LIVING WALLS AND GREEN FACADES:
A STUDY IN NICOSIA

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
OLA TARBOUSH

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Architecture

NICOSIA, 2019

OLA TARBOUSH

LIVING LIVING WALLS AND GREEN FACADES:
A STUDY IN NICOSIA

NEU
2019

LIVING WALLS AND GREEN FACADES:
A STUDY IN NICOSIA

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
OLA TARBOUSH

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Architecture

NICOSIA, 2019

Ola TARBOUSH: LIVING WALLS AND GREEN FACADES: A STUDY IN NICOSIA

Approval of Director of Graduate School of Applied Sciences

Prof. Dr. Nadire ÇAVUŞ

We certify this thesis is satisfactory for the award of the degree of Masters of Science in Architecture

Examining Committee in Charge:

Assoc. Prof. Dr. Buket Asilsoy	Co-supervisor, Department of Landscape Architecture, NEU
Assist. Prof. Dr. Çiğdem Çağnan	Supervisor, Department of Architecture, NEU
Assist. Prof. Dr. Lida Ebrahimi Vafaei	Committee Chairman, Department of Mechanical Engineering, NEU
Assist. Prof. Dr. Çiman Özburak	Committee Member, Department of Architecture, NEU
Assist. Prof. Dr. Nevter Zafer Cömert	Committee Member, Department of Architecture, EMU

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name:

Signature:

Date:

ACKNOWLEDGEMENTS

Thankfully for reach this stage of science and progress. I would like to extend my thanks and gratitude to my supervisor Assist. Prof. Dr. Çiğdem ÇAĞNAN and my co-supervisor Assoc. Prof. Dr. Buket ASİLSOY for their encouragement and assistance throughout my writing of the thesis, and to support me with all their positive energy which reflected on my work and gave me a big motivation to complete my thesis with enthusiasm. All thanks to the Faculty of Architecture at Near East University.

My sincere thanks and appreciation to my parents for their efforts and constant support me to reach these stages of science and success. Special thanks to my sister M. A. Rasha TARBOUSH and my brother M. A. Ali TARBOUSH for their encouragement me to continue this way. Finally, I dedicate this success as a support to my brothers Ahmad TARBOUSH and Ammar TARBOUSH for motivate them to reach higher scientific levels.

To my parents...

ABSTRACT

Cities are exposed to rising temperatures due to the increased development of construction and the lack of green spaces. Materials such as concrete and asphalt absorb the heat and store it during the daytime, and then release it at the night, leading to an increase in the temperature of the earth atmosphere. This phenomenon is called urban heat island (UHI). Therefore, the necessity of green architecture began to be well understood in the 21st century and new technologies began to be used in buildings such as “green walls”. The existing technology of green walls systems can maximize the building performance and can provide outdoor and indoor comfort and wellbeing with the help of functional, environmental, social and psychological benefits of plants. In addition to the lack of green areas, there is an increase of population also in north Nicosia and an intense urbanization has been experienced recently. It can be argued that there is a need for the applications of sustainable urban planning and design. So, a questionnaire was conducted in order to understand residents’ suggestions about possible implementation of green walls in the city. The obtained data were analyzed by using Statistical Package for the Social Sciences (SPSS). The results showed that participants are aware of the problems facing the city regarding the human activities. In addition, they suggested that the application of green wall systems is an important solution to reduce the air pollution, noise and temperature. Thus, the application of green walls on buildings can be a new strategy for urban rehabilitation and for making urban environments more sustainable in north Cyprus.

Keywords: Green buildings; green walls; living walls; green facades; sustainability; urban heat island

ÖZET

Kentler, yapısal alanlarının artması ve yeşil alanların olmaması nedeniyle artan sıcaklıklara maruz kalmaktadır. Beton ve asfalt gibi malzemeler ısıyı emer, gündüz depolar ve ardından geceleri serbest bırakır, böylece dünya atmosferinin sıcaklığının artmasına neden olur. Bu olguya kentsel ısı adası denir. Bu nedenle yeşil mimarinin gerekliliği 21. yüzyılda anlaşılmıştır ve "yeşil duvarlar" gibi yeni teknolojiler, binalarda kullanılmaya başlanmıştır. Mevcut yeşil duvar sistemlerine dair teknoloji, bina performansını en üst seviyeye çıkarabilir ve bitkilerin işlevsel, çevresel, sosyal ve psikolojik faydaları sayesinde dış ve iç mekan konforu ve refahı sağlayabilir.Yeşil alanların eksikliğine ek olarak, Kuzey Lefkoşa'da da nüfus artışı vardır ve son zamanlarda yoğun bir kentleşme yaşanmaktadır. Elde edilen verilen "Statistical Package for the Social Sciences" (SPSS) programı kullanılarak analiz edilmiştir. Bu bağlamda ülkede sürdürülebilir kentsel planlama ve tasarım uygulamalarına ihtiyaç duyulduğu ifade edilebilir. Bu nedenle, kent sakinlerinin olası yeşil duvar uygulamaları konusundaki önerilerini anlamak için bir anket yapılmıştır. Sonuçlar, katılımcıların, kentteki insan faaliyetlerine bağlı sorunların farkında olduğunu göstermiştir. Ayrıca, yeşil duvar sistemlerinin hava kirliliğini, gürültüyü ve sıcaklığı azaltmak için önemli bir çözüm yöntemi olduğunu düşünmektedirler ve Lefkoşa'daki binalara yeşil duvar uygulamalarını desteklemektedirler. Dolayısıyla yeşil duvarların binalara uygulanması, Kuzey Kıbrıs'ta kentsel çevrelerin daha sürdürülebilir hale getirilmesi ve kentsel iyileştirmeler için yeni bir strateji olabilir.

Anahtar Kelimeler: Yeşil binalar; yeşil duvarlar; yaşayan duvarlar; yeşil cepheler; sürdürülebilirlik; kentsel ısı adası

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

B.C: Before Christ

BLHI: Boundary Layer Heat Island

CLHI: Canopy Layer Heat Island

LWS: Living Wall Systems

SHI: Surface Heat Island

SPSS: Statistical Package for the Social Sciences

UHI: Urban Heat Island

CHAPTER 1
INTRODUCTION

There is an ongoing, rapid urbanization process worldwide (Vijayaraghavan, 2015). The vegetation areas are decreasing and built environments are increasing (Figure 1.1). Because of this mass urbanization, several problems such as global warming and climate change have emerged. Urban heat island (UHI) is one of these threats that the humanity has faced recently; it is the most documented phenomenon of climate change (Razzaghmanesh et al., 2016). As these catastrophes have been experienced, sustainable urban planning and design has become a solution. Within this framework, issues like green roofs, green buildings and green spaces have gained importance. Within the building level, the topics such as living walls and green facades that can be defined as vertical greening have also been among current scientific methods as solution (Santamouris, 2012).

Figure 1.1: Increase of built environment in north Nicosia (Wander Globe, 2017)

Vertical greening also called vertical garden, is covering vertical surfaces by vegetation. Living walls and green facades are among the main types of vertical greening. The vertical greening is convenient for urban environment because in the urban environment the vertical extent is numerous while the ground space is very limited. Vertical greening is a significant example of merging nature and structures. Green envelopes can be a variety of plants which grown-up in growing medium on a small quantity of it in order to solve environmental problems in urban areas and today's ecological issues (Perini et al., 2011).

The plants can resurrect the life to an old neglected building in the center of cities or be designed as new projects. Green envelopes have natural air purification properties, and they have cooling effect and appealing beauty so they are becoming more popular. Large amount of solar radiation can be absorbed by vegetation, where the effect of solar radiation can be reduced by plants evaporation, temperatures and humidity levels on green surfaces show lower than hard surfaces. Greening systems contribute to environmental sustainability where can rehabilitate the urban areas or rebuilt the buildings (Rakhshandehroo et al., 2015).

Current greening systems of building envelope are not covering the surfaces of building with vegetation. There are several greening systems such as green roofs and green walls. Plants induce a psychological wellbeing so the greening systems are of therapeutic effect and contribute to improving the image of cities. They work complementary acoustic and thermal protection. As a result of recent studies, the green walls contribute to ameliorate indoor thermal comfort and reduce the using of heating and cooling because of their ability to control heat losses and gains. At a city scale, the applying of green systems such as green roofs and green walls contribute to the introduction of vegetation in the urban context without occupying any area of street level (Pérez-Urrestarazu et al., 2015).

In fact, when applying the greening systems on building in urban areas, can contribute to urban biodiversity and ameliorate the urban environmental by storm water. The greening systems can mitigate of the heat island effects, reduce the temperature and ameliorate air quality, in addition to the environmental aspects, social and economic benefits. At a building scale, green wall systems contribute to building sustainability performance, where the plants has prospects to ameliorate the microclimate in winter and summer, where they have potential as a complementary insulation later in winter, and they provide shade and have potential as evaporative cooling effect in summer (Wilmers, 1990).

1.1 Thesis Problem

There are no enough green areas in cities where the urban development and shortage of green areas are noticeable. This process is causing air pollution and noise affecting the human health and it increases the need of energy sources for the thermal comfort in the buildings.

Urban heat island phenomenon is associated with urban areas, where building materials such as concrete and asphalt are considered as factors increasing heat of the surrounding atmosphere. According to the research, the vegetation has an important affect on decreasing urban heat island.

North Cyprus has faced a rapid urbanization in the last twenty years. North Nicosia is among these cities that had a fast urban development. As a result, with the lack of green areas, buildings increased leading to the construction materials such as concrete and asphalt in the city. This process is causing temperature rise in the atmosphere of urban environment of the city, noise and dust in addition; it also decreases human wellbeing and quality of life. Therefore it seems that, in order to solve problems in the city, sustainable urban planning solutions are crucial. Vertical greenings as living walls and green facades are among these sustainable solutions to mitigate the ecological problems also in north Nicosia.

1.2 The Aim of the Thesis

The rise in urban areas has led to an increase in the built-up areas of land at the expense of green areas and thus the thermal rise caused by buildings leading to urban heat island effect, so many research and experiments have been achieved to find solutions that help to reduce the urban heat island. Adding green spaces to the buildings either on horizontal surfaces such as green roofs or on the facades which are called vertical greening are among important solutions. It has many functional, environmental, social and psychological advantages and benefits for the urban environments.

Within this framework in this thesis, it is aimed at measuring north Nicosia residents' suggestions about the green walls systems on the buildings for any possible application on the new buildings or for the existing ones.

For this reason, firstly, the vertical greening forms and international examples will be explained in detail; in order to gather scientific information before the evaluation of living walls and green facades as vertical greening, urban heat island phenomenon will be examined. Afterwards, the perc**e**ptions of north Nicosia citizens' suggestions about the possible application of green walls systems are measured in this study.

1.3 Methodology of the Thesis

In this study, both qualitative and quantitative methods have been used. For the qualitative part of the study, literature review about the related topics such as urban heat island, green facades and living walls are fulfilled. After the literature review, for the quantitative part of the study, a user survey was conducted in North Nicosia with the residents to measure their perception about the application of green walls on the buildings.

1.4 Importance of the Thesis

According to the existing research, in the past studies, the green walls systems have been studied for different regions of the world. However green walls systems and their benefits have not been studied scientifically in North Nicosia. Therefore this thesis will study the urban heat island and the effect of vertical greening on it, and will collect the related data about green walls systems with the application requirements. In addition, a survey study with the participants in North Nicosia will be conducted in order to collect more specific data about the green walls application in North Nicosia.

1.5 Overview of the Thesis

This thesis examines green walls with its two systems that are green facades and living walls. It is limited with green walls systems and its benefits in the built environment. Within this framework, after examining urban heat island and defining the systems of green walls, a questionnaire is conducted with North Nicosia participants in order to understand their suggestions about application of green walls in the city. Therefore after introducing the topic in Chapter 1 as 'Introduction', in Chapter 2 urban heat island (UHI) is evaluated. Then in Chapter 3, the green walls systems are discussed, later in Chapter 4, the finding of the survey study entitled 'Measuring the perception of citizens about the application of green walls in North Nicosia' are displayed. In last chapter (Chapter 5), conclusion and recommendations are fulfilled.

Table 1.1: Thesis structure chart

CHAPTER 1	CHAPTER 2	CHAPTER 3	CHAPTER 4	CHAPTER 5
1.1 Thesis problem	2.1 Definition of urban heat island	3.1 Definition of green walls	4.1 The case of North Nicosia	Conclusion & Recommendations
1.2 The aim of the thesis	2.2 Factors affecting the formation of urban heat island	3.2 Systems of green walls	4.2 User survey method	
1.3 Methodology of the thesis	2.3 Solutions for alleviation the urban heat island	3.3 Requirements of green walls systems	4.3 Findings	
1.4 Importance of the thesis				
1.5 Overview of the thesis				

CHAPTER 2
URBAN HEAT ISLAND AND VEGETATION

2.1 Definition of Urban Heat Island (UHI)

In cities, the temperatures of air, surface and soil are almost higher than in rural areas. This phenomenon is known as Urban Heat Island (UHI), and it first came into use in the mid-20th century (City Metric, 2016).

Urban heat island refers to the relative warmth of air temperature near the ground. And the urban heat island form of the atmosphere indicates the difference in temperature between urban and rural areas. Heat island can indicate high temperature of the atmosphere with three forms; canopy layer heat island (CLHI), boundary layer heat island (BLHI) and surfaces heat island (SHI) forms. Air temperatures are measured for CLHI and BLHI by direct thermometers, while SHI is measured using remote sensors installed on satellites or aircraft (Priyadarsini, 2012).

In the 19th century, the first influence of the urban heat island has appeared in London, which had a main role with thinking and expand imagination about the urban heat island seriously that resulting to became the most prominent during the low-winds and pure-weather at night. The problems of UHI are appearing in the summer more than the winter, as the evaluating of UHI return to the periods that have arise of high temperatures (Ashie, 2008).

Urban areas are associated with thermal islands, where islands affect the population negatively, as high temperatures have a significant impact on human health. In addition, building materials such as concrete and asphalt are considered as factor that lead increasing the heating of the atmosphere, as well as the movement of population and transportation also has a role in raising the temperature of the atmosphere (Ichinose et al., 2008).

Heat island in its CLHI form density increases over time between sunset and down hours. The CLHI density is weak and negative to some extent during the day in some parts in the cities where heat is stored in building materials and the warming is delayed due to the shade which formed from high buildings so the heat island in this case is a cool island. Solar radiation affects surface temperatures in the day so the urban surfaces are warm thus the SHI density is large and very positive in the day and night. And the BLHI density is much smaller than the density of CLHI and SHI and it is positive in the day and night generally (Roth et al., 1989).

2.2 Factors Affecting the Formation of Urban Heat Island (UHI)

Urban heat island in the built environment is characterized by higher temperature than the countryside. Heat islands form by several factors like weather, geographic location, season and time of day , urban form and urban functions (Figure 2.1) (Action bio science, 2004).

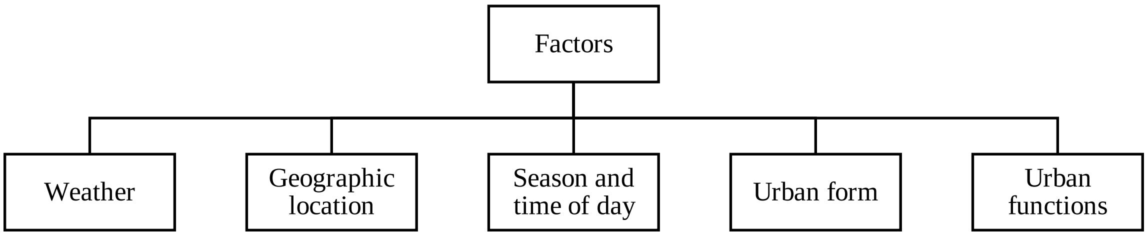

Figure 2.1: Factors affecting the formation of urban heat island

- **Weather**

The heat island is high in the calm weather and decreases with wind increasing; the heat island is affected by the climate (Action bio science, 2004). Greenhouse can effect on the UHI where in urban areas long-wave radiation can be trapped inside the polluted urban atmosphere. Anthropogenic heat generated from traffic, industrial combustion, air-conditioners and others also greatly affect UHI (WUWT, 2018).

It became clear that the Urban Heat Island (UHI) effect of urban areas was influencing air temperature records, which are used to value change of climate. It became important to remove urban pollution from weather station records to ensure their accuracy (City Metric, 2016).

- **Geographic location**

The heat island is affected by the geographical location and area topography as well as neighboring rural areas. The rural areas are characterized with humid air thus reducing the heat islands in the surrounding cities (Bernard et al., 2017).

- **Season and time of day**

Heat island degrees are different according to the times of day and night and are influenced by different seasons through the year. In the case of cities on the mid-latitudes, the heat islands in the summer are higher than in winter (Hertel et al., 2012).

- **Urban form**

The urban form includes building materials, building dimensions, spaces, green spaces and thermal properties (Action bio science, 2004).

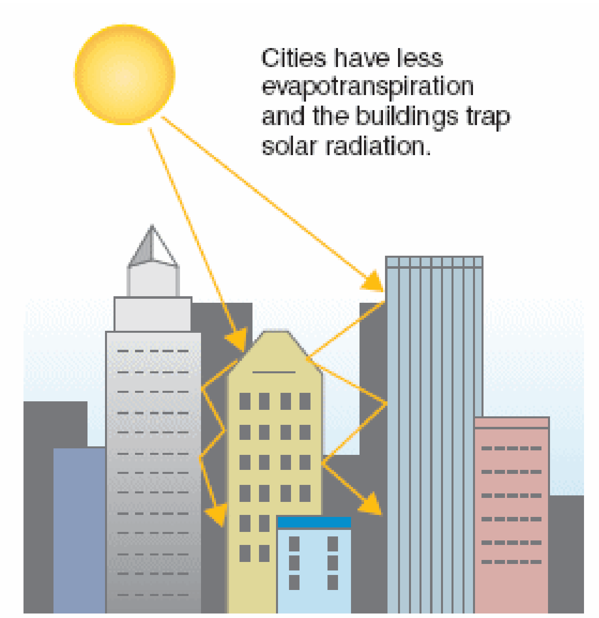

Figure 2.2: Absorption of sunlight by buildings in cities (Public health notes, 2018)

Building materials in the urban centers are impermeable and have large thermal capacity such as brick, concrete and asphalt. As shown in Figure 2.2 they can absorb the sunlight and store large amounts of energy in the day and then release them at night to the environment, leading to high air temperature, this called urban heat island phenomenon. Building materials in the cities are slow to cool and warm thus affecting the high degree of heat island. The surfaces in the cities are impervious and unable to store water so no available evaporation water contrary to the natural surfaces in rural areas (Memon et al., 2008).

