations and their effect on indoor temperatures. The research has been conducted at Near East University Campus within time duration of twelve months in Nicosia, Cyprus. Experiment consisted of three different green roof types; each green roof hut had the area of 3.5m² and the soil depth of 8cm. One control hut of the same dimensions was used for comparison in the experiment. Three different vegetation types of drought resistant ground-covers and shrubs were used: 1-Low growing ground cover succulents, 2-Mixture of low growing succulents and low shrubs 3-Mixture of low growing succulents, low shrubs and high growing foliage plants. In order to measure indoor temperatures of the huts, Elitech RC-5 temperaturedata loggers were used. Research results exhibited that the hut with highly vegetated roof had the lowest temperature in comparison to low vegetated green roof during thehot summer period in Cyprus. It has also indicated that in sustainable cities, green roofs play a vital role in terms of building insulation, reducing temperature and contribution to biodiversity. This research helps advance the development of green roof buildings in arid and tropical climate areas to mitigate the effects of temperature and reduce energy cost to create sustainable and environment friendly urbanstructure.

***Keywords*:** Cyprus, extensive green roof, vegetation, shrubs, ground cover plants

Özet

Yeşil Çatılar, Bitki Örtüsü Tipleri, Termal Etkinlik Üzerindeki Etkisi: Lefkoşa, Kıbrıs'ta Deneysel Bir Çalışma

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Şehirler, kentleşme ve iklim değişikliğinin birleşik etkisinin bir sonucu olarak büyüyen bir çevre sorunuyla karşı karşıyadır. İklim değişikliği çevre sorunları üzerinde en göze çarpan etkidir. Günümüzde enerji tasarrufu şehir plancıları için çok önemli bir konudur. Yeşil çatıların, bina yalıtımı ve şehirlerdeki kentsel ısı adası etkisini azaltma gibi çevresel faydalar sağlayabildiği bilinmektedir. Bazı araştırmalar yeşil çatıların çatı sıcaklığını düzenlediğini ve binaların iç ortam sıcaklıklarını etkilediğini göstermiştir. Bu araştırma, farklı türdeki yeşil çatı bitki örtüsünün, bitki örtüsünün kontrolü olmadan deneysel olarak incelenmesini ve bunların iç ortam sıcaklıkları üzerindeki etkisini inceler. Araştırma, Kıbrıs Lefkoşa'da bulunan Yakın Doğu Üniversitesi Kampüsünde on iki aylık süre ile gerçekleştirilmiştir. Deney üç farklı yeşil çatı tipinden oluşuyordu; yeşil çatılı kulübelerin her biri 3,5 m² çatı alanına ve 8 cm toprak derinliğine sahipti. Ayrıca deneyde karşılaştırma için aynı ölçülerde başka bir yeşil çatısız kulübe kullanılmıştır. Bu deneysel çalışma kapsamında, üç kulübenin çatısına kuraklığa dayanıklı yer örtücüler ve çalılar dikilmiştir. Üç farklı vejetasyon tipi kullanılmıştır: 1-Düşük büyüyen yer örtücü sulu meyveler 2-Düşük büyüyen sulu meyveler ve kısa boylu çalıların karışımı 3-Düşük büyüyen sulu meyveler, kısa boylu çalılar ve yüksek büyüyen yapraklı bitkilerin karışımı. Kulübelerin iç ortam sıcaklıklarını ölçmek için Elitech RC-5 sıcaklık dataloggerları kullanılmıştır. Araştırma sonuçları, yüksek bitki örtüsüne sahip kulübenin Kıbrıs'ta sıcak yaz döneminde en düşük sıcaklıklara sahip olduğunu göstermiştir. En önemlisi, çalı bitkilerinin bulunduğu kulübeler sıcak yaz koşullarında en düşük sıcaklıklara sahipti Sonuçlarımız, yeşil çatıların bina yalıtımı ve ardından gelen enerji kullanımı açısından önemli bir rol oynadığını gösterdi. Dünyanın birçok bölgesinde şehirleşmenin bir sonucu olarak, sürdürülebilir şehirlere ihtiyaç vardır. Sürdürülebilir şehirlerde yeşil çatılar, bina yalıtımı, şehir sıcaklığının düşürülmesi ve biyoçeşitliliğe katkı sağlaması açısından büyük önem taşımaktadır. Bu nedenle Kıbrıs adasında yer alan Lefkoşa şehrinde gerçekleştirdiğimiz araştırmanın bulguları sürdürülebilir şehir kavramı açısından oldukça değerlidir.

***Anahtar kelimeler**:* Kıbrıs, ekstensif yeşil çatı, bitki örtüsü, çalılar, yer örtücü bitkiler

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ABBREVIATIONS

NEU:	Near East University
SRP:	Scientific Research Project
GR:	Green Roof
CO2:	Carbon Dioxide
UHI:	Urban Heat Island
%:	Percentage
UGI:	Urban Green Infrastructure
$:	United States Dollar
NBS:	Nature-Based Solutions
m^2:	Square Meter
° C:	Centigrade Degrees
BGS:	Blue Green Solution
IUCN:	International Union for Conservation of Nature
Ha:	Hectare
FAO:	Food and Agriculture Organization
GI:	Green Infrastructure
US:	United States
Min:	Minimum
Max:	Maximum
Avg:	Average
TEEB:	The Economics of Ecosystems and Biodiversity
BCE:	Before Common Era

EU:	European Union
UK:	United Kingdom
USA:	United States of America
CEE:	Cyprus Environmental Enterprises
USB:	Universal Serial Bus
LCD:	Liquid Crystal Display
RE:	Renewable Energy
EE:	Energy-Efficient
PV:	Photovoltaic
TEEB:	The Economics of Ecosystems and Biodiversity
CEN TC 350:	The Technical Committee of the European Committee for Standardization 350

CHAPTER I
INTRODUCTION

1.1 Research Background

More than 60% of the world's population now resides in urban areas as a result of numerous immigrants' significant contribution to urbanization. So far, many significant environmental problems are identified which pose risks to world health, including air pollution, habitat fragmentation and habitat loss (Wu, 2021). Since habitat degradation and fragmentation reduces population size, encourages the loss of species genetic diversity, constricts species geographic distribution, and makes extinction of species easier, there are now particular concerns, especially with regard to global issues like these (Lino et al., 2019). In addition to changing the physical environment of living things and the carbon, nitrogen, and hydrological cycles, accelerating human activities are also directly altering the species diversity and composition of biological communities (He and Silliman, 2016).

The efforts to create different green infrastructures in cities against urbanization, loss of green space, habitat loss is well acknowledged worldwide. One of the most important green infrastructure elements is green roofs. It is known that in developed countries and cities, varrious practices are carried out on this subject and legislations and laws are developed day by day. Green roofs are known to have positive effects on the urban heat island effect with the proliferation of green areas in cities. In addition, green roof systems also have a positive effect on energy savings by cooling the heat insulation.

1.2 Research Problem

Currently, environmental problems such as global warming, climate change and the degeneration of natural resources are causing many problems. In addition, with the rapidly increasing population growth and the migration of people from rural areas to urban areas is replacing green areas in cities. Unfortunately, the intense construction and related infrastructures, which emerged as a result of urbanization, increase the rate of concretization and reduce green areas if not well planned (Buhaug and Urdal 2013).

In this situation, contact with nature, which plays a significant role in human life, is dwindling. Serious issues with the wildlife network are brought on particularly by the reduction of green space and the rise in concrete surfaces (Barnes et al., 2001). Asphalt and concrete-covered surfaces, which are common in communities, do not enable enough water to seep into the soil. Dark sidewalks and roof tops absorb and store solar energy during the day, then reflect it at night. Reduced water resources, extreme temperature disparities between urban and open regions, the heat island effect, damaged soil, altered weather patterns, and the loss of greenery in urban areas are the results. These issues can be largely resolved with green roofs (Karaosman, 2000).

According to detailed environmental research findings for Cyprus, there will likely be a greater need for space cooling and air conditioning during the night as well as during the day, which would result in more power being used on the island. Given the steady decline in rainfall that has been seen over the past three decades, climate change in Cyprus will cause further drops in precipitation of 10–15% from 2020 to 2050. Hence, there will be a growing demand for more seawater desalination plants and a focus on improving water-use efficiencies as a result of the need for both more drinking water and more water available for cultivation

Due to all these reasons, it is possible to increase the green, which decreases at the urban scale, on an architectural scale. From this perspective, green roofs, an important example of environmental problems, can help cities to improve the world on a larger scale (Jack and John, 1994).

1.3 Aim of the Study

Due to intense urbanization and population growth, cities are largely covered with cemented buildings causing scarcity of urban green spaces. Air pollution brings along many major problems for cities. The increase in the number of tall buildings causes the air to be heated by pollution, as it prevents air circulation. One of the most effective solutions against these issues is to restore the balance of atmosphere by creating green areas on the structures of already built city buildings that could help purify the atmosphere and hence reduce the drastic increase in temperature, that is to say, the greening of the roofs. Therefore, green roofs, which are among the most important examples of environmental sustainability, gain importance in this regard. On the island of Cyprus, which has a hot and arid climate, it is thought that green roofs provide an insulation effect in buildings. In this context, the aim is to find the indoor temperature effects of green roofs in Nicosia, Cyprus.

The application of green roofs has the following goals: to create a living space, to insulate in winter, to contribute to thermal insulation by providing coolness in summer, to provide sound insulation, to reduce the risk of drainage and sudden floods by holding down the rain water, to reduce the effect of temperature changeson the structure, thereby reducing thermal stress, to add aesthetic value to the structure, to adjust heat and humidity balance, to filter dust and air and water pollution, to add aesthetic value to the structure.

Based on all these reasons, it is implied that the green roof system will be a beneficial solution to the environmental problems in Cyprus, which has a typical Mediterranean climate. The aim of the project is to find out the indoor temperature effects of green roof huts with different vegetation. The experimental research method will be used to conduct the study. The instrument to measure temperature be used is the thermometer. In the experiment, the effect of different plant species on indoor temperature was observed for 1 year. In this context, green roof systems, which have many benefits within the scope of the project, can be widely designed and applied in many countries dealing with the climate change and gradual rise in temperature.

Green roofs will be very suitable to be applied on the Mediterranean island of Cyprus with regard to continuous gradual change in the climate of island. The results of this research project will guide the future green roof applications on Mediterranean concrete building roofs, particularly for semi-arid regions.

1.4 Research Questions

Depending on the examinations and literature reviews, answers to the following questions will be sought:

- Do green roofs contribute to thermal insulation in buildings in Cyprus, which has a Mediterranean climate?
- Was the effect of green roofs on indoor temperature different when comparing control huts and huts with green roofs?
- Do green roofs with different vegetation have different effects on indoor temperature?
- Which green roof vegetation provides the best thermal insulation?

1.5 Scope of the Thesis

In **Chapter 1**, the research background, research problem, aim of this research, research questions, limitations explained.

In **Chapter 2**, green roof systems in urban areas were reviewed. Addition, sustainable cities, urban green spaces, urban ecology, an overview of green roof systems, historical development of green roof systems, green roof systems in Europe,benefits of green roof systems, effects on biodiversity, green infrastructure and ecosystem services, effect of green roofs on indoor temperatures from different part of the world subjects reviewed.

In **Chapter 3**, the site plan of the experimental project, the design of the huts, the properties of the extensive green roof, the plant material, explained. In addition, materials and methodology explained.

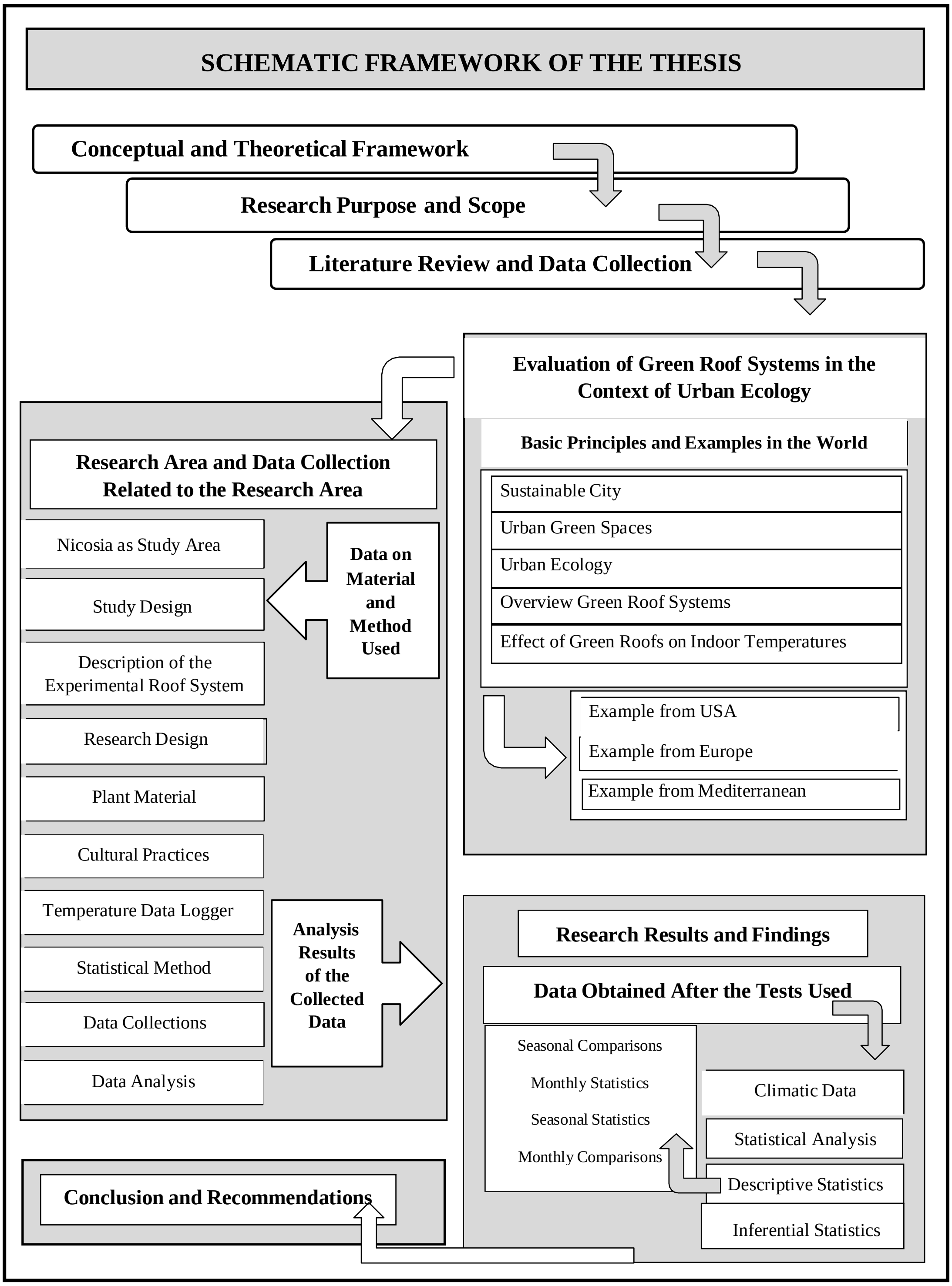
In the **4th Chapter** of the thesis, the analysis of the experiment explained.

In Chapter 5 the results of the research were interpreted by looking at other examples in the world.

In the last chapter, **Chapter 6**, by looking at the results of the scientific research, suggestions were made for future studies that can be done in Cyprus or especially in the city of Nicosia in relation to green roofs.

Figure 1.1

Schematic framework of the thesis



(Yıldırım, 2023).

1.6 Limitations

Due to the fact that the research phase of this study came to the Covid-19 period, there were many disruptions. The quarantine process, both in the implementation of the huts and planting the vegetations on the green roofs, slowed down the research. Since there is quarantine, especially when the plants need to be irrigated, some plantshave dried up because irrigation is not done regularly. In addition, since one of the thermometers used to measure the temperature failed, a clear comparison could not be made in the data obtained for one month. On the other hand, due to the weather conditions in the winter months, the doors of the experimental huts were sometimes opened. This may have affected the indoor temperature. In addition, the indoor humidity of the huts could not be measured, as the temperature data loggers were only able to measure the indoor temperatures.

CHAPTER II

EVALUATION OF GREEN ROOF SYSTEMS IN THE CONTEXT OF URBAN ECOLOGY

2.1 Sustainable City

Urban sustainability is a concern as a result of the human population's growing and global urbanization. Equity, economic, and environmental concerns are all widely considered to be part of sustainable development, which is a broad concept. Just 3% of the planet's territory is occupied by cities, but they are responsible for 75% of the world's total final energy consumption and carbon emissions. Hence, whether or not the world as a whole move towards sustainability in all of its expressions - economic, social, and environmental — will depend on the collective activities of cities. (Bai et al., 2016). As the Brundtland report states, sustainable development "seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future" (United Nations World Commission on Environment and Development 1987) (Andersson, 2006).

It can be said that sustainability concerns issues of both technology and equity. The concept of sustainable development has been applied to the so-called sustainablecity. However, this concept is difficult to define precisely because it refers to the process rather than to the end-point. The city requires the flows of energy, natural resources, services, people, information, etc. Therefore, it cannot be looked at as a single and self-contained system. These flows obviously have benefits to the residents, but sometimes uncontrollable problems are created, such as pollution, traffic congestion and waste. Currently, significant discussion of the city's environmental impacts is focused on greenhouse gas (GHG) emissions that come from the increase in consumption of energy and other resources (Girardet, 2008).

Achieving a sustainable city requires long-term visions, integration and a system-oriented approach to addressing economic, environmental and social issues (Phdungsilp, 2011).

First, the phase of sustainable development was assessed and classified based on three criteria: the pilot or planning stage, the construction stage, and the implemented stage. According to surveys, sustainable city projects have grown quickly since the 1950s. Also, it was discovered that a lot of the work involved expanding or upgrading existing cities (Werder, 2014).

Figure 2.1

Pillars for Achieving Sustainability of Cities

(Werder, 2014).

The impacts of car traffic on the livability of cities and neighborhoods, in terms of safety, air pollution, noise, but also in terms of consumption and quality of public space, are widely acknowledged. These issues are not new to the debate: since the first decades of the 20th century, with the advent and rapid diffusion of the automobile, concerns on the impacts of vehicular traffic and issues of urban livability and traffic separation have been raised by urban and transport planners. As a consequence, various models of neighborhood planning emerged, proposing solutions to limit these impacts. In order to improve accessibility, equity, health, and livability, the supermanzana model adopts the principles of neighborhood planning by identifying a main road network and creating a system of superblocks within the meshes of this network; it aims on the one hand to transform public spaces at the neighborhood level and on the other hand to reorganize the existing urban structure.

By demonstrating how the traffic separation principle can be applied to existing, dense urban contexts and reclaim public space for more livable neighborhoods and sustainable cities, the application of the supermanzana model in Barcelona offers an interesting contribution to the debate on the 15-minute city (Staricco and Brovarone, 2022).

Figure 2.2

The network of green streets and squares proposed for the Example, Barcolana district

(Staricco and Brovarone, 2022).

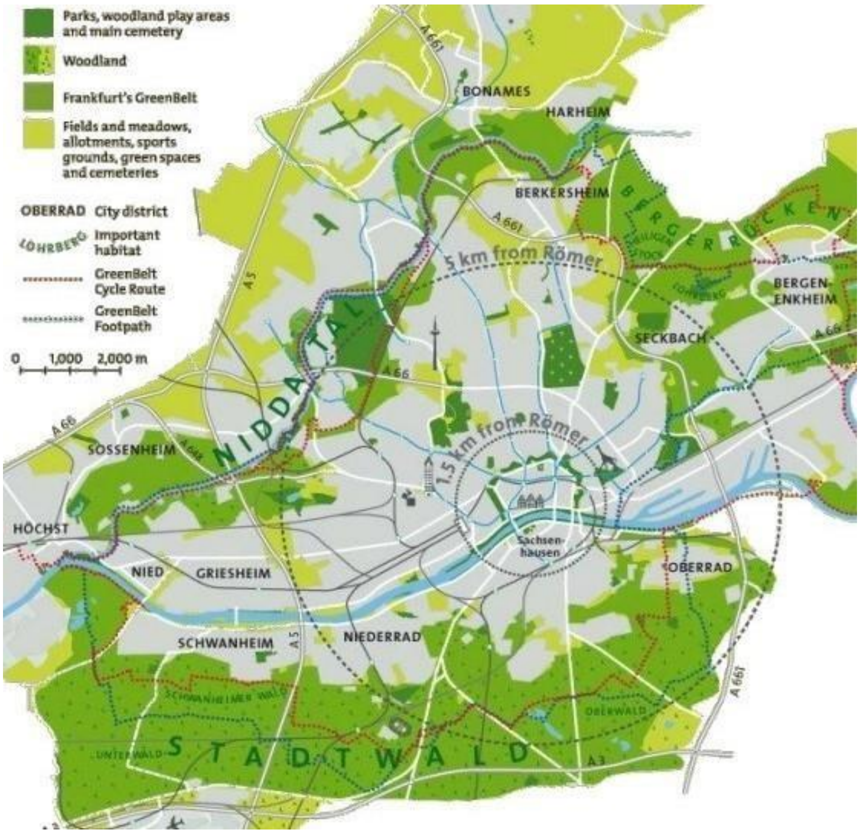
In another study proposes a case-based degrowth critique of sustainable urban development strategies. Copenhagen, European Green Capital in 2014, is considered a role model of planning for sustainability. Does this hold in a degrowth perspective? Sustainable development assumes that environmental impacts can decline while the economy grows. Degrowth maintains that such a process of absolute decoupling is infeasible. Analyzing Copenhagen’s planning documents in this perspective find three factors that make the city’s sustainability strategy ineffective for ecological sustainability. First, Copenhagen’s strategy for climate neutrality is based on externalization: only emissions produced locally are counted. Meanwhile, emissions produced outside of the city for products and services consumed locally remain high. Secondly, policies focus on the efficiency of activities rather than their overall impact: efficiency gains are considered reductions of impact, but really mean slower growth of impact. Finally, sustainability measures are proposed as a ‘green fix’, to increase competitiveness and promote economic growth, leading to increased consumption and impact. Analyzing the critical case of Copenhagen in a degrowth perspective, sheds doubts on sustainable urban development, but does not imply the rejection of all its typical planning measures. This induces reflections on how these results can contribute to a degrowth-oriented urban planning (Krähmer, 2021).

The city of Frankfurt, 710,000 inhabitants, represents today a business and financial centre, transportation and logistics hub, research and technology location in a national and international context. As a result, the city is experiencing a constant and for European settings considerable population growth. Such increase implicates a high demand for housing, infrastructure and open space development. Urban extensions would be needed, but within the municipal boundary there are no development areas left. Further growth demands will have to be met within the already built-up city. On the one hand, inner city development, re-use of brownfields and densification can reduce the consumption of green fields and suburbanization. On the other hand, it involves an increasing conflict between the demand for new developments and the preservation of open and green spaces and quality of life within the city, leading to risks for climate and environment. Suitable policies and adaptive strategies have to be prepared to cope with these changes and their impact. In Frankfurt, these include: The

Energy and Climate Protection Concept, containing over 50 actions and guidelines, with a particular focus on the construction of "passive houses"; the Master Plan 100% Climate Protection, with milestones that focus on how the city can achieve 100% renewable energy supply by 2050; the Frankfurt Green City municipal platform, which coordinates information on city policies and programmes regarding urban and environmental development; and the Integrated Urban Development Concept Frankfurt 2030 as a vision for environment, housing, economy, mobility and social coherence until that year. Recently, Frankfurt has been ranked as "the most sustainable city" worldwide by the ARCADIS Sustainable Cities Index. In both the environmental and the economic aspects, Frankfurt was evaluated first, whereas with regards to social issues, it was rated only 9th. This result makes clear that successful urban management in the environment and economy fields alone cannot solve (and may eventually even increase) social disparities, making this a major issue in all future integrated urban development efforts (Peterek, 2016).

Figure 2.3

Map of green and open spaces in Frankfurt



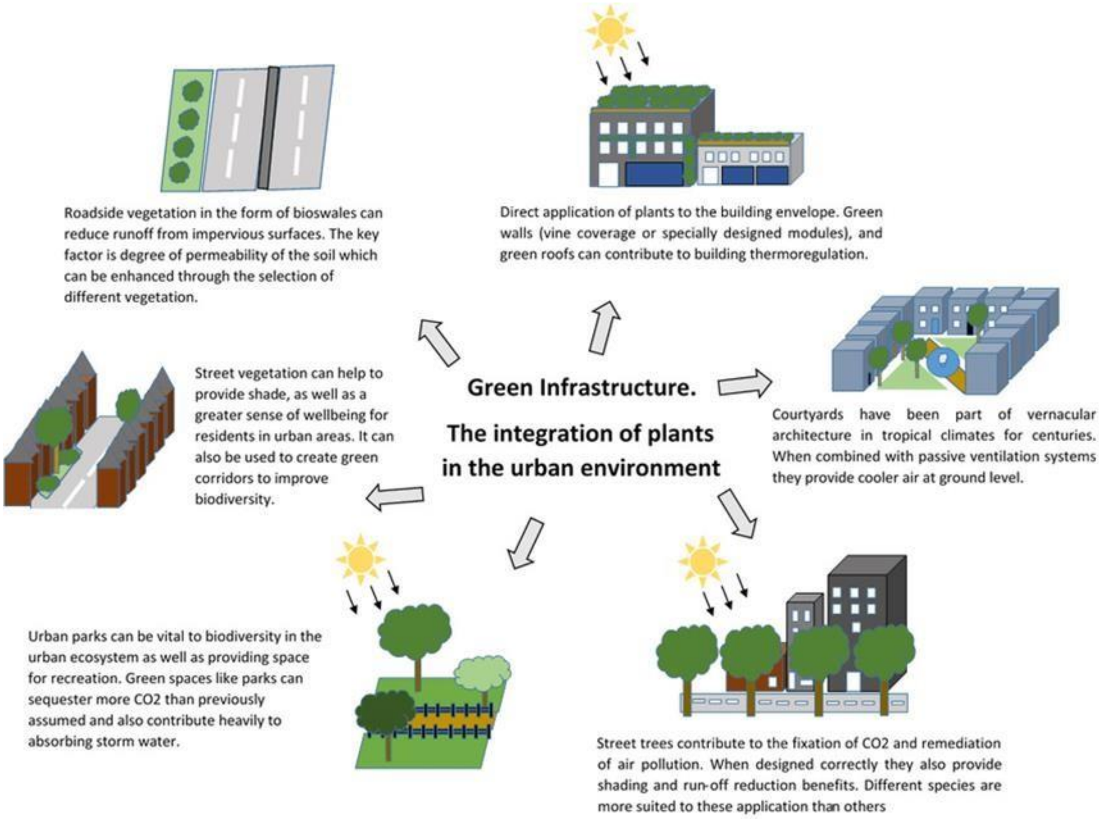
(Peterek, 2016).

