Neapolis University Paphos

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Master Thesis

The Effect of Green Walls on the Urban Environment in the City of Nicosia

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Paphos, July 2022

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Abstract

Green walls are a natural-based solution (NBS) which offers the flexibility to re-introduce Nature to existing buildings. This study presents the application of a modular living wall and its data monitoring activity, in Nicosia (Cyprus). The response if this technology is implemented has been evaluated thanks to ENVIMET, a high-resolution meteorological simulation software.

The paper is aimed to investigate the difference between a space with and without green simulation in the public area, and the outcome of modular living walls in the Cyprus Institute. The results suggest that the reduction of temperature profile may be significantly more in the urban area since it is observed a reduction in the temperatures around the buildings during the summer period in Eleftheria square, an open public space.

Firstly, after the introduction and research statement is proposed the analysis of the Case study in Eleftheria square and the general context of Nicosia as an environmental playground accounted for this paper. Before the simulation process, an example of a green building which is located near the square is analyzed and the planting selection is according to this analysis. Different proposed scenarios were investigated in microclimatic simulations in the area. Then it is also presented the Cyprus Institute installation of this NBS solution designed by an Italian company and how it has been equipped with sensors to collect recordings in different positions. It will be presented and explained the phase of determination for the selection criteria of the plants, providing an insight into the choice made for the pilot case, with the issues that the authors ended up facing during the activities.

The results are presented starting with a focus on the variable and parameters assumed by the authors as significant, then the comparison between the model estimation achieved by ENVIMET simulation and the outcome of the data collection thanks to AIRCARE sensors is discussed and properly commented, trying to provide the clearest and concise overview for the thermal behaviour observed.

The future developments identified by the presented paper are highlighting the need of improving the quality of liveable spaces by implementing NBS solutions such as one of the case studies here above discussed. A proposal is to apply this technological new building product to a higher area, to assess a more accurate analysis and model validation since the current one installed being a pilot case might be not well enough to represent an optimal coverage. Additionally, the authors wish to clarify that the time rate of growth of the plants always plays a fundamental role and influences the thermal interaction between outdoor actions and the cavity of the panels.

Keywords: living modular walls, climate change, data acquisition, built environment, Mediterranean climate

TABLE OF CONTENTS

LIST OF TABLES

Chapter 1: Introduction

1.1 The importance of green walls in the urban environment

For the past few years, the European Union has been working on strategies to create sustainable cities. According to report No 5/2009 of Europe's Congress of Local Regional Authorities, "climate changes raise new, complex challenges for the urban quality of life and the health of European citizens". (7) "High population densities means that cities are highly aware and concerned of problems associated with climate change." (7) "Health impacts of heat waves are more pronounced for vulnerable groups, such as infants, children, the elderly, and those living in deprived areas and are unable to take remedial action. More extreme weather events includingfloods, droughts, and heat waves are already more evident throughout Europe: it has been estimated that the 2003 heat wave caused more than 52 000 premature deaths (EPI, 2006)." (7)

The climate changes are a result of the "urban heat island", due to their contribution to the greenhouse effect and consequently to global warming. When the cities have dense concentrations of pavements, buildings and other hard surfaces which retain heat, this phenomenon is called "urban heat island". (24) "The urban heat island is characterized by significantly higher air temperature in the densely built environment as compared to rural temperatures. This is caused by the rapid urbanization and change of the land profile where more impervious surfaces such as asphalt, concrete and glass are found rather than grass or green area. (11)

According to several studies, living walls, reduce the urban heat island effect, because they can cover the exposed hard surfaces in the built environment. For example, "according to Ken Yeang(1998), if a skyscraper has a plant ratio of one to seven, then the façade area is equivalent to almost three times the area. So, if the building is covered two-thirds of the façade, this has contributed to doubling the extent of vegetation on site. So, a skyscraper cab become green, thus increasing the organic mass on the site." (11) As a result of the use of living walls in the cities, the cooling processes such as evapotranspiration contributes to the temperature decrease. This thesis will try to prove how living walls can reduce the phenomenon of "urban heat island".in the centre city of Nicosia in Cyprus.

1.2 Objectives of the thesis

Green walls as will be stated later in the literature review, are the natural – architectural solution for bringing nature into the buildable area. There are different types of green walls which have many advantages and benefits to the urban environment. So much research and experiments have been achieved to prove that the installation of green areas in urban development, can reduce the phenomenon of the urban heat islands. Within this framework, this thesis is aimed to find out how the greening of the buildings around the open space of Eleftheria's square in the centre of Nicosia, can reduce the urban heat island in the city centre.

As construction is increasing day by day, and the cities are getting more polluted from the urban population, living walls s a solution for the urban heat environment and the improvement of air quality. The objective of this dissertation is to present how green walls affect the change of temperature in an urban environment with dense construction and high buildings and an urban environment with low buildings and open spaces.

1.3 Research approach

Green walls are a particularly promising component of greening infrastructure. In chapter 2 the literature review contains the information on the definition, the history, the types, and the advantages of the living walls. The importance of green walls is stated in the same chapter, presenting their impact on the reduction of the urban heat environment.