As shown in Figure 2.3 below, the temperature can increase significantly in the cities because of high buildings that can prevent heat from dispersion, reducing air flow. In addition in cities, there is the lack of vegetation which can provide shade and evaporative cooling, increasing the amounts of concrete and asphalt that absorb the heat and store it. Moreover, in cities there is a warming caused by human activities (Global Change, 2009).

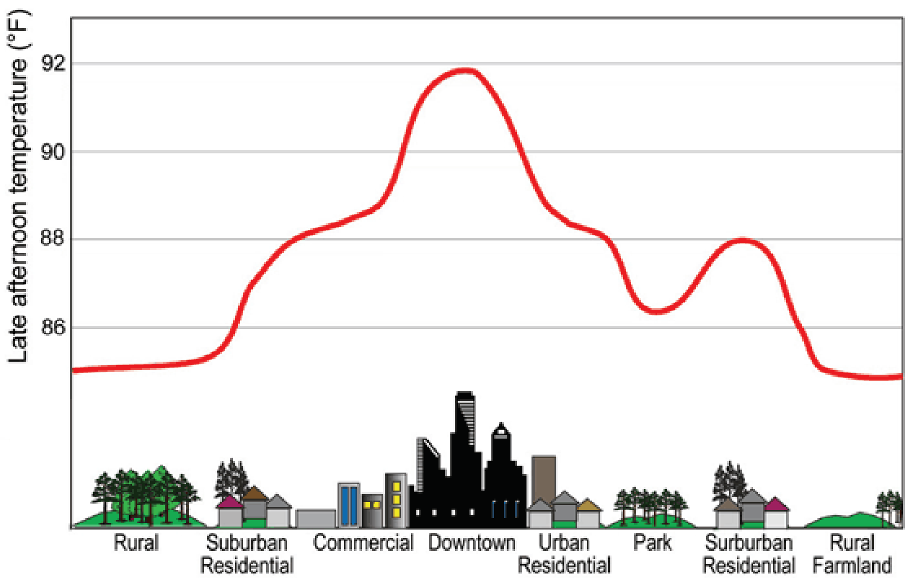

Figure 2.3: Chart of differences in temperature rise between rural and urban areas (Global change, 2009)

Building materials in urban areas have higher heat capacities and store more internal energy while in the rural areas the vegetation has lower heat capacities and cannot store as much internal energy. Temperature inside a city stays higher at night while it decreases more quickly in rural areas cooler at night (Linked in, 2013) (Figure 2.4).

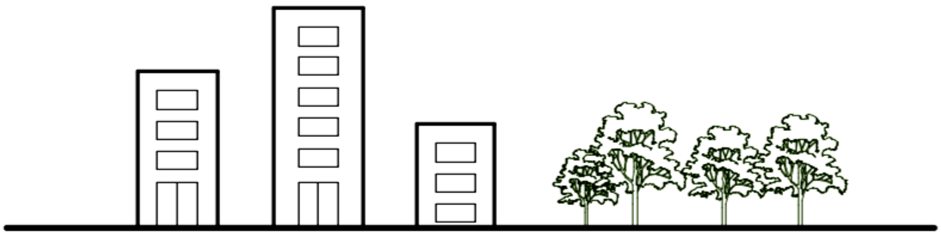

Figure 2.4: Urban area and rural area

- **Urban functions**

Cities have multiple functions and therefore pollutants are increasing in the atmosphere. The use of energy leads to high temperatures. Also the heat generated by traffic (Figure 2.5), human activities and fuel combustion all have a role in the rise of heat island. The heat island in summer increases, and as the need for air coolers rises, and thus it leads to the pollution in the atmosphere (Taha, 1997).

Figure 2.5: Traffic in the North Nicosia (Yeni duzen, 2015)

The urbanization causes the need for expansion of trade thus increasing transport and congestion in traffic. The focus is often on the development of urban centers and hence the increase in transport that negatively affects the environment and the surrounding atmosphere thus climate change. The transport has many beneficial effects on society but it also has negative effects on the environment and the car policy can cause many problems like the very vast increase of fuel consumption thus increasing urban pollution significantly. Vehicle emissions cause the formation of urban smog and global warming.

All of these conditions play an important role in the phenomenon of urban heat island that corresponds with the increasing of air temperature between the city and its surrounding space (Louiza et al, 2015).

2.3 Solutions for Alleviating the Urban Heat Island (UHI)

To mitigate the rise of heat island it is difficult to make major changes to urban surface engineering. Such as the spacing between buildings is practically impossible but there are other strategies, like the use of lightweight and light-colored materials on the facades of buildings and increase of vegetation in the urban area by the application of greening techniques on the buildings surfaces or the increase of urban green spaces (Figure 2.6). The use of plants is a biological solution that contributes to limit urban heat where vegetation provides shade and helps cool air through evaporation (Rosenfeld et al, 1995).

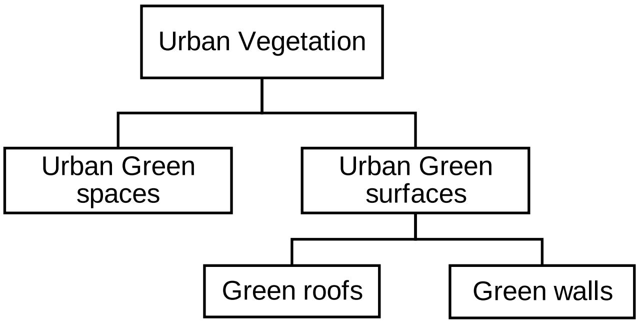

Figure 2.6: Methods of vegetation

According to monitoring the urban heat island in many areas of New York City, 2 °C difference of temperatures have found between the most vegetated areas and the least vegetated areas, that was because of the man-made building materials that substitution of vegetation (Susca et al, 2011).

Providing shade by planting trees around the buildings reduces the sun’s rays on the walls and ceilings and protects them from high temperatures (Figure 2.7), thus reducing the need for cooling energy consumption (Sailor, 1997).

Figure 2.7: Providing shade by planting trees around the buildings (Dezeen, 2018)

2.3.1 Urban green spaces

Urban green space in a city means all vegetative surfaces starting from building level up to the urban level. These green spaces constitute Urban Green Infrastructure of the city (Anguluri and Narayanan, 2017). Green roofs, playgrounds, neighborhood parks, urban parks, botanical gardens, urban forests, urban agriculture lands are all among urban green spaces. These urban green spaces can be classified according to their functions or usage types. According to usage type urban green spaces are classified in four main titles as follows:

- **Public Spaces:** are open and green spaces that benefit the whole community. All public parks and squares and streets etc.
- **Semi public Spaces:** are open and green spaces that benefit a particular segment of the citizens. Military lands, schools, campuses etc.
- **Semi private Spaces:** are open and green spaces that benefit the community partially. All mass housing sites etc.
- **Private Spaces:** are the spaces that are privately occupied, do not benefit the whole community. Residential green areas etc.

According to the functions of urban green spaces, they are classified as follows:

- **Dwelling unit urban spaces:** Residential building greeneries, roof gardens etc.

- **Neighborhood unit urban spaces:** Mass housing greeneries, neighborhood parks.
- **Quarter unit urban spaces:** Sport fields and district Parks etc.
- **City unit urban spaces:** City parks, zoo gardens, botanical parks, greenery around the vehicular roads and walkways, cemeteries and coastal landscape sites.

Trees provide shade in rural areas and promote evaporation which limits the warming of the air. The urban areas that characterized with ambient temperatures higher than the temperatures in rural areas, is called heat island. Greenery in urban area helps mitigate the urban heat island effect through trees and plants that work as barrier for the sunlight from concrete surfaces, where trees and plants absorb the sunlight for growth. Vegetation helps to purify the air and reduces excess smog by filtering out air pollutants. Deciduous trees have great effect throughout the year where in the summer they work to protect the building and the environment from high temperatures through its leaves that absorb sunlight and thus reduce the cost of cooling devices for buildings. In the winter, leaves of these trees fall, so helps to warm the building by absorbing the sun's energy by building materials (Terry, 2006) (Figure 2.8).

Figure 2.8: Urban vegetation and green spaces (Journalist's resource, 2015)

Buildings and roads make up a large area of city. They store large amounts of energy during the day and lead to higher temperatures at the night, which increases the urban heat island. If trees are planted in these places, they can greatly reduce the rise of heat islands in urban areas. Planting trees in these places also leads to shading of vehicles and thus reduces steam emissions from evaporation of fuel, which increases the rate of ozone formation. Increasing the green spaces in urban design in parks contributes to the cooling of the urban climate. These strategies contribute to saving energy costs for the owner and also benefit in improving air quality in the urban environment (Sailor, 1997).

2.3.2 Urban green surfaces

The building envelope forms a fundamental thermal barrier between the exterior and interior of the building and contributes to the conditions necessary for thermal comfort within the building. Also the building envelope has a role in reducing the use of energy needed to heat and cool a building. It is important to consider design elements for making a cooler building envelope so radiating less heat into the surrounding environment in order to lessen the environmental impacts of the building and reduce the urban heat island. Cities currently have great challenges in managing and reducing human influences on the environment. Where about the half of the world population lives in urban areas. The rapid rate of urbanization and enormous increase in the size of urban areas contribute highly to climatic differences between urban and rural areas. High temperatures in urban areas contribute significantly to global warming (Perini et al., 2012).

The synthetic materials made by human that are replacing natural vegetation in urbanized zones absorb the natural radiation then release it as heat thus lead to urban warming. The building can use about a third of the world’s energy need so it is necessary to consider sustainable design elements that contribute for cooling building envelope. It is also needed to limit the building effect on global warming and reducing its effect on the urban heat island. Implementations for sustainable design like applying reflective roofing and reflective walls on building in hot and humid climates can contribute to mitigate urban heat island because they can reflect more sunlight and absorb less heat. Green buildings contribute to reducing the energy needs of the building as the surface temperature decreases dramatically when the bio-inspired retro-reflective facades are applied on the building (Uponor, 2016) (Figure 2.9).

Figure 2.9: Applying the greening on building surfaces (Susty vibes, 2015)

Studies have proven that the greening of building envelope contributes to noise reduction. Where the study of the effect of green walls and green roofs at residential urban areas showed the decrease the spread of traffic noise and the results showed that the green surfaces provide a high potential of cooling. And that the green walls are more effective than the green roofs when applied to narrow city canyons. The integration between green roofs and green walls shows more interest (Renterghema et al., 2013) (Figure 2.10).

Figure 2.10: The integration between green roofs and green walls (Killemsetty, 2014)

- **Green roofs**

Green roofs are nothing new. The first one was constructed since 500 B.C. The hanging gardens of Babylon are one of the seven wonders of the ancient world (Figure 2.11). Centuries later, Europeans used sod to insulate the roofs in order to keep homes cool in the summer and warm in the winter. Today, Germany is the leader in green roofs where 12 percent of all the roofs of its buildings are green. This number is growing by 10 to 15 percent each year (Utitily, 2018).

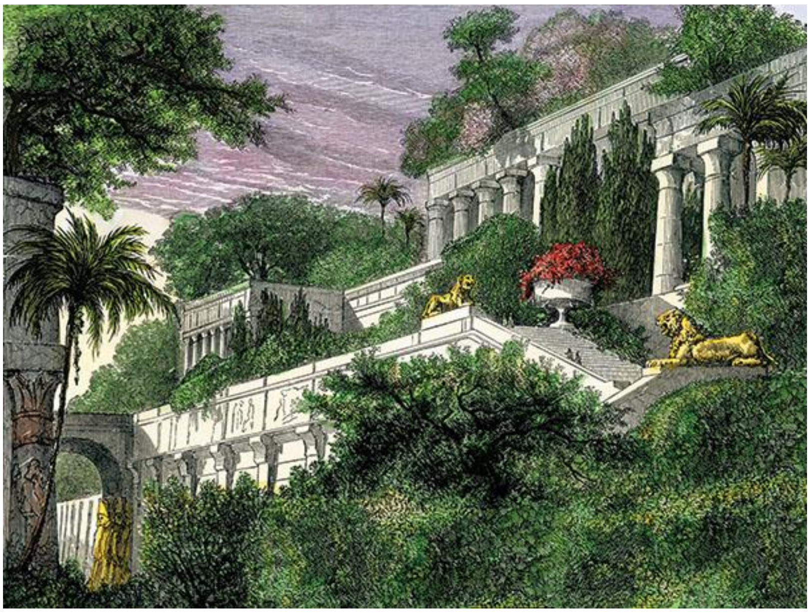

Figure 2.11: Hanging gardens of Babylon in ancient times (Utitily, 2018)

Increase of using concrete in cities leads to a shortage of green spaces. Application of green surfaces on buildings becomes needed because of the lack of green spaces. Green roofs are sustainability solutions that contribute to reducing the impact of urban heat island. According to a research, the green surfaces were applied in the city of Colombo, the capital of Sri Lanka, and the results showed a significant reduction in the temperature of the city. Green roofs have many benefits like improving the performance of buildings to save energy to reduce rainwater runoff, increasing biodiversity, filtering water and air, in addition, elongating the life span of roofs and mitigating the urban heat island (UHI) effect (Wijerathne et al., 2010). The design of roofs in Nan Yang Technology University is an example of green roofs application (Figure 2.12).

Figure 2.12: Green roofs in Nan yang Technological University School of art, design and media (News detail, 2015)

The green roof as a vegetated roof provides urban greening for environment. In recent decades, the use of the green surface has become common in Europe and North America where pilot projects for the green roof have been built in several cities. The green roof contributes to support the vegetation and can be flat or sloped. Soil depths can range from a few centimeters to 20 cm, for a dense roof of prosperous plants. Soil depths can be up to 1 meter or more for denser garden roofs. Green roof systems contribute to improve rainwater management, reduce the rate of energy needs for cooling, decrease urban heat island effects (Dvorak et al., 2010). Greening the roofs of buildings contributes to the reduction of thermal accumulations over the building as the vegetation uses a large amount of energy for evaporation. This technique is called Green roofs (Sailor, 1997).

- **Green walls**

Green walls are a modern method of greening and can integrate living nature with urban environments. Green walls can be interior or exterior, free-standing or wall-attached. It has many benefits in addition to aesthetic benefit (Figure 2.13) (Naava, 2017).

Figure 2.13: Green walls are attractive elements (Azkorra et al., 2015)

Green walls have two systems; green facades and living walls. In green facades, the plants are rooted in the ground and need long time for covering the surface (Naava, 2017) (Figure 2.14).

Figure 2.14: Green facades take time to get full coverage (Earth, 2016)

Living walls include the growth medium of plants in its structural system or on the surface and it contributes to the quick coverage of the surface (Figure 2.15). The green walls are characterized by many benefits including air purification and ambient temperature reduction in addition to the feature of decorating the urban environment built from concrete and bricks. Moreover, studies have shown that nature positively affects the psychological state and reduces tension because our bodies are automatically affected by nature and this is called the concept of "Biophilia" (Naava, 2017).

Figure 2.15: Living walls covering building (Pérez et al., 2014)

2.4 Green Surfaces on Buildings and Vegetation

The buildings normally require large amounts of energy, water and raw materials for design, construction and maintenance. It leads to generating enormous quantities of waste causing water and air pollution. Whereas green buildings is the only solution where creating healthier and more resource efficient models of construction, renovation, employment and maintenance (Radwan et al, 2015).

A building is green when it helps reduce the negative effect it leaves on the urban environment and on the health of its residents. The use of sustainable materials and resources, that have a minimal environmental impact and low embodied energy, are key elements in the green construction, as is the efficacious use of water by appliances, the grey water recycling, and the reuse of rain water for vegetation (Sun power, 2017).

The definition of green is relatively simple, while the sustainability has a more accurate meaning derived from the term “sustainable agriculture” which is the production of any plant or animal products using farming techniques that protect the environment, public health, human communities and animal welfare. According to the Agency of Environmental Protection in United States, sustainability creates and maintains the conditions which humans and nature can be providing the social, economic and other requirements of present and future generations. Sustainable products reduce the negative effects on the environment by using environmental products; which are either completely renewable or sustainably harvested. Sustainably harvested source materials are gathered in a way that do not affect the surrounding environment and air negatively. As an example, Illawarra Flame House created by University of Wollongong in New South Wales, Australia (Figure 2.16), a 1960s suburban fibro home designed by Australian students to attain net-zero energy consumption, won the 2013 world's biggest energy competition (Sourceable, 2015).

Figure 2.16: Illawarra Flame House created by University of Wollongong (Sourceable, 2015)

The integration of greenery with building envelope is commonly considered as an aesthetic element and a qualitative improvement of urban climate. The applying of vegetation on building provides shading effect - lower absorption of solar radiation on the wall and creates different conditions for heat convection on the building surfaces (Grabowiecki et al., 2017). Although green roofs can include both solar and vegetation, most recent regulations specifically recommend greening of the roofs (Utility, 2018).

In this chapter, urban heat island, its effect on the urban areas, factors affecting the formation of urban heat island and solutions for alleviating the urban heat island have been evaluated. Within this framework, next chapter will investigate the green walls systems.

CHAPTER 3
APPLICATION OF GREEN WALL SYSTEMS

3.1 Definition of Green Wall

The connotation of green walls refers to the greening systems of vertical surfaces such as, walls, facades, partition walls, blind walls, etc with plants, including the growing of plants on, up or within the wall of a building. The green walls can be divided into three main types according to the species of the plants, types of growing media and construction method. These three types are wall-climbing green walls, hanging-down green walls and module green walls (Sheweka et al., 2011).

A. Wall-climbing green wall

This type of green wall depends on climbing plants that grow in soil on the ground or in planted box and it needs minimal supporting structure for its construction. The wall-climbing type is very common and traditional method. The climbing plants cover the walls of building naturally and they are grown upwards on trellis or by other supporting systems (Sadeghian, 2016) (Figure 3.1).