2.1.1 Green Infrastructure

In response to interdependent challenges, city planners are increasingly adopting "green infrastructure" (GI) (Grabowski et al., 2022). The health benefits of green space are well known, but the health effects of green infrastructure less so. Green infrastructure goes well beyond the presence of green space and refers more to a strategically planned network of natural and seminatural areas, with other environmental features designed and managed to deliver a wide range of ecosystem services and possibly to improve human health (Nieuwenhuijsen, 2021).

Figure 2.4

Examples of urban green infrastructure and their potential contributions to thehealth and wellbeing of urban dwellers



(Wootton-Beard, 2016).

Green infrastructure benefits generally can be divided into five categories of environmental protection: (1) Land-value, (2) Quality of life, (3) Public health, (4) Hazard mitigation, and (5) Regulatory compliance. Examples of "green" infrastructure and technological practices include green, blue, and white roofs; hard and soft permeable surfaces; green alleys and streets; urban forestry; green open spaces such as parks and wetlands; and adapting buildings to better cope with floods and coastal storm surges (Foster, 2011).

Studied to what extent Portland's green infrastructure initiative reduced neighborhood violence by increasing the availability of new trees to residents of underserved communities as a modality for green infrastructure intervention. They determined whether an increase in new street trees resulted in reduced violent crime counts in the years following the planting of the trees. Results indicated that there was a strong negative correlation between the number of trees planted and violent crimes in the years following the planting of trees, net of neighborhood covariates. This effect was especially pronounced in neighborhoods with lower median household income. These findings suggest that the inclusion of new street trees in underserved neighborhoods may be one solution to the endemic of violence in such neighborhoods (Burley, 2018).

2.2 Urban Ecology

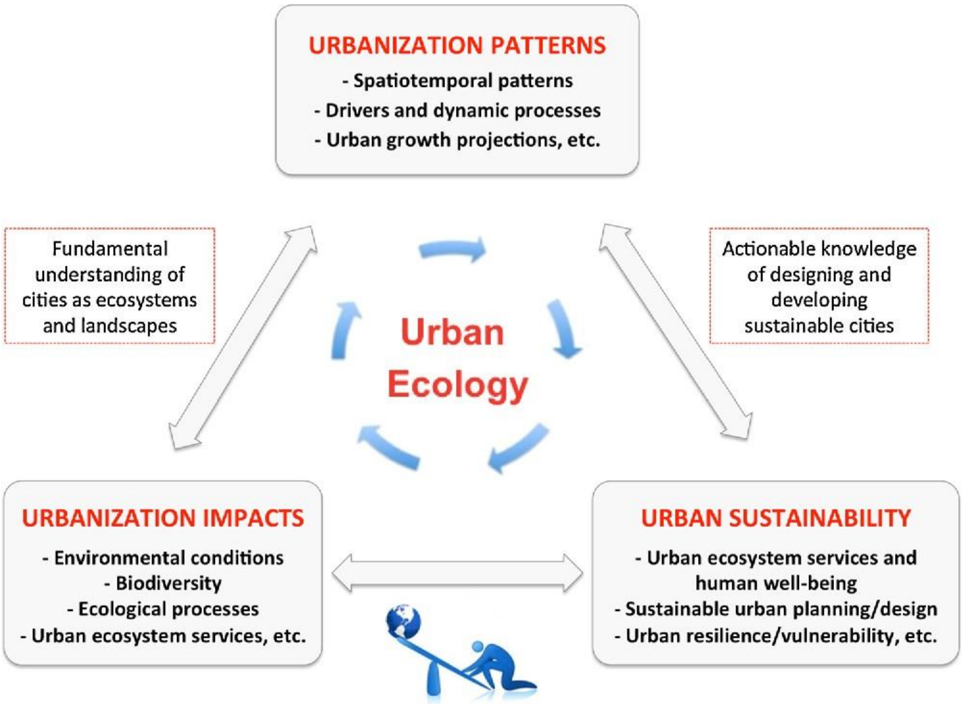
The recent increase in bio-ecologists' interest in urban areas may be due to a number of factors, such as growing environmental concerns about the effects of urbanization, the emergence of ecological viewpoints that emphasize non-equilibrium and patch dynamics, and the pervasive influences of the ongoing sustainability movement. (Wu, 2014).

Urban regions are home to a variety of natural habitats, including semi-natural habitats, parks, and other biotopes that have been heavily modified by humans and their associated species assemblages. In order to preserve this urban biodiversity for the benefit of the locals and for its own sake in the face of rising population and expanding cities, ecological knowledge needs to be more effectively incorporated into urban planning. Understanding ecological patterns and processes in urban environments is required to accomplish this goal. Identification of the types of nature that exist in cities is the first step in the necessary urban ecological research. Second, knowledge about ecological processes important in urban nature is required. Although ecological processes in cities are the same as in rural areas, some of them, such as invasion by alien species, are more prevalent in urban than in rural conditions. Finally, management plans protecting the diversity of urban nature should be developed based on ecological understanding. Protection of urban nature, such as that found in urban national parks, should also be a part of these protocols. Finally, multidisciplinary research including the natural and social sciences is essential for a holistic approach to incorporating ecology into the process of urban planning because ecology alone cannot give the complex knowledge regarding human influence on urban ecosystems (Niemelä, 1999).

A symbol of urban ecological or green civilization, an ecological corridor serves both ecological and cultural purposes. Because of this, it has emerged as a hot topic in the fields of landscape ecology, urban ecology, and ecological planning. Building urban ecological corridors is highly difficult since there is a clear conflict between regional ecological conservation and economic growth, as well as between the rising ecological demands of urban people and the degradation of natural ecosystems. On the other hand, with contemporary urbanization and ecological civilization development, the standards and requirements for the construction of urban ecologicalcorridors are set higher and higher. Constructing an urban ecological corridor is therefore particularly important, and must adopt a spatial approach that balances the relationship between ecological protection and economic development (Peng et al., 2017).

Figure 2.5

A triadic conceptualization of contemporary urban ecology, showing that the spatiotemporal patterns, environmental and socioeconomic impacts, and sustainability of urbanization interact with each other in the study of cities, making urban ecology a truly interdisciplinary and transdisciplinary science that integrates research with practice



(Wu, 2014).

2.3 Urban Green Spaces

The relationship between exposure to natural green space and human health has been the subject of numerous evaluations of empirical studies. These reviews have covered a range of subjects, such as violence, mental illness, and children. Although more than half of the world's population already lives in urban regions and that number is projected to rise to two-thirds by 2050, very few of these assessments have concentrated on studies that expressly relate to urban green space as opposed to nature in any form (Kondo et al, 2018).

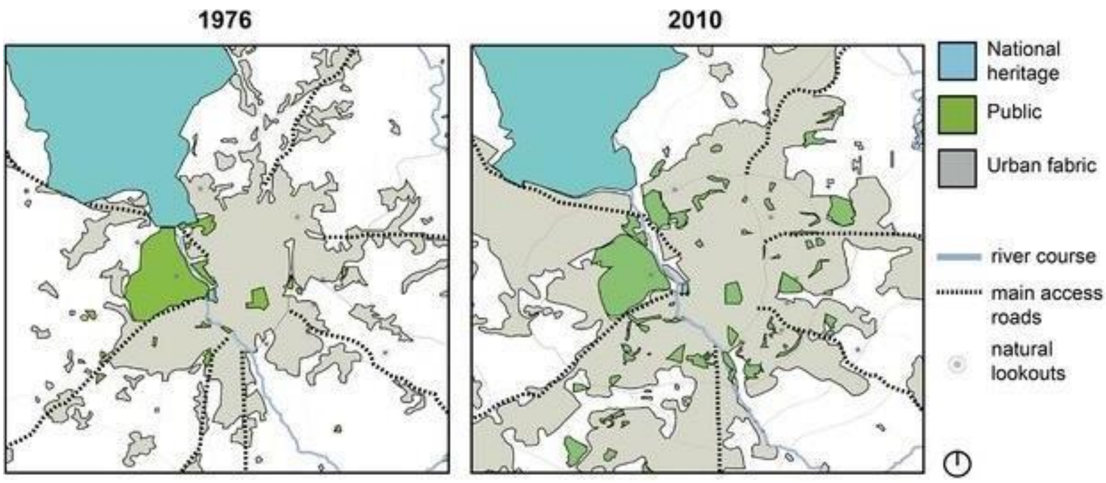
Through their alleged effects on physical exercise, green areas have been connected to health and psychological advantages. 7 Physical activity has been shown to have a variety of positive health consequences, including reductions in the risk of depression, osteoporosis, cardiovascular disease, and injuries caused by falls. 8–15 Also, it enhances mental performance, mental health, and well-being16–22 and might have long-term psychological advantages. 23 There have also been reported advantages for longevity 24. Although there is no doubt that urbanization has a negative influence on health, it is unclear if parks and other green areas, which are supposedly good for your health, actually have those benefits. Urban development projects are expensive. Therefore, it is crucial that decisions on urban design and planning are supported by strong evidence (Lee, 2011).

In a study on urban green spaces, the planning processes of Tampere in Finland and Stuttgart in Germany were compared. In addition, the prevailing trends of cities and the participation of residents were analyzed. The results showed that landscape and green building planning are mandatory parts of land use planning processes in Stuttgart, required by law, and can be implemented nationwide in Germany. A particular distinction was the balancing method and habitat network planning, which affected the planning process in Stuttgart on many levels and defined each green space as part of a green structure (Suomalainen, 2009).

A study that was carried out in Madrid, a major city in southwest Spain, examined the parks. By applying multifunctionality criteria to the planning, design, implementation, maintenance, and durability phases, evaluation is done on a range ofscales, from the local to the regional. It is feasible to appreciate the necessity for networks to be established to integrate urban periphery into the metropolis thanks to the study's findings, which show a high environmental and social service delivery value. According to the findings from the researches carried out, it was concluded that Madrid provides ideal conditions for the implementation of a supra-municipal strategy for green infrastructures, exhibiting peripheries starting from large forest parks, connecting them with the urban green network, in the southwest of Madrid. The Móstoles Green Network and the Bosquesur are two strategic projects that together with the forest parks form a working framework within which the Trans- municipal Strategy for Open Spaces in Southwest Madrid can be designed (Verdú et al., 2021).

Figure 2.6

Historical green spaces and new developments in the city of Madrid 20th-21th Centuries



(Rodríguez Romero et al., 2018).

2.4 Overview Green Roof Systems

More and more people around the world are moving from rural to urban places to live. Urban areas around the world are the habitat type that are expanding the fastest (Faeth et al., 2011). Climate change has increased environmental risks, most notably by lengthening and intensifying weather extremes including heat waves, floods, and droughts, all of which have an influence on biodiversity and ecosystem services (Morss et al., 2011). To solve the complicated issues associated to resource depletion, population growth, and a fast-declining standard of living for people, new attitudes are needed. One of the main worries from these global challenges has started to be the sustainability issue. Global sustainability was first utilised in the IUCN's World Conservation Strategy in 1890. According to the FAO definition, sustainability is the management and conservation of natural resources as well as the direction of institutional and technical change to ensure the continual satisfaction of human needs for both the present and future generations. The expansion of impermeable man-made structures and coverings is one of the main issues with growing urbanisation. This has caused a lot of environmental and infrastructure problems in numerous towns and cities (Berndtsson, 2010).

Cities face an increasingly serious environmental dilemma as a result of urbanisation and climate change. Environmental risks are made worse by climate change, particularly because there is a higher probability of extreme weather. Urbanization not only contributes to environmental issues in cities, but it also forces planners and designers to come up with solutions in ever-shrinking areas (Knaus and Haase, 2020). Recent years' rising energy demand and heavy reliance on fossil fuels have resulted in numerous environmental issues. The most notable repercussion is climate change. Energy conservation is one of the issues that has compelled humanity to investigate solutions, and it has drawn a lot of attention recently. Buildings account for about one-third of total energy consumption and a significant portion of CO_2 emissions, in addition to other energy-demanding sectors like transportation and industry. Residential and commercial buildings in the United States accounted for over 40% of the country's total energy usage in 2012 (Movahed et al., 2020).

Even if the construction industry is concentrating on the sustainability of environmentally friendly building methods, several industrialised nations in Europe and the United States have adopted the green-roof concept as the key idea in sustainable development. Green-roof sustainability is determined by several development actors, including building owners, government, and industry (Yuliani et al., 2020). Loss of urban green space is correlated with increased urbanisation because new or infill projects frequently destroy parks and natural areas. But the amount of green or vegetated rooftops, a fresh and elevated form of urban green space, is fast expanding in many cities. There are already significant amounts of green roof space in several cities. Stuttgart, for instance, has green roofs covering more than 200 ha, whereas Dusseldorf has 73 ha, Zurich has 87 ha, Tokyo has 55 ha, and Paris has 44 ha (Dromgold et al., 2020).

With the original documentary evidence of the hanging gardens of Semiramis in Syria, roof gardens have a long history. Modern beautiful roof-garden projects are a contemporary equivalent of designs for prestigious worldwide hotels, business hubs, and individual residences. Such green roofs are referred regarded as "intense" green roofs because they have deep soil profiles and a variety of vegetation, which resemble regular ground-level gardens (Oberndorfer et al., 2007). "Green roofs" or "vegetated covers" are significant not just for their aesthetic qualities but also for their potential to reduce energy use (Peri et al., 2012).

Implementing green infrastructure (GI) projects has become one of the most effective ways for both developed and developing nations to revive urban living areas. There are numerous varieties of GI in use. One of the GI techniques, the Green Roof, also known as a living roof, has several benefits in addition to a few drawbacks. Although this has been done for centuries, it has recently drawn increasing attention because of its advantages in terms of the environment, energy, and economy, notably in Australia. By keeping a structure warm in the winter and serving as a shield from the sun's heat in the summer, it lowers the energy required for air conditioning in both seasons. As green roofs are roughly three times as durable as conventional roofs, it lowers (a) the life cycle costs of the roof; (b) building waste, which lowers construction costs; and (c) sound propagation because the thicker roof acts as an insulation medium.

Buildings with green roofs would command greater rent and have increased resident retention due to improved amenities. The following are some environmental advantages: (a) by acting as a medium that can hold the moisture and water content, it reduces the passage of storm water, thereby reducing erosion; (b) it improves the air quality; and (c) it lessens the urban heat island effect, which occurs when urban areas are hotter than rural areas during the summer. The rise of educational and employment opportunities, the provision of space for food production, and the creation of green space for leisure purposes are all social advantages. The green roofs act as sound insulation and shield the roof from extreme temperature changes and wear. By trapping carbon dioxide, they also enable an increase in the quality of the air. There are primarily two types of green roofs. These green roofs are both extensive and intensive (Rasul and Arutla, 2020).

Although the city and the building itself benefit from green rooftops' abiotic elements and living flora, growing conditions on rooftops are far more difficult than those at ground level. The substrate depth of green roofs is constrained, and they frequently experience quite high levels of solar radiation and wind speed. Increased wind speed and sun radiation encourage water evaporation, and limited substrate depth reduces the amount of water that is available at any given time, which contributes to the emergence of drought conditions. Because of these growing conditions, only plants with shallow, non-penetrating root systems and the ability to survive periodic drought should be chosen for extensive green roofs, especially those with substrate depths of less than 15 cm. (Figure 2.7) (Tran et al., 2019).

Figure 2.7

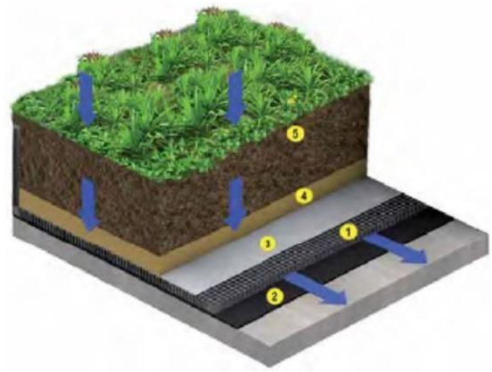
Typical Extensive Green Roof System. (1) Waterproofing Membrane (2) Drainage System (3) Filter Fabric (4) Cellular Confinement Cells (5) Lightweight Growing Medium

(Rasul and Arutla, 2020).

The growing medium is thicker for intensive (more than 300 mm) than for extensive (less than 300 mm) green roofs. Intensive green roofs need a deep soil layer and skilled labour, and higher maintenance than extensive green roofs. The different layers of the green roof are a vegetation layer, substrate layer, water retention layer, filter layer, drainage layer, root barrier layer and protection layer. (Figure 2.8) (Rasul and Arutla, 2020).

Figure 2.8

Typical Intensive Green Roof System. (1) The Drainage System (2) Water Proofing Membrane (3) Filter Fabric (4) Sand and (5) Lightweight Growing Medium



(Rasul and Arutla, 2020).

Although they have been around for a while, green roofs have become much more common recently. 2008 saw a 35% increase in the number of green roof systems in North America. Although these built-in ecosystems offer a variety of benefits, the most extensively researched topics are the reduction of heat fluctuation into buildingsand storm water detention and retention. It is also envisaged that a larger-scale deployment of green roofs will help reduce the urban heat island effect (Lundholm etal., 2010).

Northern Europe was the location of a large portion of the early research into green roof systems (Germany, Switzerland, and Scandinavia). Germany has made the most use of green roof technology in Europe; it is estimated that this sector was worth $77 million in 2008. This equated to 14% of all flat roofs or 13.5 km2 of green roofs. When compared to "intense roof systems," 80 percent are "extensive systems," offering the most affordable choice (Castleton et al., 2010). European green roofs may support abundant numbers of insects, birds, and other species, making them ecologically rich. The discoveries include the presence of butterflies, birds, and invertebrates as well as endangered plant species. For instance, one of the world's oldest green roofs in Zurich, Switzerland, contains 170 plant types, including 9 native rare or endangered orchid species (Dvorak and Volder, 2010).

People can profit from living roofs in more ways than only an aesthetic and psychological sense. Additionally, they benefit human health. Urban agriculture is supported by green roofs, which also serve to reduce noise pollution by absorbing sound waves (Oberndorfer et al., 2007). For the benefits they provide in urban settings, living roofs are becoming increasingly regarded. It is well known that they have a number of advantages, such as lowering building heating and cooling needs, reducing urban heat islands by cooling roofed surfaces, adding aesthetic value, collecting rainwater to prevent runoff and flooding, enhancing air quality by trappingpollutants, cooling photovoltaic panels and possibly increasing their ability to produce electricity, and providing habitat for local wildlife. (Blaustein et al., 2016).

Urban greening is widely acknowledged to improve city livability, with implications for citizen productivity, social interactions, working capacity, and health. It is important to consider the ability of urban vegetation to improve air quality and collect fine dust in order to lessen respiratory illnesses. Green roofs that are accessible could provide areas for physical activity, preventing sedentary lives and associated ailments (e.g., obesity). The physiological benefits of green spaces for public health are also related; according to Wilson, human contact with nature is crucial since human metabolisms require nutrients and oxygen (Rosasco and Perini, 2019).

Green roofs offer passive cooling by limiting the penetration of solar radiation into the spaces below. Numerous studies have been conducted over the last ten years to assess the potential advantages of green roof systems. Such research found that greenroof systems can be advantageous in both the winter and summer (lower heating) (Castleton et al., 2010).

A research by Castleton (2010) evaluated the heat gain of two distinct roof systems in Toronto (Canada), each of which included 75–100 mm of thin growth material. According to his study's findings, a green roof reduces heat intake by between 70 and 90% in the summer and heat loss by between 10 and 30% in the winter. On the other hand, it is well recognised that urban hard surfaces resistant to water can increase storm water runoff and cause more erosion (Lundholm et al., 2010). Studies conducted in Germany revealed that large roof systems and intensive green roofs might both minimise annual runoff by between 28% and 85%. (Berndtsson, 2010).

Results from the US's Chicago, Philadelphia, and Portland have demonstrated that large green roofs can increase rainwater retention by an average of about 75%. (Scholz and Barth, 2001). Media depths and vegetation kinds are the key factors affecting reported results variation (Villarreal and Bengtsson, 2005). Future suggestions for study directions might cover topics like planting styles, enhanced growth media, rooftop gardening, water quality, water runoff, irrigation systems, using grey water, pollution reduction, carbon sequestration, health advantages, etc (Rowe, 2011).

2.4.1 Historical Development of Green Roof Systems

Architecture is defined as the most common way of arranging the physical environment to accommodate human requirements Architecture. This action has evolved with him ever since the existence of man and has reached to our day. As it is known, the architectural adventure that extends from today's steel and glass skyscrapers to wooden and glass skyscrapers formed from the caves where the primitive people live and from the built civilization covers a wide development process from prehistoric times to the present.

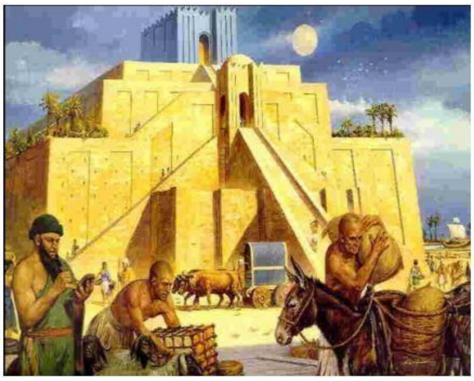
Social variations of all kinds have an impact on this process. Architecture itself can change, which then affects society and has the potential to alter society; alternately, the opposite can occur. Gothic cathedrals came into being as a result of the veneration of scholastic philosophy in the Middle Ages and the strong impact of religion on society. Descartes' rationalist philosophy had an impact on the establishment of modernization, the manufacture of steam engines, and the advancement of their art and architecture in the 17th century, as well as the beginning of positive thinking and technological development. All of these advancements are seen as a turning point that sped up the development of modern architecture, the industrial revolution, and the innovations it brought. Years of the modern movement's global activity correspond to the early years of the Republic of Turkey. The building industry in Turkey at the time was more traditional, with smaller apertures and frequently sloped roofs because of poverty and limitations. However, terrace roofs have been one of the key features of buildings in examples of modern architecture in our nation (Bulut, 2005).

As old wine in a fresh bottle, the history of the green roof may be traced back to antiquity. The origins and steady evolution of the cultural legacy can be interpreted using archaeological findings, historical documents, and modern geographical-ecological evaluations. Numerous studies have revealed that early structures used a variety of organic components. In order to survive, people who live in hostile regions require weatherproof enclosures that are extremely effective. Green roof development and introduction found their birthplace in the resource-poor Arctic region. Since Neolithic times, earth has been utilised extensively to construct homes, making it a versatile and very ubiquitous material that has provided learning opportunities regarding its qualities and uses. Earth daubing was used to seal the crude, weak conical structures, allowing nature's seed rain to create a vegetative layerthat would later spontaneously develop into a green roof predecessor known as a meadow roof. Later development of the house form, which separated the walls and roofs, necessitated inventions to improve weather resistance and durability.Plastering was inferior to cutting mat-like sods from natural meadows with soil connected by thick fibrous roots into transportable strips for roofing. It allowed for quick vegetation development and avoided the bare-earth stage, which is subject to erosion. This was equivalent to moving the sod ecosystem in its entirety from nature to the roof. The invention marked the beginning of the purposeful sod roof. With the use of legacy technology, the components and building techniques of the conventional multi-layered sod roof are described. Research findings are used to identify and explain 18 putative ecological functions of sod roofs in comparison to modern analogues (Jim, 2017).

A survey of the origins of the roof gardens will take us up to 2500 years ago. The first known historical references to man-made gardens are the zigurats in ancient Mesopotamia (civilization between Iraq and Egypt). Zigurats are large stepped pyramid towers made of stone (Figure 2.9). The temple takes on the task. It was also made in stages. There is a vegetation layer on the roofs. These pyramidal bumps are very different from the pyramids in Egypt. These buildings, which are symbolic between the world and paradise, have been planned as a meeting point of people. (Cunningham, 2001).

Figure 2.9

Ur Ziggurat with Roofs Covered with Vegetation in Ancient Mesopotamia



(Spengen, 2010).

As one of the Seven Wonders of the Ancient World, the Hanging Gardens of Babylon (500 BCE), green roofs have a long history. However, green roofs were mostly used as ornamental features and representational features from ancient times to the 18th century, and as a result, they remained largely an imperial luxury (Knaus and Haase, 2020).

The Hanging Gardens of Babylon are the roof garden with the most enviable reputation. One of the few foundational pieces of the Mesopotamian Kingdom is the building (Erkul, 2012). In Figure 2.10, The city walls were supported by terraces that were exceptionally large, stepped, and densely planted, according to the archaeological finds. To prevent moisture from damaging the brick construction, the building's designers installed an insulation system and a semi-mechanical irrigation system. Today, roof gardens (green roofs) with parallel details are designed for high- profile international hotels, business centers and residences. In classical Rome and Pompeii, green roofs were designed as a response to population density in the urban area (Cunningham, 2001).

Figure 2.10

Hanging Gardens of Babylon

(Erkul, 2012).

The concept of the green roof was widely embraced in many locations and civilizations in the early modern period thanks to varied continents. The concept of a living roof on top of a concrete roof was introduced in the middle of the 1880s by new technology; the first model of this roof debuted in the 1867 World Expo in Paris. The model depicts a green roof with drainage and waterproofing features, which is the first design for a sizable green roof. The pioneers of modern architecture(Le Corbusier, Alvar Aalto, and Frank Lloyd) began incorporating green walls and roofs into their designs in the 20th century in an effort to blend the built environment with nature. Their famous designs are a clear sign of this concept (Villa Shodhan, Villa Mairea, and Millard House) (Figure 2.11) (Abass et al., 2020).