A case study with research methodology and results is presented in chapter 3. The thesis with the case study at Cyprus Institute in Nicosia is a part of the comparison in chapter 5.

The main body of the dissertation is chapter 4 which presents the analysis of the case study Eleftheia's square and the results of the simulation result.

Chapter 2: Literature Review

2.1 The definition of the vertical garden – green walls

“Vertical garden could be a more modern approach with a variety of succulents hanging from the wall or an edible vertical garden.” There are a lot of types of the vertical garden which are the result of vegetated wall surfaces. Natural green walls, artificial green walls, vertical systems, landscape walls and vegetated walls modular living walls are the types and systems of vertical gardens. Also, green walls are part of the vertical garden system. (22)

“Green walls are formed of plants grown up in vertical supported systems that are in general connected to either internal or external walls, in rough cases, however, they can be self-supporting.” (9) Green walls are also known as vertical gardens or vertical greening systems that can be divided into two groups. According to the vegetation type and the supporting structures that are used, green walls are called green facades or living walls. (17)

Green facades are a term which is used to refer to all forms of vegetated wall surfaces which can be anchored to existing walls or buildings as freestanding structures. (19) This freestanding structure is covered with plants which can be rooted into the ground or in panels attached to the structure. Also living wall is a system of devised and pre-vegetated panels or planted blankets which are “designed from expanded polystyrene, plastic, synthetic fabric, metal clay and concrete, allowing them to withhold great density and diversity of various plants” (22)

2.2 History of green walls – examples

Nowadays societies are in a need for making a conscious choice to switch to a more sustainable way of life and one of the strategies to achieve that is the planting and preservation of greenery in urban areas. Green walls are one of the most known components that are used in existing buildings to achieve sustainable urban development. Nevertheless, throughout history, the concept of green walls was a strategy to increase the insulation and improve the aesthetics.

The concept of green walls is an ancient one and it dates 2500 years back, between 3rd BC and 17th AD Romans trained grapes on garden trellises and villa walls. One of the seven ancient wonders of the world, “Hanging Gardens of Babylon” *(figure 1)*, which is built by King Nebuchadnezzar II, is the first example in architectural history. (19) Trees and ornamental plants were cultivated in elevations, and it is considered to be a precursor of today’s green walls.

It has also been recorded that during “Viking Age”, when Vikings used stone, timber and peat bricks to build their habitation, the grass was growing naturally on peat bricks *(figure 2,3)*. As a result of the use of these materials, the habitation was covered with vegetation and transformed the brick walls into green walls. Even if these green walls were not created on purpose, nature created a strong and sustainable wall. (16)

In recent history, green walls were constructed in the Soviet Union as well as in France during the 18th century. At the beginning of the 20th century and specifically in 1920s, the British and North American garden city movement promote the integration of house gardens through features like trellis structures, pergolas and self-climbing plants. (16) The use of climbing plants was also very common in Europe.

Figure 1. Papadopoulou (2013)

Figure 2.worldkings.com

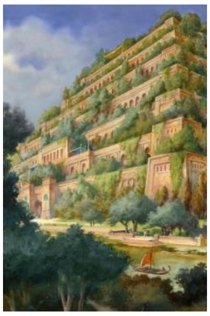


Figure 3. thegardenstrudt.blog

In 1988 a new type of green wall is invented by Patrick Blanc. A stainless steel cable system, where plants can grow vertically, without soil and with no contact with the wall, is the modern green wall. The project of Patrick Blanc that used the new green wall type3 was the Avignon, Les Halles – Caixa Forum, in Madrid. After that, different systems and various applications like cable and wire–rope net systems and modular trellis panel systems important for the spread of green walls were enter the North American marketplace. (16)

A lot of examples of green walls and different types of them are stated in the past years. In 1993 the first major application of the trellis panel system is located at Universal City Walk in California and one year later the first indoor living wall with the bio-filtration system was installed in Canada Life Building in Toronto, Canada. In Zurich, Switzerland a project featured over 1300 climbing plants in the MFO Park and 2005, the Japanese federal government-sponsored a massive Bio Lung exhibit, the centrepiece of Expo 2005 in Aichi, Japan, which was the biggest in the world. The wall is comprised of 30 different modular green wall systems. More recently, in 2007 Seattle implements the Green Factor, which includes green walls and the GRHC launches a full day Green Wall Design which is the first on the subject in North America. Also in 2008 GRHC, launches the Green Wall Award of Excellence and Green Wall Research Fund. (19)

2.3 Types of green walls - examples

As mentioned before, green walls can be divided into two main categories according to various features. The two main categories are the green facades and the living walls which are divided into subcategories according to supporting elements, growing media, vegetation, and drainage and irrigation system. Green facades are “the systems that mostly consist of climbing plants or vines that are attached to existing walls or built as freestanding structures”. (16) For this system the plants that are used are soil-rooted and their selection depends on the climate and the wall orientation.