Figure 3.1: Wall-climbing green wall (Green walls, 2017)

B. Hanging-down green wall

This type of green wall depends on plants with long hanging-down stem where grow in soil into plants box on every storey. The construction of hanging-down green wall needs planted boxes and supporting structure that built according storey. The hanging-down type is also another common method of green walls. It can easily form a complete vertical green belt on multi-storey building through planting at every storey (Sadeghian, 2016) (Figure 3.2).

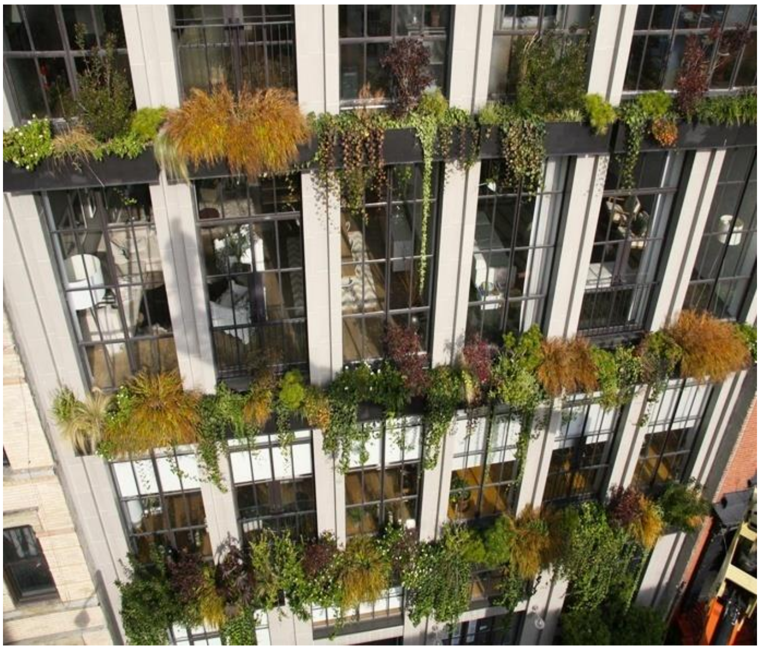

Figure 3.2: Hanging-down green wall (6sqft, 2014)

C. Module green wall

This type of green wall depends on short plants where grow in lightweight panel of growing media such as compressed peat moss. Construction of this type of green wall needs supporting structure for hanging or placing modules built on facades. The module type is the most common method of green wall. In addition it is the most expensive type and it requires more intricate planning and design considerations (Jonathan, 2003) (Figures 3.3 and 3.4).

Figure 3.3: Module green wall, detail (Building review journal, 2015)

Figure 3.4: Module green wall (Japan for sustainability, 2011)

The plants in urban areas have quantitative benefits with financial returns, and they have social, environmental and aesthetic benefits. Plants in urban areas contribute to air cooling through two mechanisms, direct shading and evapotranspiration. Plants that provide shade for the building are used in green wall systems, shade depends on the density of these plants, leading to decrease in temperature in the building and surrounding environment. Plants especially filter airborne particles through their leaves and branches. During photosynthesis, plants absorb gaseous pollutants and release oxygen into the atmosphere, helping to improve air quality (Safikhani et al., 2014).

A green wall has a water retention capacity that helps control water flow from the surfaces and protects cities from floods that may occur as a result of heavy rains and the inability of drainage to store and distribute storm water in the ground. The impurities which existing in rainwater such as nitrogen and phosphorus can associate with the types of soil, then plants roots absorb these impurities for growth, thus reduce the impurities of the soil and help filtering the water before it enters to the groundwater aquifer. Plants which cover the walls of building work as a sound barrier and reduce noise in the urban areas where the plants absorb sound frequencies (Rakhshandehroo et al, 2015).

3.2 Systems of Green Wall

There are two main systems of green wall (Figure 3.5). These systems are green facades system and living walls system. Green facades depend on climbing plants that grow along the wall covering it, while living walls support a variety of plants and help create a uniform growth along the surface (Manso et al., 2015).

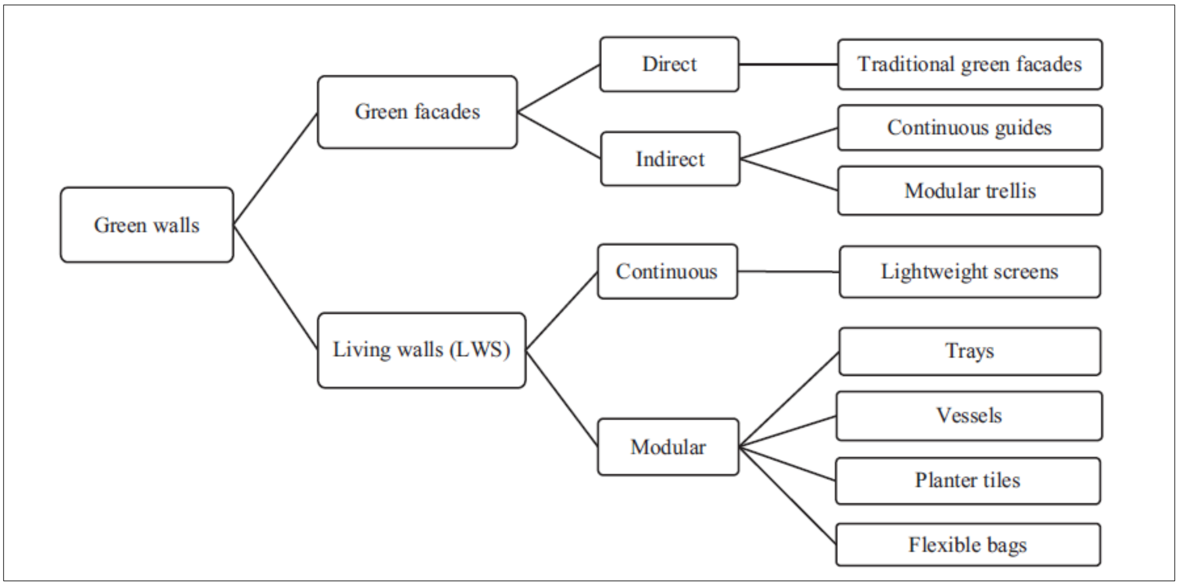

Figure 3.5: The green wall systems classification (Manso et al., 2015)

3.2.1 Green facades system

The green facades system adopts two principles of plants, climbing plants that grow up on the vertical surfaces like traditional examples, and plants hanging along the wall which grow-down on the vertical surface as suspended at a certain height (Köhler, 2008).

Green facades can be categorized as direct or indirect. In the direct green facades the plants are directly on the wall as in traditional green facades where plants are rooted directly in the ground. The direct type of green facades depends on climbing plants that grow along the wall (Figure 3.6) while the indirect green facades include a supporting vegetation structure, and the facades are double and form a space between the wall of the building and the vegetation, as in the new solutions of green facades (Perini et al., 2013) (Figure 3.7).

Figure 3.6: Applying of direct green facades on Bratislava Slovakia building (Pixabay, 2016)

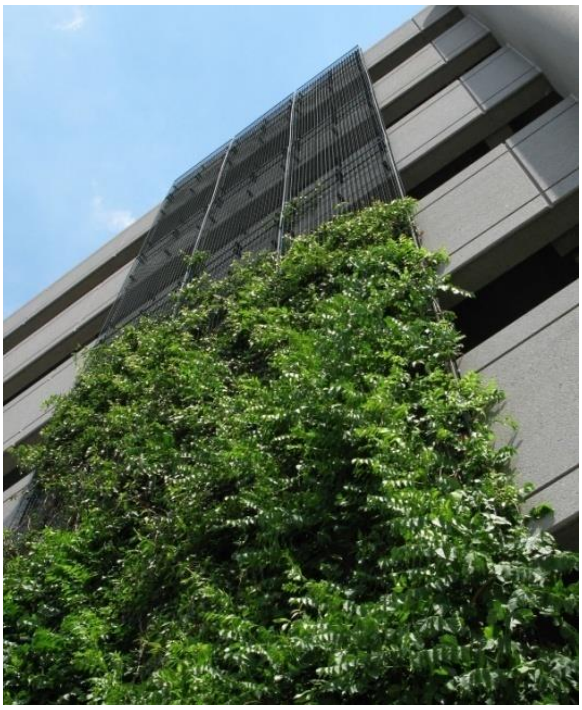

Figure 3.7: Example of indirect green facades (Best Design Gallery, 2012)

3.2.2 Living walls system (LWS)

Living walls system is a modern system of covering the facades of buildings. It allows quick coverage of large surfaces and supports the growth of plants consistently along the vertical surface, which helps to integrate green walls that envelope the high buildings. Living walls can incorporate a variety of plants and build all types of buildings. According to the method of application, living wall systems can be classified into continuous and modular. Continuous living wall systems depend on the application of lightweight and permeable screens in which plants are inserted individually. Continuous LWS are also called as vertical gardens (Ottelé et al., 2010) (Figure 3.8).

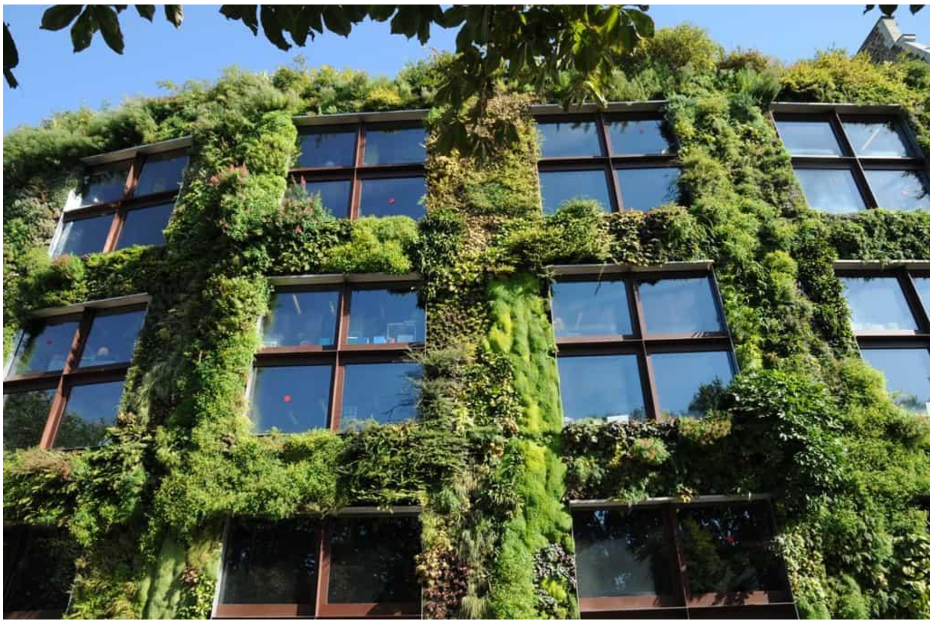

Figure 3.8: Example of continuous living walls systems (JLL, 2017)

Modular living wall systems are elements either supported by a supplementary structure or constant directly on the vertical surfaces, these elements have a specific dimension. Elements of the living wall systems include development media that contribute to growth of plants (Lu et al., 2015) (Figure 3.9).

Figure 3.9: Example of modular living walls systems (Vertology, 2015)

3.3 Requirements of Green Wall Systems

According to the related literature review, the green walls at the last years have become an interested method for urban areas which don’t have enough green spaces. They have an important role in urban design, so there is a need to understand the techniques and requirements of their installation. Green wall systems are related to a set of elements that have a role in the system's ability to adapt to all types of buildings and contribute to improving the thermal performance of the building (Tamási et al., 2015).

3.3.1 Supporting elements

The direct type of green façade depends on the climbing plants that grow along the wall. However there will be a danger of falling, because the climbing plants are not supported on the wall. But in the indirect type of green facades, the facades are double, forming a space between the wall of the building and the vegetation; plants are fixed on the support structure either continuous or modular. So this support structure helps to avoid the fall of the plants where the resistance is greater for natural factors such as rainfall and wind. The indirect green façades are often applied on modular trellis that supports plants individually in units each includes pot filled with a supporting structure. This can be aesthetic feature where the modular trellis can be applied in the form of curves and using different plants between units and distributed on the wall at different heights giving a new and three-dimensional shape of the green façade (Elgizawy, 2016).

Living wall systems depend on a frame includes the plant support elements. In continuous living walls, the frame is fixed on the wall of the building and has a base that protects the wall from moisture, this base are covered with screens fixed on it, these screens are permeable, flexible and root proof to facilitate the formation of pockets by cutting it and unloading to insert plants in an individually (Bribach et al., 2012).

Modular living wall can be in different shapes and structures (trays, vessels, planter tiles and flexible bags). Modular trays living wall consists of a set of modules, each of which contains interlocked system on the sides to enable bonding. These modules are made of lightweight materials such as plastic or metal sheets like stainless steel, these modules have a front cover that prevents the fall of plants. It can be attached to the wall of the building in a horizontal or vertical frame through hooks or mounting brackets located on the back surface (Kmieć, 2015) (Figures 3.10 and 3.11).

Figure 3.10: Grid of trays (Plantups, 2016)

Figure 3.11: Example of modular trays living wall (Plantups, 2016)

Modular vessels living wall are made of polymeric materials, it is characterized by the possibility of installing a group of plants in separate elements and each element contains a type of plants in a row, it gives a special character to the wall of the building (Deutsch-Aboulmahassine et al., 2009) (Figure 3.12).

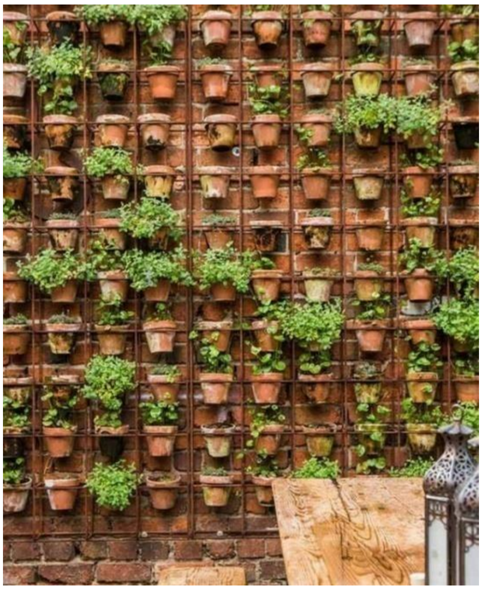

Figure 3.12: Example of modular vessels living wall (EPIC Gardening, 2014)

Modular planter tiles living wall consists of a flat back that they are installed by it on the wall of the building where it can be glued to the wall vertically or installed by mechanical machining, and a front part is to farming plants individually (Figure 3.13). These tiles are connected to each other by juxtaposition and are made of light materials such as plastic or ceramics (Bribach et al., 2012).

Figure 3.13: Example of modular planter tiles living wall (Urban gardens, 2013)

Modular flexible bags living wall is made of flexible plastic material filled with growing media and the plants are inserted into them, these bags can be attached individually to the wall or in modular form (Deutsch-Aboulmahassine et al., 2009) (Figure 3.14).

Figure 3.14: Modular flexible bags living wall (Home grown, 2010)

3.3.2 Growing media

In the direct green facades and continuous green facades there is no need to growing media, but the modular green facades need growing media which are lightweight, and the elements are suspended individually on the wall of building and each element is adapted to the plant species selected as appropriate to the environmental conditions. In the continuous living wall systems there is no need to growing media, they use lightweight absorbent screens which cut to form pockets and inserting plants in them individually. The continuous LWS depend on hydroponic method. They need permanent supply of water and nutrients because of the lack of substrate, where in the hydroponic systems the plants can grow without soil by wet screens as part of the irrigation systems, where the nutrients for growth of plants are provided through irrigation water that are transmitted to these screens via irrigation pipes (Haas et al., 2011).

Modular living wall systems of all shapes (trays, vessels, planter tiles and flexible bags) can be filled by growing media which help plant roots to reproduce and grow. Growing media can be in the form of organic and inorganic compounds or shall be a layer of inorganic substrate, often in the form of foam for light weight. In most living wall systems the base substrate is a light mixture of granular materials, expanded or porous to achieve greater water retention capacity. This substrate contributes to plant growth in addition to nutrients such as (organic matter mixed with inorganic fertilizers). In some modular living walls systems are inserted growing media into geotextile bags either be fully cover the unit to assist in the introduction of a group of plants or these bags can be individual to insert the plants individually (Jørgensen et al., 2014).

3.3.3 Vegetation

Vegetation relates to a range of factors, such as the characteristics of the building on which the green wall is applied, the surrounding conditions and the climatic conditions of the area. These factors, in addition to plant type, play a role in the longevity of vegetation, where there are many plant species that can be used for greening the building. The most common are climbing plants, which are the cheap greening solution. It can be divided into two types, depending on the type of leaves; plants with evergreen leaves and deciduous plants. Evergreen plants maintain their leaves throughout the year. Deciduous plants lose their leaves during the fall, resulting in an optical change throughout the year (Adams, 2009).

Climbing plants can be self-supporting as they can bind themselves to the wall automatically (root climbers and adhesive-suckers), they may need a support structure such as a trellis to extend across the entire wall (twining vines, leaf-stem climbers, leaf climbers and scrambling plants). Climbing plants differ in their ability to extend in different distances depending on their species, some achieve an extension of 5-6 m, others 10m and others achieve about 25m, and they take 3-5 years to fully cover the wall. Surface covering speed varies depending on temperature variations, climatic conditions, rainfall variation throughout the year, and leaf density (Perini et al., 2012).

Living wall systems contribute to the development of the green wall concept and add an aesthetic feature. They enable the greening of a surface by combining a different set of plants and using different patterns in color, texture, density and growth. This helps integrate different types of plants such as grasses, shrubs and others while maintaining their water and nutrient requirements. Water systems can assist in the selection of vegetation according to the aesthetic effect, where a wider growth of different groups of plants can be achieved. They can be seeds or cuttings or grown plants, taking into account the importance of analyzing the development of plants in terms of color, flower shape, leaf density and global plant composition, requiring an appropriate irrigation system and special nutrients for plant development (Adams, 2009).

In order for a greening system achieving the sustainability objectives, local plants adapted to climatic conditions should be selected and the vegetation with a low irrigation needs. Modular living wall systems add feature to use succulent carpets instead of shrubs and perennials plants, where is possible to apply a range of plants that are light weight, low maintenance, drought tolerant and thus reduce the need for irrigation systems. Continuous and modular living wall systems are the new concepts of green wall that contribute to the integration of vegetables and aromatic herbs in the green façades; they are suitable solutions for cities with low agricultural land and this gives more functional possibilities for the greening system (Inkmason, 2015).