Figure 2.11

A) Green Gardens at the Top of Rockefeller Centre in New York, B) Roof Garden at Villa Mairea Designed by Alvar Aalto in Noormarkku, Finland., C) Green Roofs at Monastery of La Tourette Designed by Le Corbusier's in Lyon, France

(Abass et al., 2020).

2.4.2 Green Roof Systems in Europe Countries

Modern improvements in building methods and materials such as the discovery of reinforced concrete brought about a significant increase in the construction industry throughout the 19th century. This allowed for the development of new structural infrastructure for green roofs in Europe. The subsequent rise in popularity of modern green roofs has its roots in Germany, where in the late 19th century a technique was devised to replace the commonly used, highly combustible tar with sand and gravel membranes for fire protection. The wild meadows that finally developed on these rooftops as natural seeds quickly colonised them remained undisturbed for the ensuing decades. These roof systems gained popularity in the early 20th century as essential principles of contemporary architecture because of their function(s) and endurance (Knaus and Haase, 2020).

The Technical Committee of the European Committee for Standardization 350 (CEN TC 350) has created European standards, such as EN 15804 (for construction items) and EN 15978, to evaluate the sustainability of construction activities (for buildings). Currently, these criteria allow for the calculation of seven environmental impact indicators: eutrophication, global warming, ozone depletion, depletion of abiotic resources-elements, and depletion of abiotic resources-fossil fuels. The prospect of including biodiversity as a new environmental effect category in European standards is being discussed by CEN TC 350 (Brachet et al., 2019).

In Europe, there has been approximately 50 years of green roof product development and study. In recent years, green roofs have gained popularity across Europe. A green roof is a vegetated roof or deck intended to provide urban greening for buildings, people, or the environment. Following extensive use of the technology throughout Europe, norms and standards were finally developed, supported by university-led research, field observations, and the creation of products or componentry. The FLL Guidelines, which are published by the ForschungsgesellschaftLandschaftsentwicklungLandschaftsbau [German Landscape Development and Design Research Institute], are arguably the most popular collection of recommendations for green roofs in Europe. The potential for the transfer of German directives, which may be discussed and applied in many geographic and climatic contexts, was a key criterion for the direction. For 25 years, FFL has been developing standards for green roof technology. Green roofs are a tool, even though they do not offer a solution to the country's problems. The general consensus is that this German directive does not conflict with or displace American norms. However, the FFL guidance, which is based on your experience and is built around millions of square feet of green roof, is a really useful tool. The guide covers green roof design, construction, and upkeep (Dvorak and Volder, 2010).

A major contributor to creating more sustainable economies and communities, lowering pollution, and decreasing the consequences of climate change has also been the use of renewable energy (RE) sources and the adoption of energy-efficient (EE) practises. Even with commercially accessible solutions, adopting new, cleaner technologies continues to be a difficult and time-consuming effort for policymakers. These challenges have prompted governments all over the world to adopt various measures, including as legislation or incentives, to boost the adoption rate of RE and EE practises. To encourage the global rate of adoption of RE and EE practises, governments have recently passed a number of legislation and regulations. For instance, the French parliament mandated that all new structures in commercial zones throughout the nation have photovoltaic (PV) panels and green roofs (GR) installed. The majority of new construction projects in San Francisco are required by law to cover between 15% and 30% of their rooftops with PV panels, GRs, or a combination of both. The city of Denver passed a similar law requiring GRs, PV panels, or a combination of the two in any structures over 25,000 square feet. The most recent (and most thorough) rule addressing green technologies has been passed in California as of 2019, and starting in 2020, all new buildings must have PV panels installed (Ramshani et al., 2020). Because it consumes about half of all non- renewable resources utilised globally, the building industry is regarded as the least sustainable sector (Opoku, 2019).

Global energy consumption contributes to environmental pollution, degradation and greenhouse emissions. There are four sectors which are greatest consumer of energy, these are: industrial, building (residential/commercial), transportation and agriculture. (Dvorak and Volder, 2010).

The Netherlands, Hungary, Denmark, and the United Kingdom had all expressed a strong interest in using green roof systems that met international criteria. The building industry in the European Union (EU) is responsible for more than 40% of total energy usage. For both practical and moral grounds, the building sector is currently giving more importance to sustainability issues. Buildings' energy certification in Europe has encouraged advancements in their thermal efficiency. Significant energy savings are possible with improved building designs and operational practises. Consequently, architects may play a significant role in resolving energy usage issues by choosing the appropriate designs, materials, and integrating buildings into other building components. The first stage in lowering energy usage and maintaining comfortable indoor temperatures, according to some sources, is the use of thermal insulation materials (Pargana et al., 2014).

The green roof can, in total, reduce air pollution by 35% to 100%. More so than extensive green roofs, intensive green roofs would aid in reducing negative environmental effects. Therefore, low-rise buildings in Sydney or other climates with a similar amount of coastline land are advised to instal intensive green roofs. The same advantages of switching to raw materials with a lower carbon footprint need to be studied. A crucial consideration when deciding whether to use green roofs is life cycle cost analysis (Rasul and Arutla, 2020).

Green infrastructure, which includes green roof systems, promotes sustainability and offers numerous advantages, including lower energy use, heat reduction, and pollution removal. But little research has been done on the direct impacts of urban green infrastructure on the quality of indoor air (Pyrri, et al., 2020).

Green roofs are being used by architects and designers more frequently to lessen the effects of climate change on the built environment. Extremes in temperature and faster runoff are two examples of these effects. In recent years, there have been more observations of these events. Extreme temperature has a direct impact on public health. determined that the 2003 heatwave was to blame for an additional 70,000 deaths in Europe. Evapotranspiration on green roofs, a relatively low-cost, low-tech design element that may be incorporated into new construction or retrofitted on existing structures, can reduce urban heat islands (Sněhota et al., 2020).

At the end of the 19th century, green roof ideas saw their first significant widespread application in Germany. Apartments for low-paid industrial workers were built, however they made up less than 1% of total buildings. A layer of gravel and sand with the addition of some soil made up the green roof system that was used. As a fire prevention measure, this system was put to the roofs (Köhler, 2006).

In contrast to typical terrestrial landscapes, green roofs present an intriguing scenario for examining how people perceive the symbolism currently connected to traditional nature, such as woods or lakes (Mesimaki et al., 2017). Review the studies on green roofs for evaluations of building energy savings. This study in the UK has demonstrated the enormous possibilities for retrofitting already-existing structures (Castleton et al., 2010).

Figure 2.12

Nine Houses in Switzerland, consisting of 9 residences, built with the idea of integrating the building into the environment as much as possible

(Külekçi, 2017).

In Basel, Switzerland, in 1970, green roof pilot projects were initially seen as an environmentally friendly method to building. Energy savings, well-being, health promotion, rainwater retention, and temperature regulation are the motivations for green roofs. Following the 1995 European Union Year of Nature Conservation, the first Basel green roof campaign (1996–1998) was launched with financial assistance for the building of green roofs. The initial campaign's funding came from a "Energy saving fund" that the Basel municipality utilized to support building energy-saving measures. In Basel, there were about 220,000 m2 of green roofs before the first campaign, and an additional 80,000 m2 were built as a result of the first campaign. Green roofs made up over 290,000 m2 of Basel's flat roofs in 1998 (Kantor, 2015).

Different policy tools are utilised to encourage green roof systems throughout the world as part of climate change plans (i.e. subsidies). Policies must be aware of how different groups, including low-income families, can receive the benefits provided by green roofs because such instruments demand social equality access (Mesimaki et al., 2017). Many green roofs were built after 1980 with the intention of boosting urban greenery. The development of green roofs in Berlin is traced in (Köhler and Keeley, 2005).

In Germany, there was a revolution in urban planning that took place in the early 1980s. Renovations were to be made to apartment structures that date to the early industrial era. Residents preferred to live in the established town centre neighbourhoods rather than the modern multistory centres. Apartments were added to already-existing buildings. Existing structures had additional levels added, so a typical apartment building with four stories got a fifth floor with roof windows and terraces. Because of the pitiful insulation, these new apartments were very cold in thebeginning. Town planners started to rethink the use of new green roof technologies, though, as a result of the influence of urban ecologists. A new building regulation was created that specifies that flats in the city's core should have substantial green roofs. Incentives programmes were also implemented, which reduced installation's additional expenses (Köhler, 2006).

Green roofs are multi-benefit solutions that improve the quality of the urban environment. Green roof research has been started all over the world in the last ten years. It's amazing how simple it is to put green roofs on almost any form of structure and in almost any climate (Köhler and Kaiser, 2019).

The city may seem more appealing the greener it is. Examples from other countries, such as Basel or Stuttgart, demonstrate how green roofs are frequently paired with architectural characteristics to create a landmark that draws (international) notice. If roofs are nearly at ground level or otherwise publicly accessible, and cover a big area, such as parks on parking garages, it makes up for a lack of green on the ground level. Another intriguing side effect for the public area is the acoustic reduction of background or traffic noise (Van der Meulen, 2019).

However, inner-urban green spaces support the preservation of biodiversity and raise quality of life for people. A network of artificially created and (semi-)natural green areas and features is known as urban green infrastructure (UGI). It can provide a variety of ecological services as well as high-quality habitats for biodiversity. Parks, street trees, urban forests, cemeteries, community gardens, green roofs and façades, wetlands, and riverbanks are a few examples of the various components of this green network. The EU biodiversity plan to 2020, the European Commission's report on "Green Infrastructure (GI) Enhancing Europe's Natural Capital," and the TEEB research on "The Economics of Ecosystems and Biodiversity (TEEB)" all place a significant emphasis on the importance of urban green infrastructure. Similar to this, in Germany, the "30-hectare target which intends to seal no more than that area per day up to 2020 according to Germany's National Sustainability Strategy and the enhancement of green spaces in terms of habitat quality are closely related (Knapp et al., 2019).

2.4.3 Green Roof Systems in Countries with a Mediterranean Climate

Even in Mediterranean conditions, green roofs significantly minimize storm water runoff by reducing runoff volume and lengthening concentration times. However, performance levels may be decreased during times of high precipitation. (Fioretti et al., 2010).

In terms of urban water management, green roofs provide a sustainable option to lowering flood risk. Few of these studies have been conducted on full-scale rooftop installations; the majority have been done on pilot scales. These studies examined the hydrologic effectiveness of green roofs and the elements that influence how well they work. Despite the fact that several models have been developed, only few of them have examined how the physical aspects of green roofs impact performance benchmarks. The results of a monitoring analysis of a substantial green roof in the Mediterranean climate zone are discussed in a research at the University of Calabria in Italy from a broader context viewpoint. This was achieved by collecting data from 62 storm events that occurred between October 2015 and September 2016 to analyze the subsurface runoff coefficient, peak flow decrease, peak flow lag-time, and delay to the commencement of runoff at an event scale. These results are consistent with earlier studies and demonstrate the hydraulic performance of this specific green roof in a Mediterranean setting. The average subsurface runoff for the whole dataset was 32.0%, and 50.4% for 35 wet occurrences (mostly larger than 8.0 mm). To understand how the depth of the substrate affected the preservation of the green roof, modeling was done. In order to simulate the characteristics, different values of soil depth (6 cm, 9 cm, 12 cm, and 15 cm) were collected over the course of six months in a Mediterranean environment using the HYDRUS-1D program (PC-Progress s.r.o., Prague, Czech Republic). A streamlined evaporation method was used to test the hydraulic characteristics of the soil. The findings demonstrated that the particular soil substrate was able to reduce runoff volume by 22% to 24% by increasing soil depth (Palermo et al., 2019).

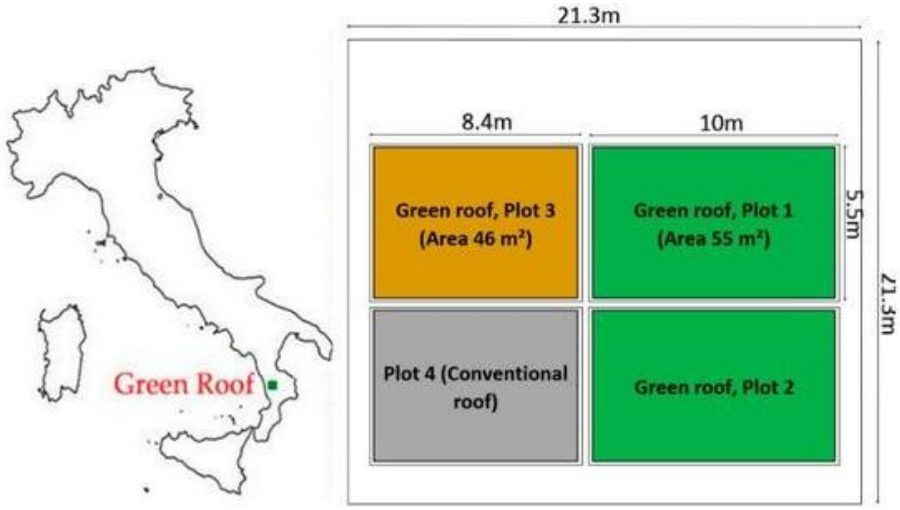
Innovative building technologies are required by building sustainability trends to support energy efficiency and environmentally friendly constructions. Green roofs are intriguing architectural solutions because they can enhance both the ecological and the aesthetics. Long-term study is conducted in a paper to assess and enhance thethermal behavior and sustainability of big green roofs. Also, this work provides experimental data for specific Mediterranean continental climate conditions. The experiment's goal is to evaluate the thermal behavior and energy usage of three identical cubicles that resemble houses in Puigverd de Lleida, Spain, with the exception of the roof. In the reference example, the roof is a standard flat roof with insulation, while in the other two cubicles, an extensive green roof with a 9 cm depth has taken the place of the insulation layer (comparing recycled rubber crumbs and pozzolana as drainage layer materials). Throughout 2012 and a portion of 2013, the electrical energy usage of a heat pump system was measured for each cubicle. When it's warm outside, both extensive green roof cubicles use less energy than the reference one (16.7% and 2.2%, respectively), however when it's cold outside, both extensive green roof systems use more energy (6.1% and 11.1%, respectively) than the reference one (Coma et al., 2016). (Knaus and Haase, 2020). A green roof substrate is made up of both inert (75–80% mass) and organic (20–25%) fractions.It's important to consider components like fertilisers, which can create further challenges (Peri et al., 2012).

In Athens, Greece, measurements of the thermal behavior of two residential buildings outfitted with a green roof system have been made. The particular energy and environmental performance of the planted roofs system has been meticulously assessed and calibrated using experimental data. Both free-floating and thermostatically regulated environments have been simulated. The anticipated energy savings as well as potential enhancements to interior thermal comfort have been evaluated. The heating needs of insulated structures operating in the Mediterranean environment are shown to be only little impacted by green roofs. On the other hand, it has been discovered that the green roof system significantly reduces the cooling demand of buildings with thermostats. An approximate 11% reduction in cooling demand has been computed for the residential structures under consideration. Additionally, it has been shown that during the summer, green roofs help free- floating structures maintain a comfortable temperature. Nearly 0.6°C is the greatest projected reduction in the temperature of the roof surface and inside air. Such a decline helps to lower by 0.1 the building's summertime absolute Predicted Mean Vote Comfort Index values (Sfakianaki et al., 2009).

Measurements made over the course of a year on three different types of green roofs with various layering, thickness, and insulation configurations. The research determined when indoor cooling or heating could be necessary, both with and without green roofs, and it showed how beneficial green roofs are at reducingtemperature swings and roof temperature, which was especially notable in the summer. Finally, it appears that the green roof without an insulation layer would perform better since in the Mediterranean environment, the thermal disparities between green roofs and conventional roofs in summer are much bigger than those inwinter (Maiolo et al., 2020).

Figure 2.13

The Experimental Green Roofs Located at the University of Calabria in a Mediterranean Climate



(Maiolo et al., 2020).

A significant step toward attaining environmental sustainability and the accompanying decrease in carbon emissions is integrated water and energy management. Understanding water and energy variations between structures and their surroundings is a current concern for urban sustainability and comfortable living. One of the suggestions from the European Union Thematic Strategy on the Urban Environment is sustainable construction. Sustainable building practises can improve energy savings and lower daily resource use. Greening technologies (green roofs, vegetated roofs, eco-roofs, or nature roofs) have gained popularity in this sector and can play a significant part in alternative rooftop coverage solutions (Ekşi, 2013).

Urban areas' lack of evaporation surfaces and human-caused combustion processes are to blame for the current warming, for which remedies must be sought. To counteract these effects, politicians and planners are looking for solutions. One study claims to provide a solution for urban building surfaces. Almost half of the land is often covered by buildings in metropolitan areas. Building greening may be useful in this situation. Green roofs could be utilised as an alternative to hard roofs made of tiles or gravel and actively contribute to the reduction of these heat islands (Köhler and Kaiser, 2019).

The high temperatures in cities relative to nearby suburban and rural areas are caused by a phenomenon known as a "heat island," which is brought on by heavy human urban activity. The result is a decline in the residents' comfort levels. Several climate change models predict increases in the summertime maximumtemperatures of 1.5 to 6 °C for the Spanish city of Seville. According to this study, which was carried out in Spain, green roofs can supplement urban green spaces and help to mitigate the detrimental effects of rising maximum temperatures brought on by climate change. The normalised difference vegetation index, which is based on data from the Landsat 7 ETM+ and Sentinel-2 satellites, has been used to confirm theinverse relationship between land surface temperature and the quantity of vegetation. In the worst-case scenario, Seville should adopt a 740-ha green roof surface, which would entail covering 40.6% of the city's existing structures. According to the most optimistic scenario, 207 hectares (11.3% of the roofs) of green roof surface will be needed (Herrera Gomez et al., 2017). (Figure 2.14).

Figure 2.14

Green Roof in Loredo, Spain

(https://images.app.goo.gl/qYZgySyCmkGNngFHA).

Research on the thermal characteristics of a typical big green roof system was conducted by Istanbul University in Istanbul. A bituminous membrane roof's thermal characteristic was compared to those of the green roof (reference roof). The results of this study supported the idea that a typical large green roof with a medium 50 mm thickness offered thermal protection from extremely high temperatures. The system of green roofs decreased the effects of high temperatures by 79%. These findings demonstrate that green roofs are a viable choice for climates like those in İstanbul, Turkey (Eksi and Uzun, 2013).

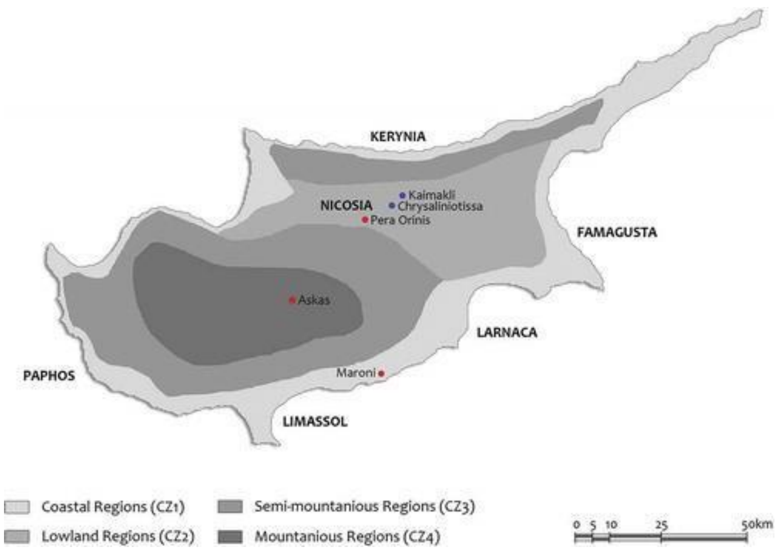
2.4.4 Green Roof Systems in Cyprus

If Cyprus is seen on the globe, it is the third largest island in the Mediterranean after Sicily and Sardinia. It lies between latitudes 30.33 and 35.41 and longitudes 32.23 and 34.55. The Republic of Cyprus gained its independence from Britain in 1960. Today, the island has two parts: North – administered by Turks, and South – administered by Greeks since 1974. North Cyprus covers an area of 3,355 square kilometres. The neighbours of North Cyprus are Turkey, 65 km to the north, Syria, 100 km to the east and Egypt, 420 km to the south (Nadiri and Hussain, 2005). Summers are dry and hot, and winters are warm and rainy, as in many other Mediterranean countries. During the summer months (July–August) the temperature ranges between 37 and 401C and there are 12 h of sunlight per day. During the winter months (January–February), temperatures range from 9 to 121C. The average precipitation is 397.6 mm/y, and average sunlight hours are 5 h/day.2.2 (Işık and Tülbentçi, 2008). Cyprus can be divided into four different climatic regions; namely, coastal (CZ1), lowland (CZ2), semi-mountainous (CZ3) and mountainous regions (CZ4) (Figure 2.15).

A key feature of the Cypriot climate is the high variation between day and night. The prevalent winds blow mainly southwest and east in the winter, and west and north in the summer (Philokyprou and Michael, 2020).

Figure 2.15

Map of Cyprus Showing the Three Rural (Marked Red) and Two Urban Settlements (Marked Blue) Under Study Located in Different Geomorphological and Climatic Regions



(Philokyprou and Michael, 2020).

Over the past few years, the building sector has received a lot of attention due to the urgency of global climate change. Today, the building industry is in charge of emitting between 23 and 40 percent of all greenhouse gases in the world. This is conceivable given the wide range of environmentally harmful materials employed by the modern construction industry and the obvious contemporary design aesthetic. Traditional construction materials, in contrast to modern structures, have been shown to be environmentally friendly and to leave almost no carbon footprints. However, the modernist construction industry has denigrated traditional building techniques as primitive because of its unquenchable desire for autonomy. Additionally, the absence of industrialization's objects has been said to conform to poverty (Obafemi and Kurt, 2016).

Due to the climate of Cyprus, this study will focus on green roofs that are environmentally beneficial. The entire island of Northern Cyprus is covered by the studies, according to the research. The entire island's districts have been considered. The topic has to do with green roofs. The emergence of all the observable green roofs in Northern Cyprus has been looked at. The temperature, topography, and history of the Mediterranean region are strongly correlated with cultural, economic, and ecological sustainability, according to evidence gathered in Northern Cyprus. Priorities for sustainability in building design include maximising longevity and durability, conserving water, making the building healthy, raising community awareness, reducing material consumption, protecting the site, and choosing low impact materials. Therefore, the housing sector also has an impact on the environment in the following ways: using land for housing, using natural resources for construction materials, consuming energy to produce those materials, consuming energy during construction, and requiring energy for heating and cooling throughouta building's life. (Isik and Tulbentci, 2008).

The reasons for the existence of green roofs in Northern Cyprus were investigated. First, the applied green roofs were identified. 5 designs were found. 2 of them are in the hotel. One belongs to a semi-state-semi-private university. The remaining two were implemented in private property. The Merit Royal Hotel in Kyrenia, one of the largest hotels on the island, has 2 green roofs. These; extensive and intensive green roofs. It was learned that these landscaping practices were built in response to intensive construction depending on the negotiations with the construction group of the hotel. In addition, it has been determined that the hotel is made to meet the green space usage needs of the users (Figure 2.16).

The other green roof design belongs to the Merit Hotel in Nicosia. The reason for this is to increase the visual effect with plant groups. It was learned that one of the other roofs belonging to private property was built because the landlords did not have gardens. The other green roof was built by the owner agricultural engineer. The landlord is aware of the benefits of the green roofs and stated that the design that provides the insulation effect is made for trial purposes. Lastly, the reason for the construction of the green roof design at Girne American University in Kyrenia was not found because the authorized person could not be reached.

Figure 2.16

Green Roof at Kyrenia Merit Royal Hotel Cyprus

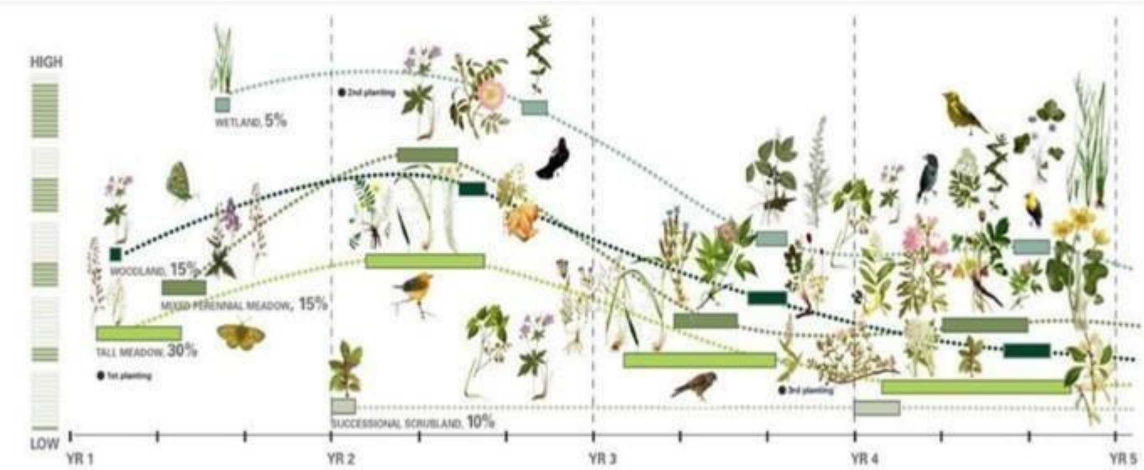
(Yıldırım, 2015).

2.4.5 Biodiversity: New Ecosystems to Support Species Diversity

In reality, urban environments represent a special kind of ecosystem that can maintain significant pools of biodiversity, including rare and endangered nativespecies. Urban areas are frequently considered as damaged places with little ecological significance. The design and management of urban green spaces have a significant impact on their value for biodiversity conservation (Gonsalves et al., 2022). The fragmentation and complexity of the urban landscape brought on by changes in land use is one of the primary challenges to urban biodiversity. For instance, it has been demonstrated that an increase in impervious surfaces reduces thediversity of urban plants, that a decline in natural habitats significantly reduces the available habitat for species, and that the fragmentation of the landscape results in the homogenization of some communal activities. In addition, it has been demonstrated that fragmentation of the urban landscape reduces the variety of species within the entire system by impeding gene flow across populations. Therefore, under the influence of urbanization, urban biodiversity is confronted by multiple challenges (Wang, 2022).