Green facades are divided into two primary types according to the structure of the system. The *grid and wire-rope net system* and the *modular walls hung trellis (figure 4)*. The main system of the modular trellis *(figure 6)* is a three-dimensional panel system, rigid and lightweight prefabricated panel, which has a distance from the bare wall surface to be easier the maintenance. The welded wire steel that is included in the system, supports the vegetation which does not attach to the building surface. The panels are joined together to cover large areas. (9)

Figure 4. ELHady (2019)

Figure 5. ELHady (2019)

A *grid and wire-rope net system (figure 7)* is the type of green wall which is suitable for the support of faster-growing plants with denser foliage. Both systems grid and wire-rope net, are using steel cables with high tensile and anchors. Cross clamps are used and are provided with different patterns and sizes. (9)

Figure 6. www.greenscreen.com

Figure 7. christianbarnardblog.blogspot.com

Living walls (figure 8) are also called bio-walls or vertical gardens and are the second type of green walls. This wall system is made of pre-vegetated panels, modules or bag-shaped boxes which are fixed to a structural frame or wall. The panels are made of plastic, expanded polystyrene, synthetic fabric, clay, metal and concrete and they support plant species of different densities. This system can support a large number of plants and irrigates itself using an automatic system.

Living walls (figure 9) are divided into two types according to the growth of vegetation. The hydroponic walls use the circulation of water to deliver nutrients directly to the roots of the plant and, the soil or growing media-based wall which is made of modules that keep growth media to sustain plant material. (16)

“Hydroponics” is the type of living walls in which the plants are growing with a liquid that contains mineral nutrients and there is no soil in the structure. On the contrary, growth media is the type of living walls which are made of modules that keep growth media to sustain plant material.

Figure 8. ELHady (2019)

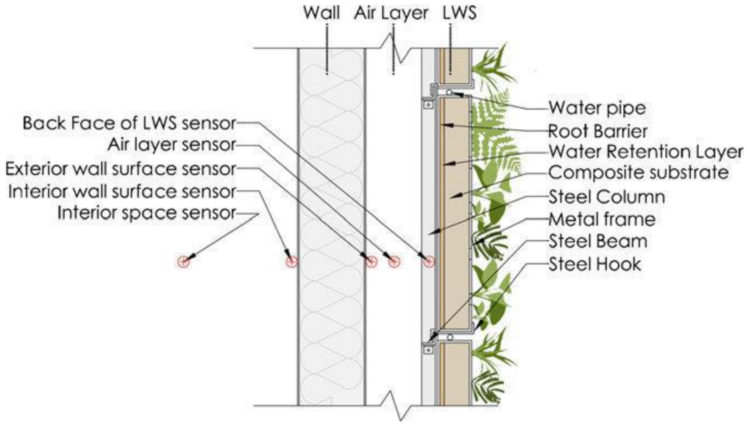


Figure 9. www.researchgate.net/figure/details-of-the-living-wall-system

Except from the types of living walls, there are various forms of living walls with the main differences occurring between interior and exterior designs. The main systems forms are modular walls, vegetated mat wall, biofiltration and landscape walls.

The modular living walls *(figure 10)* evolved from the usage of modules in green roof applications, resulting in numerous technological breakthroughs. Panels with rectangular and square shapes retain the growing media to support vegetative material in these systems. Flexible bags, jars, trays, and planter tiles are all part of the system. The growing medium composition could be tailored to the specific combination of selected vegetation as well as other design considerations. The growing material inside the modules contains the majority of the vegetation's nutrient requirements. The irrigation, on the other hand, is given with a modular system on several levels alongside the building shell, employing gravity to allow the water to flow through. (9)

Vegetated Mat Wall *(figure 11)* is a unique green-wall style. It is made up of two synthetic fabric layers with pockets that physically support growth material and flora. Because of the high moisture content, it is backed by a waterproof membrane and supported by a frame beside the building's shell. The nutrients, on the other hand, are generally dispersed by an automatic irrigation system that irrigates the water from the top to the bottom of the system. (9)

The biofiltration *(figure 12,13)* is the third form of living walls. An 'active' living wall is one that is designed to be incorporated into a building's infrastructure and to provide biofiltration and thermal regulation. It's a hydroponic system fed by nutrient-rich water recirculated from a manifold at the top of the fabric wall system and collected in a gutter at the bottom. Microbes and a dense root mass are sandwiched between two layers of synthetic cloth. (19)

Landscape Walls are a strategic instrument in an approach to "living" architecture that evolved from landscape "berms." Noise reduction and slope stabilization are the principal functions of landscape walls, which are often sloping rather than vertical. They are usually built of some sort of stacking material, such as plastic or concrete, with space for growing soil and plants. (19)

Figure 10. ansgroupglobal.com

Figure 11.Caixa Forum, Madrid, pinterest

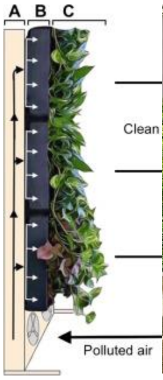


Figure 12. Irga (2019)

Figure 13. archello.com/product-multi-family-living-wall-biofilters

2.4 Advantages – benefits of green walls

Researchers are becoming increasingly aware of the potential and positive effects that urban greening efforts can have on a range of urban features. In recent years, green walls have sparked this interest, sparking responses and additional research into how they vary from other urban green infrastructures. The following is a comprehensive analysis of the unique benefits of green walls, with a focus on their ecological, environmental, economic and social implications.