The plants of outdoor vertical or horizontal garden are periodically exposed to pests and insects, therefore it is essential to protect the plants and surrounding environment from insects. If the plants are healthy, they can survive for a while, but they can not remain protected forever. Therefore, plants should be monitored and inspected regularly and pesticides should be used when necessary, taking into account the use of natural pesticides instead of chemical pesticides (Lush living walls, 2018).

3.3.4 Irrigation and drainage

Plants need large amounts of water for the success of green wall, so sources of water that are not suitable for drinking must be used for irrigation. Plant needs for water are estimated by plant type, vegetation density and ambient climate. High density plants require irrigation with a high rate of water at least in high-temperature months, if not in year-round, depending on the environment and the exposure of façade to the sun. Therefore, recycled water should be used as much as possible in irrigation. The water drainage system must be effective so that it filters the surface and groundwater of the green wall to ensure the integrity of the building's structural integrity and in addition the plants must not be negatively affected by the increase in water (Loh, 2008).

The drainage system should be suitable for the types of climbing plants selected for greening the facades. Drainage holes must be provided in the side of container in which they are higher than the level to which the container is filled in order to maintain the top of growing substrate without freezing water. Drip trays can be putted under the container to collect water that flows from the base of the growing container. Green wall systems contain two types of irrigation systems: recirculation and direct irrigation. Recycled irrigation systems rely on recycling of water so that a water tank is regularly filled near the green wall and a supply of water is supplied from the reservoir to the green wall so that the water is properly distributed to the plants. Naturally, by gravitational effect, excess water will flow downwards so the drip trays are placed under the green wall to collect the water and return them to the reservoir thus this water can be used for irrigation several times, while maintaining the cleanliness of the tank and water purification and removal of impurities from them regularly to avoid germs and diseases that may affect the plants and thus polluting the surrounding environment (Franco-Salas et al., 2014).

The direct irrigation system does not contain a reservoir, but the water reaches directly from its main source so that the water is directed to the green wall and distributed to the plants. The surplus water that flows from the green wall with gravity downwards is directed directly to the sewage and is not recycled. A time controller is turned on the green wall that tells the irrigation system about the time of shut down and opening. The irrigation system can be divided into several sections on the green wall that are suitable for different types of plants and their different irrigation needs. Because the large green walls can contain different types of plants, some of which require more water than others. There is a third type of irrigation, a manual irrigation, which depends on a portable tank on wheels and the person who takes care of the green wall gives water to plants, and this method can be used for small walls (Medl et al., 2018).

Modular and continuous LWS require water supply to plants through irrigation system. Irrigation water can be injected with fertilizers and plant nutrients to improve the development of vegetation. Continuous LWS depend on permeable screen distributing water and nutrients uniformly across the entire surface. Modular LWS in its trays form in the top face of module include a recess to insert the irrigation tube, and there are several holes in the recess of trays for watering the growing media by gravity, and in trays bottom there are drainage holes to allow surplus water to irrigate the modules underneath. The irrigation tubes and connectors are produced by different materials such as piping thermoplastic; rubber; plastics; silicone and irrigation hose, and they contain different outputs such as pipe; sprinkler; drip and holes with allocation and density adapted to the plants irrigation needs. The irrigation system can also contain a filtration system in order to prevent lockage of the tubes (Manso et al, 2015).

3.3.5 Green wall maintenance

The maintenance of a living wall should be no more exhausting than the maintenance of landscape planting. The living wall that is placed high on a building can be designed as a removable screen in order to reduce the use of lift equipment to maintain it. The early understanding of living wall in the building design can greatly decrease maintenance costs. The maintenance regime should be established well-understood at the designation stage in order to improve the likelihood of survival of the wall (Loh, 2008).

Regarding the maintenance of green walls, including routine and special ones, involves a range of processes: these processes are, vegetation growth monitoring; irrigation equipment check; in-service control of materials and components; number of pruning planned per year. While special maintenance is included, anti-parasitic treatments; material and components repair and replacement and irrigation system repairs (Giordano et al., 2017).

3.3.6 Green wall installation

The installation of climbing species of green facades is very cost-effective but this type of green wall systems displays difficulties in ensuring the sustainability of vegetation. Some types of climbing plants require guidance during growth in order to ensure full surface coverage. In addition, climbing plants may affect the surface of the building because its roots enter the cracks and destroy the surface, to avoid this, it is possible to plant the plants at different altitudes on the surface so that their load is distributed on the surface and allow for the replacement of unsuccessful plants. Modular LWS in some types allow disassembling each module individually. The other types include a removable front cover for maintenance of the green wall or replacement of plants. Modular LWS reduce installation, maintenance and replacement problems. Continuous LWS allow the presence of a variety of plants in the construction of the green wall and can be lighter compared to modular LWS. Continuous LWS need a permanent supply of water and nutrients, which leads to a higher rate of irrigation demand and maintenance costs. It is important to understand the different green wall systems in terms of composition, key characteristics, cost and maintenance requirements in order to choose a system suitable for the building's characteristics and surrounding climatic conditions where each green wall system has its own advantages and disadvantages (Manso et al., 2015).

3.4 Applications of Green Wall Systems in Different Climates

Climate is the most influential factor in the study of green walls. In the hotter and drier climate, the effects of the green coverage on the urban temperature are more significant. The green surfaces can be effective in the humid climates for urban temperature reduction, especially when both walls and roofs are green. The greening of surfaces contributes to absorb more solar radiation and leads to higher reduction of temperature. So, the hotter and drier the climate, the higher is the efficiency of the green wall as well as temperature reduction. This degree of temperature reduction can result in a significant annual saving.

The LWS creates more stable relative humidity in the air layer near the wall surface without increasing the relative humidity of indoor air (Zarandi and Pourmousa, 2018).

The huge influence of weather conditions must be considered for the potential of vertical greening systems with regards to saving energy in buildings. In addition, the effect of climate on the thermal performance of building, the effect of weather on the plants' growth and on their physiological responses must also be determined. Thus the thermal behaviour of vertical greenery systems will also depend on weather conditions which consequently will affect the results. According to many researches, the Köppen Climate Classification System can be suggested to be used for the appropriate consideration of the climate for the vertical green systems (Pérez et al., 2014). The Köppen Climate Classification System, period (1980-2016) is displayed in the Figure 3.15 below.

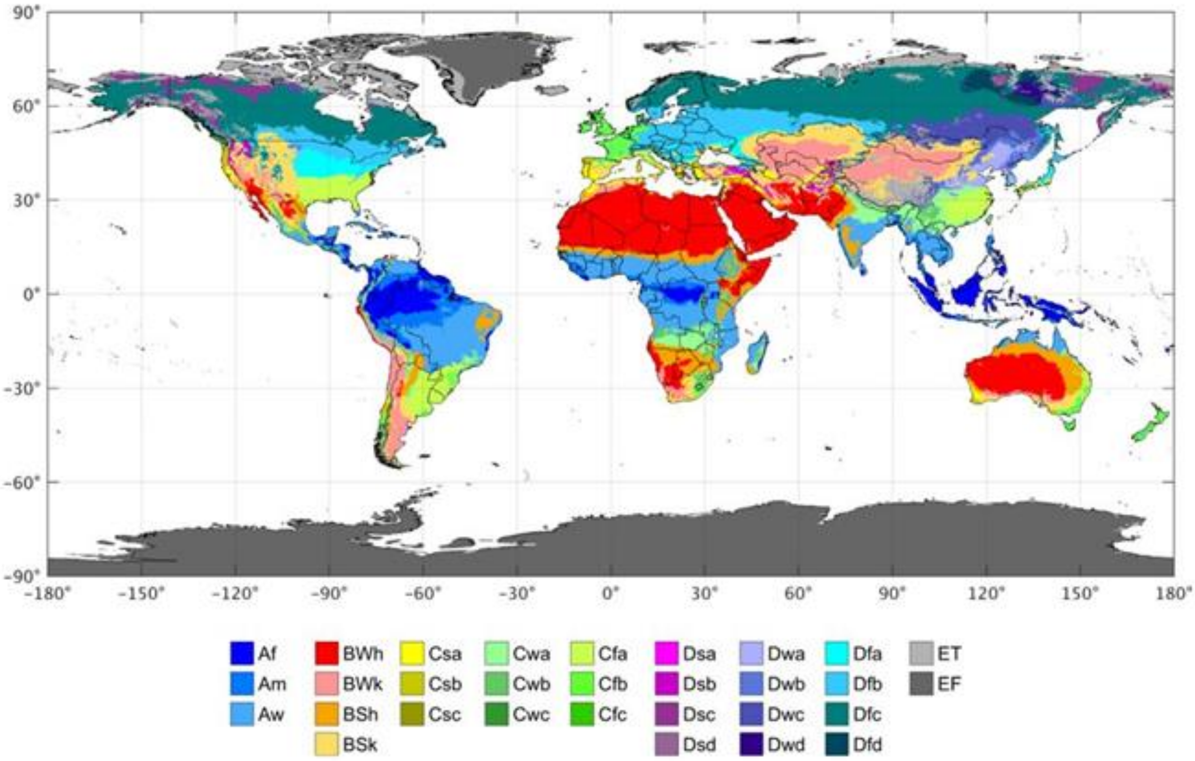

Figure 3.15: The Köppen Climate Classification (Beck et al., 2018)

3.4.1 Application of green wall systems in Melbourne, Australia

Council House 2 is the municipal offices of the City of Melbourne opened in October 2006. It was the first six-star rated green building in Australia. The building has nine storey and supports a semi-extensive green roof and green wall (Rayner et al., 2010).

Table 3.1: Application of green wall systems on the Council House 2 of Melbourne

	• The façade consists of 90 molded black plastic containerized planters. • The planters placed on small balconies on the north side of building. • Each planter 0.3m * 0.97m at the surface, 0.89m in depth, volume 260 L. • Steel cable x-tend mesh trellis, 1m in width (150mm aperture size) was built behind and above the planters, forming a vertical screen the full height of the building.
Climate region	Temperate subtropical oceanic, with mild winters and pleasantly warm summers.
Green wall system	Modular living wall system.
Vegetation	One hundred and sixty-four plants from five taxa were planted: *Clematis aristata, Kennedia nigricans, Kennedia rubicunda, Pandorea pandorana and Trachelospermum jasminoides.* A total of 60.9% of plants were classified as ‘failed’ due to death or poor cover values. Pest infestation and stress symptoms were particularly prevalent in surviving *Kennedia spp*. of the five plants used in the project, only *Pandorea pandorana* had low rates of failure (6.2%). Across all species the greatest rates of failure were located in the lower levels and eastern sides of the building.
Irrigation system	Sub-irrigation system encompassing as small cistern at the base (100 mm depth), controlled by a foot valve connected to the weather supply. Each cistern houses vertical, inverted cone-like ‘columns’ rising upwards in the substrate and filled with Hydrocell™ flakes to form a capillary irrigation ‘wick’ into the container proper.

3.4.2 Application of green wall systems in Genoa, Italy

The National Institute of Social Insurance (Istituto Nazionale di Previdenza Sociale) is located in Genoa’s Sestri Ponente district in north of Genoa, Italy (Magliocco and Perini, 2015).

Table 3.2: Application of green wall systems on the building of National Institute of Social Insurance in Genoa, Italy

<table>
<tr><td></td><td>The green facade was installed in the last century in october and november 2014 on the south wall of the building.
Building structure: concrete pillers and beams.
The facade is exposed to solar radiation several hr/day in summer and 1–2 hr/day during winter.</td></tr>
<tr><td>Climate region</td><td>Mediterranean, with mild, rainy winter and hot, sunny summer.</td></tr>
<tr><td>Green wall system</td><td>Living wall system.</td></tr>
<tr><td>Vegetation</td><td>The living wall system consists of a mat planted with different plant species (climbing plants, shrubs, evergreens).
The mat contains an aggregate mix and is composed of two layers of special geotextile.</td></tr>
<tr><td>Irrigation system</td><td>The system is irrigated with a drip line in each module and is designed primarily to use recycled condensate water from a network of air conditioning units.</td></tr>
</table>

3.4.3 Application of green wall systems in Berlin, Germany

The Paul-Lincke-Ufer research project was the first urban research project in Berlin. The project began in 1984 as the restoration of a 100-year-old apartment building. *Parthenocissus tricuspidata* (Boston ivy) and other climbers were planted in vegetation pots on the facades and on the garden level (Köhler, 2008).

Table 3.3: Application of green wall systems on apartment building in Berlin, Germany

- Paul-Lincke-Ufer.
- The restoration of a 100-year-old apartment building.
- The facades had been covered by the *Parthenocissus tricuspidata* (Boston ivy) after about 10 years.
- During the survey, over a 10 year period, the ground-based climber species had reached the gutter at the edge of the roofs.

Climate region	Moderately continental, characterized by cold winters, with average temperatures around freezing (0 °C or 32 °F), and moderately warm summers, with daytime temperatures hovering around 24 °C (75 °F).
Green wall system	Green façade.
Vegetation	Hanging planter boxes and Boston ivy was planted to bring the most possible vegetation into the small inner courtyard.

After defining the green walls and explaining the systems of green walls and their requirements and citing some examples about the application of green wall systems in deferent climate regions in this chapter, in the next chapter the perception about the application of green walls in north Nicosia will be founded and the findings of the questionnaire will be inserted.

CHAPTER 4

SURVEY STUDY: MEASURING THE PERCEPTION OF CITIZENS ABOUT THE APPLICATION OF GREEN WALL IN NORTH NICOSIA

4.1 The Case of North Nicosia

Cyprus is located in the eastern Mediterranean, where its location plays an important role in shaping its 10,000-year history. It has become an important commercial center over the past decades. Cyprus is one of the most important tourist destinations in Europe. It has 340 days of sunshine throughout the year. It also has a beautiful coastline with sandy and other rocky areas with clean beaches and its water is also considered the cleanest water in the Mediterranean Sea. Cyprus has magnificent landscapes, a country of work and entertainment, and life in the East and West. Cyprus as a country has an ancient historical charm with many ancient monuments and historical rural and urban sites. It also has a beautiful landscape characterized by its mountainous ranges, beautiful beaches, attractive gardens, farms and orchards full of citrus and olive trees, clean green spaces, and unique historical monuments such as castles, walled cities, churches and temples (Cyprus Profile, 2018). North Cyprus has five main provinces as Nicosia, Famagusta, Kyrenia, Güzel yurt and Iskele. North Nicosia is capital city of north Cyprus. According to 2011 Census north Nicosia population is 94,824 (49,838 male, 44,986 female).

4.1.1 Natural characteristics of north Nicosia

According to the macro climate classification of north Cyprus, it is among the climate zone called semi-arid. It is hot and dry in the summer due to its location on a Mediterranean island; Mediterranean climate is seen where the winter is warm and less rainy. The average annual temperature in north Cyprus is 19.0 °C. The hottest month throughout the year is usually July. During this month, the air temperature is between 37.0 °C and 40.0 °C during the day. The coldest month of the year is usually January and the temperature is between 9.0 °C - 12.0 °C during the day and the coldest nights of the year are mostly experienced in this month. On such nights, the temperature of the soil with the decrease of the air temperature drops below 0.0 °C, especially in the inner parts, causing frost events in places (KKTC Meteor, 2019).

Cyprus is the third largest island in the Mediterranean, dominated by two mountain ranges: the Troodos, which covers much of the southern and western parts of the island, and the Girne Mountains that extend along the north coast of Cyprus, where Girne's city is located. The Troodos Mountains occupy an area and a higher altitude than the Kyrenia Mountains. The island of Cyprus is generally characterized by mild weather and hot summers, but its climate is affected by fluctuations, sea impacts and storms. The temperature of the island varies between night and day. This difference is more pronounced in the summer, with winter variations between 8 °C and 10 °C in low areas and between 5 °C and 6 °C in high areas, while the summer weather variations reach 16 °C in the low areas and from 9 °C to 12 °C in high areas (Republic of Cyprus, 2019).

4.1.2 Architectural and urban characteristics of north Nicosia

In 1565 the Venetian defensive walls were used in Nicosia by the rulers of Venice, where these walls were built around the city of Nicosia. The Venetian walls are one of the best defensive fortifications preserved in the eastern Mediterranean region and are considered an important tourist landmark in the capital city of Nicosia (Figure 4.1). In the time of the British occupation, the city of Nicosia was still surrounded by Venetian walls, and it also had private gardens, large green spaces and public fountains with water channels. The streets of Nicosia at the time were wide and unpaved, but in 1881 the city's roads were organized and narrowed and connected to the main roads of the coastal cities. In 1882 the city's borders were expanded beyond the fortifications of the 500-meter-long stretch. Construction began outside the city of old Nicosia and private villas were spread at that time. In 1931 a gate was opened (Lonely Planet, 2017).

Figure 4.1: The Venetian defensive walls in Nicosia (David's been here, 2016).

In the 1930s, the history of modern architecture began in Cyprus, where ideas were presented by European architects who came to Cyprus to present modern architectural ideas. After the Second World War, the constructions have been expanded such as hospitals, offices, schools, kindergartens, villas and palaces in which traditional Cypriot architecture emerged. At present, new materials and modern technologies are using while maintaining the traditional building system (Harakis, 2018).

4.2 User Survey Method

In this study, the quantitative method has been used for measuring the perception of applying green walls in Nicosia. The study involved a questionnaire having three sections with a set of the questions about the problem of air pollution in Nicosia, the benefits of applying green walls and the participants' demographic data. The questionnaire have been distributed to individuals living in Nicosia in order to understand the level of their awareness about air pollution problem and its impact on their health, the extent of general knowledge of green walls and the benefits of their application to buildings.

4.2.1 Sampling approach

The questionnaire was distributed in different locations of Nicosia and participants interviewed face-to-face who filled out the form; it took three weeks to complete the field study of survey. 125 individuals were selected randomly from different age groups and levels of education in order to obtain results and statistics for measuring the possibility of applying green walls in Nicosia.

4.2.2 User survey design and measures

The measure includes a set of questions divided into three sections (A, B, C). Section **A** which is titled as "perception about urban problems" investigates urban problems and it includes three questions as Likert-style with five items (strongly agree, agree, unsure, disagree and strongly disagree). Section **B** that is titled as "perception regarding living walls and green facades" includes eight questions as Likert-style with five items (strongly agree, agree, unsure, disagree and strongly disagree). Section **C** which is titled as "socio-demographic data" includes ten questions.