Figure 2.17

The Emergence of a Wild and Biodiverse Ecological System over the Time



(Salih et al., 2021).

Increasing urbanization of many regions of the world has resulted in the decline of suitable habitat for wild flora and fauna (Fioretti et al., 2010). Green roofs can provide several environmental benefits in urban cities and can also create habitat for living organisms thus help to enhance biodiversity (Wooster et al., 2022). Animal- aided design can boost the richness of animals in artificial wetlands instead of just considering engineering requirements. For instance, a number of species find man-made wetlands more appealing due to their diversified vegetation, barrier-free shorelines, and heterogeneous surroundings (Knapp et al., 2019).

Green roofs are currently considered as a desirable sustainable design element by several green building assessment methodologies, but the approach used to evaluate the biodiversity aspect in these approaches is neither obvious or efficient. The goal of a study on this subject is to find out how green roofs might improve biodiversity in urban settings and to create a useful system for evaluating green roofs. Research studies and governmental regulations about biodiversity and green roofs are being developed in some urban areas of Europe and North America. A useful amount of information was gathered after evaluating the standards for green roofs and green building assessments in order to create a methodical way to evaluate the impacts on biodiversity. The method comprises of six major factors: (a) species diversity and richness, (b) substrate type and depth, (c) plant species selection, (d) connectivity to natural environment, (e) green roof ratio and (f) ecologically responsible development (Hui and Chan, 2011). Many bug species can find refuge on green roofs, and shorebirds and wading birds can use them as a place to nest. As a result of avian and wind distribution, it has also been noted that plant species that were not initially planted have established themselves on green roofs. Several studies have attempted to estimate the biodiversity benefits of urban green roofs in comparison to conventional roofs because there is a lot of observational evidence of biodiversity on top of green roofs (Wooster et al., 2022).

With information scattered across unpublished reports and local databases, investigations over the past 20 years on more than 100 different green roofs in six cities throughout Switzerland have produced an unprecedented dataset on ground beetles. This article represents the first synthesis of the state of knowledge of ground beetle communities from green roofs in Switzerland. 91 species of ground beetles were described, totaling 19,428 individuals, and trends of species distribution and composition on green roofs and in cities were highlighted. The majority of the roofs are home to populations of ground beetles that are dominated by five widely distributed migratory species with a variety of ecological needs. In addition, nine species (10% of all species collected) that are conservation concerns in Switzerland and Central Europe as well as numerous stenotopic species (from grasslands and pioneer vegetation). This shows that green roofs can provide optimal ecological conditions of high conservation importance in addition to maintaining local populations of common species. In order to boost the ecological value of green roofs for species with the widest range of ecological needs, it was suggested that both their design (vegetation composition and configuration, soil depth, and substrate composition), as well as their integration into urban planning, be improved (Pétremand et al., 2018).

2.5 Effect of Green Roofs on Indoor Temperatures

Building construction always progresses in tandem with economic growth. There will be 43 megacities with a population of more than 10 million by 2030, accordingto estimates. Nearly 40% of the world's total energy consumption is consumed by the building industry, which is directly linked to a 3% rise in greenhouse gas emissions between 2000 and 2010 and an increase in energy consumption brought on by human activity. Due to the vulnerability of the living environment, it will be crucial to develop mitigation strategies across all commercial and public sectors and nations, particularly in those that heavily rely on the usage of fossil fuels. As building roof surfaces covers of 20–25% of the urban areas, they can effectively be used to lessen the surface and air temperature of the urban areas. A green roof is a horizontal living system, which helps to mitigate several environmental problems (Abass et al., 2020).

2.5.1 Examples from USA

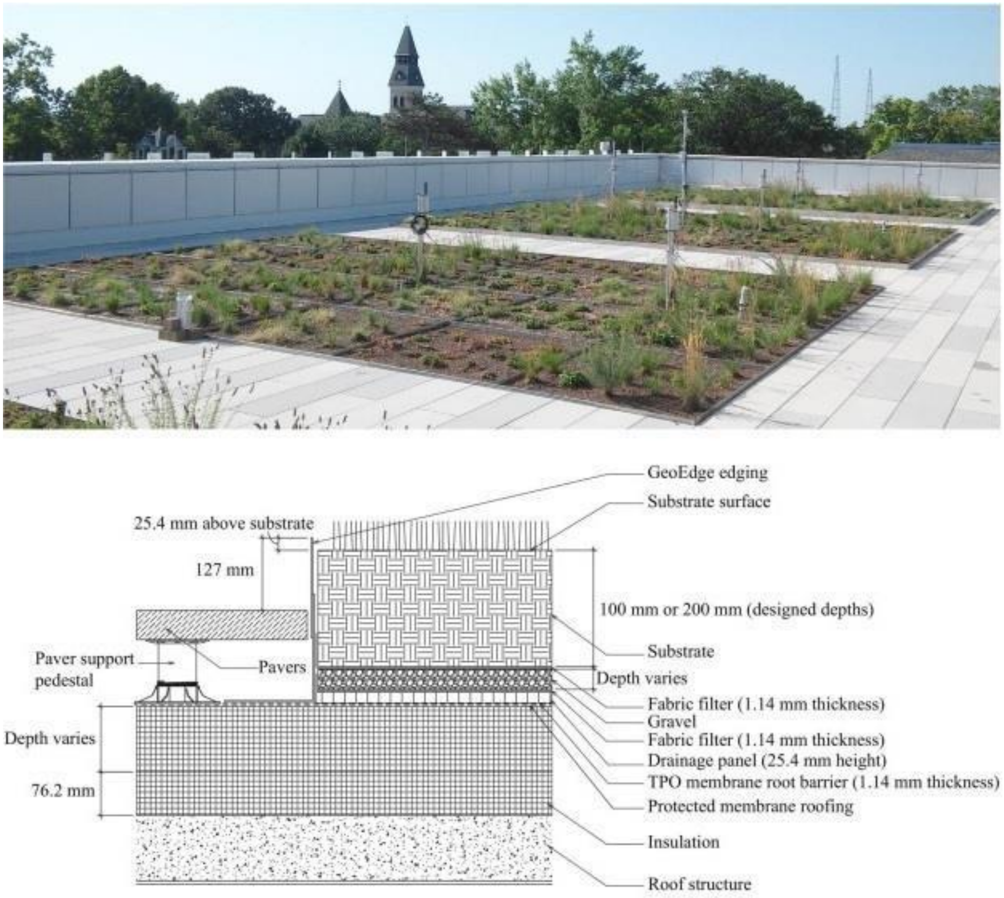
Over the past twenty years, green roof technology, which has its roots in Europe, has evolved in North America. Many prairie plant ecosystems resemble the challenging and demanding growing conditions of green roofs. Numerous studies have shownthat green roofs lower the temperature inside buildings (Barnhart et al., 2021).

Given that evapotranspiration, shade, thermal insulation, and thermal mass are all involved, the method by which a green roof reduces temperature is extremely complicated. In accordance with earlier research, green roofs demonstrated a range of thermal and energy capabilities in relation to diverse climatic conditions, building attributes, and water availability. Consequently, the effect of green roofs on building energy usage would likewise vary (He et al., 2020).

For instance, little research has been done on prairie plant communities and how they fare on green roofs in the Mid-Continent Region of the United States, which has a hot summer environment. In the Flint Hills Ecoregion, which has some of the most widespread covering of intact tallgrass prairie in North America, we analysed the first-year growth (June to October 2018) on an experimental green roof in order to investigate more sustainable, diversified green roof ecosystems (Figure 2.18). Two substrates, a commercial substrate (rooflite® extensive 800) and a regionally mixed substrate (Kansas BuildEx), were placed at two depths: 6.0-13.0 cm (referred to as the "shallow depth") and 16.5-25.5 cm (referred to as the "deep depth"), where a mixture of plants (four native prairie grasses and two sedums) were grown. We examined plant height, coverage, stomatal resistance, survival, visual appearance, and volumetric substrate water content. Each experimental plot received equal amounts of additional irrigation during the growing season. The regionally mixed substrate was shown to have a stronger impact on plant height at shallow depths and on coverage at deeper depths. However, the commercial substrate often had a larger volumetric water content. Visual appeal and leaf stomatal resistance were unaffected by substrate type. At low soil moisture levels, the relationship between substrate moisture and leaf stomatal resistance was inverse. While *Sedum reflexum* had limited survival and coverage, all prairie species survived. In a community of green roofs, *Bouteloua curtipendula*, *Bouteloua gracilis*, *Schizachyrium scoparium*, and *Sedum rupestre* did well. *Bouteloua dactyloides* grew very well, but may be too aggressive when planted with sedums. The findings of this study will be of practical value for the design of mixed-species green roof systems in similar mid-continental regions with hot summers (Liu et al., 2019).

Figure 2.18

Experimental Green Roof on the Roof of Seaton Hall at Kansas State University in Manhattan, Kansas, USA



(Liu et al., 2019).

Building envelope design, human behaviour, and regional temperature conditions are some of the variables that influence how cool roofs affect the internal thermal environment and energy consumption of structures (Piselli et al., 2017).

Conducted an experimental investigation in New York, USA, and found that compared to a white roof, a green roof resulted in energy savings of about 40–100%. It is obvious that the thermal advantage of green roofs over cool roofs varies depending on the climate. As a result, extrapolating the thermal or energy performance of both roofs from one situation to another is challenging. A local field experimental investigation is needed in order to produce an appropriate judgement and assessment (He et al., 2020).

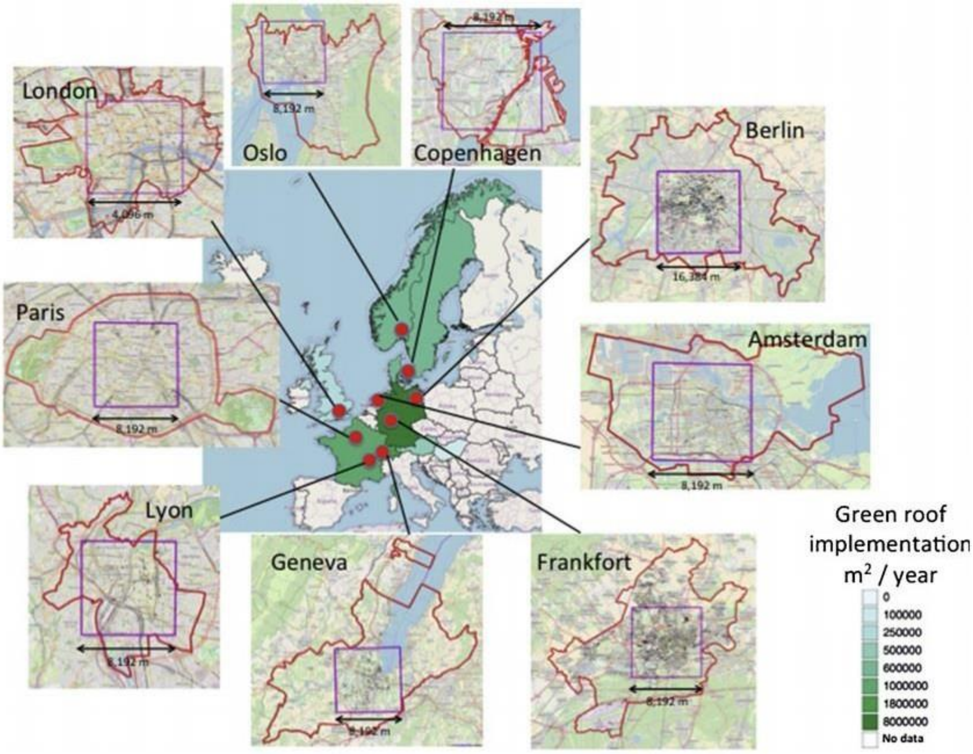
2.5.2 Examples from Europe

As one of the potential assets to help with the re-naturing of cities, green roofs (GR) are currently being increasingly used in urban settings. Green roofs are regarded as Nature-Based Solutions (NBS) or Blue Green Solutions (BGS), which are multipurpose tools that can improve a variety of ecosystem functions (Versini et al., 2020). To meet the challenge of sustainable urbanisation promoted by the present European Research and Innovation agenda, green infrastructure is essential, especially green roofs. In the recent decades, a number of documents were published in Europe to regulate the planning, building, and maintenance of roof greening. Due to their thoroughness and established building- and landscaping heritage, the real German rules in particular have been widely used as a reference framework for greenroof design and regulation worldwide (Catalano et al., 2018). At the moment, Stuttgart and Berlin in Germany, those cities have the highest percentages of rooftop vegetation. Green roof coverage rates range from 3 to 8%, however just 1% of all buildings have vertical green systems, often known as living walls or green facades. However, up to 50% of all structures have the ability to green their roofs (Köhler andKaiser, 2021).

In Figure 2.19, annual green roof implementation given with prioritized nations included Germany, France, Switzerland, the United Kingdom, Holland, Scandinavia, Austria, and Belgium. The availability of such spatial information, i.e., the precise site where green roofs are implemented, was then inquired about from the national green roof federations and many cities. Paris and Lyon (France), Amsterdam (Netherlands), Central Activities Zone of London (UK), Berlin and Frankfurt (Germany), Geneva (Switzerland), Copenhagen (Denmark), and Oslo (Norway). Most of these cities have launched some incentive policies to promote the implementation of green roofs (Versini et al., 2020).

Figure 2.19

Annual Green Roof Implementation in European Countries Estimated from the European Federation of Green Roofs and Walls (EFB) Database. For the Studied European Cities, Red Polygons Represent Cities Contours Where Green Roofs Inventories were Available and Purple Squares the Areas Over which Fractal Dimension Computed



(Versini et al., 2020).

According to a survey and experiment conducted in Singapore and Greece, using a green roof effectively lowered the interior temperature and reduced the space's cooling burden by 17–79%. However, when the doors and windows were shut and there was no air conditioning, the inside temperature of green roofs was greater than that of conventional roofs. Additionally, a significant portion of the ongoing studies on green roofs focus on the consumption of interior energy. A summertime experiment by showed that the use of green roofs as thermal mass in conjunction with nighttime ventilation is advantageous to the thermal environment inside.

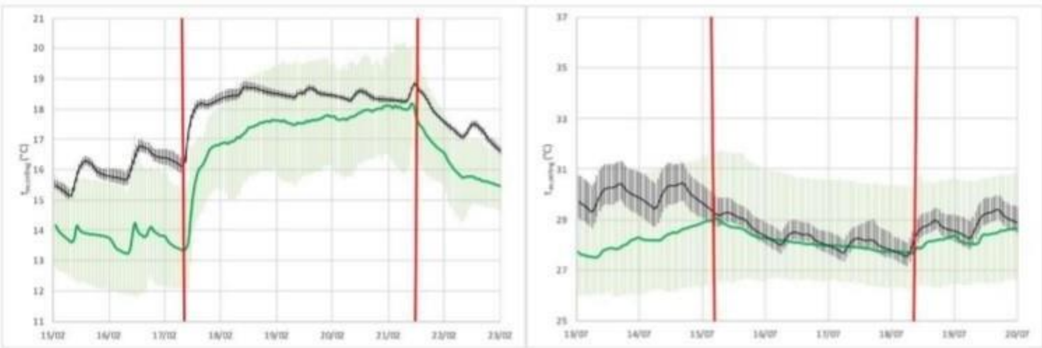
Clearly, ventilation and green roofs are the best ways to enhance indoor thermal comfort and use less energy, and when they work together, the potential for energy savings is increased (Ran and Tang 2017). The majority of studies on green roofs and vertical greenery systems have focused on thermal issues, such as temperature,energy, and thermal physical qualities. The foundation of almost all related research was experimental, simulation, or modelling studies. Numerous thermal environmental factors both inside and outside, as well as the energy performance, were looked into and analysed. The outdoor air temperature and relative humidity, solar radiation intensity, the external and internal surface temperatures of walls, the indoor air temperature, and in particular the outdoor air temperature and external surface temperature of walls are some of the parameters that are frequently studied. In addition, the energy consumption and heat flux variables are often the focus of the researchers because of its importance in the reduction of greenhouse gas emissions (Hao et al., 2020).

The construction sector is significant in the effort to improve energy efficiency in human activities, which would lead to a more sustainable use of resources, as it accounts for roughly 40% of both energy consumption and air pollution emissions. Techniques aiming at enhancing the energy performance of building envelopes are crucial for this purpose. Among them, green roofs are growing in popularity as a result of their potential to lower the (electric) energy requirements for (summer) climatization of buildings, therefore also favorably improving the occupants' levels of indoor comfort. It is obvious that trustworthy techniques for modelling these envelope components are required, and this necessitates the availability of sufficient field data. This paper demonstrates the effects of this technology on indoor comfort and energy consumption, as well as on the reduction of direct and indirect CO_2 emissions related to the climatization of the building, starting with the findings of a case study designed to estimate how the adoption of green roofs on a Sicilian building could favourably affect its energy performance. In particular, the surface temperatures of various rooms' ceilings that were under six different kinds of green roofs were measured (Figure 2.20).

The collected information was then fed into one of the most popular simulation models, EnergyPlus, to assess the indoor comfort levels and potential energy demand reductions for the analysed building. These field analyses revealed that, despite some discomfort circumstances appearing to worsen during transitional periods, green roofs help to reduce indoor air temperatures, improving comfort conditions, especially in summer (Cirrincione et al., 2020).

Figure 2.20

Comparison between Scenario #1 (green lines) and Scenario #2 (black lines) for Winter (Left) and Summer (Right) Conditions



(Cirrincione et al., 2020).

2.5.3 Examples from Mediterranean

According to an experimental study that monitored three summers in a row on a large green roof in a climate zone along the Mediterranean Sea, dense vegetation enables a 60% reduction in the heat gain that enters the roof when compared to a roofwith no vegetation. Since the summertime energy loss for dense vegetation was roughly 9% more than the summertime energy gain, the passive cooling method was shown to be beneficial. The energy consumption of wide green roofs (rubber crumbs and pozzolana) compared to a typical gravel roof in Puigverd de Lleida, Spain, was evaluated for house-like cubicles with just the roof construction system different. According to the trials, the rubber crumbs and pozzolana cubicles' green roof cubicles were able to cut electrical energy by 21.8% and 1.6%, respectively, during the course of one week in July. However, the same cubicles used 6.8% and 11.8% more electrical energy in a week of December than the reference unit, with a somewhat lower percentage in a week of January (Bevilacqua et al., 2020).

Lisbon has a Köppen-Geiger classification of Csa Mediterranean climate, which is characterised by hot and dry summers, mild to cool rainy winters, strong sun radiation, and irregular rainfall patterns. In this case, a parametric analysis with 26 tests on an experimentally validated simulation model was used to assess the energy performance of green roofs in a Mediterranean environment. The case study that was used to conduct this analysis is particularly relevant because the green roof is where the majority of heat fluxes pass. As a result, it made it possible to determine the vital indicators of the green roof's energy efficiency and measure the impact they had on energy requirements and consumption. The most important variables during the heating season were soil depth and vegetation height. A reduction of soil depth decreased the thermal resistance and consequently increased the winter energy needs by up to 140%. A reduction of vegetation height and LAI, in turn, decreased heating energy needs by up to 23% and 18%, respectively, namely due to higher evapotranspiration and shading effects (Gomes et al., 2019).

2.6 Chapter Conclusion

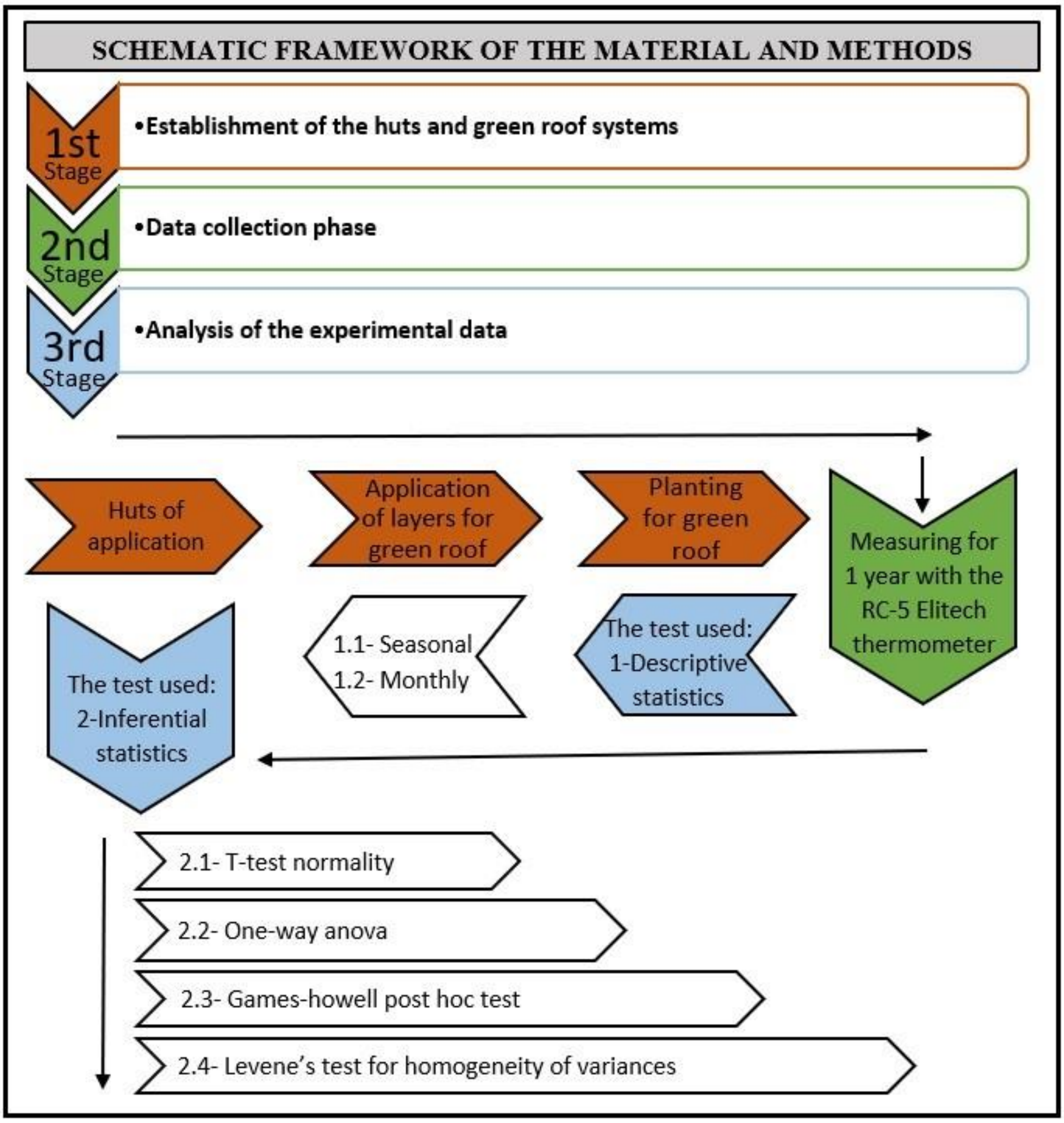
The growing global warming phenomenon, along with the expansion of densely populated and impermeable metropolitan areas, has exacerbated severe environmental challenges such as flash floods, soil erosion and storm water management, urban heat islands, air quality, and noise pollution. In this context,there has also been a greater understanding of the global environment's impact on energy consumption. Two complementary approaches are commonly used to resolve these concerns: I energy source sustainability; (ii) energy efficiency. Many countries with varying weather conditions and construction characteristics have proposed green roofs. Their cooling and heating potential, however, is highly dependent on the climate. If not managed, the increase in thermal capacity of green roofs above traditional roofs has been found to increase cooling and heating demands (La Roche and Berardi, 2014).

CHAPTER III
MATERIAL AND METHODS

A suitable place on campus was determined for the experimental setup, and a total of four wooden huts were established. Insulation materials for the green roof system were established on three of the huts. After the insulation materials were placed, three different vegetation types were created. Finally, temperature data loggers were placed inside each hut, and temperatures were recorded every two hours for 12 months.

Figure 3.1

Schematic Framework of the Material and Methods



(Yıldırım, 2023).

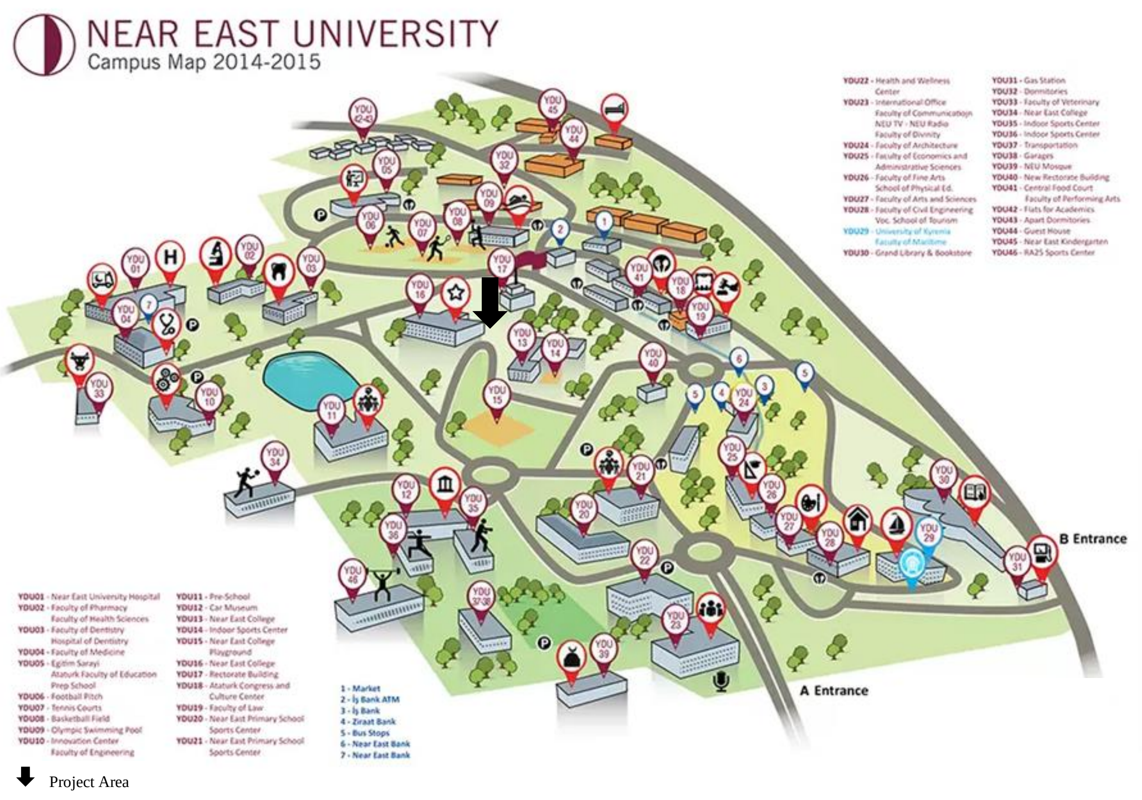
3.1 Nicosia as Experimental Study Area

The experimental research, whose applications were accepted with the project code (BAP) FEN 201-2-007, to measure the indoor temperature of green roof huts, was carried out in Northern Cyprus. After Sicily and Sardinia, Cyprus is the third-largest island in the Mediterranean. The area experiences warm winters and hot, dry summers, which are typical of Mediterranean coastal locations. It is situated between latitudes of 30.33 and 35.41 degrees and longitudes of 32.23 and 34.55 degrees. Syria is 100 kilometres to the east, Turkey is 65 kilometres to the north, and Egypt is 420 kilometres to the south of North Cyprus (Nadiri and Hussain, 2005). Whereas daily mean temperatures range from 9 to 12 degrees Celsius during the winter months (January–February). The average annual precipitation is 397.6 mm, and the average sunshine is five hours during the winter period. The great variance between day and night is a key element of the Cypriot climate. In the winter, the predominant winds are usually southwesterly and easterly, and in the summer, westerly and northerly (Philokyprou and Michael, 2020).