Social Benefits

The social consequences of green walls are divided into two categories: physiological and aesthetic, and they depict the interaction between human activities and behavior and vertical green walls.

Physiological

Plants in the office have been proved in numerous studies to minimize sick days and enhance productivity. Despite being attractive to look at, plants also provide fresh oxygen to a place, making it more appealing. Greenery can also be linked to food, health, and life, as well as a subconscious connection. Because the majority of humanity lives and works in cities, and spends the majority of their time indoors, empty walls and interiors can be brightened and energized by the sensation of wealth provided by plants. (22)

Aesthetic

Most green wall initiatives currently have aesthetic enhancements as their primary design goal. Green walls can be used to improve the aesthetics of large parking structures, campus buildings, urban streets with repeating facades, public park buildings, transit shelters, and retail buildings. Patterns, rhythms, and shapes, as well as plant textures and the welcoming aspects of designing with nature, can all help to improve aesthetics.

Green walls, both wall mounted and freestanding, can be utilized to screen and isolate vistas. Mechanical equipment, service spaces, storage access, and other components of a building's system requirements that distract from the aesthetic experience can all be hidden with them.

These possibilities are also available for interior applications and integration with rooftop surroundings. Plant materials for green facades and living walls can be flowering, changing color as the seasons change, or deciduous, drastically changing their visual character. The vertical form of a green "wall" allows them to produce enormous and efficient green zones with a compact footprint.

Aesthetic value is concerned with human connection rather than the quantitative evaluation of a building's materials and system performance. Making green wall features for a waiting zone, a healing garden, a building entrance, or a rooftop garden could benefit from the demonstrable benefits that plants can bring. This particular benefit is an enhancement of the human experience in the built environment.

It's critical to choose plant species that will survive in the particular site circumstances when planning a green wall design. In colder climates, for example, there are vine species that keep their foliage throughout the winter. The seasons should be considered while designing a green wall for a temperate climatic zone, as well as how different plants adapt to this cycle. A green wall's aesthetic perception can be substantially influenced by these modifications. Plants chosen may have to withstand frigid conditions in the winter and also bloom fully in the summer heat. Plant selections could include both quick and slow-growing species, requiring a combination of structures such as a wire-net and cable system. (19)

Ecological

In most cases, urban regions are known to have fewer biodiversity than the preurban ecosystem. Because the acreage committed to protected areas is insufficient to prevent biodiversity loss, new ecological concepts and methods to preserve Earth's biodiversity have been developed. In this context, reconciliation ecology tries to alter and diversify anthropogenic ecosystems in order to support a wider range of species while maintaining land usage.

Vertical gardens and green roofs are good examples of reconciliation ecology since they provide habitat for plants and animals on land that is directly used by humans for living space. By allowing spontaneous plants to colonize these systems, they increase urban biodiversity and consequently the urban environment. They provide habitat for birds and insects that perform a variety of functions and ecosystem services, such as pollination and biological control, because they can resemble natural vertical habitats like cliffs or vegetated waterfalls. They can also be used to produce species that can fill in for specific functions that are lacking in the urban environment, most notably the ability of plants to filter toxins from the air.

Observations on living walls, however, are still anecdotal, despite the numerous research on the ecological implications of green roofs. New and particular wall-oriented studies are thus desirable to untangle the true ecological potential of living walls as well as the best design features that allow for increased urban biodiversity. (17)

Environmental

Plants are increasingly being used to improve the quality of their surroundings in modern building developments that seek not only an esthetic impact but also a means of providing environmental services such as natural air cooling, water filtration, and mitigation of a variety of environmental problems. In the case of indoor living walls, the reported positive effects of vegetation on air quality may benefit a building's interior environment, which are not only related to the plants' ability to adhere particles from the air but also to their efficiency (along with microorganisms found in the substrate) in absorbing air pollutants.

Aside from pollution reduction, air temperature and humidity are other important aspects of indoor air quality that are closely linked to human comfort and can be influenced by indoor living walls. Temperature reductions of up to 4–6°C have been seen in the vicinity of an indoor living wall in hot areas. The evapotranspiration process of plants and substrate demands energy from the indoor air, which lowers air temperature and raises humidity. This physical process causes "evaporative cooling," which is influenced by a variety of factors, including vegetation type and exposure. When air is cooled by evaporation, the humidity inside the house rises. Because interior air is typically too dry, especially when internal heating or cooling systems are employed, the humidity boost supplied by the living wall may be useful. However, in other cases (for example, humid environments), ventilation may be essential to avoid health concerns linked with high humidity.