4.3 Findings

The followings are the tables and charts of percentages of the questionnaire results in north Nicosia. Each question has its own table with a chart showing percentages of the participants' answers.

4.3.1 The findings of section A

A.1: The traffic and human activities are increasing and causing air pollution in the city of Nicosia.

58.4% of the 125 participants were strongly agree, 28.8% were agree, 5.6% were unsure, 4.0% were disagree and 3.2% were strongly disagree.

Table 4.1: Participants responses about "The traffic and human activities are increasing and causing air pollution in the city of Nicosia" (%)

The traffic and human activities are increasing and causing air pollution in the city of Nicosia			
		Frequency	Percent
Valid	Strongly agree	73	58,4
	Agree	36	28,8
	Unsure	7	5,6
	Disagree	5	4,0
	Strongly disagree	4	3,2
	Total	125	100,0

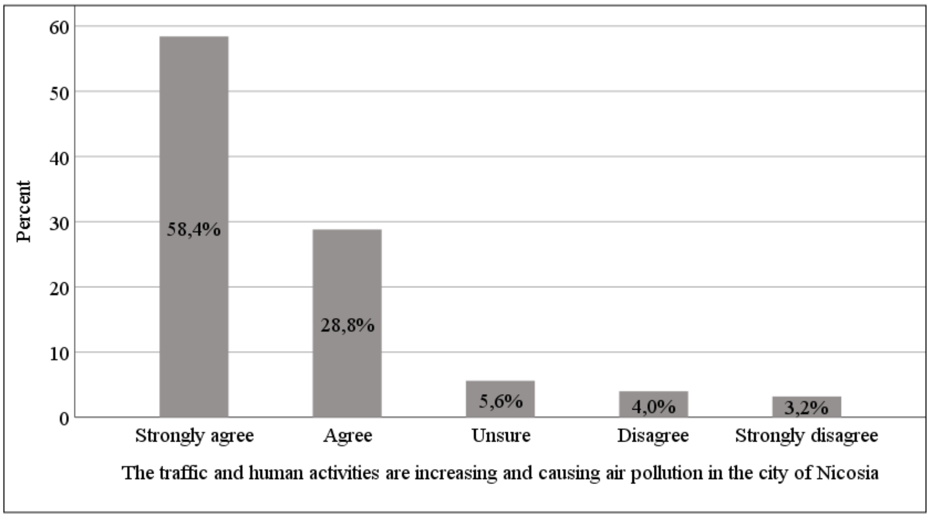

Figure 4.2: Participants responses about "The traffic and human activities are increasing and causing air pollution in the city of Nicosia" (%)

A.2: The lack of green space and the increase of built-up areas in some cities of Cyprus such as Nicosia is one of the causes of air pollution and rising temperature.

53.6% of the 125 participants were strongly agree, 32.0% were agree, 8.8% were unsure, 1.6% were disagree and 4.0% were strongly disagree.

Table 4.2: Participants responses about **"**The lack of green space and the increase of built-up areas in some cities of Cyprus such as Nicosia is one of the causes of air pollution and rising temperature" (%)

The lack of green space and the increase of built-up areas in some cities of Cyprus such as Nicosia is one of the causes of air pollution and rising temperature			
		Frequency	Percent
Valid	Strongly agree	67	53,6
	Agree	40	32,0
	Unsure	11	8,8
	Disagree	2	1,6
	Strongly disagree	5	4,0
	Total	125	100,0

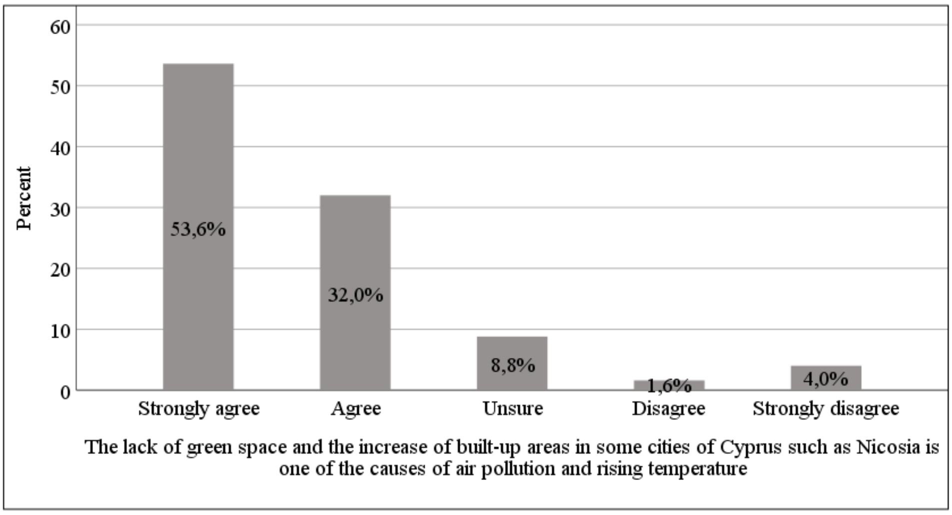

Figure 4.3: Participants responses about **"**The lack of green space and the increase of built-up areas in some cities of Cyprus such as Nicosia is one of the causes of air pollution and rising temperature" (%)

A.3: The vegetation in urban environments contributes to the rainwater absorption and purification before entering the drainage.

43.2% of the 125 participants were strongly agree, 30.4% were agree, 22.4% were unsure, 1.6% were disagree and 2.4% were strongly disagree.

Table 4.3: Participants responses about "The vegetation in urban environments contributes to the rainwater absorption and purification before entering the drainage" (%)

The vegetation in urban environments contributes to the rainwater absorption and purification before entering the drainage			
		Frequency	Percent
Valid	Strongly agree	54	43,2
	Agree	38	30,4
	Unsure	28	22,4
	Disagree	2	1,6
	Strongly disagree	3	2,4
	Total	125	100,0

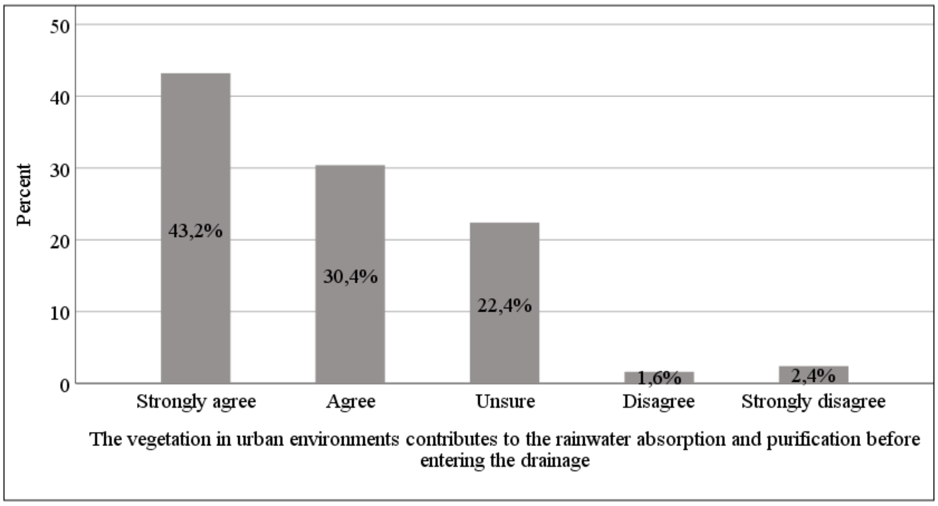

Figure 4.4: Participants responses about "The vegetation in urban environments contributes to the rainwater absorption and purification before entering the drainage" (%)

According to the results of the section A, the largest proportion of participants strongly agree that air pollution in Nicosia is increasing 56%, indicating that participants are aware of the problem facing the area and the factors affecting the weather such as traffic, human activities and lack of green spaces.

4.3.2 The findings of section B

B.1: The living plants that make up the green walls contribute to filtering the air from the impurities and thus the access to more pure air in the cities.

56.8% of the 125 participants were strongly agree, 30.4% were agree, 8.0% were unsure, 3.2% were disagree and 1.6% were strongly disagree.

Table 4.4: Participants responses about “The living plants that make up the green walls contribute to filtering the air from the impurities and thus the access to more pure air in the cities” (%)

The living plants that make up the green walls contribute to filtering the air from the impurities and thus the access to more pure air in the cities			
		Frequency	Percent
Valid	Strongly agree	71	56,8
	Agree	38	30,4
	Unsure	10	8,0
	Disagree	4	3,2
	Strongly disagree	2	1,6
	Total	125	100,0

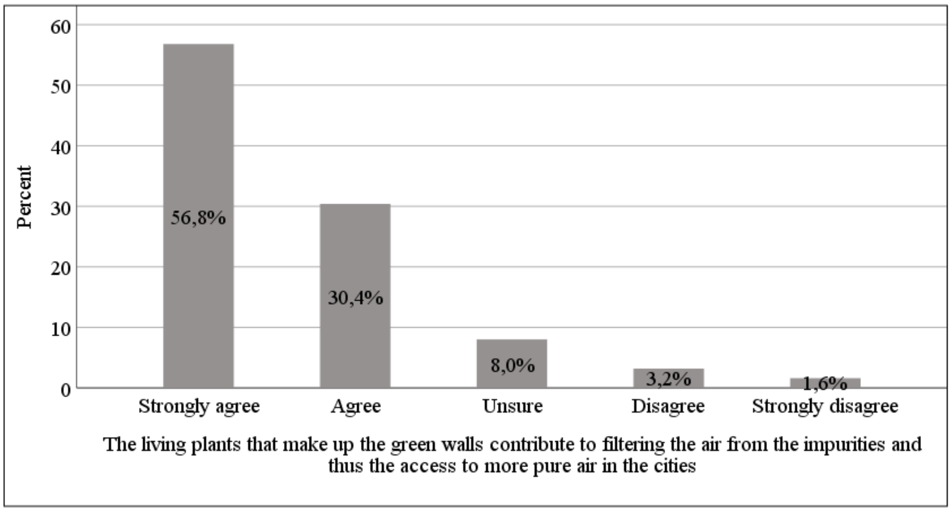

Figure 4.5: Participants responses about “The living plants that make up the green walls contribute to filtering the air from the impurities and thus the access to more pure air in the cities” (%)

B.2: The green walls contribute significantly to reducing the temperature of atmosphere and thus the phenomenon of global warming.

46.4% of the 125 participants were strongly agree, 37.6% were agree, 11.2% were unsure, 3.2% were disagree and 1.6% were strongly disagree.

Table 4.5: Participants responses about "The green walls contribute significantly to reducing the temperature of atmosphere and thus the phenomenon of global warming" (%)

The green walls contribute significantly to reducing the temperature of atmosphere and thus the phenomenon of global warming			
		Frequency	Percent
Valid	Strongly agree	58	46,4
	Agree	47	37,6
	Unsure	14	11,2
	Disagree	4	3,2
	Strongly disagree	2	1,6
	Total	125	100,0

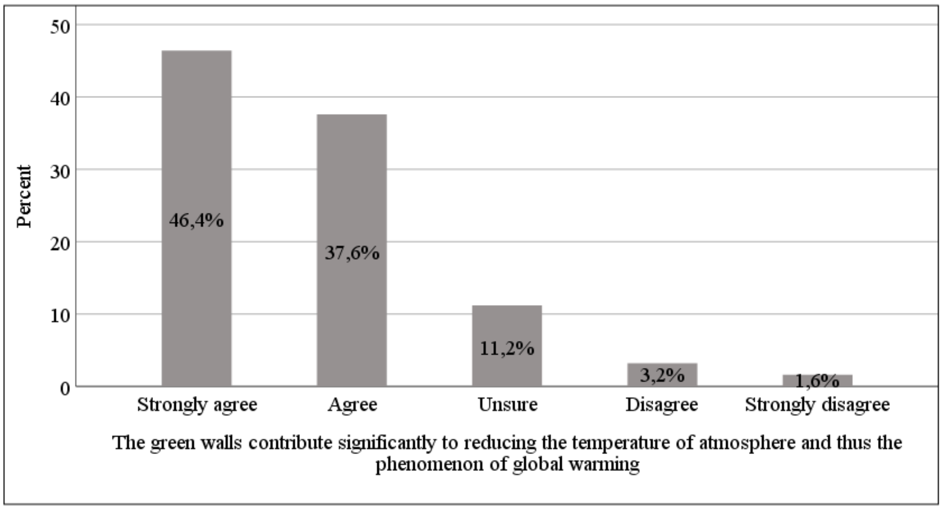

Figure 4.6: Participants responses about "The green walls contribute significantly to reducing the temperature of atmosphere and thus the phenomenon of global warming" (%)

B.3: Plants in green walls absorb sound frequencies where they work as a sound barrier and reduce noise, thus reducing the noise pollution in the urban areas.

32.0% of the 125 participants were strongly agree, 28.0% were agree, 31.2% were unsure, 5.6% were disagree and 3.2% strongly disagree.

Table 4.6: Participants responses about "Plants in green walls absorb sound frequencies where they work as a sound barrier and reduce noise, thus reducing the noise pollution in the urban areas" (%)

Plants in green walls absorb sound frequencies where they work as a sound barrier and reduce noise, thus reducing the noise pollution in the urban areas			
		Frequency	Percent
Valid	Strongly agree	40	32,0
	Agree	35	28,0
	Unsure	39	31,2
	Disagree	7	5,6
	Strongly disagree	4	3,2
	Total	125	100,0

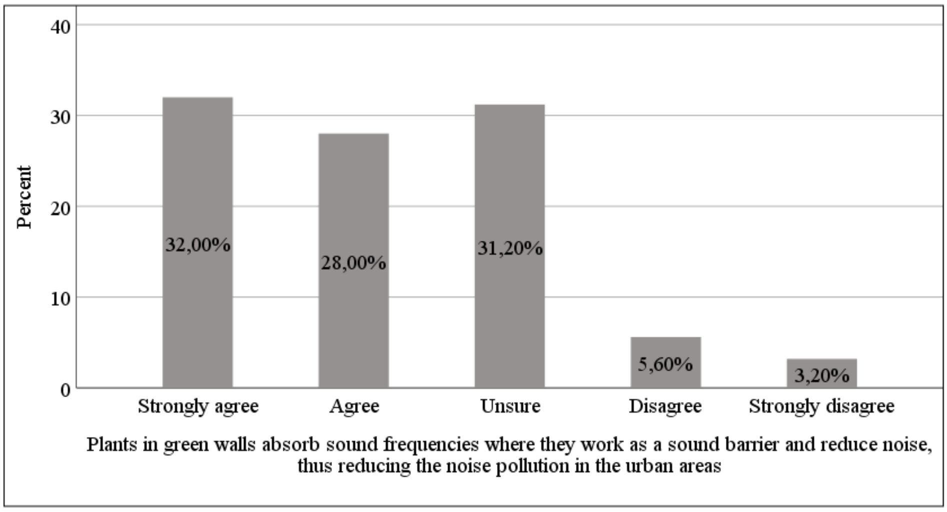

Figure 4.7: Participants responses about "Plants in green walls absorb sound frequencies where they work as a sound barrier and reduce noise, thus reducing the noise pollution in the urban areas" (%)

B.4: Green walls give the city an aesthetic advantage.

64.0% of the 125 participants were strongly agree, 24.0% were agree, 5.6% were unsure, 3.2% were disagree and 3.2% strongly disagree.

Table 4.7: Participants responses about "Green walls give the city an aesthetic advantage" (%)

Green walls give the city an aesthetic advantage			
		Frequency	Percent
Valid	Strongly agree	80	64,0
	Agree	30	24,0
	Unsure	7	5,6
	Disagree	4	3,2
	Strongly disagree	4	3,2
	Total	125	100,0

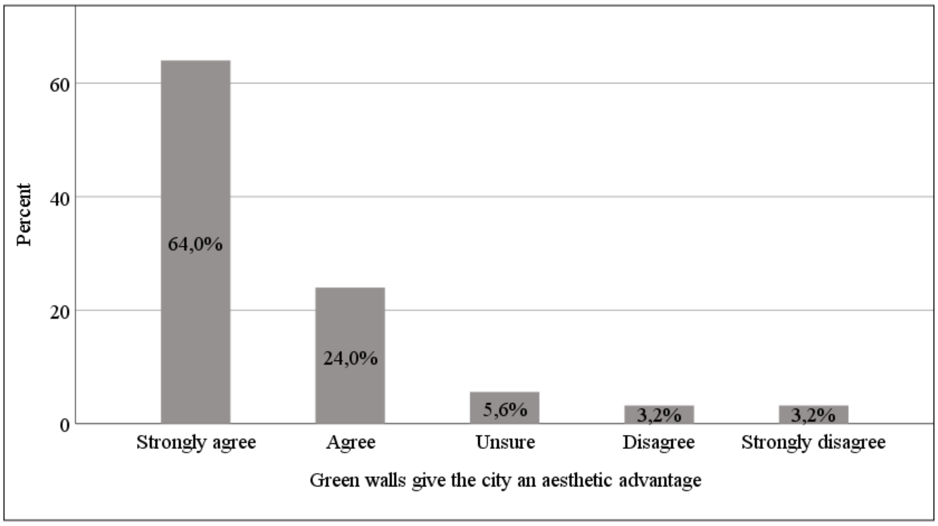

Figure 4.8: Participants responses about "Green walls give the city an aesthetic advantage" (%)

B.5: The application of green walls on buildings contributes to thermal insulation thus saving energy costs for the building owner.

30.4% of the 125 participants were strongly agree, 35.2% were agree, 28.0% were unsure, 2.4% were disagree and 4.0% strongly disagree.