The research was carried out in the Near East Kindergarten located in the Near East University campus in Nicosia, the capital city of Cyprus. Nicosia, the capital of Cyprus for the last ten centuries, is currently Europe's last divided city, with the northern (Turkish) and southern (Greek) sections separated by a UN buffer zone (Oktay, 2007). Although Nicosia was not physically divided during this period, the two major communities of the town, the Turks and the Greeks, were already living in separate residential areas defined by their religious centres: the Turkish districts (mahalles) were located around the mosques, while the Greek districts developed around the Greek Orthodox churches (Diaz-Berio, 1982).

Figure 3.2

The Map of Near East University



(https://ideas.neu.edu.tr/2015/02/03/campus-map/).

The huts used in the experiment were located in the garden of the Near East Kindergarten all 4 of the huts were placed on the same front. The front side of all the huts, whose conditions were all the same, was in the east direction and the back side was in the west direction (Figure 3.2). The huts were exposed to direct sun between 12:00 and 14:00 when the day was the sunniest. However, in the afternoon, they were in the shadow of the nursery building to the west of the huts. In the garden ofthe Kindergarten where the huts were located, there were no trees or shrubs that would affect the hot temperature of the huts and give shade. In addition, the green roof type used and applied in the research was the extensive green roof.

Figure 3.3

The Garden of the NEU Kindergarten and the Area where the Huts are Placed

3.2 Description of the Experimental Roof System

For this research, an extensive green roof system was used. Due to its light weight, thin growing material, minimal to no care requirements, low cost, and broad potentialfor use over new or existing lightweight structures, extensive green roof systems are frequently used. Green roof tests were conducted outdoors on four ground-level wooden huts on the east façade of NEU Kindergarten School. These three huts were covered with all the necessary green roof insulation layers, while one was left bare as the control. The layers used for the green roof construction were determined by CEE (Cyprus Environmental Enterprises) Ltd. (Figure 3.3). The roof system consisted of:

a) Plants**:** The plants selected were in accordance with the Mediterranean climate conditions, and additionally, we also considered the plants' contribution to the aesthetic value of the building. Preferred plants were sun- and drought-resistant ground-cover and shrub-type plants;

b) Plant Carrier Layer: Lava; pumice-based materials synthesized using various processes in the plant carrier layers of the garden roof system; and natural tile crumbs used as substitute, frost resistant, non-combustible infrastructures, meet all of the nutritional requirements of the chosen plants. The Red Mediterranean soil type is ideal for green roofs (Terra Rossa). In the Mediterranean climate zone, these soils are developed on limestone (limestone). Its color is red due toits strong iron oxide content. Red soil, pumice stone, tile fracture, and shrub soil are the most suited soil mixtures for forming the plant carrier layer that was produced for the layer of green application;

c) Filter and Drainage Layer: Rainwater from the upper layers is collected and filtered by a filter layer for rainy days. If the buildup becomes excessive, the plants are drained and discarded to avoid rot;

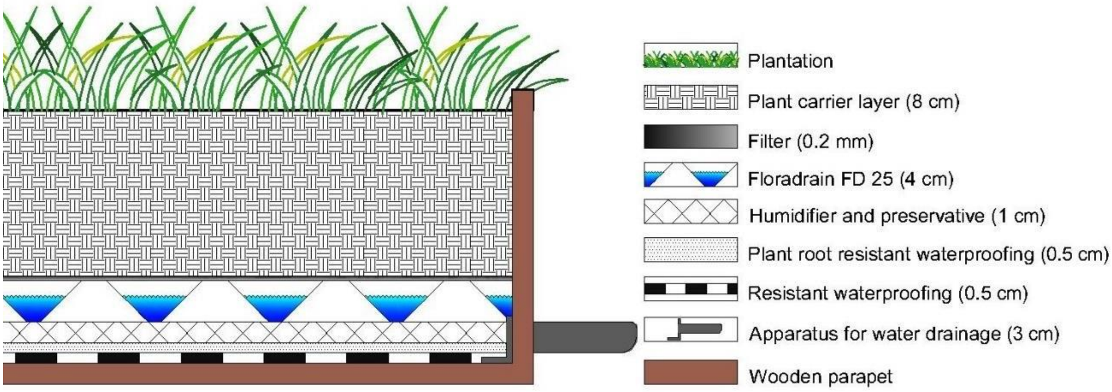
d) Protective and Moisture Retaining Layer Against Mechanical Effects: This layer is for any mechanical impacts on plant roots. The protecting layers must be compressive-strength resistant;

e) Root Holder Layer: The waterproofing layers should not be damaged by plant roots. Special root-holding layers or waterproofing that guard against roots should be utilized for this reason;

f) Waterproofing and Roof Construction: The presence of appropriate waterproofing and solid roof construction with sufficient weight-bearing ability is the most crucial prerequisite for roof greening. There is no need for a root retaining layer if the waterproofing materials are resistant to plant roots.

Figure 3.4

Extensive Green Roof Layers



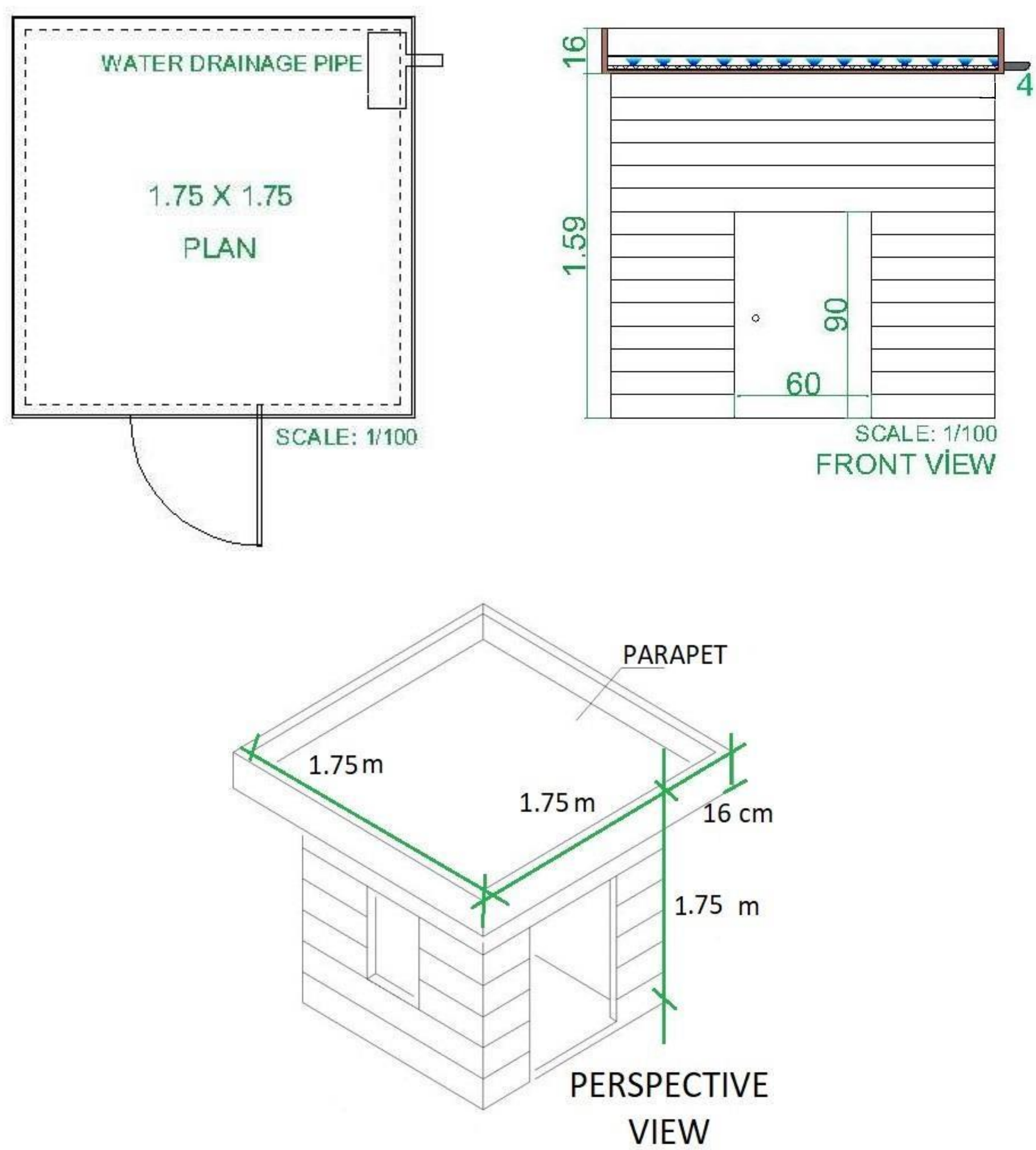
(Yıldırım, 2022).

3.3 Research Design

There are 4 huts used in the experiment. The conditions and dimensions in whichthey are all found are the same. The structure of the huts is wooden. Their height is 1 meter 75 cm in total. 16 cm of this measurement covers the parapet height. The front of each huts faces east. There is a door at the entrance of the huts on the east side of the huts. The width of this door is 60 cm and the length are 90 cm. Also, the distance between each hut is 85 cm. An example of a hut designed to find the indoor temperature effect of green roofs is shown in figure 3.4.

Figure 3.5

Plan, View and Perspective Drawings of the Huts used in the Experiment



The roof size of each hut used in the experiment was 3.5 m^2. A total of 143 plants were used by calculating the diameters of each hut separately. Of these plant species, eight different species were used, five of which were shrubs and three of which were ground-cover species (Figure 3.5).

Three of the four wooden huts with the same conditions were planted in June for the green roof experiment. While only the ground-cover species were planted in the first hut, both ground-covers and shrubs were planted in the second hut. In the third hut, only shrubs were planted. The distance between the plants was adjusted considering the growth diameter of the plants. All plants were planted in mixed order. While ponding was done every day during the first week, plants were generally irrigated twice a week.

Figure 3.6

(a) Green Roof with Ground-covers; (b) Green Roof with Mixed Vegetation; (c) Green Roof with Shrubs

(a) (b) (c)

(Yıldırım, 2022).

The sprinkle irrigation method was used as the irrigation method. Thermometers were placed in all green-roofed huts, including the control hut, and the experiment was fully set up to determine their indoor temperature. In this process, while all the ground-cover plants continued to grow without wilting, a few of the shrub species could not withstand exposure to excessive heat and perished.

3.4 Plant Material

Plant morphological traits are important contributors to the processes governing green roof and subsequent rainfall retention and cooling performance (Brandão et al.,2017). In terms of specific plant species used, many previous green roof studies used Sedum species (*succulents*), which are mostly non-native to North America, due to their ability to survive and grow under harsh roof microclimatic conditions. However, there is significant interest in using a broader range of plant species, including native species in green roof installations (O'Carroll et al., 2023).

In this study, all the plants used were selected in accordance with the Mediterranean climatic conditions. In this context, plants that are resistant to sun exposure and do not require excess water were used in the green roof experiment. Green roofs were installed on three of the four huts provided for the experiment, and each hut was planted with different species of plants. One of the huts was planted with only ground-cover plants, the other with shrubs, and the third with both ground-covers and shrubs. Preferred ground-covers: *Sedum angelina, Sedum spurium, Santolina spp*. The bush types were: *Gaura lindheimeri, Thymus vulgaris, Lavandula officinalis, Canna indica, Pelargonium spp.* (Table 3.1).

Table 3.1

Detailed Information About the Huts.

Hut 1 (With ground-cover plants)	Here, insulation and all layers forming the green roof were used, and ground-covers were preferred as the plant material. These species used are *Sedum angelina* and *Sedum spurium.* Twenty-five of *Sedum spurium* and twenty-two of *Sedum angelina* were planted. Planting was applied in a mixed order (Figure 3.6).
Hut 2 (With mixed vegetation)	Here, insulation and all layers forming the green roof were used, and both ground-cover and shrubs were preferred as plant material. These species were *Thymus vulgaris, Sedum angelina, Sedum spurium, and Pelargonium spp. Sixteen* of *Sedum spurium*, eighteen of *thymus vulgaris*, thirteen of *Sedum angelina*, and six *Pelargonium spp.* were planted Planting was applied in a mixed order (Figure 3.7).
Hut 3 (With shrubs)	Here, insulation and all layers forming the green roof were used, and only shrubs were preferred as the plant species. These species are *Gaura lindheimeri, Thymus vulgaris, Lavandula officinalis, Canna indica, Santolina spp.*, and *Pelargonium spp.* Six plants of *Thymus vulgaris, Lavandula officinalis, Gaura lindheimeri*, and *Pelargonium spp.*; four plants of *Canna indica*; and fifteen plants of S*antolina spp.* were planted. Planting was applied in a mixed order (Figure 3.8).
Hut 4 (Control Hut)	This hut was left completely empty and used without vegetation and insulation as a control.

Figure 3.7

Green Roof System with Ground-Cover Plants and its Layers

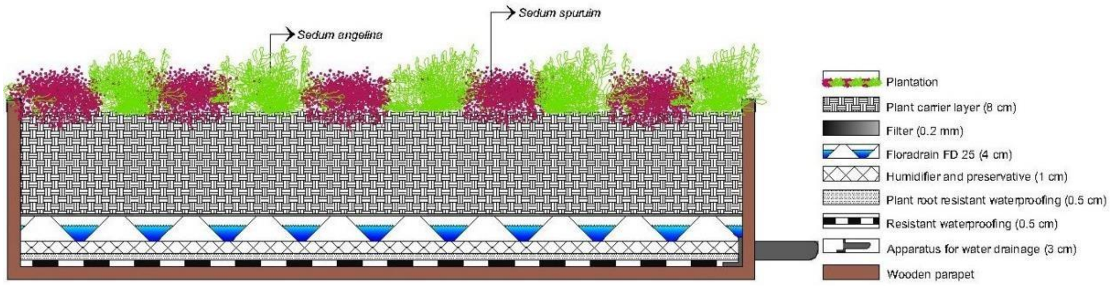


Figure 3.8

Green Roof System with Mix Vegetation and its Layers

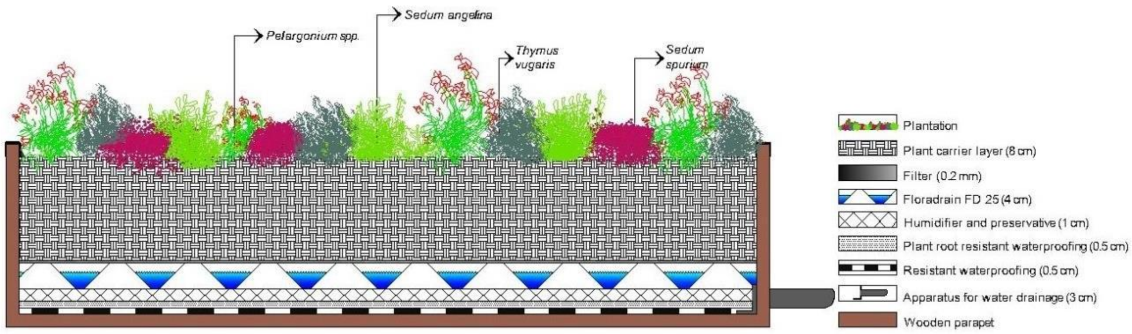
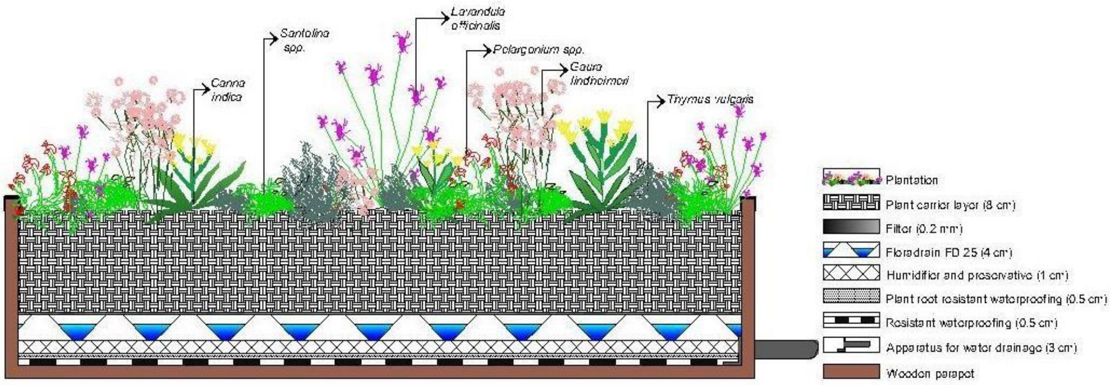


Figure 3.9

Green Roof System with Shrubs and its Layers



With 420 species, *Sedum* is the largest and most widespread genus in the Crassulaceae family. This genus includes annual and perennial herbs with succulent leaves and stems that are mostly found in arid climates from temperate to subtropical regions. The Mediterranean Sea, Central America, the Himalayas, and East Asia have the most species diversity.

The results of a Spanish study support the use of succulent species as effective green roofs to enhance the thermal conditions of buildings in Mediterranean cities. This shows that green roofs could be made more attractive without sacrificing their energy efficiency by using a variety of succulent species (i.e., not just Sedum spp.). *Thymus vulgaris* L., known as garden thyme or common thyme, is a Lamiaceae family perennial aromatic plant used for ornamental, culinary, and medicinal purposes. *Thymus vulgaris* is native to the Mediterranean and adjacent countries, northern Africa, and parts of Asia. Thyme has been used as a flavoring agent, culinary herb, and herbal medicine for millennia. The plant can be used as an infusion to treat coughs, diabetes, colds, and chest infections, as well as syrup to treat stomach ailments. Thyme is beneficial for sore throats since it has antibacterial, antibiotic, andantifungal properties. *Canna indica* is a perennial herb in the Cannaceae family. It has long been used in traditional medicine to treat a variety of ailments. The Lamiaceae family includes the genus *Lavandula*, which grows natively throughout the Mediterranean basin from the North Atlantic to the Middle East.

Plants in this family are distinguished by quadrangular stems with opposing, decussate leaves. Fine *lavender* and *lavender* aspic are herbaceous biennial plants that thrive in dry, sunny, calcareous (fine *lavender* and lavender aspic), or siliceous (*lavender* stoechas) soils.

3.5 Cultural Practices

During this experiment, weeding was done manually with one-week interval to control weeds in order not to hinder the root growth of the chosen plants. Irrigation was provided twice weekly in August, September, and October, which were the first months of planting. However, due to the rains in November, December, January, and February, irrigation frequency was reduced to once a week. During some weeks when there was heavy rainfall, no irrigation was provided. Irrigation was carried out once a week in the spring season, and in the summer months of June and July, due to the very hot weather, drip irrigation was applied twice a week for few weeks. The excess water was discharged with a water drainpipe (Figure 3.9). This water drain is placed at the bottom of all layers before the insulation phase of green roofs.

Figure 3.10

(a) Water Discharge Apparatus; (b) Draining Excess Water Accumulated on the Green Roof

(a) (b)

(Yıldırım, 2022).

3.6 Temperature Data Logger

A data logger (Model RC-5 Elitech) was placed in all four huts to measure the internal temperatures (Figure 3.10). The Elitech RC-5 USB temperature data has a USB port interface that is plug-and-play. It enables quicker access to data gathered throughout any cold chain management operation. Pharmaceuticals, food, life science, cooler boxes, medical cabinets, fresh food cabinets, freezers, and laboratories might all be examples. Any Elitech USB data logger may export data in PDF/Excel using data management software for faster data analysis. It can also makeuse of the multi-function LCD. Elitech USB temperature data logger has replacementbattery, optional mounting bracket, double button operation, protective grade, and double bracket for simplicity and dependability.

Figure 3.11

RC-5 Elitech Temperature Data Logger

(http://www.elitechlog.com/usb-temperature-data-logger/).

The dataloggers were programmed to record temperatures at 2 hours intervals for a complete year. Detailed information about these huts is shown in Table 3.1. At the end of each month, thermometers were taken out of the huts, one month's data was recorded, adjusted for the new month, and then placed again into the huts to obtain new measurements. This process continued uninterruptedly every month for twelve months, from 1 August (2021) to 1 August (2022).

3.7 Statistical Method

The quantitative analysis was based on the following process:

- Each hut data was checked for normality. If data were normally distributed, step 2 was skipped.

- Multiple data transformations (outlier check, log, square-root, and reciprocal transformation) were applied separately to test for normal distribution. If data were still not normally distributed, a robust test against main assumptions was applied.

- Levene's Test for Homogeneity of Variances was applied to each group sample. If Levene's test failed, a robust post hoc test was applied.

- If both main assumptions were not violated, a simple Anova test was applied. However, if there were violations on main assumptions, a One-Way Anova was applied because of robustness against normality and homogeneity of variance.

Based on this process, a One-way Anova was used in the pursuance of concerning the significant differences between the control hut (control group) and experimental groups (ground-cover plants, mixed vegetation, shrubs), and also between experimental groups themselves.

- Additionally, a T-test was applied for the correlated data.

CHAPTER IV
FINDINGS

4.1 Climatic Data Results

Four RC-5 Elitech data loggers were used to detect indoor temperature data. These data loggers are set to measure for a month, every two hours during the day, before being placed in the huts. Celsius was used as the unit of temperature measurement. Then, four separate thermometers were placed inside four huts, three of which had green roofs and one was empty. At the end of each month, thermometers were taken out of the huts, one month's data were taken, adjusted for the new month, and placed in the huts to measure. This process continued uninterruptedly every month for twelve months from 2021 August to 2022 August. Measurements were made regularly in all other months except October and the results were obtained. However, at the end of October, we could not take that month into account because the thermometer in the green-roofed hut with bush plants did not record. According to the data results of August, while the monthly maximum temperature was 59 °C in thecontrol hut without green roof, it was measured as 49 °C in the green roofed hut with ground cover. While the maximum temperature in the control hut in September was 54 °C, the average indoor temperature of the green-roofed hut where shrubs were planted was 43,6 °C. In November, when the plants are fully grown and the bloomersare blooming and the highest temperature is noticed, the monthly maximum temperature in the control hut was 44.1, while it was 32 °C in the bushes planted hut.

The thermometer results for December, which is the beginning of the winter months, showed a striking difference compared to the other months. The data obtained in this cold month, when the air temperature drops the most, reflects that the temperature inside the three huts with green roofs is higher than that of the hut without a green roof. While the indoor temperature was measured as 23 °C at the most in the control hut, it was measured as 27.2 °C in the green roofed huts. In other words, it can be said that huts with green roofs maintain the indoor temperature by 4.2 °C in winter compared to the ones without green roofs. Including all these data, the temperature data measured as maximum and minimum are also given in Table 4.1 in detail.

Table 4.1

Temperature Data as Maximum, Minimum and Average of All Months

First month data (August)											
Hut with ground-cover plants			Hut with mix vegetation			Hut with shrubs			Control hut		
Min.°C	Avg. °C	Max. C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C
20.9°C	34.4 °C	49 °C	20.7 °C	33.8 °C	49.4 °C	21 °C	33.6 °C	49.2 °C	20.5 °C	35 °C	59 °C

Note: The average temperature difference between the control hut and the green roofed hut, which reduces the temperature the most, is 1,4°C.

Second month data (September)											
Hut with ground-cover plants			Hut with mix vegetation			Hut with shrubs			Control hut		
Min.°C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C
18.9°C	30.2 °C	45.8 °C	17.4 °C	29.1 °C	46 °C	17.2 °C	28.7 °C	43.6 °C	15.5 °C	30.5 °C	54 °C

Note: The average temperature difference between the control hut and the green roofed hut, which reduces the temperature the most, is 1,8 °C.

Third month data (October)											
Hut with ground-cover plants			Hut with mix vegetation			Hut with shrubs			Control hut		
Min.°C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min.°C	Avg. °C	Max.°C	Min.°C	Avg. °C	Max.°C
15.9°C	26.2 °C	40.3 °C	14.4°C	24.3 °C	40.7°C	°C	°C	°C	12.9 °C	25.7 °C	49.2 °C

Note: Since the thermometer in the green-roofed hut with shrub plants did not record, the maximum reduced temperature in October could not be determined.

Fourth month data (November)

Hut with ground-cover plants			Hut with mix vegetation			Hut with shrubs			Control hut		
Min. °C	Avg. °C	Max.°C	Min.°C	Avg. °C	Max.°C	Min.°C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C
11.1 °C	20.3 °C	35.3°C	9.9 °C	18.8 °C	34.5°C	9.6 °C	18 °C	32 °C	7.7 °C	19.2 °C	44.1 °C

Note: The average temperature difference between the control hut and the green roofed hut, which reduces the temperature the most, is 1,2 °C.