The substrate where plants grow has a sound-absorbing effect and gives acoustic benefits derived from noise isolation, therefore living walls can also be utilized as noise barriers. The more greenery coverage there is, the higher the sound absorption. When erected domestically, the living wall can also be used to safeguard speech privacy. When rainwater is harvested on roofs to irrigate the living wall, a well-designed system can also have good impacts on urban hydrology, avoiding rapid discharges of storm water into sewers, especially if it is combined with green roof technologies that act as water buffers. (17)

Economic

Green walls provide economic benefits in addition to environmental benefits. The economic benefits of green walls can be realized by the use of plants on building facades, which decreases climatic stress while also safeguarding the structural integrity, resulting in building lifetime. Additionally, using a green wall lessens environmental effects on the building envelope, lowering energy usage. (9)

2.5 Risks of vertical gardens

Green walls (both green façades and living walls) face a number of challenges and concerns as a new and unique technology in its early stages, ranging from major economic to simple cleanliness. Cost barrier, irrigation, mold and moisture problems, wall damages, salt accumulation, attraction of insects and the excessive of pollen are the main “problems” and concerns of green walls.

The most significant disadvantage of green wall installations is the cost. Most people consider that to be a form of luxury. Some types of green walls (particularly living walls) are highly pricey since they use cutting-edge technologies and high-end materials or plants. This is also due to the fact that upkeep and building are expensive, resulting in a potential investor's refusal to pay. However, the more installations built, the worst characteristics are avoided and the cost is reduced. As a result, there is hope that this will alter in the future. Fortunately, there are several sorts of well-functioning vertical planted walls that are affordable.

There is a problem with improper irrigation, either by under- or over-irrigation, that has been discovered. This issue is an installation fault that can cause damage to plants and materials.

To assist prevent hazardous molds from growing, proper air and water flow must be provided.

Because moisture can cause structural deterioration, the walls must be sufficiently isolated from the framework. Overall, mold and moisture are intertwined: moisture must be regulated to prevent mold formation.

This is a problem that has been discovered in Ivy-planted green façade projects. Ivy-covered buildings, according to Building Design and Construction, are aggressive, self-clinging plants that grow without particularly constructed support and are known to harm walls and obstruct building maintenance. Nonetheless, this is a contentious subject.

According to Greenscreen, excessive sodium (Na) from salt degrades soil structure, elevates soil pH, limits water infiltration and soil aeration, resulting in soil compaction and water runoff. Photosynthesis and other plant activities such as respiration and transpiration can be hampered by this accumulation.

Green installations, according to reports, might attract unwelcome creatures such as spiders and termites. The latter, in particular, causes challenges for timber constructions. Green barriers, on the other hand, help to increase biodiversity.

The selection of plants that do not release excessive pollen, as this contributes to the formation of unfavorable health conditions in the surrounding area, is an important consideration. Other issues to be addressed include faulty plant selection, the use of the incorrect growth medium, and plant leaf fall. (16)

2.6 Urban heat island definition

"Urban heat island is characterized by significantly higher air temperature in densely built environment as compared to rural temperatures." (3) This is due to increased urbanization and a shift in land profile that favors impermeable surfaces like asphalt, concrete, and glass over grass and green space. The cause of urban heat island can be characterized as Canyon Geometry, Building Materials, greenhouse effect, anthropogenic heat source, evaporative cooling source, and wind pattern, based on studies conducted around the world.

2.7 Reduction of the urban heat island

Researchers are increasingly aware of the potential and beneficial effects that urban greening projects have on a variety of characteristics of the urban environment. The scientific community has made several attempts over the last 25 years to shine light on the numerous ecological, environmental, and social benefits of green roof systems. Green walls have piqued this attention in recent years, prompting replies and additional research into their differences from other urban green infrastructure. The following is a thorough examination of the specific advantages of green walls, with an emphasis on their ecological, environmental, and social ramifications.

The main cause of urban heat island creation is the increasing replacement of natural surfaces by concrete surfaces throughout urbanization. Vegetation and liquid soils are common in natural places.

As a result, they use a significant portion of the absorbed radiation in the evapotranspiration process, releasing water vapor that cools the air around them. Concrete or constructed surfaces, on the other hand, have a high proportion of non-reflective and water-resistant construction elements. This means they absorb a substantial quantity of incident radiation, which is then emitted as heat.

Natural cooling processes such as photosynthesis and evapotranspiration are activated when vegetation is reintroduced into urban developed settings. The evapotranspiration from green walls, in particular, adds to the temperature drop near the greenery. As a result, the ambient air temperature drops, resulting in energy savings for cooling the building interiors as well as urban heat island reduction, especially in higher climates. (16)

Chapter 3: The case of The Cyprus Institute

This chapter will present the methodology. The local climatic conditions and the planting selection of the thesis, "A nature-based solution for Mediterranean climates – Design, monitoring and evaluation of a modular living wall installed at The Cyprus Institute" by Magdalene Charalambous. (5) A comparison between the results of the two thesis will be present at chapter 5.

3.1 Research method

In order to achieve the objectives of the thesis, the author designed a research method of six stages. First, a modular living wall was created and then they ran a quantitative experiment to track its progress *(figure 14).* The first thing before create the modular living was to select the right location and then they order the panels according to the façade and its dimensions. Following that, they went through a plant selection process and determined which plants would work best in the application. After that, a plantation layout was created by the team and they planted them according the drawings.