Table 4.8: Participants responses about "The application of green walls on buildings contributes to thermal insulation thus saving energy costs for the building owner" (%)

The application of green walls on buildings contributes to thermal insulation thus saving energy costs for the building owner			
		Frequency	Percent
Valid	Strongly agree	38	30,4
	Agree	44	35,2
	Unsure	35	28,0
	Disagree	3	2,4
	Strongly disagree	5	4,0
	Total	125	100,0

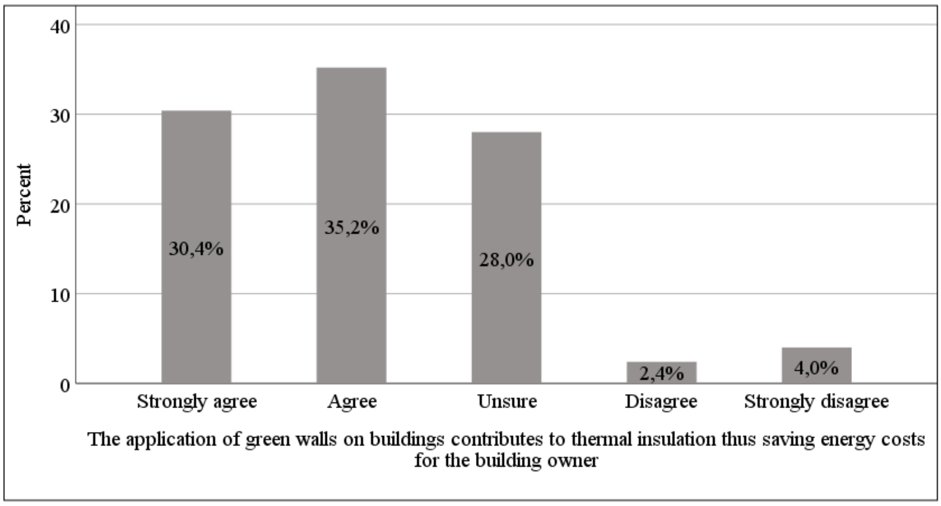

Figure 4.9: Participants responses about "The application of green walls on buildings contributes to thermal insulation thus saving energy costs for the building owner" (%)

B.6: Green wall systems can be part of sustainability and urban rehabilitation and building retrofitting.

28.8% of the 125 participants were strongly agree, 41.6% were agree, 24.0% were unsure, 3.2% were disagree and 2.4% strongly disagree.

Table 4.9: Participants responses about "Green wall systems can be part of sustainability and urban rehabilitation and building retrofitting" (%)

Green wall systems can be part of sustainability and urban rehabilitation and building retrofitting			
		Frequency	Percent
Valid	Strongly agree	36	28,8
	Agree	52	41,6
	Unsure	30	24,0
	Disagree	4	3,2
	Strongly disagree	3	2,4
	Total	125	100,0

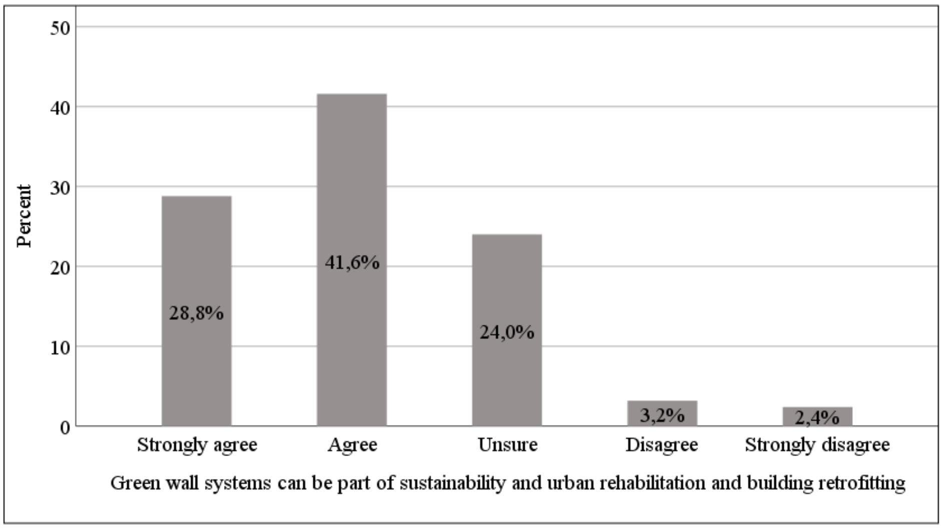

Figure 4.10: Participants responses about "Green wall systems can be part of sustainability and urban rehabilitation and building retrofitting" (%)

B.7: Plants induce a psychological wellbeing thus the green wall systems are the therapeutic effect.

49.6% of the 125 participants were strongly agree, 40.0% were agree, 8.8% were unsure, 0.8% were disagree and 0.8% strongly disagree.

Table 4.10: Participants responses about “Plants induce a psychological wellbeing thus the green wall systems are the therapeutic effect” (%)

Plants induce a psychological wellbeing thus the green wall systems are the therapeutic effect			
		Frequency	Percent
Valid	Strongly agree	62	49,6
	Agree	50	40,0
	Unsure	11	8,8
	Disagree	1	,8
	Strongly disagree	1	,8
	Total	125	100,0

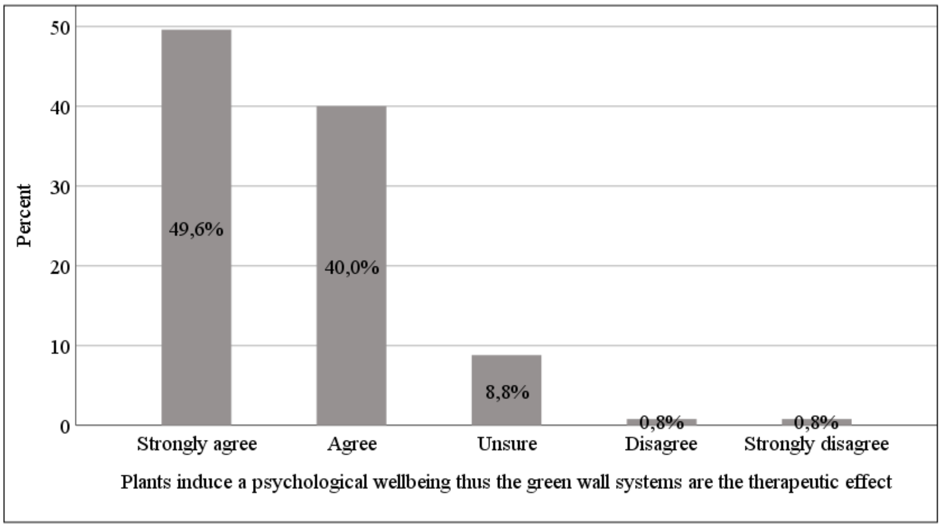

Figure 4.11: Participants responses about “Plants induce a psychological wellbeing thus the green wall systems are the therapeutic effect” (%)

B.8: I encourage the adoption of a green walls strategy in the buildings in Nicosia.

50.4% of the 125 participants were strongly agree, 35.2% were agree, 9.6% were unsure and 4.8% strongly disagree.

Table 4.11: Participants responses about "I encourage the adoption of a green walls strategy in the buildings in Nicosia" (%)

I encourage the adoption of a green walls strategy in the buildings in Nicosia			
		Frequency	Percent
Valid	Strongly agree	63	50,4
	Agree	44	35,2
	Unsure	12	9,6
	Strongly disagree	6	4,8
	Total	125	100,0

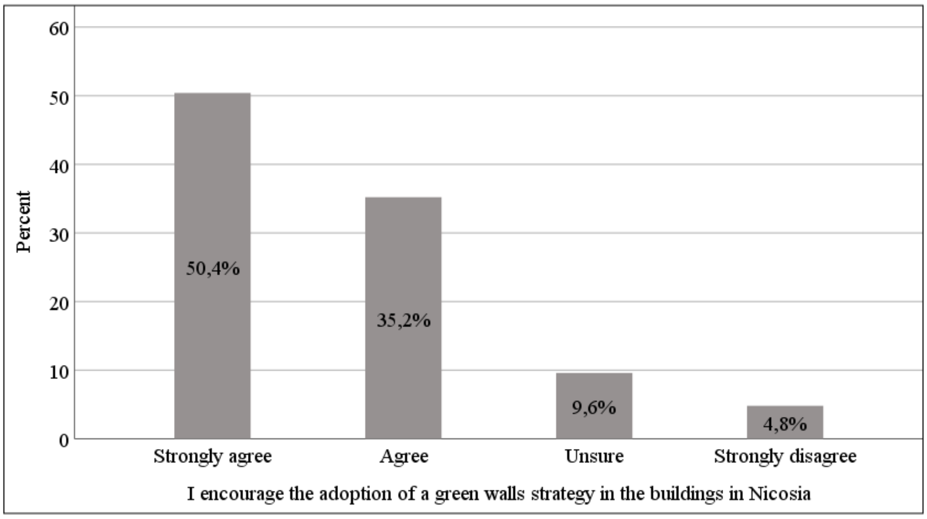

Figure 4.12: Participants responses about "I encourage the adoption of a green walls strategy in the buildings in Nicosia" (%)

The results of the section B statistics indicate the participants' agreement with the importance of vegetation and the positive impact of plants on the environment and encourage them to use green walls in North Nicosia where in B.8 question of section B, 50.4% strongly agree and 35.2% agree of the participants to the adoption of green walls strategy in the buildings in North Nicosia.

4.3.3 The findings of section C

C.1: Gender.

48.0% of the 125 participants were female and 52.0% were male.

Table 4.12: Participants responses about "Gender" (%)

Gender			
		Frequency	Percent
Valid	Female	60	48,0
	Male	65	52,0
	Total	125	100,0

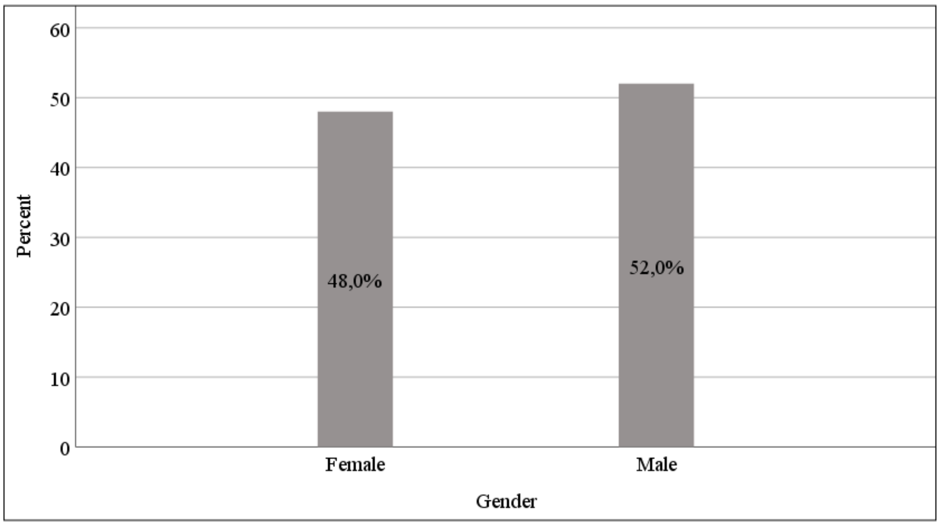

Figure 4.13: Participants responses about "Gender" (%)

C.2: Age.

52.0% of the questionnaire participants had an age of 18-25 years, 35.2% were between 26-40 years old, 9.6% were between 41-55 years old, 2.4% were between 56-65 years old and 0.8% were between 66-75 years old.

Table 4.13: Participants responses about “Age” (%)

Age			
		Frequency	Percent
Valid	18-25	65	52,0
	26-40	44	35,2
	41-55	12	9,6
	56-65	3	2,4
	66-75	1	,8
	Total	125	100,0

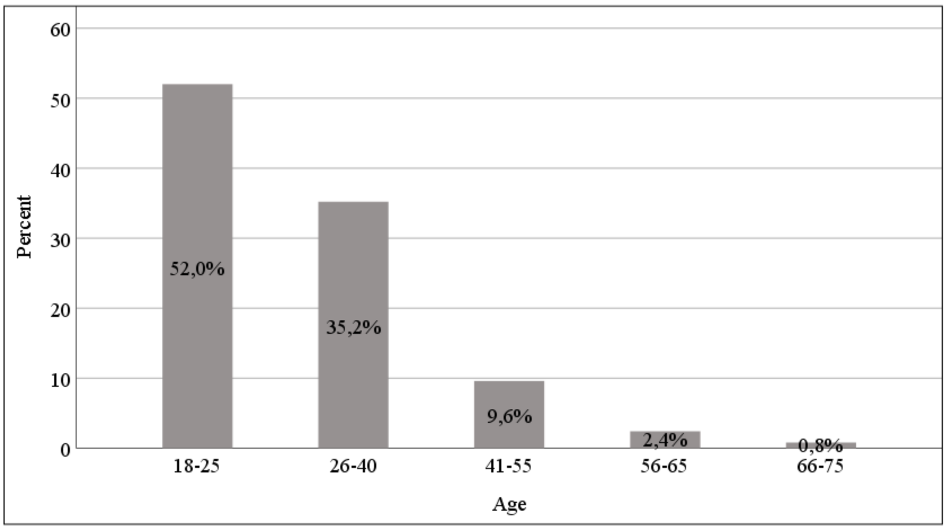

Figure 4.14: Participants responses about “Age” (%)

C.3: Nationality.

53.6% of the 125 participants were Cypriot nationals, 32.6% were Turkish nationals and 13.6% were from other nationalities.

Table 4.14: Participants responses about "Nationality" (%)

Nationality			
		Frequency	Percent
Valid	Cyprus	67	53,6
	Turkey	41	32,8
	Other nationality	17	13,6
	Total	125	100,0

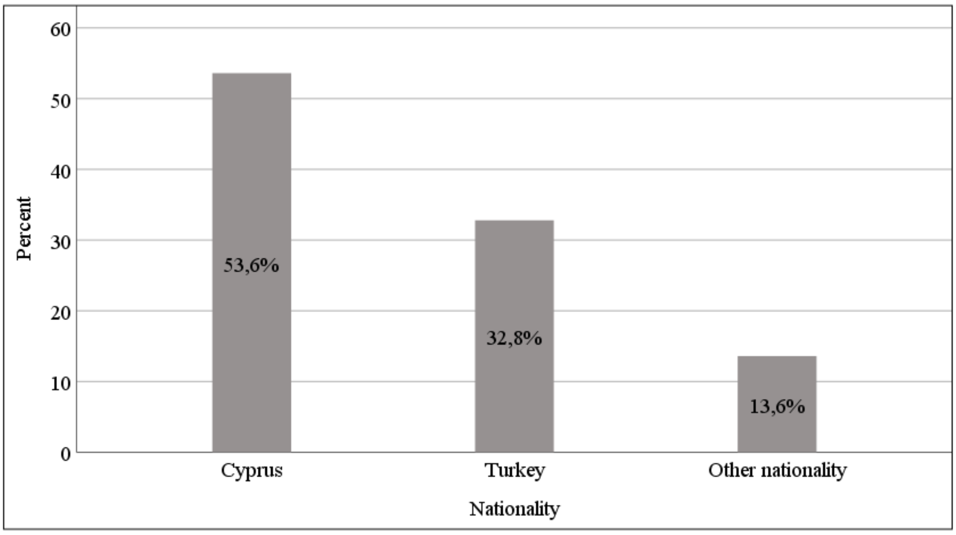

Figure 4.15: Participants responses about "Nationality" (%)

C.4: Education.

1.6% of the questionnaire participants had secondary school degree, 16.0% had high school degree, 64.8% had university degree and 17.6% had master or PhD degree.

Table 4.15: Participants responses about "Education" (%)

Education			
		Frequency	Percent
Valid	Secondary school degree	2	1,6
	High school degree	20	16,0
	University degree	81	64,8
	Master or PhD degree	22	17,6
	Total	125	100,0

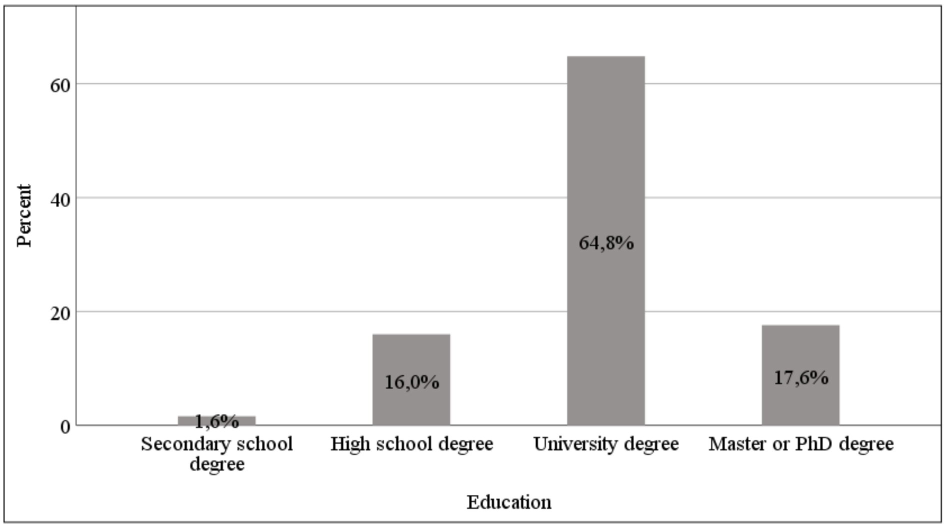

Figure 4.16: Participants responses about "Education" (%)

C.5: The people who you live together.

23.2% of the participants live with 1 person, 27.2% live with 2 persons, 29.6% live with 3 persons and 20.0% live with 4 or more persons.

Table 4.16: Participants responses about “The people who you live together” (%)

The people who you live together			
		Frequency	Percent
Valid	1	29	23,2
	2	34	27,2
	3	37	29,6
	4 and/or more	25	20,0
	Total	125	100,0

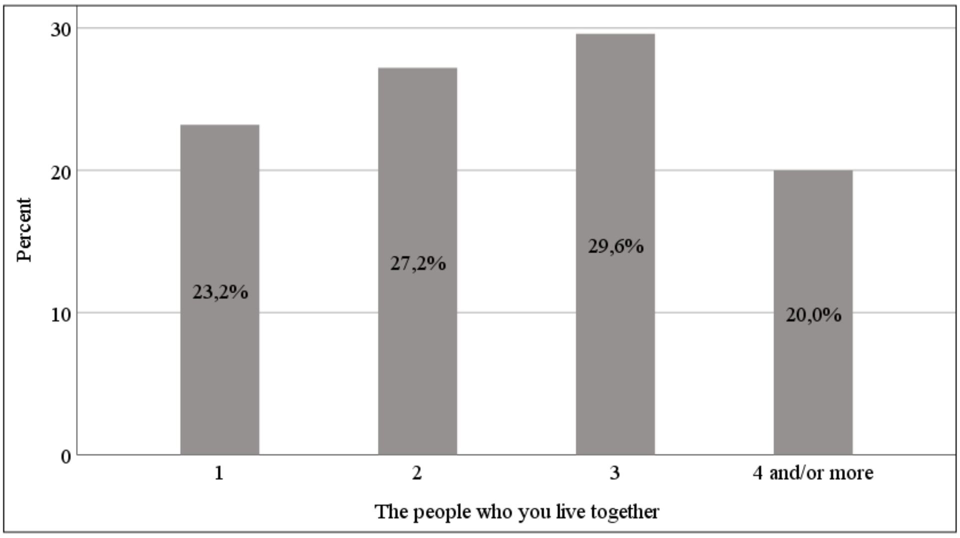

Figure 4.17: Participants responses about “The people who you live together” (%)

C.6: How long have you been living in Nicosia?