Fifth month data (December)

Hut with ground-cover plants			Hut with mix vegetation			Hut with shrubs			Control hut		
Min.°C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C
5.5 °C	14.6 °C	27.2 °C	2.4 °C	13 °C	26 °C	5 °C	13.8 °C	23.8 °C	4.3 °C	13.3 °C	23 °C

Note: The average temperature difference between control hut and the green roofed hut, which reduces the temperature the most, is 0,3 °C.

Sixth month data (January)

Hut with ground-cover plants			Hut with mix vegetation			Hut with shrubs			Control hut		
Min.°C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C
1.9 °C	10.1 °C	21.5 °C	2.7 °C	10.9 °C	23.4°C	2.8 °C	11.1 °C	22.8 °C	1 °C	10.8 °C	26.3°C

Note: The average temperature difference between the control hut and the green roofed hut, which reduces the temperature the most, is 0,7 °C.

Seventh month data (February)											
Hut with ground-cover plants			**Hut with mix vegetation**			**Hut with shrubs**			**Control hut**		
Min.°C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C
5,1°C	13,2°C	27°C	5,2°C	14,3°C	29,5 °C	6 °C	15,2 °C	29 °C	3,5 °C	14,2 °C	32 °C

Note: The average temperature difference between the control hut and the green roofed hut, which reduces the temperature the most, is 1°C.

Eighth month data (March)											
Hut with ground-cover plants			**Hut with mix vegetation**			**Hut with shrubs**			**Control hut**		
Min.°C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C
3,3°C	14,6°C	45,8°C	3°C	14,3°C	48,9 °C	2,3 °C	13,3 °C	35,7 °C	0,9 °C	14,9°C	41,5 °C

Note: The average temperature difference between the control hut and the green roofed hut, which reduces the temperature the most, is 1,6 °C.

Ninth month data (April)											
Hut with ground-cover plants			**Hut with mix vegetation**			**Hut with shrubs**			**Control hut**		
Min.°C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C
3,3°C	14,6°C	45,7°C	2,8°C	14,3°C	48,8°C	8,9 °C	22,4 °C	39,2 °C	6,8 °C	23,3 °C	49,7°C

Note: The average temperature difference between the control hut and the green roofed hut, which reduces the temperature the most, is 8,7 °C.

Tenth month data (May)											
Hut with ground-cover plants			Hut with mix vegetation			Hut with shrubs			Control hut		
Min.°C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C
10,1°C	22,5 °C	38,5 °C	14 °C	27,2°C	44,7°C	13,9°C	27,4°C	44,9°C	12,1°C	29,2°C	56°C

Note: The average temperature difference between the control hut and the green roofed hut, which reduces the temperature the most, is 6,7 °**C**.

Eleventh month data (June)											
Hut with ground-cover plants			Hut with mix vegetation			Hut with shrubs			Control hut		
Min.°C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C
21,5°C	30,6 °C	45 °C	20,9 °C	30,3°C	45,3°C	20,8°C	30,7°C	46,8°C	18,6°C	31,9°C	54,1°C

Note: The average temperature difference between the control hut and the green roofed hut, which reduces the temperature the most, is 1,6°C.

Twelfth month data (July)											
Hut with ground-cover plants			Hut with mix vegetation			Hut with shrubs			Control hut		
Min.°C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C	Min. °C	Avg. °C	Max.°C
22,1°C	33,2 °C	51,7°C	22,7°C	32,9°C	48°C	33,3°C	22,4°C	54,2°C	20,3°C	34,8°C	58,4°C

Note: The average temperature difference between the control hut and the green roofed hut, which reduces the temperature the most, is 12,4°C.

In another research have demonstrated, extensive green roofs with a shallow depth contribute to the cooling of a building in summer while they incur increased heating penalty during winter. In contrast, dense green roofs with a deeper substrate depthare predicted to contribute more to building heat insulation (Kotsiris et al., 2013). A research at the University of Palermo in Italy looked at a four-story structure with a basement with and without a green roof. Lighting, cooling, heating, occupation, and natural and mechanical ventilation were all studied on a set schedule. In comparison to the traditional roof, the authors discovered that the green roof had the most consistent temperature throughout the day and year; they also discovered that the building with the green roof saved more energy in the winter than in the summer due to the use of air conditioning in the summer. (Ávila Hernández et al., 2020).

4.2 Statistical Analysis

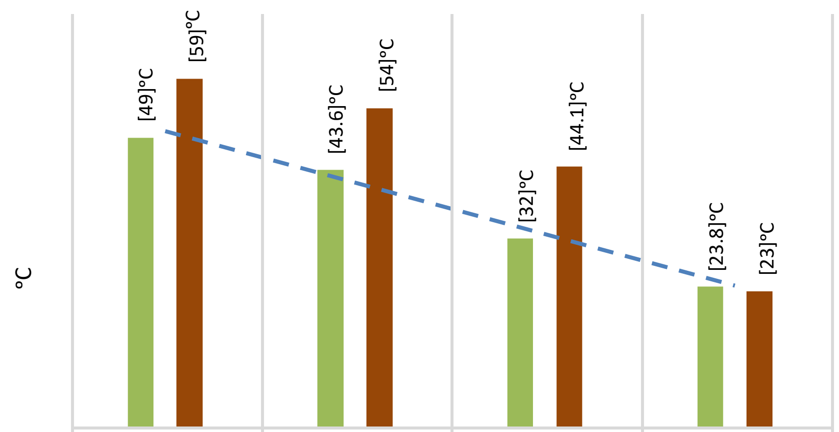
In Mediterranean claimed reported that during summer a green roof had an exterior surface temperature 12 °C lower than a lightweight concrete roof and it maintained the surface temperature 4 °C higher than the concrete roof in winter (Chagolla Aranda et al., 2017). The outcomes indicate that of an experimental other study conducted at the University of Calabria in Italy in the Mediterranean climate, in the winter, green roofs had a smaller impact on regulating roof temperature than in the summer. Even in the winter, the green roof helped to keep chilly weather at bay. The temperature beneath the green roof was greater in the inter, with variances ranging from 4.6 to 0.2 °C, according to the monthly average figures.

The temperature under the green roof was cooler in the summer, with variances ranging from 5 to 11.3 degrees Celsius. The measured roof temperature swings in the conventional roof ranged from 20 to 48.5 °C, and the research revealed that green roofs greatly reduced average roof temperature fluctuations, with temperature fluctuations in all three green roofs being less than 2 °C (Maiolo et al., 2020).

When we compare our own test results in these studies, we show that the green roof huts reduce the temperature by a maximum of 12.1 °C and a minimum of 0.8 °C. In addition, a general temperature drops of 10 °C was recorded between the control huts and the green roof huts (Figure 4.1).

Figure 4.1

Data on the Difference between the Green-roofed Hut and the Control Hut that brought the Temperature down the most, showing that the Temperature Dropped by 10°C on Average (August-December)



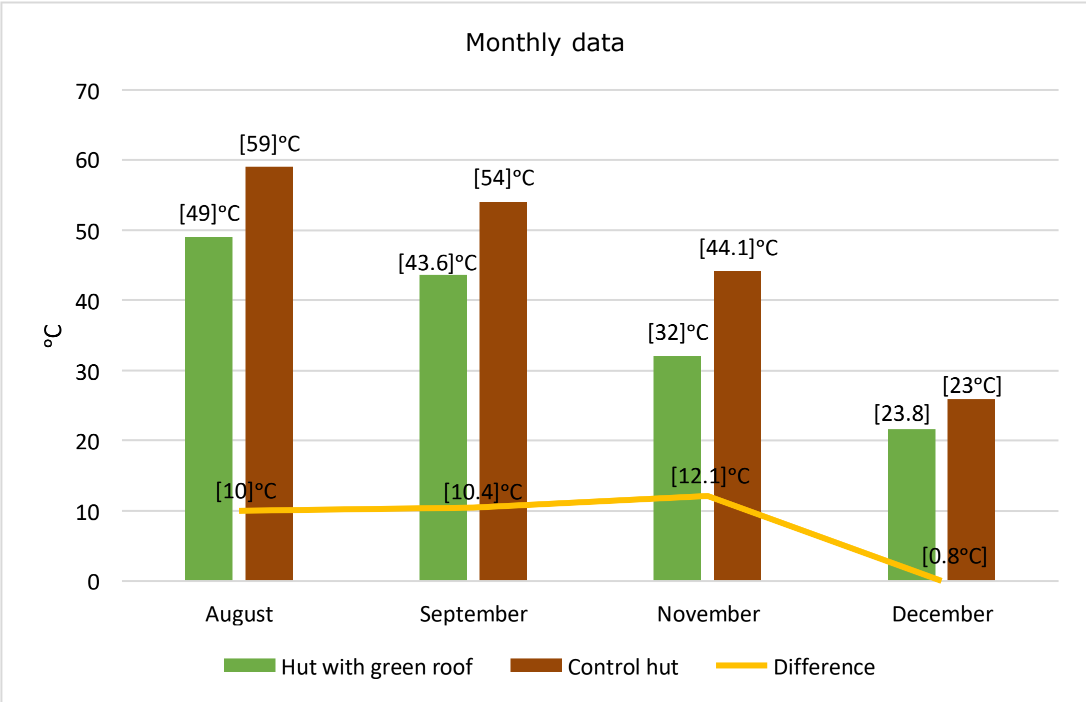
	August (Hut with ground-cover plants)	September (Hut with shrubs)	November (Hut with shrubs)	December (Hut with shrubs)
The hut that lowers the temperature the most	49	43.6	32	23.8
Control hut	59	54	44.1	23

(Yıldırım, 2022).

At the same time, when the three huts with green roofs were compared among themselves, it was determined that the hut with bush species lowered the indoor temperature more than the other huts with green roof. However, in the first month of August, the hut that reduced the temperature the most was the hut with ground cover plants. As the plants grew, the green roof hut with the bushes that grew the most showed the greatest difference (Figure 4.2). In November, when the temperature difference was the highest with 12.1 °C, it was the green roofed hut made up of shrub plants that provided this difference (Figure 4.3).

Figure 4.2

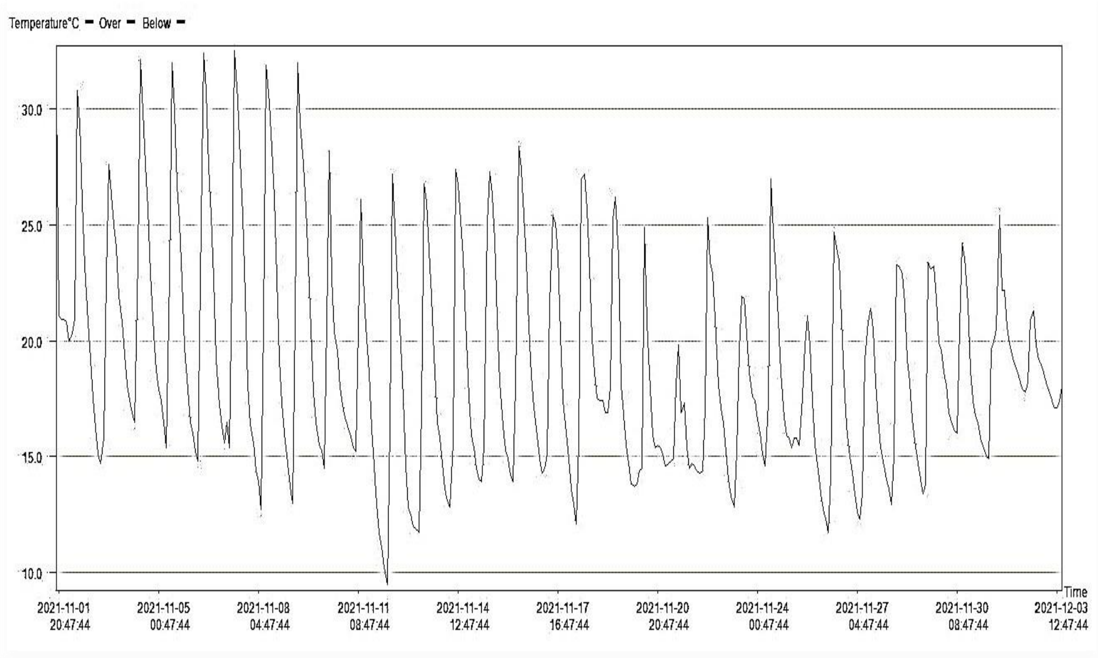
The Temperature Difference between the Control Hut and Green Roof with Shrub Plant that Reduces the Temperature the Most



(Yıldırım, 2022).

Figure 4.3

Green Roof Hut Data with Shrub Plants that Reduce the Temperature the most in November, when the Temperature Difference is the Highest

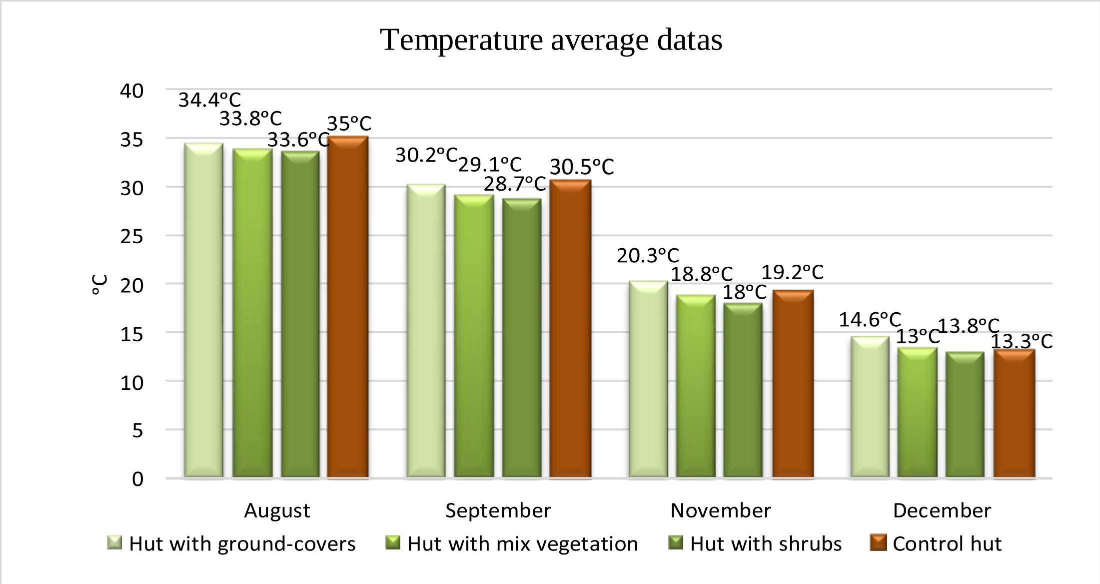


(Yıldırım, 2022).

The efficacy of the green roof system is mostly determined by three factors: the building's geographic position, the leaf area index, and the depth of the growth substrate (soil). The higher the depth of the soil, the greater the rate of reduction in consumption due to the increase in the value of the insulation and the thermal mass (Malik and Hashem, 2020). In this context, differences are observed in the averages of monthly measurements according to thermometer results (Figure 4.4).

Figure 4.4

Average Temperature Results for the First Four Months



(Yıldırım, 2022).

4.3 Descriptive Statistics

Summary statistics and figures are used for explaining and comparing temperatures of different hut types between 1 August 2021 and 1 August 2022, both seasonally and monthly.

4.3.1. Seasonal Comparisons

As shown in Table 4.2, during the summer months, there was a slight difference in minimum temperatures at night between the different hut types. However, as expected, large differences were seen in maximum temperatures during the daytime. The control hut experienced the highest temperature, 60.6 °C. The temperature difference between the control group and shrubs and ground-cover plants was 4.2 °C, whereas mixed vegetation had a difference of 11.2 °C. In addition, mixed vegetation and shrubs have an average temperature of around 30.5 °C, and ground-cover plants and the control hut had 31.2 °C and 31.6 °C, respectively. Table 4.2 also show that the control hut was warmer, on average, than the huts in the experimental groups between August 2021 and 2022. All data were statistically analyzed using T-tests and One-Way Anova tests.

During the winter months, the lowest temperature (1.0 °C) was recorded in the control hut, and the highest minimum temperature among groups was 2.82 °C from the shrub-planted hut. The mean temperatures among groups had small differences. It should be noted that the mixed vegetation hut had a lower average temperature than the control hut by 0.12 °C between August 2021 and August 2022. Although spring and autumn seasonal maximum temperatures were similar, the main difference observed was in the minimum temperatures. There was a difference of around 6–7 °C between spring and autumn minimum temperatures for each group. Even though the highest temperature in autumn was recorded in the control hut, it also had the lowest maximum temperature at 44.14 °C in spring among all hut groups. Ground- cover and control huts showed very close mean temperatures in autumn between 25 °C and 26 °C. On the other hand, average temperatures for all groups in spring were between 20 °C and 21 °C.

Table 4.2

Descriptive Statistics by Seasons

		N	Minimum	Maximum	Mean	Std. Deviation
Summer	Ground-cover plants	1584	12.10	56.00	31.238	8.520
	Mix vegetation	1584	14.00	49.40	30.565	7.834
	Shrubs	1584	13.90	56.41	30.498	7.748
	Control Hut	1584	13.00	60.61	31.617	10.105
Winter	Ground-cover plants	1019	1.90	27.19	13.08	4.95
	Mix vegetation	1019	2.40	27.90	12.64	4.98
	Shrubs	1019	2.82	29.03	13.41	5.13
	Control Hut	1019	1.00	30.00	12.76	5.54
Spring	Ground-cover plants	1161	3.25	56.00	21.01	10.31
	Mix vegetation	1161	3.00	48.90	20.31	9.03
	Shrubs	1161	2.52	44.90	20.10	8.91
	Control Hut	1161	1.30	44.14	20.01	9.72
Autumn	Ground-cover plants	1075	11.15	45.80	25.94	7.60
	Mix vegetation	1075	9.80	46.00	24.34	7.54
	Shrubs	1075	9.50	43.60	23.9	7.51
	Control Hut	1075	7.70	53.83	25.56	10.43

4.3.2. Monthly Explanatory Statistics

Table 4.3 provides summary statistics of both control and experimental groups monthly.

Table 4.3

Summary Statistics Monthly

	1 August 2021- 1 August 2022					
2021		N	Minimum	Maximum	Mean	Std. Deviation
August	Ground-Cover Plants	355	24.40	49.00	34.62	6.97
	Mixed Vegetation	355	22.90	49.400	33.99	7.18
	Control Hut	355	21.61	58.77	35.09	9.62
	Shrubs	355	22.90	49.20	33.75	6.90
September	Ground-Cover Plants	352	18.90	45.80	30.38	6.76
	Mixed Vegetation	352	17.40	46.00	29.23	7.22
	Control Hut	352	15.57	53.83	30.50	10.30
	Shrubs	352	17.20	43.60	28.74	6.49
October	Ground-Cover Plants	359	15.90	40.30	26.49	6.84
	Mixed Vegetation	359	14.40	40.70	24.48	6.67
	Control Hut	359	12.91	49.24	26.10	10.18
	Shrubs	7	20.10	36.00	27.54	6.26
November	Ground-Cover Plants	352	11.15	36.67	21.06	6.20
	Mixed Vegetation	352	9.80	34.70	19.43	5.26
	Control Hut	352	7.70	43.90	20.18	8.10
	Shrubs	352	9.50	32.50	19.06	4.90
	Ground-Cover Plants	315	5.53	27.19	15.05	4.88
	Mixed Vegetation	315	2.40	26.00	13.43	5.14

December	Control Hut	315	4.30	25.40	13.74	4.06
	Shrubs	315	5.00	25.40	14.23	4.12
January	Ground-Cover Plants	357	1.90	23.50	11.18	4.45
	Mixed Vegetation	357	2.70	23.60	11.18	4.56
	Control Hut	357	1.00	25.10	11.08	5.18
	Shrubs	357	2.82	26.12	11.70	5.00
February	Ground-Cover Plants	360	4.70	26.70	13.57	4.80
	Mixed Vegetation	360	4.90	27.90	13.76	4.93
	Control Hut	360	3.00	30.00	13.92	6.58
	Shrubs	360	4.37	29.03	14.74	5.57
March	Ground-Cover Plants	360	3.25	30.32	12.72	5.92
	Mixed Vegetation	360	3.00	32.30	12.71	6.23
	Control Hut	360	1.30	36.20	12.44	7.35
	Shrubs	360	2.52	30.07	12.07	5.87
April	Ground-Cover Plants	360	9.73	45.77	21.92	7.51
	Mixed Vegetation	360	4.61	48.90	21.54	8.15
	Control Hut	360	6.80	43.20	20.47	9.04
	Shrubs	360	8.90	39.20	21.58	7.46
May	Ground-Cover Plants	429	12.10	56.00	27.26	10.61
	Mixed Vegetation	429	14.00	44.70	25.71	7.23
	Control Hut	429	13.00	44.14	26.01	7.43
	Shrubs	429	13.90	44.90	25.66	7.16
June	Ground-Cover Plants	361	20.41	44.99	30.24	6.37
	Mixed Vegetation	361	20.20	46.02	30.16	6.79
	Control Hut	361	17.40	54.13	31.69	10.13
	Shrubs	361	20.00	46.58	30.18	6.89

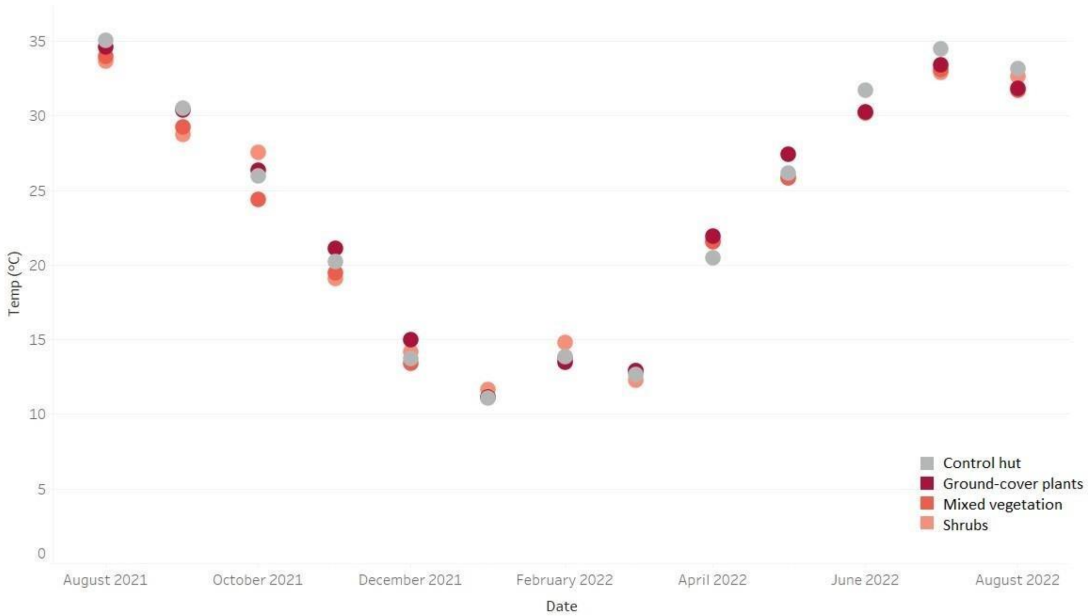
	Ground-Cover Plants	361	23.63	47.23	33.38	6.91
July	Mixed Vegetation	361	22.64	48.00	33.07	7.38
	Control Hut	361	20.80	55.38	34.45	10.66
	Shrubs	361	22.43	47.74	32.90	7.19

According to the statistics above, control group exposed the highest temperature (60.61°C) in the first five days of August 2022 whereas ground cover plants exposed it on May 2022, shrubs and mixed vegetation on August 2021. The difference between maximum temperatures between control group and experimental groups is almost 10°C in August 2021. This difference is also high on April, May 2022 and October 2021, compared to other months. Even though the difference in minimum temperatures is low compared to difference in maximum temperatures among months, October and April have the similar discrepancy compared to other months. Italso should be noted that deviation from the mean is higher on months with wide ranges and possible outliers. For example, since winter months do not have high range of distribution, their standart deviations are low. On the other hand, summer and spring months tend to have higher deviations from the mean with the effect of high temperatures.

Statistics also show that control group has higher mean temperatures on hot months. Figure 4.5 supports the mean temperature statistics of Table 4.3 It shows the monthly mean temperatures for each group. According to the figure, control hut has higher mean temperatures on June, July, August and September. However, October, November and December data prove that ground-cover plants and shrubs exposed higher temperatures. Even though mean temperatures are very close on January 2022, shrubs have higher mean temperature compared to others on February.

Figure 4.5

Monthly Average Temperatures in All Huts



(Yıldırım, 2022).

Also, it should be bearing in mind that March mean temperatures are lower than February mean temperatures. On last 2 months of spring, ground-cover plants have highest mean temperature among groups.

Table 4.4 shows the frequencies of 6 temperature intervals based on 10°C for each month. As expected, summer months do not have any temperature between 0°C and 20°C. 45-50% of temperature data on summer months relies between 20°C and 30°C. This number is above 50% for experimental groups whereas it is 42.7% for control group on June 2022. On the contrary, this number drops to 45% for experimental groups and increases to 48% for control group. On the other hand, control hut exposed temperatures above 50°C during summer months. The highest percentagesof control hut for temperatures above 50°C is 12% and 8% on July 2022 and August 2021, respectively.