The monitoring was started using two methods: environmental sensing and infrared thermal imaging. For the environmental sensing they used two multi-sensors fusion units in order to compare the atmospheric conditions. The first one was placed behind the modular living wall and the other on front of the façade next to the modular living wall. The one in front of the façade was the reference for conditions to which that side of the building is exposed to *(figure 16).*

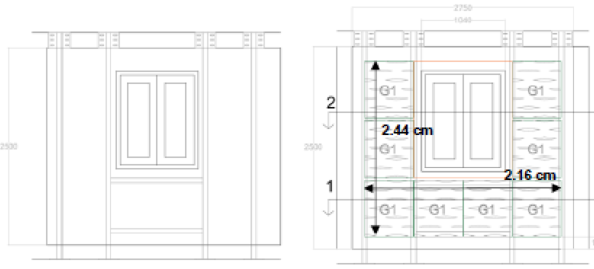


Figure 14. Charalambous (2021)


Figure 15. Charalambous (2021)


Figure 16. Charalambous (2021)

3.2 Local climatic conditions

In the middle of Cyprus, at 35°8'N, 33°16'E and 224m above sea level, is located Nicosia *(figure 17)* which has a subtropical steppe/low-latitude semiarid hot climate. The total annual precipitation averages 345mm[10] and the mean annual temperature is 19.2°C *(figure 18).* These climates feature hot or extremely hot summers and warm to cool winters with little to no precipitation. The experimental living wall is located in the Athalassa campus, at Aglantzia which is opposite to Athalassa National Forest Park, an open space without buildings or other obstacles.

Figure 17. Charalambous (2021)

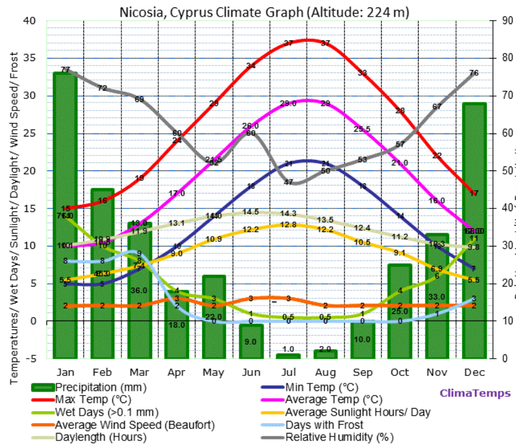


Figure 18. Charalambous (2021)

3.3 Planting selection

The selection of the right plants is crucial for the success of a green wall installation. The success of green walls heavily depends on how suitable the plants are for that application, hence plant selection must be done. The green wall's geographic location and the prevailing weather conditions to which it will be subjected rank among the most crucial criteria. Also, the environmental pressures that the plants must withstand, such as temperature, rain, snow, drought, and extreme weather events, are determined by this information. The selection process should take into account other plant physiological factors as canopy structure, foliage, and density. Sensitivity to pollutants, nutrient requirements, and plant growth rate are further crucial considerations.

In the thesis of Cyprus Institute, after the determining and taxonomizing the selection criteria, they searched in the literature for plants that were chosen or proposed for green wall applications or green roof applications. Then they created a list of plants that were carefully investigated through databases, and their features were according to the selection criteria. Some of those plants are *Sedum album murale* which is used widely in dry climates, *Allium schoenoprasum*, aromatic plants such as *Origanum vulgare, Thymus serpyllium, Lavandula angustifolia* and *Rosmarinus officinalis* which are most commonly found in Cyprus. Additionally, two of the most common mint types, *Salvia officinalis, Campanula carpatica, Gazanias rigens, After alpinus* which are popular plants for dry climates and *Santolina chamaecyparissus.* In conclusion, they listed 20 potetntial candidate plants *(figure 20).*

After three more selections according to variety of criteria, they finally selected seven plants. These plants, are *Gazania rigens var. leucolaena*, *Lavandula angustifolia*, *Mentha spicata*, *Origanum vulgare, Portulaca grandiflora*, *Rosmarinus officinalis* and *Thymus vulgaris (figure 19).*

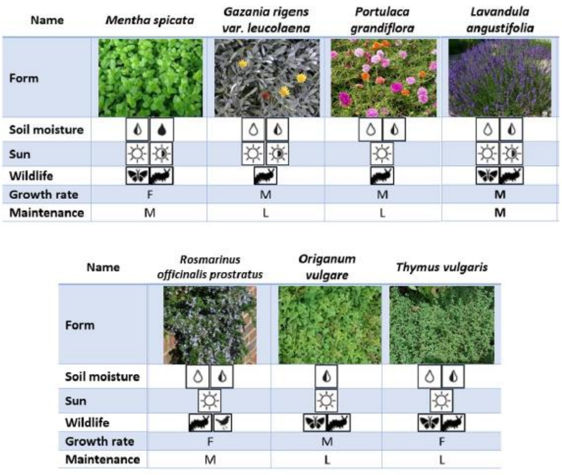


Figure 19. Charalambous (2021)