40.8% of the participants have been living in Nicosia for 1-5 years, 12.0% have been living in Nicosia for 6-10 years, 12.0% have been living in Nicosia for 11-20 years and 35.2% have been living in Nicosia for 20 years or more.

Table 4.17: Participants responses about "How long have you been living in Nicosia?" (%)

How long have you been living in Nicosia?			
		Frequency	Percent
Valid	1-5 years	51	40,8
	6-10 years	15	12,0
	11-20 years	15	12,0
	20+	44	35,2
	Total	125	100,0

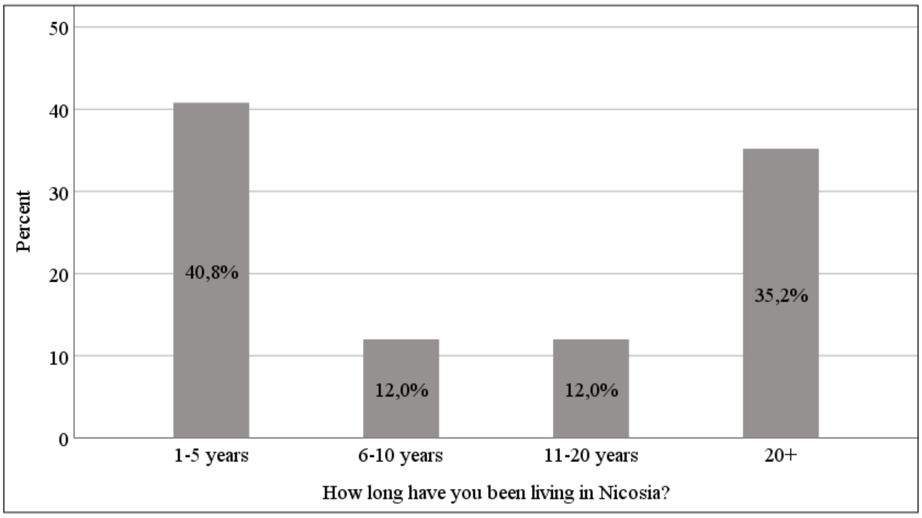

Figure 4.18: Participants responses about "How long have you been living in Nicosia?" (%)

C-7: Type of the house you are living in.

24.0% of the participants are living in detached house, 14.4% are living in villa and 61.6% are living in apartments.

Table 4.18: Participants responses about "Type of the house you are living in" (%)

Type of the house you are living in			
		Frequency	Percent
Valid	Detached house	30	24,0
	Villa	18	14,4
	Apartment	77	61,6
	Total	125	100,0

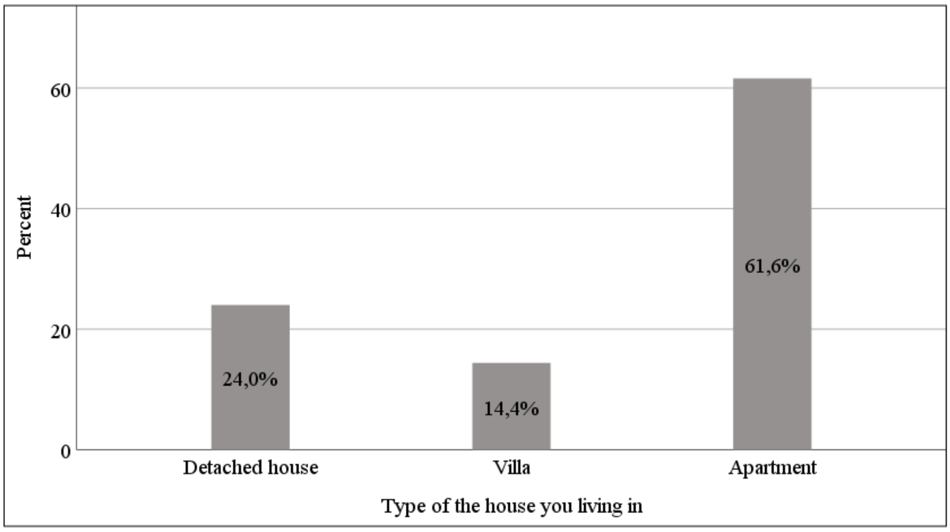

Figure 4.19: Participants responses about "Type of the house you are living in" (%)

C.8: Have you ever used a living wall or green facades in your living environment?

24.0% of the participants have used a living wall or green facades in them living environment and 76.0% have never used it.

Table 4.19: Participants responses about "Have you ever used a living wall or green facades in your living environment?" (%)

Have you ever used a living wall or green facades in your living environment?			
		Frequency	Percent
Valid	Yes	30	24,0
	No	95	76,0
	Total	125	100,0

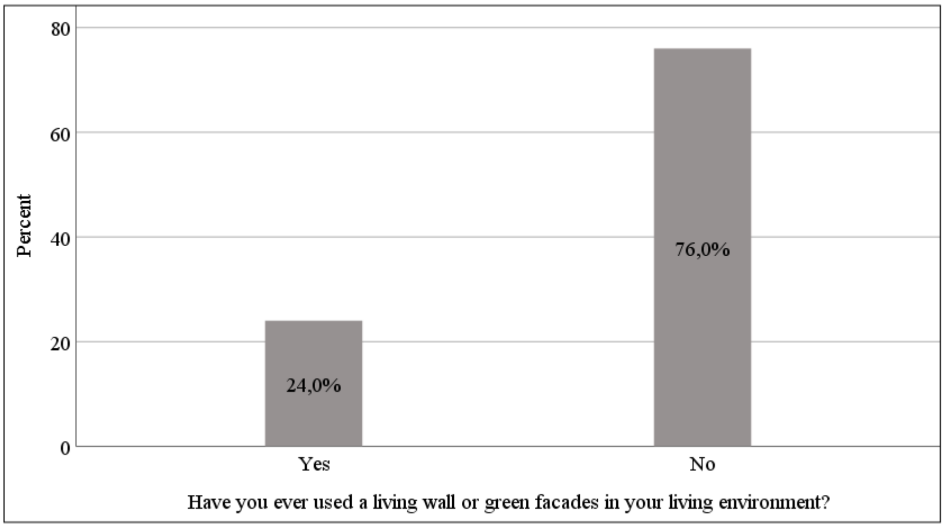

Figure 4.20: Participants responses about "Have you ever used a living wall or green facades in your living environment?" (%)

C.9: Have you ever used living plants for making shady environments such as car parking, semi-open/semi-closed spaces?

37.6% of the 125 participants have used living plants for making shady environments such as car parking, semi-open/semi-closed spaces and 62.4% have never used that.

Table 4.20: Participants responses about "Have you ever used living plants for making shady environments such as car parking, semi-open/semi-closed spaces?" (%)

Have you ever used living plants for making shady environments such as car parking, semi-open/semi-closed spaces?			
		Frequency	Percent
Valid	Yes	47	37,6
	No	78	62,4
	Total	125	100,0

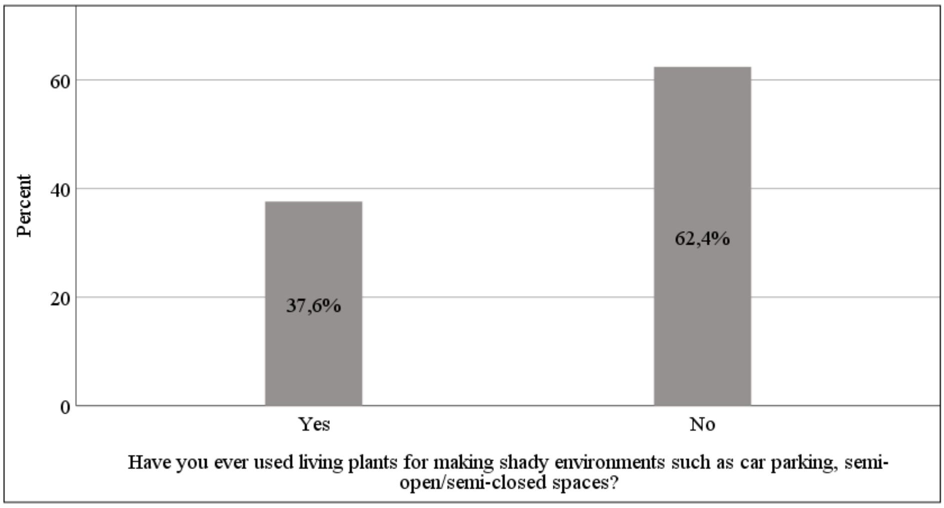

Figure 4.21: Participants responses about "Have you ever used living plants for making shady environments such as car parking, semi-open/semi-closed spaces?"(%)

C.10: For choosing a new house, how important is the existence of a living wall or a green facade?

For choosing a new house, it is very important to existence of a living wall or a green facade for 56.8% of the 125 participants, it is a little important for 36.8% of the participants and it is not important for 6.4% of the participants.

Table 4.21: Participants responses about "For choosing a new house, how important is the existence of a living wall or a green facade?" (%)

For choosing a new house, how important is the existence of a living wall or a green facade?			
		Frequency	Percent
Valid	Very	71	56,8
	Little	46	36,8
	Not important	8	6,4
	Total	125	100,0

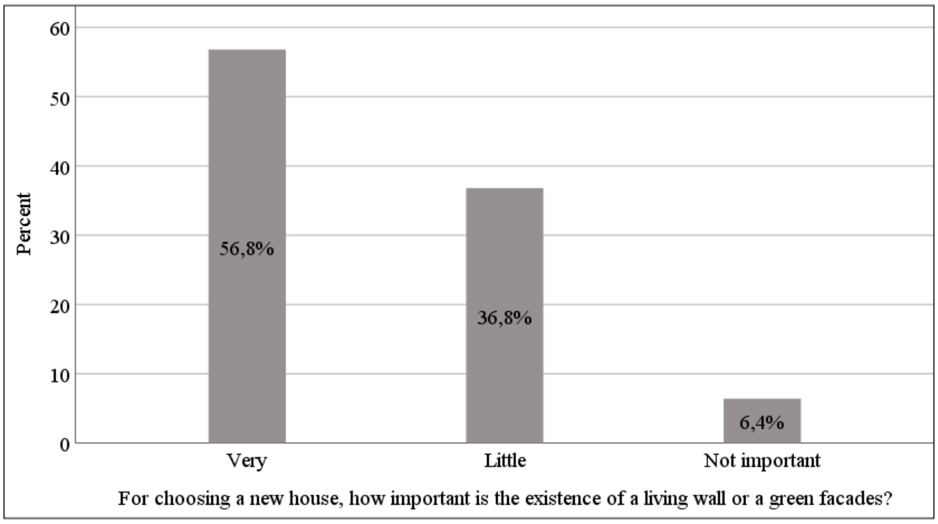

Figure 4.22: Participants responses about "For choosing a new house, how important is the existence of a living wall or a green facade?" (%)

According to the results of section C, 53,6% of the participants are Cypriot, 64,8% have university degree and 56,8% suggested that is very important for choosing a new house to existence of a living wall or a green façade.

CHAPTER 5
CONCLUSION & RECOMMENDATIONS

Buildings consume a lot of natural resources and this makes them cause many environmental problems. The increasing number of buildings and the development of urban construction lead to the increase of solid building materials such as concrete that can absorb the heat of the sun during the day and release it at night, increasing the temperature of the surrounding atmosphere.

Urban heat island phenomenon refers to high temperatures in cities where increased construction and lack of green space. According to the related research and studies in recent years, green buildings are among the most important solutions that can be applied in cities to solve environmental problems and mitigate the negative impact of buildings on urban environments; where urban residents need clean air, clean water, reduced pollution, improved environmental conditions and green spaces.

The greening of buildings can be either horizontal greening such as green roofs or vertical greening, which is also called vertical gardens such as green walls. In recent years green walls have become more widespread and numerous studies and research have been done about their benefits and application systems in deferent climates, where climate is the most influential factor in the study of green walls.

Green walls in north Nicosia have not been applied before despite the city is developing significantly as well as increasing population and increasing construction in recent times. Thus the aim of this thesis was to collect information about green walls and their benefits to the environment; their application systems and citing some examples about the application of green wall systems in deferent climate regions. Then a questionnaire study on the participants from the north Nicosia is founded in order to find out their perception about the application of green walls on the buildings in the city. The data were obtained by using Statistical Package for the Social Sciences (SPSS).

According to the results of the questionnaire, 53.6% of the 125 participants strongly agreed that the lack of green space and the increase of built-up areas is one of the causes of air pollution and rising temperature in north Nicosia.

46.4% of the 125 participants strongly agreed that the green walls contribute significantly to reducing the temperature of atmosphere and thus the phenomenon of global warming.

64.0% of the 125 participants strongly agreed that the green walls give the city an aesthetic advantage.

30.4% of the 125 participants strongly agreed and 35.2% agreed that the application of green walls on buildings contributes to thermal insulation thus saving energy costs for the building owner.

28.8% of the 125 participants strongly agreed that the green wall systems can be part of sustainability, urban rehabilitation and building retrofitting, 41.6% agreed, 24.0% were unsure, 3.2% disagreed and 2.4% strongly disagreed.

50.4% of the 125 participants strongly agreed about the adoption of a green walls strategy in the buildings of north Nicosia.

56,8% suggested that is very important for choosing a new house to existence of a living wall or a green façade.

In brief, according to the results of the questionnaire and the participants' positive suggestions, the application of green walls on buildings can be encouraged and adopted as a new strategy in north Nicosia, for the new buildings or on the walls of existing buildings. It has the potential for urban rehabilitation and making Nicosia city more sustainable.

REFERENCES

Action Bio Science. (2004). *Urban Heat Islands: Hotter Cities*. Retrieved December 10, 2018,fromhttp://www.actionbioscience.org/environment/voogt.html?newwindow=true

Adams, J. (2009). *Vegetation - climate interaction: how plants make the global environment.* Seoul, Ripublic of Korea: Springer Science & Business Media.

Anguluri, R., and Narayanan, P. (2017). Role of green space in urban planning: Outlook towards smart cities. *Urban Forestry & Urban Greening, 25*, 58-65.

Ashie, Y. (2008). Management of urban heat environment. *In Urban Environmental Management and Technology* , 215-238.

Azkorra, Z., Pérez, G., Coma, J,. Cabeza, L. F., Burés, S., Álvaro, J. E., and Urrestarazu, M. (2015). Evaluation of green walls as a passive acoustic insulation system for buildings. *Applied Acoustics, 89,* 46-56.

Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., and Wood, E. F. (2018). Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Scientific data, 180214*(5), 3.

Bernard, J., Musy, M., Calmet, I., and Bocher, E. (2017). Urban heat island temporal and spatial variations: Empirical modeling from geographical and meteorological data. *Building and Environment, 125* , 423-438.

Best Design Gallery. (2012). *Green screen trellis*. Retrieved November 18, 2018, from https://wallpaper-santabanta.irim.us/files/images/green-screen-trellis.html

Bribach, C. J., and Rossomano, D. (2012). Vertical garden panel. *River day properties and river day properties a california corp* , 141,294.

Building review journal. (2015). *Landscaping for urban spaces and high rise*. Retrieved November 15, 2018, from http://brj.com.sg/tag/landscaping/

City Metric. (2016). *The Urban Heat Island, explained: Why are cities warmer than the countryside?* Retrieved Novamber 20, 2018, from https://www.citymetric.com/horizons/urban-heat-island-explained-why-are-cities-warmer-countryside-1777

Cypnet. (2017). *North Cyprus General Info*. Retrieved February 10, 2019, from http://www.cypnet.com/north_cyprus_about_cyprus_general_info.php

Cyprus Profile. (2018). *Cyprus overview*. Retrieved February 02, 2019, from https://www.cyprusprofile.com/en/country-information/overview/

Davids' Been Here. (2016). *Top 10 Things to Do in Nicosia, Cyprus*. Retrieved December 01, 2018, from http://davidsbeenhere.com/2016/07/09/top-10-things-to-do-in-nicosia-cyprus/

Deutsch-Aboulmahassine, E. D and Rossomano, D. (2009). Modular, wall-mounted plant growing system. *U.S. Patent No. 7* , 627,983.

Dezeen. (2018). *Sidewalk Labs unveils design for neighbourhood in Toronto "future city"*. Retrieved November 07, 2018, from https://www.dezeen.com/2018/08/15/quayside-sidewalk-toronto-sidewalk-labs-waterfront-canada-smart-city-development/

Dvorak, B. D., and Volder, A. (2010). Green roof vegetation for North American ecoregions: A literature review. *Landscape and Urban Planning 96* , 197–213.

Earth. (2016). *Your world: our favorite instagram photos of green facades*. Retrieved November 12, 2018, from https://www.earth.com/news/instagram-photos-green-facades/

Elgizawy, E. M. (2016). The effect of green facades in landscape ecology. *Procedia Environmental Sciences, 34* , 119-130.

EPIC Gardening. (2014). *8 Awesome Vertical Gardening Ideas For Your Garden*. Retrieved November 16, 2018, from https://www.epicgardening.com/awesome-vertical-gardening-ideas/

Franco-Salas, A., Pérez-Urrestarazu, L., Fernández-Cañero, R., and Egea-Cegarra, G. (2014). Irrigation systems evaluation for living walls. *Journal of Irrigation and Drainage Engineering, 140(4)* .

Giordano, R., Montacchini, E., Tedesco, S., and Perone, A. (2017). Living wall systems: a technical standard proposal. *Energy Procedia, 111* , 298-307.