Table 4.4

Frequency Table, Monthly

		Ground Cover Plants		Mixed Vegetation		Shrubs		Control Hut	
		Frequency	%	Frequency	%	Frequency	%	Frequency	%
August	0-10°C	0	0%	0	0%	0	0%	0	0%
	10-20°C	0	0%	0	0%	0	0%	0	0%
	20-30°C	138	38.9%	143	40.3%	147	41.4%	155	43.7%
	30-40°C	99	27.9%	124	34.9%	121	34.1%	95	26.8%
	40-50°C	118	33.2%	88	24.8%	87	24.5%	74	20.8%
	50<°C	0	0%	0	0%	0	0%	31	8.7%
September	0-10°C	0	0%	0	0%	0	0%	0	0%
	10-20°C	2	0.6%	16	4.5%	17	4.8%	47	13.4%
	20-30°C	187	53.1%	192	54.5%	190	54%	156	44.3%
	30-40°C	125	35.5%	107	30.4%	124	35.2%	59	16.8%
	40-50°C	138	10.8%	37	10.5%	21	6%	76	21.6%
	50<°C	0	0%	0	0%	0	0%	14	4%
October	0-10°C	0	0%	0	0%	-	-	0	0%
	10-20°C	75	20.9%	122	34%	-	-	147	40.9%
	20-30°C	161	44.8%	150	41.8%	-	-	91	25.3%
	30-40°C	122	34%	85	23.7%	-	-	72	20.1%
	40-50°C	1	0.3%	2	0.6%	-	-	49	13.6%
	50<°C	0	0%	0	0%	-	-	0	0%
November	0-10°C	0	0%	1	0.3%	1	0.3%	3	0.9%
	10-20°C	197	56%	218	61.9%	217	61.6%	214	60.8%
	20-30°C	112	31.8%	118	33.5%	123	34.9%	87	24.7%
	30-40°C	43	12.2%	15	4.3%	11	3.1%	36	10.2%
	40-50°C	0	0%	0	0%	0	0%	12	3.4%
	50<°C	0	0%	0	0%	0	0%	0	0%
December	0-10°C	40	12.7%	90	28.6%	40	12.7%	63	16.8%
	10-20°C	216	68.6%	187	59.4%	245	77.8%	241	76.5%
	20-30°C	59	18.7%	38	12.1%	30	9.5%	21	6.7%
	30-40°C	0	0%	0	0%	0	0%	0	0%

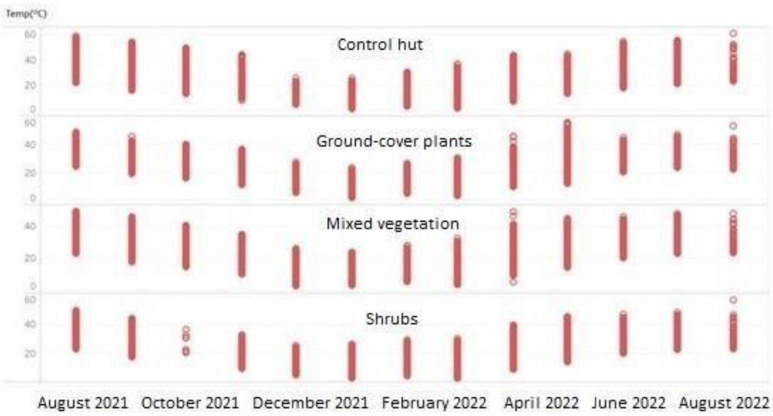
	40-50°C	0	0%	0	0%	0	0%	0	0%
	50<°C	0	0%	0	0%	0	0%	0	0%
January	0-10°C	142	39.8%	150	42%	141	39.5%	162	45.4%
	10-20°C	206	57.7%	192	53.8%	185	51.8%	173	48.5%
	20-30°C	9	2.5%	15	4.2%	31	8.6%	22	6.2%
	30-40°C	0	0%	0	0%	0	0%	0	0%
	40-50°C	0	0%	0	0%	0	0%v	0	0%
	50<°C	0	0%	0	0%	0	0%	0	0%
February	0-10°C	96	26.7%	92	25.6%	80	22.2%	127	35.3%
	10-20°C	218	60.6%	219	60.8%	204	56.7%	155	43.1%
	20-30°C	46	12.8%	49	13.6%	76	21.1%	78	21.7%
	30-40°C	0	0%	0	0%	0	0%	0	0%
	40-50°C	0	0%	0	0%	0	0%	0	0%
	50<°C	0	0%	0	0%	0	0%	0	0%
March	0-10°C	139	38.6%	139	38.6%	146	40.6%	159	44.2%
	10-20°C	176	48.9%	174	48.3%	177	49.2%	144	40%
	20-30°C	43	11.9%	43	11.9%	36	10.0%	47	13.1%
	30-40°C	2	0.6%	4	1.1%	1	0.3%	10	2.8%
	40-50°C	0	0%	0	0%	0	0%	0	0%
	50<°C	0	0%	0	0%	0	0%	0	0%
April	0-10°C	2	0.6%	7	1.9%	7	1.9%	24	6.7%
	10-20°C	173	48.1%	278	49.4%	169	46.9%	176	48.9%
	20-30°C	117	32.5%	222	30.8%	125	34.7%	89	24.7%
	30-40°C	65	18.1%	58	16.1%	59	16.4%	60	16.7%
	40-50°C	3	0.8%	6	1.7%	0	0%	11	3.1%
	50<°C	0	0%	0	0%	0	0%	0	0%
May	0-10°C	0	0%	0	0%	0	0%	0	0%
	10-20°C	153	35.7%	0	0%	0	0%	0	0%
	20-30°C	115	26.8%	2127	29.6%	125	29.1%	123	28.7%
	30-40°C	88	20.5%	173	40.3%	187	43.6%	164	38.2%
	40-50°C	63	14.7%	119	27.7%	105	24.5%	128	29.8%
	50<°C	10	2.3%	10	2.3%	12	2.8%	14	3.3%
June	0-10°C	0	0%	0	0%	0	0%	0	0%
	10-20°C	0	0%	0	0%	1	0.3%	29	8%
	20-30°C	181	50.1%	182	50.4%	190	52.6%	154	42.7%
	30-40°C	160	44.3%	140	38.8%	132	36.6%	89	24.7%

	40-50°C	20	5.5%	39	10.8%	38	10.5%	78	21.6%
	50<°C	0	0%	0	0%	0	0%	11	3%
July	0-10°C	0	0%	0	0%	0	0%	0	0%
	10-20°C	0	0%	0	0%	0	0%	0	0%
	20-30°C	163	45.2%	165	45.7%	164	45.4%	175	48.5%
	30-40°C	100	27.7%	104	28.8%	108	29.9%	67	18.6%
	40-50°C	98	27.1%	92	25.5%	89	24.7%	75	20.8%
	50<°C	0	0%	0	0%	0	0%	44	12.2%

Temperatures on September and October are mostly between 20°C and 30°C. The main transition to cold regime starts on November for every group. 60% of temperature data relies on 10°C and 20°C interval for every group. In addition, mostly, temperatures are around 10°C and 20°C on December and January. Figure 4.6 is a graphical representation temperature range for each month among groups. April has the widest temperature range among months. November and May also have a big difference between maximum and minimum temperatures. Since August 2022 has only 5 days of data, it seems that there are a lot of outliers. However, it should not be considered in that way because of lack of data. On the other hand. Ground- cover plants and mixed vegetation have outliers on April 2022. During April and May 2022, experimental groups exposed longer temperature ranges than control group. December and January have the shortest temperature range for all groups.

Figure 4.6

Temperature Intervals Monthly



(Yıldırım, 2022).

4.3.3. Seasonal Explanatory Statistics

Table 4.5 presents the summary statistics of experimental groups and control group by seasons.

Table 4.5

Summary Statistics by Seasons

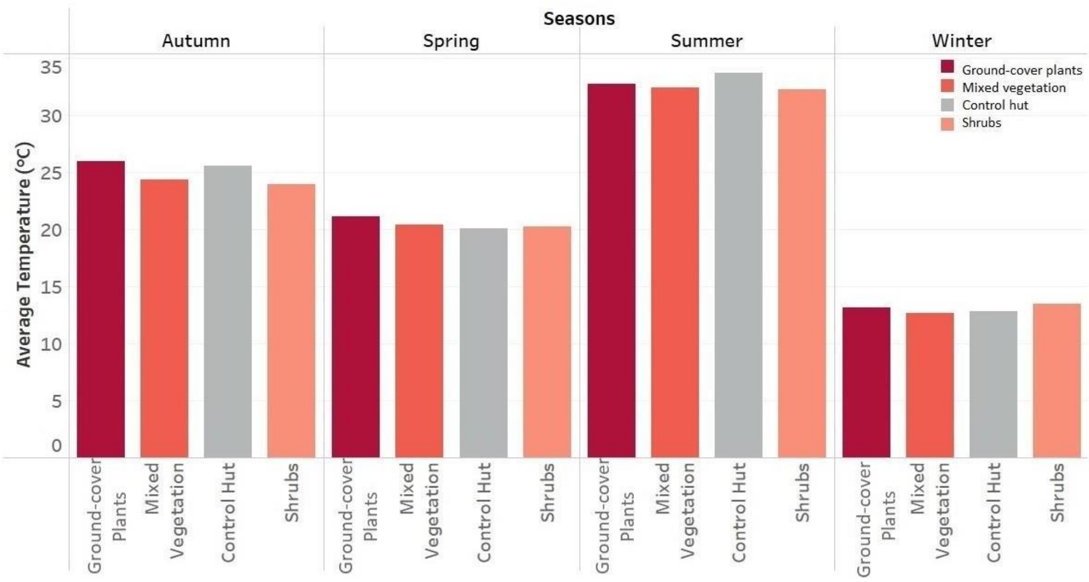
		N	Minimum	Maximum	Mean	Std. Deviation
Summer	Ground-Cover Plants	1584	12.10	56.00	31.238	8.520
	Mixed Vegetation	1584	14.00	49.40	30.565	7.834
	Shrubs	1584	13.90	56.41	30.498	7.748
	Control Hut	1584	13.00	60.61	31.617	10.105
Winter	Ground-Cover Plants	1019	1.90	27.19	13.08	4.95
	Mixed Vegetation	1019	2.40	27.90	12.64	4.98
	Shrubs	1019	2.82	29.03	13.41	5.13
	Control Hut	1019	1.00	30.00	12.76	5.54
Spring	Ground-Cover Plants	1161	3.25	56.00	21.01	10.31
	Mixed Vegetation	1161	3.00	48.90	20.31	9.03
	Shrubs	1161	2.52	44.90	20.10	8.91
	Control Hut	1161	1.30	44.14	20.01	9.72
Autumn	Ground-Cover Plants	1075	11.15	45.80	25.94	7.60
	Mixed Vegetation	1075	9.80	46.00	24.34	7.54
	Shrubs	711	9.50	43.60	23.9	7.51
	Control Hut	1075	7.70	53.83	25.56	10.43

According to the Table 4.5 during summer, control hut exposed the highest temperature and highest mean temperature. Ground-cover plant also exposed a high temperature of 56 °C, and a mean temperature 0,4 °C below control hut. Moreover, the lowest max temperature among groups is 49°C which is mixed vegetations. Sincethe temperature range is high, the deviation from the mean is also high for control hut during summer. During winter, control hut has the second lowest mean temperature, highest and lowest temperatures, compared to experimental groups. Shrubs and ground-cover plants have the highest means, 13,08°C and 13,41°C,respectively.

During spring, ground-cover plants exposed a high temperature around 56°C whereas other groups have maximum temperatures between 40-50°C. On the other hand, lowest temperature,1.30°C during this season is exposed by control hut. Mean temperatures for mixed vegetation, shrubs and control hut are around 20°C whereas ground-cover plant has a 1°C higher mean temperature compared to other groups.

Figure 4.7

Average Temperature by Seasons



(Yıldırım, 2022).

During autumn, the difference between control group and experimental groups are between 7°C and 10°C. Also, similar to winter and spring, control hut has the lowest temperature in this season. Considering mean temperatures, as it can be seen from the figure 4.7, ground-cover plants and shrubs have mean temperatures around 26°C whereas others have 1-1.5°C lower mean temperatures.

Table 4.6

Frequency Table by Seasons

		Ground-Cover Plants		Mixed Vegetation		Shrubs		Control Hut	
		Frequency	%	Frequency	%	Frequency	%	Frequency	%
Autumn	0-10°C	0	0%	1	0.1%	1	0.1%	3	0.3%
	10-20°C	278	25.9%	361	33.6%	234	21.8%	412	38.3%
	20-30°C	468	43.5%	467	43.4%	316	29.4%	339	31.5%
	30-40°C	290	27.0%	207	19.3%	139	12.9%	170	15.8%
	40-50°C	39	3.6%	39	3.6%	21	2.0%	137	12.7%
	50<°C	0	0%	0	0%	0	0%	14	1.3%
Winter	0-10°C	285	27%	339	32.1%	269	25.5%	349	33.1%
	10-20°C	656	62.2%	614	58.2%	649	61.5%	585	55.5%
	20-30°C	114	10.8%	102	9.7%	137	13%	121	11.5%
	30-40°C	0	0%	0	0%	0	0%	0	0%
	40-50°C	0	0%	0	0%	0	0%	0	0%
	50<°C	0	0%	0	0%	0	0%	0	0%
Spring	0-10°C	143	12.3%	148	12.7%	155	13.4%	186	16%
	10-20°C	506	43.6%	484	41.7%	477	41.1%	446	38.4%
	20-30°C	281	24.2%	332	28.6%	352	30.3%	303	26.1%
	30-40°C	155	13.4%	181	15.6%	165	14.2%	201	17.3%
	40-50°C	66	5.7%	16	1.4%	12	1%	25	2.2%
	50<°C	10	0.9%	0	0%	-	0%	0	0%
Summer	0-10°C	0	0%	0	0%	0	0%	0	0.0%
	10-20°C	0	0%	0	0%	1	0.1%	29	2.5%
	20-30°C	509	44.5%	517	45.2%	527	46.1%	511	44.7%

30-40°C	387	33.9%	397	34.7%	388	33.9%	275	24.1%
40-50°C	246	21.5%	229	20%	226	19.8%	236	20.6%
50<°C	1	0.1%	0	0%	1	0.1%	92	8%

For each season, table 4.6 represents the frequency of temperature intervals, similarto Table 4.5 and 4.4 During autumn season, ground-cover plants and mixed vegetation have more frequency on the interval 3 (20°C-30°C) than shrubs and control hut. In addition, percentage dispersion on interval 40°C-50°C is 9-10% higher on control hut compared to experimental groups. In winter, mixed vegetation and control hut has 32.1% and 33.1% percentage dispersion on interval 0°C-10°C, respectively. In contrast, ground cover plants and shrubs have more percentage dispersion on interval 10°C-20°C. On the other hand, spring has the longest temperature range for all groups among seasons. There are dispersions for all intervals, except last one.

However, ground-cover plants have 0.9% dispersion on last interval (50<°C). Also, above 40% of the data is located between 10°C -20°C for experimental groups. Lastly, control group is the only one that exposed temperatures above 50°C in summer. Shrubs and ground-cover plants only exceed 50°C once. Although most of the data points relies between 30°C and 40°C, all groups have dispersion on 40°C- 50°C around 20%.

Figure 4.8

Average Temperature by Seasons

(Yıldırım, 2022).

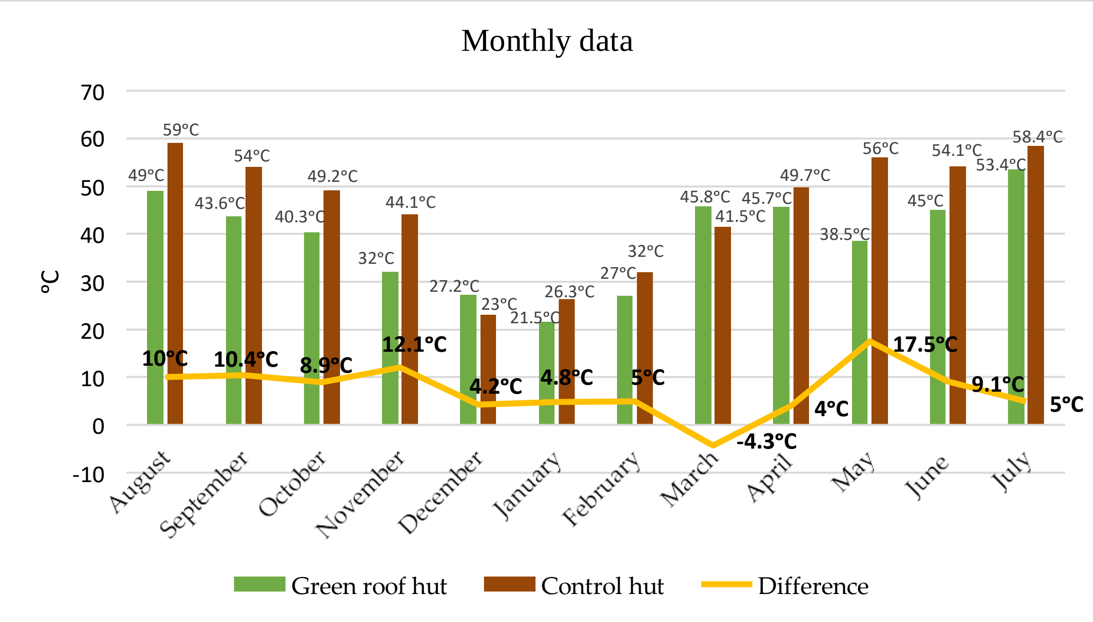
Figure 4.8 shows the temperature range for every group on different seasons. The short temperature range on winter and long on other seasons is significant. The longest temperature range is mixed vegetation on spring. Ground-cover plants and control hut also have long temperature ranges. In overall, control hut has multiple long temperature ranges compared to other groups. Also, the variability of difference in temperature changes over time is mostly seen on spring.

4.3.4. Monthly Comparisons

According to the monthly results, it was observed that the green-roofed huts reduced the indoor temperature by ~10 °C, compared to the control hut, while the maximum temperature difference was 12.1 °C and was never less than 4.2 °C. At the same time, when the three huts with green roofs were compared among themselves, it was determined that the hut with bush species lowered the indoor temperature more than the other huts with green roofs. As the plants grew, the green roof hut with the bushes that grew the most showed the greatest difference (Figure 4.9).

Figure 4.9

Temperature Variation and Difference between the Green-roofed Hut and the Control Hut

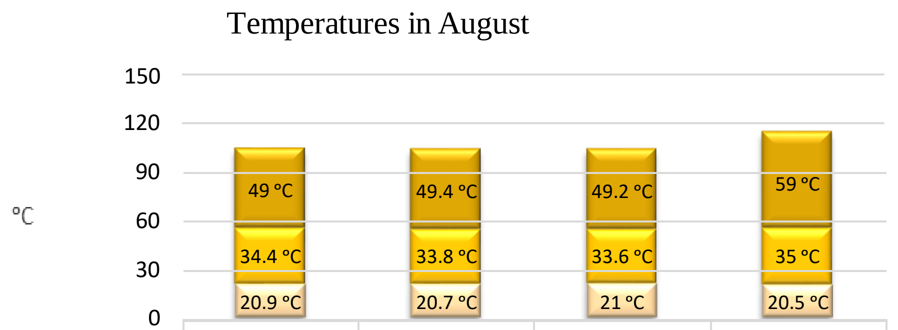


(Yıldırım, 2022).

Eight months of data from the control hut show that the temperature was measured at its highest at 59 °C in August, and at its lowest at 23 °C in December. In August (2021), the monthly maximum temperature recorded was 59 °C in the control hut without a green roof, while the maximum recorded was 49 °C in the green-roofed hut. The hut where the temperature was reduced the most was the hut with mixed vegetation (Figure 4.10).

Figure 4.10

Temperature Data for Four Huts in August



	Hut with ground-cover plants	Hut with mix vegetation	Hut with shrubs	Control hut
Maximum Temperature	49	49.4	49.2	59
Average Temperature	34.4	33.8	33.6	35
Minimum Temperature	20.9	20.7	21	20.5

(Yıldırım, 2022).

While the maximum recorded temperature in the control hut in September was 54 °C, the maximum indoor temperature of the green-roofed hut where shrubs were planted was 43.6 °C. In October, data could not be measured because there was a problem with the thermometer on the green roof with shrubs. Therefore, it could not be compared with other huts in october.

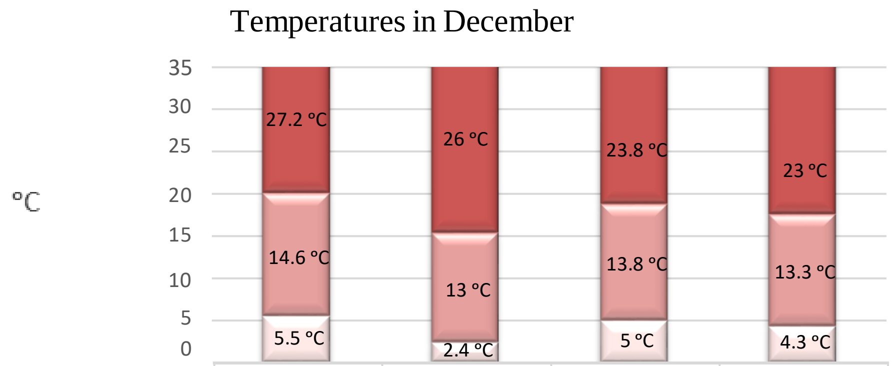
The temperature data of the green-roofed hut with bush plants were thus unavailable. Therefore, the monthly maximum temperature of the control hut was 49.2 °C, while it was 40.3 °C in the ground-cover planted hut which reduced the temperature the most. In November, when the plants were fully grown and in bloom, and the highest temperature occurred, the monthly maximum temperature in the control hut was 44.1, while it was 32 °C in the hut with bushes. Except for August and October, the hut where the temperature dropped the most in all other months was the green roof hut with bush plants. In May, it was observed that the temperature difference was the highest in the hut with ground-cover plants.

Recorded temperatures for December, which is the beginning of the winter months, showed a striking difference compared with other months. The data reveals that the temperature inside the three huts with green roofs is higher than that of the hut without a green roof.

While the highest indoor temperature was 23 °C in the control hut, it was 27.2 °C in the green-roofed huts. In other words, huts with green roofs maintained a higher indoor temperature by 4.2 °C compared to the control hut (Figure 4.11).

Figure 4.11

Temperature Data for Four Huts in December



	Hut with ground-cover plants	Hut with mix vegetation	Hut with shrubs	Control hut
Maximum Temperature	27.2	26	23.8	23
Average Temperature	14.6	13	13.8	13.3
Minimum Temperature	5.5	2.4	5	4.3

(Yıldırım, 2022).

The January results showed a monthly maximum temperature of 26.3 °C in the control hut. Among the green-roofed huts, the hut that lowered the temperature the most was that with bushes planted, at 21.5 °C. According to the data results in February, while the maximum temperature in the control hut was 32 °C, the bush green-roofed hut had the highest temperature difference. Moreover, as in other months, it was the hut that experienced the lowest temperature at 27 °C.

4.4. Inferential Statistics

This section consists of statistical tests that were used for drawing inferences from the sample data. T-Tests, One-Way Anova tests, and multiple assumption tests were used for hypothesis testing to draw conclusions about differences in temperature in different hut types.

4.4.1. T-Test

As all vegetation groups were strongly correlated with each other, paired T-tests were conducted using SPSS software. According to the T-test results, the mean temperature difference between the control group and mixed vegetation was –0.16 °C. The control group mean temperatures were significantly higher than mixed vegetation and shrubs, 0.59 °C and 0.48 °C, respectively. According to the 95% confidence interval of difference, the mean temperature differences of pair 2 (control vs. mixed vegetation) and pair 3 (control vs. shrubs) were between 0.44 °C and 0.73 °C and 0.34 °C and 0.62 °C. Therefore, the control hut was slightly cooler than ground-cover plants and warmer than mixed vegetation and shrubs. However, when we compared the ground-cover hut with the control hut only for the summer period, results indicated that the control hut was on average 1 °C warmer than the ground- cover hut.

On the contrary, the mean difference between ground-cover plants and other experimental groups was higher than the mean difference between the control hut and other experimental groups. The estimate for the mean temperature difference in ground-cover plants and mixed vegetation was 0.76 °C, whereas it was 0.61 °C for shrubs. Accordingly, the main results state that the mixed vegetation hut and shrub-covered hut was cooler than the ground-cover plant-covered hut (Table 4.7).

Table 4.7

Paired T-Test for Correlated Data

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Control Hut—Ground Cover Plants	-.1698740	4.591005	.0689694	-.3050886	-.0346593	-2.463	4430	.014
Pair 2	Control Hut—Mixed Vegetation	.5923944	4.952765	.0744041	.4465252	.7382636	7.962	4430	.000
Pair 3	Control Hut—Shrubs	.4845088	4.542312	.0712262	.3448664	.6241512	6.802	4066	.000
Pair 4	Ground Cover Plants—Mixed Vegetation	.7622684	3.486955	.0523836	.6595703	.8649665	14.552	4430	.000
Pair 5	Ground Cover Plants—Shrubs	.6195554	4.344322	.0681216	.4859997	.7531111	9.095	4066	.000
Pair 6	Mixed Vegetation—Shrubs	-.0322300	4.710460	.0738628	.1770417	.1125816	-.436	4066	.663

4.4.2. Normality Test

The normality of temperature of different groups was assessed. According to Table 4.8, results for both the Kolmogorov–Smirnov and Shapiro–Wilk tests indicated the violation of normality assumption for both control and experimental groups. Results for the Kolmogorov–Smirnov test suggest the statistically significant test results for the control hut (W (4431) =0.064, $p < 0.001$); ground-cover plants (W (4431) =0.051, $p < 0.001$); mixed vegetation (W (4431) =0.044, $p < 0.001$); and shrubs (W (4067) =0.054, $p < 0.001$). On the other hand, similarly, the Shapiro–Wilk test results demonstrate the rejection of the null hypothesis for the control hut (W (4431) =0.963, $p < 0.001$); ground-cover plants (W (4431) =0.979, $p < 0.001$); mixed vegetation (W (4431) =0.979, $p < 0.001$); and shrubs (W (4067) =0.978, $p < 0.001$). Furthermore, Q–Q (Quantile–Quantile) Plots and Histograms under Figure 4.12 support the normality tests' claim.