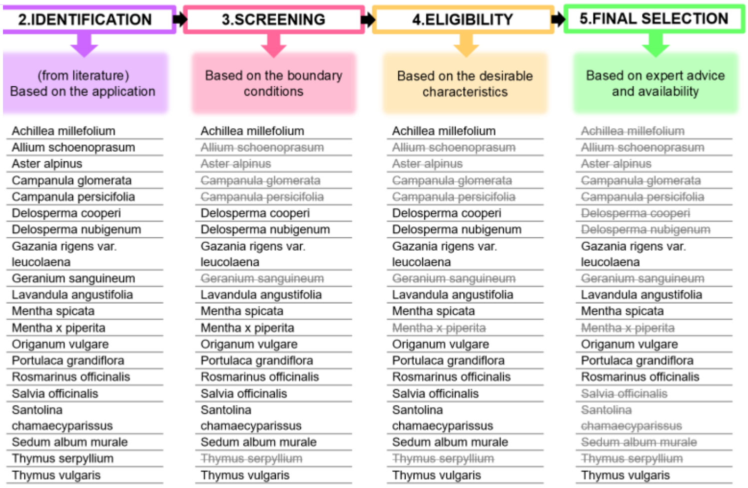


Figure 20. Charalambous (2021)

3.4 Results of monitoring

The experimental monitoring of atmospheric variables was achieved for two years. For the year 2021, there are comparable results with the Department of Meteorology for Athalassa park. The results that have been analyzed, concern the 4 months that we are studying in this thesis – March, June, September and December. For this comparison we have the average temperatures for two specifically hours during the day, 08:00 and 13:00.

For March, at 08:00, the average temperature was 14.1°C and at 13:00 was 18.7°C. After installing the green wall on the façade of the building, the results for these days and hours, were 16.96°C and 19.99°C respectively. So, during the March, the results showed increased of temperature but within thermal comfort levels.

During the June 2021, the average temperatures were 27.30°C at 08:00 and 33.00°C at 13:00. The installation of green wall in The Cyprus Institute building, resulted a reduction of temperatures. Specifically, during the morning the reduction was 0.31°C and respectively at 13:00 was 4.33°C. In this case, the reduction of temperature during midday, is important because through the installation of green walls we can achieve thermal comfort in the microclimate of the area.

For September the results showed an increase in temperature by an average of 5°C. This increain of temperature, has a negative impact on thermal comfort. Also, in December, the green wall installation is resulted an increase of temperatures approximately 3.5°C. Due to low temperatures during the winter, this increase helped to achieved thermal comfort.

In conclusion, green walls are a strategy to create thermal comfort during the year, except for the period of September when it increases the temperatures. The experimental process carried out at The Cyprus Institute and its results were the trigger for the further investigation of green walls in open public spaces.

MARCH 2021		
TIME/HOUR	8:00	13:00
DEPARTMENT OF METEOROLOGY	14.10°C	18.70°C
THE CYPRUS INSTITUTE	16.96°C	19.99°C

JUNE 2021		
TIME/HOUR	8:00	13:00
DEPARTMENT OF METEOROLOGY	28.20°C	32.40°C
THE CYPRUS INSTITUTE	27.89°C	28.07°C

SEPTEMBER 2021		
TIME/HOUR	8:00	13:00
DEPARTMENT OF METEOROLOGY	27.30°C	33.00°C
THE CYPRUS INSTITUTE	33.45°C	36.85°C

DECEMBER 2021		
TIME/HOUR	8:00	13:00
DEPARTMENT OF METEOROLOGY	10.50°C	16.60°C
THE CYPRUS INSTITUTE	15.60°C	18.64°C

Table 1: Average temperatures in Athalassa's park and in The Cyprus Institute

Chapter 4: Research Methodology - Results

4.1 Introduction

The purpose of the current thesis is to explain the environmental concept of green walls, examine it, and then discuss how it may affect the microclimate of a Mediterranean urban center. Initially in this chapter is presented and analyzed the environmental and climatic characteristic of the case study which is Eleftheria's square in Nicosia. Furthermore, is presented the example of the architect Jean Nouvel's building which is located near the case study in which the planting is incorporated the inside of the building and creates a type of green wall. Also, in this chapter is presented the research methodology, the experimental design and the description of the simulation. Finally, the results are stated and presented on graphs.

4.2 The Case study Eleftherias square in Nicosia

Nicosia is one of the cities which is not observed green areas *(figure 21)*. There are two organized green areas, the linear park of the river Pediaios and Athalassas park which are located around the center of Nicosia. One of the most important area in the city, is Eleftheria's square with the new transformation into an urban park. After the implementation of the idea of a park, Eleftheria's square is now an area mainly made of concrete, a series of tree-lined promenades, paved plazas, green spaces and water *(figure 22,23)*. "The park is intended to be the starting point for the architects' plan to encircle the old city with a "green belt". (26) The case study that have been chosen is Eleftheria's square in order to give alternative solutions for greening the area and also to render thermal comfort to residents and visitors, both in square area and inside the buildings.