Global Change. (2009). *Urban Heat Island Effect*. Retrieved April 05, 2019, from https://nca2009.globalchange.gov/urban-heat-island-effect/index.html

Grabowiecki, K., Jaworski, A., Niewczas, T., and Belleri, A. (2017). Green solutions-climbing vegetation impact on building–energy balance element. *Energy Procedia, 11* , 377-386.

Green walls. (2017). *Sihl City Green Wall Structure 2*. Retrieved November 15, 2018, from http://www.green-walls.co.uk/projects/view/sihl-city-green-wall-zurich/sihl-city-green-wall-structure-2/

Haas, E. M., Perini, K., Ottelé, M., and Raiteri, R. (2011). Greening the building envelope, façade greening and living wall systems. *Open Journal of Ecology, 1(01)* , 1.

Harakis. (2018). *History of Cyprus architecture. From antiquity to present days*. Retrieved February 20, 2019, from https://www.harakis.com/history-of-cyprus-architecture-from-antiquity-to-present-days-2/

Hertel, W., Snyder, P. K., and Twine, T. E. (2012). December. Factors Contributing to Urban Heat Island Development: A Global Perspective. *In AGU Fall Meeting Abstracts* .

Home grown. (2010). *Plants on Walls – an easy vertical garden design*. Retrieved November 22, 2018, from http://homegrown.org/blog/2010/03/plants-on-walls-an-easy-vertical-garden-design/

Ichinose, T., Matsumoto, F., and Kataoka, K. (2008). Counteracting urban heat islands in Japan. *In Urban Energy Transition* , 365-380.

Inkmason. (2015). *VEGETATION IN BUILDING – GREEN WALL*. Retrieved November 25, 2018, from http://www.inkmason.com/vegetation-in-building-green-wall/

Japan for sustainability. (2011). *Suntory Midorie Installs Japan's Largest Green Wall System, 'Flower Wall'.* Retrieved November 17, 2018, from https://www.japanfs.org/en/news/archives/news_id030614.html

JLL. (2017). *How vertical gardens are greening Europe's cities*. Retrieved November 20, 2018, from https://www.jllrealviews.com/trends/sustainability/how-vertical-gardens-are-greening-europes-cities/

Jørgensen, L., Dresbøll, D. C., and Thorup-Kristense, K. (2014). Root growth of perennials in vertical growing media for use in green walls. *Scientia Horticulturae, 166* , 31-41.

Journalist's resource. (2015). *Health benefits of urban vegetation and green space: Research roundup*. Retrieved November 09, 2018, from https://journalistsresource.org/studies/environment/cities/health-benefits-urban-green-space-research-roundup/

Killemsetty, N. (2014). Integrated Study of Measures & Techniques in Green Building Construction. *IOSR Journal of Mechanical and Civil Engineering* , https://www.researchgate.net/profile/Namesh_Killemsetty/publication/284455746_Integrated_Study_of_Measures_Techniques_in_Green_Building_Construction/links/57db330c08ae72d72ea37a55/Integrated-Study-of-Measures-Techniques-in-Green-Building-Construction.pdf

KKTC Meteor. (2019). *Kuzey Kıbrıs'ın Genel Hava Durumu*. Retrieved May 08, 2019 from http://kktcmeteor.org/meteorolojikbilgi/kibris-iklimi

Kmieć, M. (2015). Green wall technology. *Czasopismo Techniczne* .

Köhler, M. (2008). Green facades—a view back and some visions. *Urban Ecosystems, 11(4)* , 423.

Linked in. (2013). *Cool Roofs Benefits: Introduction*. Retrieved November 06, 2018, from https://www.slideshare.net/ProkopisPerdikis/cool-roofs-benefits-introduction

Loh, S. (2008). Living walls–A way to Green the Built Environment. *Environment Design Guide* , 1-7.

Lonely Planet. (2017). *Venetian Walls*. Retrieved February 01, 2019, from https://www.lonelyplanet.com/cyprus/nicosia-lefkosia/attractions/venetian-walls/a/poi-sig/1435204/358811

Louiza, H., Zéroual, A., and Djamel, H. (2015). Impact of the Transport on the Urban Heat Island. *Louiza H. et al. Impact of the Transport on the Urban Heat Island* , 252.

Lu, M., and Lin, A. (2015). Research on the Modular Living Walls System Based on Microclimate Adjustment in Severe Cold Areas of China. *Environment and Ecology Research, 3(5)* , 132-135.

Lush living walls. (2018). *Pest control in a vertical garden*. January 01, 2019 tarihinde https://lushlivingwalls.com/pest-control-in-a-vertical-garden/ adresinden alındı

Magliocco, A., and Perini, K. (2015). The perception of green integrated into architecture: installation of a green facade in Genoa, Italy. *AIMS Environ. Sci, 2*, 899-909.

Manso, M., and Castr -Gomes, J. (2015). Green wall systems: a review of their characteristics. *Renewable and Sustainable Energy Reviews, 41* , 863-871.

Medl, A., Florineth, F., Kikuta, S. B., and Mayr, S. (2018). Irrigation of 'Green walls' is necessary to avoid drought stress of grass vegetation (Phleum pratense L.). *Ecological engineering, 113* , 21-26.

Memon, R. A., Leung, D. Y., and Chunho, L. (2008). A review on the generation, determination and mitigation of Urban Heat Island. *Journal of Environmental Sciences, 20(1)* , 120-128.

Naava. (2017). *What are Green Walls - the definition, benefits, design and greenery*. Retrieved February 10, 2019, from https://www.naava.io/editorial/what-are-green-walls

News detail. (2015). *NTU moves up in 18 subject rankings, with three subjects in the global top 10 for the second year* . Retrieved November 15, 2018, from https://media.ntu.edu.sg/NewsReleases/Pages/newsdetail.aspx?news=f254866e-f67c-4220-a6ce-bfa4bb60df37

Ottelé, M., van Bohemen, H. D., and Fraaij, A. L. (2010). Quantifying the deposition of particulate matter on climber vegetation on living walls. *Ecological Engineering, 36(2)* , 154-162.

Pérez, G., Coma, J., Martorell, I., and Cabeza, L. F. (2014). Vertical Greenery Systems (VGS) for energy saving in buildings: A review. *Renewable and Sustainable Energy Reviews, 39*, 139-165.

Perini, K., Otteléb, M., Fraaij, A., Haas, E. M., and Raiteri, R. (2011). Vertical greening systems and the effect on air flow and temperature on the building envelope. *Building and Environment, 46(11)* , 2287-229.

Perini, K., and Magliocco, A. (2012). The integration of vegetation in architecture, vertical and horizontal greened surfaces. *International Journal of Biology, 4(2)* , 76.

Perini, K., and Rosasco, P. (2013). Cost–benefit analysis for green façades and living wall systems. *Building and Environment, 70* , 110-121.

Pixabay. (2016). *Bratislava slovakia building plush*. Retrieved November 19, 2018, from https://pixabay.com/photos/bratislava-slovakia-building-plush-1138414/

Plantups. (2016). *GW 6"-Green Wall Vertical Planter Kit for 6" grow pots*. Retrieved November 21, 2018, from https://plantups.co/products/8-vertical-planter-kit-12-plants-3-trays

Priyadarsini, R. (2012). Urban Heat Island and its Impact on Building Energy Consumption. *In Advances in building energy research* , 267-276.

Public health notes. (2018). *Urban Heat Island, Its Effects and Mitigation Measures*. Retrieved November 10, 2018, from https://www.publichealthnotes.com/urban-heat-island-effects-mitigation-measures/

Radwan, M. R., Kashyout, A. E., ELshimy, H. G., & Ashour, S. F. (2015). Green building as concept of sustainability Sustainable strategy to design Office building. *2 nd ISCASE-2015 Dubai* , 41.

Rakhshandehroo, M., Yusof, M., Johari, M., and Deghati, N. M. (2015). Green façade (Vertical Greening): Benefits and Threats. *In Applied Mechanics and Materials, Vol. 747* , 12-15.

Rayner, J. P., Raynor, K. J., and Williams, N. S. G. (2010). Façade greening: A case study from Melbourne, Australia. *Acta horticulturae, 881*, 709-713.

Razzaghmanesh, M., Beecham, S., and Salemi, T. (2016). The role of green roofs in mitigating Urban Heat Island effects in the metropolitan area of Adelaide, South Australia. *Urban Forestry & Urban Greening 15*, 89-102.

Renterghema, T. V., Hornikx, M., Forssen, J., and Botteldooren, D. (2013). The potential of building envelope greening to achieve quietness. *Building and Environment, 61*, 34-44.

Republic of Cyprus. (2019). *Department of meteorology*. Retrieved February 15, 2019, fromhttp://www.moa.gov.cy/moa/ms/ms.nsf/DMLcyclimate_en/DMLcyclimate_en?OpenDocument

RIAC. (2010). *The Resolution of the Cyprus Conflict: A Catalyst for East Mediterranean Security and Cooperation*. Retrieved November 25, 2018, from https://russiancouncil.ru/en/analytics-and-comments/analytics/the-resolution-of-the-cyprus-conflict-a-catalyst-for-east-me/

Rosenfeld, A. H., Akbari, H., Bretz, S., and Fishman, B. (1995). Mitigation of urban heat islands: materials, utility programs, updates. *Energy and buildings, 22(3)* , 255-265.

Roth, M., Oke, T. R., and Emery, W. J. (1989). Satellite-derived urban heat islands from three coastal cities and the utilization of such data in urban climatology. *International Journal of Remote Sensing, 10(11)* , 1699-1720.

Sadeghian, M. M. (2016). A Review on Green Wall, Classification and Function. *International Journal of Scientific Research in Science and Technology, 2* , 47-51.

Safikhani, T., Abdullah, A. M., Ossen, D. R., and Baharvand, M. (2014). A review of energy characteristic of vertical greenery systems. *Renewable and Sustainable Energy Reviews* , 450-462.

Sailor, D. J. (1998). Simulations of annual degree day impacts of urban vegetative \ augmentation. *Atmospheric Environment, 32(1)* , 43-52.

Santamouris, M. (2012). Cooling the cities – a review of reflectiive and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar energy 103*, 682-703.

Scribol. (2009). *8 Incredible Green Roofs*. Retrieved November 10, 2018, from http://scribol.com/art-and-design/green-design/8-incredible-green-roofs/

Sheweka, S., and Magdy, A. N. (2011). The living walls as an approach for a healthy urban environment. *Energy Procedia, 6* , 592-599.

Sourceable. (2015). *The difference between green and sustainable*. Retrieved December 06, 2018, from https://sourceable.net/difference-green-sustainable/

Sun power. (2017). *What is green building? Explaining eco - friendly construction*. December 07, 2018 from https://businessfeed.sunpower.com/articles/explaining-what-is-green-building

Susca, T., Gaffin, S. R., and Dell'Osso, G. R. (2011). Positive effects of vegetation: Urban heat island and green roofs. *Environmental pollution, 159(8-9)*, 2119-2126.

Susty vibes. (2015). *What Really is A Green Building?* Retrieved November 10, 2018, from https://sustyvibes.com/really-green-building/

6sqft. (2014). *The Flowerbox Building: A Sustainable Gem in a Storied Setting*. Retrieved November 14, 2018, from https://www.6sqft.com/the-flowerbox-building-a-sustainable-gem-in-a-storied-setting/

Taha, H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. *Energy and buildings, 25(2)* , 99-103.

Tamási, A., and Dobszay, G. (2015). Requirements for Designing Living Wall Systems– Analysing System Studies on Hungarian Projects. *Periodica Polytechnica Architecture, 46(2)* , 78-87.

Terry. (2006). *Climate change in urban areas f.a.q. (moccia mix)*. Retrieved November 10, 2018, from http://www.terry.ubc.ca/2006/02/08/climate-change-in-urban-areas-faq-moccia-mix/

Uponor. (2016). *How Green Buildings Can Reduce the Urban Heat Island*. Retrieved February 06, 2019, from https://web.uponor.hk/radiant-cooling-blog/how-green-buildings-can-reduce-the-urban-heat-island/

Urban gardens. (2013). *Concrete Indoor-Outdoor Modular Green Wall Tiles From France*. Retrieved November 22, 2018, from https://www.urbangardensweb.com/2013/12/02/benjamin-pawlica-concrete-modular-vertical-garden-green-wall-tiles/

Utility. (2018). *Top down green buildings*. Retrieved December 15, 2018, from https://utilitysmartpro.com/2018/04/top-down-green-buildings/

Vertology. (2015). *Viridiwall™ living wall system*. Retrieved November 20, 2018, from http://www.vertology.uk.com/products/viridiwall.html

Vijayaraghavan, K. (2016). Green roofs: a critical review on the role of components, benefits, limitations and trends. *Renewable and sustainable energy reviews 57*, 740-752.

Wander Globe. (2017). *A GUIDE TO INDEPENDENT TRAVEL IN CYPRUS.* Retrieved May 05, 2019, from http://www.wanderglobe.org/guide-independent-travel-cyprus/.

Wijerathne, S. N., and Halwatura, R. U. (2010). The Impact of Green Roofs on Urban Heat Island Effect. *Proceedings of the 16th Annual symposium Engineering research unit, At University of Moratuwa, Sri Lanka.* Sri Lanka.

Wilmers, F. (1990). Effects of vegetation on urban climate and buildings. *Energy and buildings, 15(3-4)* , 507-514.

World Population Review. (2019). *Cyprus Population 2019*. Retrieved November 24, 2018, from http://worldpopulationreview.com/countries/cyprus-population/

WUWT. (2018). *The Climate Sciences Use Of The Urban Heat Island Effect Is Pathetic And Misleading*. Retrieved December 05, 2018, from https://wattsupwiththat.com/2018/12/20/the-science-of-the-urban-heat-island-effect-is-pathetic-and-misleading/

Yeni duzen. (2015). *Mağusa - Lefkoşa anayolunu kullanacak olanlar dikkat: Mağusa-Lefkoşa anayolunu kullanacak olanlar dikkat* . Retrieved November 07, 2018, from http://www.yeniduzen.com/magusa-lefkosa-anayolunu-kullanacak-olanlar-dikkat-49164h.htm5

Zarandi, M. M., and Pourmousa, M. (2018). A comparative study on details of green walls in different climates. *Environmental Resources Research, 6(2)*, 187-194.

APPENDIX

APPENDIX

LIVING WALL AND GREEN FACADES: A STUDY IN NICOSIA

A) PERCEPTION ABOUT URBAN PROBLEMS

Listed below are statements about the urban problems. Please indicate the degree to which you agree with each item. Choose the number of your response for each statement using the following scale. The scale is from 1 to 5.

1= STRONGLY AGREE, 2= AGREE, 3= UNSURE, 4= DISAGREE, OR

5= STRONGLY DISSAGREE

PLEASE TICK **ONE** BOX ONLY

---

1. **The traffic and human activities are increasing and causing air pollution in the city of Nicosia.**
   ☐1 ☐2 ☐3 ☐4 ☐5
2. **The lack of green space and the increase of built-up areas in some cities of Cyprus such as Nicosia is one of the causes of air pollution and rising temperatures.**
   ☐1 ☐2 ☐3 ☐4 ☐5
3. **The vegetation contributes to the rainwater absorption and purification before entering the drainage.**
   ☐1 ☐2 ☐3 ☐4 ☐5

B) PERCEPTION REGARDING LIVING WALLS AND GREEN FACADES

Listed below are statements about the green walls. Please indicate the degree to which you agree with each item. Choose the number of your response for each statement using the following scale. The scale is from 1 to 5.

1= STRONGLY AGREE, 2= AGREE, 3= UNSURE, 4= DISAGREE, OR

5= STRONGLY DISSAGREE

PLEASE TICK **ONE** BOX ONLY

---

1. **The living plants that make up the green walls contribute tofiltering the air from the impurities and thus the access to more pure air in the cities.**
   ☐1 ☐2 ☐3 ☐4 ☐5

2. **The green walls contribute significantly to reducing the temperature of atmosphere or the phenomenon of global warming (Urban Heat Island).**
   ☐**1** ☐**2** ☐**3** ☐**4** ☐**5**
3. **Plants in green walls absorb sound frequencies where they work as a sound barrier and reduce noise, thus reducing the noise pollution in the urban areas.**
   ☐**1** ☐**2** ☐**3** ☐**4** ☐**5**
4. **Green walls give the city an aesthetic advantage.**
   ☐**1** ☐**2** ☐**3** ☐**4** ☐**5**
5. **The application of green walls on buildings contributes to thermal insulation thus saving energy costs for the building owner.**
   ☐**1** ☐**2** ☐**3** ☐**4** ☐**5**
6. **Green wall systems can be part of sustainability and urban rehabilitation and building retrofitting.**
   ☐**1** ☐**2** ☐**3** ☐**4** ☐**5**
7. **Plants induce a psychological well being thus the green wall systems are of therapeutic effect.**
   ☐**1** ☐**2** ☐**3** ☐**4** ☐**5**
8. **Do you encourage the adoption of a green walls strategy in the buildings in Nicosia?**
   ☐**1** ☐**2** ☐**3** ☐**4** ☐**5**

C) SOCIO-DEMOGRAPHIC DATA

1. **Gender**
- ❑ Female
- ❑ Male

2. **Age**
- ❑ 18-25
- ❑ 26-40
- ❑ 41-55
- ❑ 56-65
- ❑ 66-75

3. **Nationality**
- ❑ Cyprus
- ❑ Turkey
- ❑ Other nationality

4. Education

- ❑ None
- ❑ Primary school degree
- ❑ Secondary school degree
- ❑ High school degree
- ❑ University degree
- ❑ Master or PhD degree

5. The people who you live together

- ❑ 1
- ❑ 2
- ❑ 3
- ❑ 4 and/or more

6. How long have you been living in Nicosia?

- ❑ 1-5 years
- ❑ 6-10 years
- ❑ 11-20 years
- ❑ 20 +

7. Type of the house you living in!

- ❑ Detached house
- ❑ Villa
- ❑ Apartment

8. Have you ever used a living wall or green facades in your living environment?

- ❑ Yes
- ❑ No

9. Have you ever used living plants for making shady environments such as car parking, semi-open/semi-closed spaces?

- ❑ Yes
- ❑ No

10. For choosing a new house how important is the existence of a living wall or a green facade?

- ❑ Very
- ❑ Little
- ❑ Not important