Table 4.8

Normality Test for Each Sample

	Kolmogorov–Smirnov			Shapiro–Wilk		
Group	Statistic	df	Sig.	Statistic	df	Sig.
Control Hut	0.064	4431	.00*	0.963	4431	.00*
Ground-cover Plants	0.051	4431	.00*	0.979	4431	.00*
Mixed Vegetation	0.044	4431	.00*	0.979	4431	.00*
Shrubs	0.054	4067	.00*	0.978	4067	.00*

Lilliefors Significance Corrections

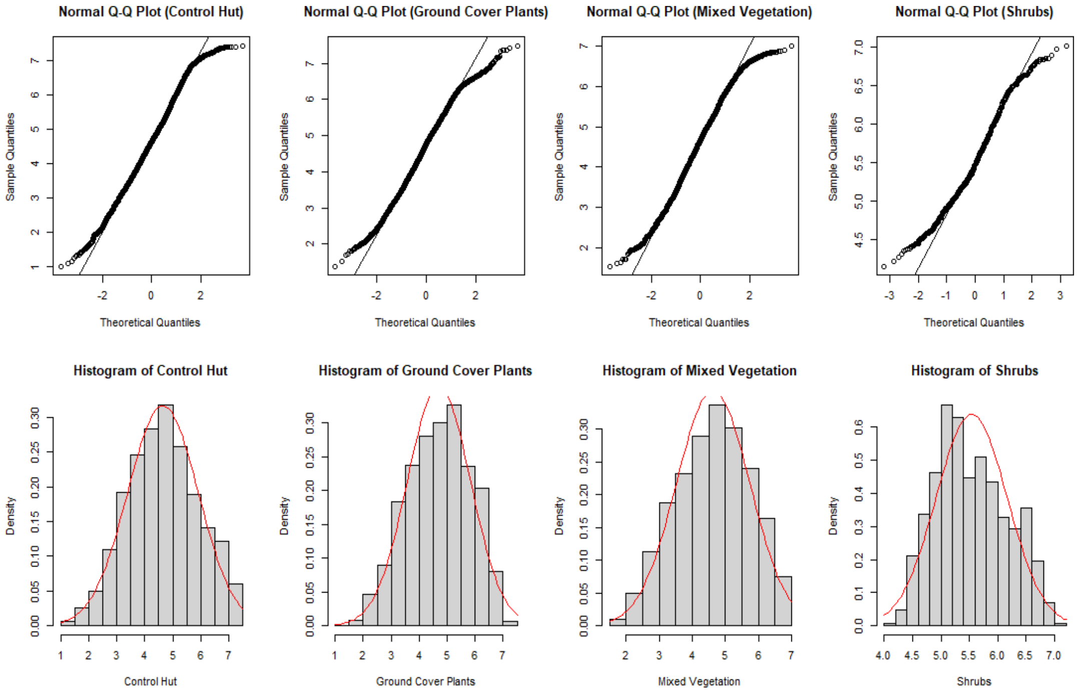
*The mean difference is significant at the 0.05 level.

(Kolmogorov–Smirnov and Shapiro–Wilk are the normality test types. Group: group name; Statistic: the test statistic (result of mathematical formula to test data normality); Df: degrees of freedom—sample size/data size/number of observations; Sg: significance (p value)).

Figure 4.12 shows the distribution of each hut type. The top row of the Figure shows the Quantile−Quantile plots which is used to compare the sample distribution to normal distribution. The normal distribution represented by straight line is the base distribution. Its quantiles are plotted along x−axis as “Theoretical Quantiles” whereas each sample’s quantiles are plotted along y−axis as “Sample Quantiles”. As it can be seen from the top row, although points match at most of the quantiles, there are deviations from the straight line on the higher and lower quantiles for each sample. This shows the non−normality of the data for each sample. On the other hand, the bottom row of Figure 4.12 represents the histograms of each sample. Even though all samples except Shrubs look like a bell shaped, upper and lower side of histograms represents the deviation from the normal distribution, as in the top row. Therefore, both Q−Q plots and histograms are in line with the result of Table 4.8.

Figure 4.12

Q–Q Plots and Histograms



(Yıldırım, 2022).

4.4.3. Levene's Test for Homogeneity of Variances

Table 4.9 has shown the results of Levene's Test. According to the results based on means, the null hypothesis is rejected, $F (3,17356) = 39.313$, $p < 0.001$. In addition, even though optimal choice depends on the mean, Levene's test based on median provides better robustness against non-normal data. Similar to results based on mean, results based on median indicate the rejection of null hypothesis at $\alpha=0.00$. Thus, an alternative hypothesis which indicates heteroskedasticity is accepted.

Table 4.9

Levene's Test for Homogeneity of Variances for Checking Homoskedasticity

		Levene Statistic	**df1**	**df2**	**Sig.**
Temp (°C)	Based on mean	39.313	3	17,356	0.00*
	Based on median	31.806	3	17,356	0.00*
	Based on median and with adjusted df	31.806	3	16,469.926	0.00*
	Based on trimmed mean	36.201	3	17,356	0.00*

*The mean difference is significant at the 0.05 level.

4.4.4. One-Way Anova

Since assumptions of normality and homogeneity of variances were violated, One-Way Anova with Welch and Brown–Forsythe tests were performed to check whether there were any statistically significant differences between the mean temperature of different hut types. According to the results of One-Way Anova on Table 4.10, there is a statistically significant difference in the average temperature according to hut type, F (3) =6.905, $p < 0.001$. Although One-Way Anova proves the statistically significant difference in means of temperatures of different hut types, Welch and Brown–Forsythe post hoc tests were applied to compare all possible combinations of group differences.

Table 4.10

One-Way Anova.

Temp. (°C)	**Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
Between Groups	2407.971	3	802.657	6.905	0.00*
Within Groups	2,017,388.6	17,356	116.236		
Total	2,019,796.5	17,359			

* The mean difference is significant at the 0.05 level.

(Sum of Squares: the sum of squared differences between each observation and ground mean; Df: degrees of freedom; Mean Square: sum of squares divided by its associated degrees of freedom; F: F statistics (variation between sample means/variation within the samples); Sig.: significance (p value); Between Groups: total variation between each group mean and overall mean; Within Groups: total variation in the values in each group and their group mean).

4.4.5. Games-Howell Post Hoc Test

According to Table 4.11, the Games-Howell test revealed that the mean temperature (°C) is statistically significantly lower in the shrub experimental group than in the control hut by 0.704 °C ($p < 0.05$). On the other hand, even though the results indicate that mixed vegetation provides almost 0.6°C lower mean temperature for that hut, the p value is close to being statistically significant ($p=0.06$). For the comparison between multiple experimental groups, results suggest that the mean temperature (°C) of the ground-cover plant hut is statistically significantly higher than both mixed vegetation and shrubs by 0.76°C ($p < 0.05$) and 0.87 °C ($p < 0.05$), respectively.

Table 4.11 *GamesHowell Post Hoc Test for Multiple Comparisons*

(I) group 1	**(J) group 2**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval Lower Bound**	**Upper Bound**
Control Hut	Ground-Cover Plants	-.169874	.239864	.894	-.78621	.44646
	Mixed Vegetation	.592394	.236901	.060	-.01633	1.20112
	Shrubs	.704325*	.240855	.018	.08544	1.32321
Ground-Cover Plants	Control Hut	.169874	.239864	.894	-.44646	.78621
	Mixed Vegetation	.762268*	.220892	.003	.19468	1.32986
	Shrubs	.874199*	.225128	.001	.29572	1.45268
Mixed Vegetation	Control Hut	-.592394	.236901	.060	-1.20112	.01633
	Ground-Cover Plants	-.762268*	.220892	.003	-1.32986	-.19468
	Shrubs	.111930	.221969	.958	-.45843	.68229
Shrubs	Control Hut	-.704325*	.240855	.018	-1.32321	-.08544
	Ground-Cover Plants	-.874199*	.225128	.001	-1.45268	-.29572
	Mixed Vegetation	-.111930	.221969	.958	-.68229	.45843

Multiple Comparisons, Dependent Variable: Temp. (°C), Games-Howell

(Group 1 and group 2: groups that are compared; Mean Difference (I-J): difference in group means; Std. Error: standard error of the difference; Sig.: significance (p value); Lower Bound: lower bound of 95% Confidence Interval; Upper Bound: upper bound of 95% Confidence Interval).

4.5 Observation Results on the Growth and Shading Rates of Plant Species

As the summer months are hot and the winter months are dry on the island of Cyprus, which has a Mediterranean climate, it was very important to choose plants suitable for the dry climate. Therefore, the morphological characteristics of the selected plants in the green roof experiment became our first criterion.

In this study, the total number of drought resistant 143 plants were planted consisting of 8 different plant species. The plant species were: *Sedum angelina, Sedum spurium, Santolina spp., Gaura lindheimeri, Thymus vulgaris, Lavandula officinalis, Canna indica, Pelargonium spp*. During the 12-month trial period, while the indoor temperatures of the huts were measured, the growth and development rate of the plants were also observed.

It has been observed that *Gaura lindheimeri, Pelargonium spp, Lavandula officinali and Canna indica* plants grew larger than succulent plants such as *Sedum angelina, Sedum spurium.* In addition, particularly *Canna indica* plants did not require too much irrigation and their leaf diameters provided quite large growth and threfore they provided a large amount of shading to the roof.

On the other hand, *Thymus vulgaris* and *Sedum* species did not dry out during the entire trial period.

CHAPTER V
DISCUSSION

The current study examined how can different green roof types may affects the interior temperature of building in Nicosia. Cyprus. Observations were conducted continuously for 1-year duration. It has been found that the hut with shrubs vegetation was the most effective relating to building insulation and the control hut with no vegetation was the least effective. For example, in November, when the difference between the maximum temperatures in the control hut and the hut with theplanted shrubs was 44,1 °C and 32 °C, respectively. Temperature data have been shown that green roofs can play a crucial role relating to thermal regulation issue in Cyprus, which usually has high summer temperatures.

On the other hand, urban heat island mitigation in city centres offers thermal insulation to buildings, energy savings, and year-round thermal comfort in addition to the many advantages of green roofs, such as promoting biodiversity and fostering an attractive environment. One research calculates the energy savings from green roofs, which is a difficult topic in a Mediterranean environment with different heating and cooling seasons. The thermal behaviour of a green roof case study in Lisbon, Portugal, was evaluated through an experimental campaign conducted throughout the heating and cooling seasons of 2013. These experimental results were subsequently utilized to calibrate an Energy Plus building energy simulation. The numerical model was validated before being used to compare the energy performance of intensive, semi-intensive, and extended green roofs. The three green roof options result in equivalent heating energy needs, however extensive green roof solutions require 2.8 and 5.9 times more cooling energy than semi-intensive and intensive green roof solutions, respectively. In addition, the performance of each type of green roof and various insulating features was compared to typical roof options. Extensive green roofs need 20% less energy than black roofs and have a similar annual behaviour as white roofs when there is no thermal insulation. The energy consumption of semi-intensive and intense green roofs is 60-70% and 45-60% lower than that of black and white roofs, respectively. Well-insulated roofs do not fully utilize evapotranspiration cooling benefits, which is especially visible when compared to highly reflective white roofs (Silva et al., 2016).

In the research conducted in Athens, Greece, measurements of in-situ temperature and humidity were made over the course of the winter. While the surface temperature of the green roof appeared to be up to 1,6 °C higher than that of the cement roof floor in the morning, the surface temperature of the normal concrete roof floor was discovered tobe up to 21,9 °C higher than that of the planted area during the day. The various plants on the green roof had their surface temperatures monitored, and an ideal combination of plants was suggested for the system's best performance. Furthermore, simulations for this building were run using the Energy Plus tool. It was determined that a non-air-conditioned building's interior air temperature might drop by up to 1,1°C on an average summer day and rise by up to 0,7 °C on an average winter day. Finally, a total annual reduction in the building's energy use of 15.1% was computed (Foustalieraki et al., 2017). It is anticipated that dense green roofs with a deeper substrate depth will increase building heat insulation (Kotsiris et al., 2013).

Insulation of buildings is a very important subject in terms of Energy Saving and Sustainable cities. Urban heat island (UHI) impacts and consequent human-caused greenhouse gas emissions have contributed to the long-term increase in global temperatures. The modelling findings show that greening systems have a significant beneficial influence on enhancing the urban environment in hot and humid tropical regions. Urban greening reduces air temperature, radiant temperature, humidity, and solar gain. Buildings with green roofs and walls use less energy overall and require less district cooling, by 10.5% and 13%, respectively. The building's energy efficiency and air quality are both significantly improved by the greening technologies. Thus, by incorporating green technology and systems into constructed settings, the present study's findings can assist urban planners and residents in developing methods for creating green spaces in crowded urban environments (Pragati et al., 2023).

The findings of this research have shown that the bush group plants and large -leaf plants can make the buildings of the buildings in the summer with a positive effect in summer and make buildings cool. On the other hand, in this study, it was observed that the plants in question have developed well, although the plant species that require low water were selected. In the summer, the internal temperature of the hut where shrub plants were used in density was 1.8 ° C less than other huts. No insulation material and non -vegetative club on it was 4.6 ° C warmer than otherhuts. In addition, when we look at the winter months, the hut, where the shrub plant group was used in density, was 1.2 ° C warmer than other huts.

The similar results and effectiveness of green roof applications can be found in other research conducted in Athens, Greece. The thermal behaviour and energy efficiency of an intensive green roof system consisting of local aromatic plants that needed less irrigation, which was installed on the roof of a low -energy office building with a low -energy low -energy office building, was investigated. The surface temperature of the green roof was found to be 15 k lower than a traditional roof. With dense vegetation, it was found that plants with low -absorbing feature of solar radiation offer a much lower surface temperature and a higher mitigation potential. It was found that the surface temperature of the plants was highly affected by the ambient air temperature. Using simulation techniques, it has been calculated that such a green roof type can reduce the average internal temperature of a building without air conditioning to 0.7 k and significantly reduce the annual cooling and heating need (Karachaliou, et al., 2016). This experimental research to measure the temperature effect of green roofs on the interior shows that green roofs keep warm in the summer months and cool in the winter months.

CHAPTER VI
CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study has shown the great importance of implementing green roofs in urban areas due to their contribution to the regeneration process in their surroundings and the increasing environmental performance of these buildings. Considering the contribution of green roof systems towards energy efficiency and environmental benefits from an ecological perspective, this should be seen as an effective approach to mitigate the threatening consequences of global warming.

Using green roofs results in several beneficial effects. For example, the reduction of ambient temperature, providing an insulation effect in the buildings, and the vegetation acts as a particle trap for dust and other airborne particles. Furthermore, green roofs increase the oxygen production and reduces the carbon dioxide rate by the processes of photosynthesis, and consequently filters air pollutants out of the system. Additionally, green roofs can potentially act as a tool for the rainwater runoff problem in urbanized areas. The vegetation will reduce rainwater runoff, which results in a higher absorption rate of rainwater into the soil, helping to reduce the risks of floods and erosion from precipitation. These aforementioned aspects have positive contribution to the disaster-resilient city approach, which is one of the main features to improve the of sustainability of buildings and cities, especially with the ongoing climate change.

Cyprus has a Mediterranean climate with hot and dry summers and warm and less rainy winters. The thermal benefits of green roofs in cities like Nicosia are visible all year round. In accordance with findings of other studies, the results of this research show that there are significant seasonal and thermal benefits to the implementation green roofs. A study conducted in a temperate French climate analyzed the cooling and heating effect of green roofs on indoor temperature. As a result, it was found that green roofs reduce the indoor temperature by 2 °C in summer and reduce the annual energy need by 6% (Jaffal and Belarbi, 2012).

Another study conducted in Singapore showed how green roof systems play a role in air temperatures, by obtaining that green roof systems reduce the roof floor temperatures by 18 °C (Aras, 2019). The main conclusion is that high vegetation coverage reduces the indoor air temperature during the summer months (i.e., July and August). Furthermore, this research has observed that green roofs also have positive insulation effects during the cold winter months (i.e., December and January). These findings imply the benefits with regard to sustainable energy use in Mediterranean cities. The insulation of buildings should be included in modern architecture and green city initiatives, especially due to anthropogenic climate change and the related global warming. Therefore, the positive effects of green roofs in regulating urban climate and as building insulation in (semi-) arid countries will play an important role in future sustainable planning.

We also observed that it can keep interiors warmer during the cold winter months (December and January). The results are also important in terms of sustainable energy use for future cities in the Mediterranean region. Due to anthropogenic climate change and concomitant warming, the insulation of buildings has been included in the agenda of modern architecture and green city initiatives. Therefore, the positive effects of green roofs in regulating urban climate and as building insulation in semi-arid or arid countries will play an important role in future sustainable planning.

Future research is needed to enhance the urgency of implementing green roofs in urbanized areas. Multi-dimensional, multi-actor and interdisciplinary studies should be carried out in Cyprus to promote the implementation of green roofs, which offer numerous advantages. Diverse research and development initiatives, as well as academic works such as master's and doctoral theses, articles, papers and reports, should be conducted to analyze the effects of green roofs on building performance from different perspectives in Cyprus. State entities should provide funding and support for these studies, while non-governmental organizations should assist in raising awareness among users and owners.

6.2 Recommendations

In the future, especially in large urbanized areas such as Nicosia, it is important to legalize green roofapplications in order to provide good thermal insulation in buildings all year round. Sanctions for more widespread green roof applications in the TRNC laws will also have a positive effect on the increase of green patches in cities. Consequently, this will support the existence and expansion of ecological ecosystems in cities, resulting in a beneficial impact on biodiversity. Furthermore, the use of green roofs will also reduce flood risks in cities. In arid climatic conditions, it is advisable to incorporate *Canna* and *Lavender* plants in forthcoming green roof design, due to their proficient shading capability and low water requirement.

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Appendix A

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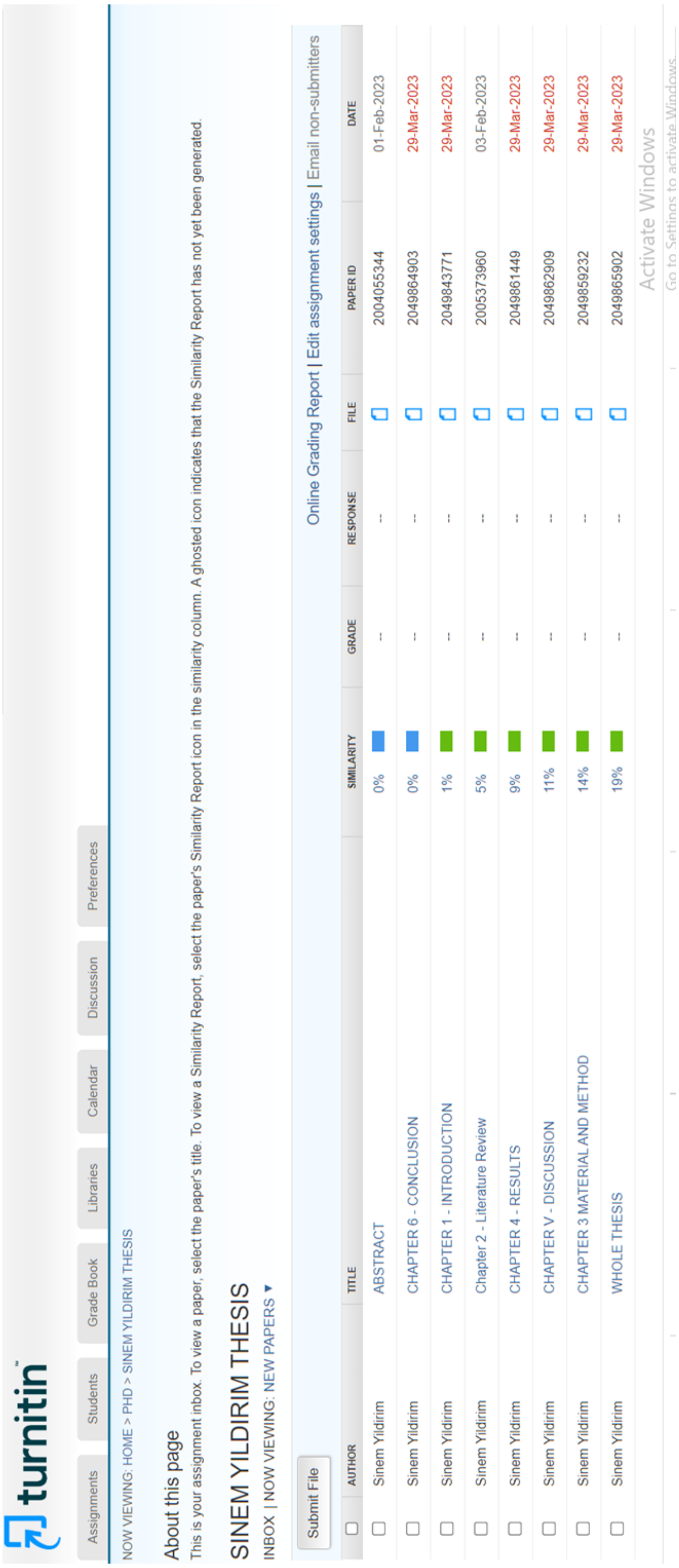
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Name: Sinem Yıldırım

Date of Birth: 24 February 1992

Place of Birth: Nicosia – Cyprus

Title: M. Sc. Lecturer and Landscape Architecture

Institution: Near East University

Education:

Degree	Field	Institution	Date
BSc	Faculty of Architecture Department of Landscape Architecture	Near East University	2015
MSc	Faculty of Architecture Department of Landscape Architecture	Near East University	2018
PhD	Faculty of Architecture Department of Architecture	Near East University	2018- continues

- **Graduated from undergraduate education as the top of the faculty**

Work Experience:

	Institution	Date
Lecturer and student advisor	Faculty of Architecture Department of Landscape Architecture	2015-to date

Research Interests: Landscape Ecology, Environment and Green Roof Systems

Honors and Awards: 2016 and 2018 Young Researcher Award, NEU

Scientific and Professional Society Membership: Member of Landscape Architecture Nicosia, TRNC

Project Duties:

1- Spatiotemporal patterns of marine debris deposition along the shoreline of North Cyprus (2017 January until now working as research assistant funded by NEU BAP Project and collaborated with Exeter University)

2- Social Cohesion and Neighborly Interactions within a Turkish Cypriot Community (self-funded project, worked as research assistant, completed research)

3- Landscape park project for the Gönyeli Municipality, KKTC

4- "Green roof systems with different soil depths and different vegetation cover, their effect on indoor temperatures and biodiversity in Semi- Arid Climate Region" BAP project titled (completed research)

Workshop / Courses Attended:

Name of the Course / Workshop	Location
Biyoistatistik ve SPSS Kursu	NEU, Hospital
DESAM ‘‘Sosyal Bilimler Alanında Makale Yazım Kursu’’	NEU, Hospital
ULUSAL PEYZAJ MİMARLIĞI GÜNÜ/Yeşil Kampüs Projesi	NEU, Landscape Architecture
AB Atık Azaltma ve Geri Dönüşüm Forumu	Bedesten, Nicosia
Herbalism&Health Semineri	Nicosia/Home for Cooperation,
AB Bilgi Merkezi/Enerji Verimli Binalar ve Yeşil Enerji Paneli	KTMMOB, Auditorium
Bilimsel Araştırma Projeleri Yazım Kursu	NEU, Hospital
Rain Bird Sulama Sistemleri	Grand Pasha Hotel/ Kyrenia
‘‘Eko-Urbanism and Eco Neighbourhood Examples from Europe’’	NEU-AKM
Mendeley Kullanımı (Workshop)	NEU, Eğitim Sarayı
Eğiticinin Eğitimi	NEU-AKM
Flipped Learning Kursu	NEU-İnovasyon, Eğitim Sarayı
‘‘The Soul of Nicosia Streets’’ a workshop by Faculty of Architecture Students	Nicosia Walled City Trip, NEU-Faculty of Architecture
‘‘Wildlife Workshop on Best Practices for Conservation’’	Taşkent Nature Park, Cyprus Organized by Cyprus Wildlife Research Institute
Seminar: Resilient Beekeeping for Ecosystem Services Assurance	NEU, Library
Seminar: İklim Değişimi ve Kentsel Peyzaj	NEU, Faculty of Agriculture, Online
Seminar: Urban Landscapes	NEU, Faculty of Agriculture, Online
Symposium: Güncel Sorunlar Işığında Makale Yazımı	NEU, İrfan Günsel Kongre Merkezi

Scientific Papers:

Paper Title	Journal Name	Journal Category	Status
Evaluation of Environmental Worldview from the Perspectives of Undergraduate Students in N. Cyprus (Asilsoy B., Laleci S., **Yıldırım S**., Uzunoğlu K., Fuller Ö. Ö., 2016)	European Journal of Sustainable Development	Special Issue, Volume 5, Issue 4.233-241	Published
Environmental Awareness and Knowledge among Architecture Students in North Cyprus (B. Asilsoy, S. Laleci**, S. Yıldırım**, K. Uzunoğlu, Ö. Özden 2017)	International Journal of Educational Sciences	Volume 19, Issue 2-3, p. 136- 143	Published
Social Cohesion and Neighbourly Interactions within a Turkish Cypriot Community (Selin Laleci, Buket Asilsoy, **Sinem Yıldırım**, Özge Özden Fuller, 2018)	Journal of Near Architecture	April, Volume 1, Issue 2, 76 -86	Published
Positive Effects of Vegetation: Biodiversity and Green Roofs for Mediterranean Climate (**Sinem Yıldırım**, Özge Özden, 2018)	International Journal of Advanced and Applied Sciences	-	Published
Urban Resident Views About Open Green Spaces. A Study in Güzelyurt (Morphou), Cyprus (**Sinem Yıldırım**, Buket Asilsoy, Özge Özden, 2020)	European Journal of Sustainable Development	Issue 9,2 441-450	Published
Plant Biodiversity and Values of Cultural Landscapes in Cyprus (Özge Özden, **Sinem Yıldırım**, 2019)	International Journal of Advanced and Applied Sciences	Volume 6, Issue 11, p. 1	Published
Anthropogenic Marine Litter on the North Coast of Cyprus: Insights into Marine Pollution in the Eastern Mediterranean (Özge Özden, **Sinem Yıldırım**, Wayne Fuller, Brendan J. Godley, 2021)	Science Direct	Volume 165	Published

Green Roofs, Vegetation Types, Impact on the Thermal Effectiveness: An Experimental Study in Cyprus (**Sinem Yıldırım**, Çimen Özburak, Özge Özden, 2023)	Sustainability	Volume 15	Published

Other Article Pubblisher

Article	**Topic**
İnşaat Dünyası Köşe Yazısı	Peyzaj Mimarlığı Tasarımlarından Yeşil Çatılar
Mimarlık Fakültesi Dergisi	Green roofs: New Ecosystems to Support Species Diversity