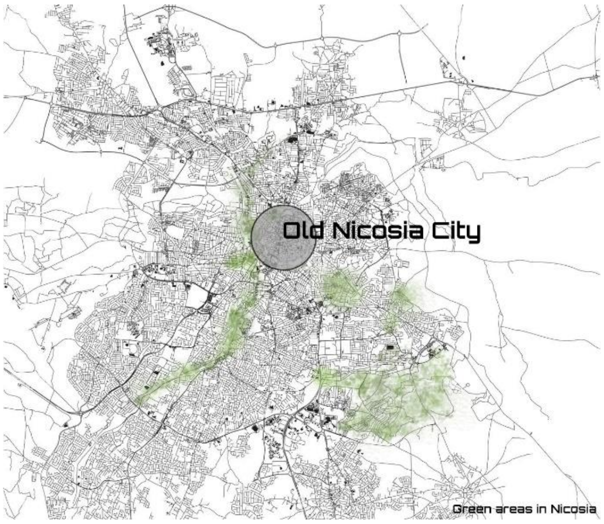


Figure 21. Green areas of Nicosia city

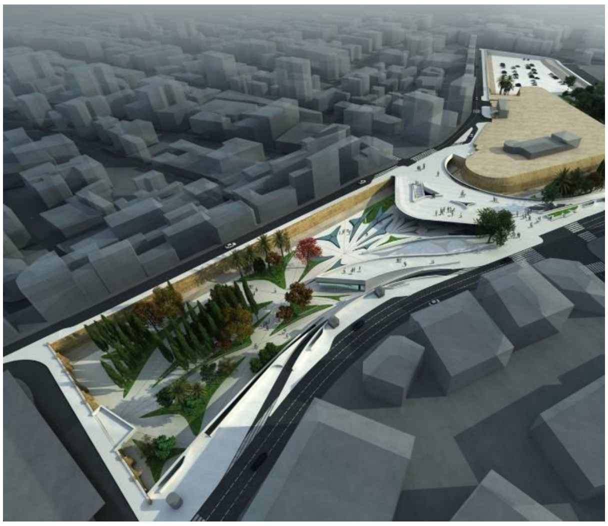


Figure 22. Eleftheria's square – draftworks.eu

The location chosen for the simulation is Eleftheria's square which is located in Nicosia *(figure 24)*. This area is the main square in central Nicosia and it forms the intersection of Ledra and Onasagorou street with Stasinou, Omirou, Kostaki Pantelidi, Konstandinou Palaiologou and Evagorou avenues. The history of the square dates back to 1567 and today the area is transformed into an urban park by the office of Zaha Hadid Architects.

Figure 23. Planting plan – draftworks.eu

Eleftheria’s square *(figure25)* connects the historic area of Nicosia with the new part of the city with a literal bridge of 3500square meters. The square also includes the area that runs alongside the historic Venetian Walls and the dry moat that encircles Nicosia. Also, is a new public square that is defined in the center of the city by elevating the topography of the moat to create an upper level bridge that meets the surrounding streetscape. This design directly connects to the city's urban fabric. In the new part of Nicosia there are new high-rise buildings with the tallest to be 67 meters and are made of concrete. On the other part – norther of the square, we can see buildings with the maximum 6 levels, no gap in between them, and are made of the traditional stone called “pouropetra”

Figure 24. zaha-hadid.com

Figure 25. zaha-hadid.com

Figure 26 zaha-hadid.com

As is stated before, Nicosia has a subtropical steppe/low-latitude semiarid hot climate. The summers are hot, humid, arid, and clear and winters are cold, windy, and mostly clear. During the year the temperatures vary from 6°C to 33°C *(figure 27, 28, 29).*

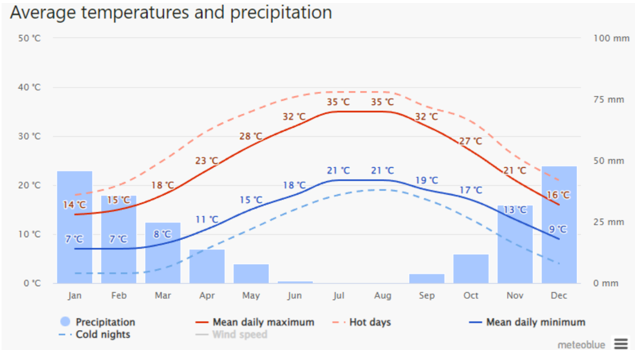


Figure 27. meteoblue.com

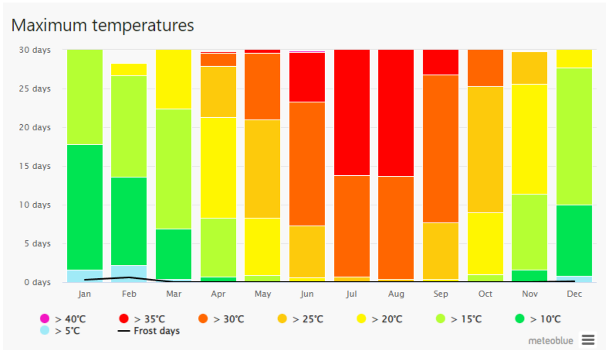


Figure 28. meteoblue.com

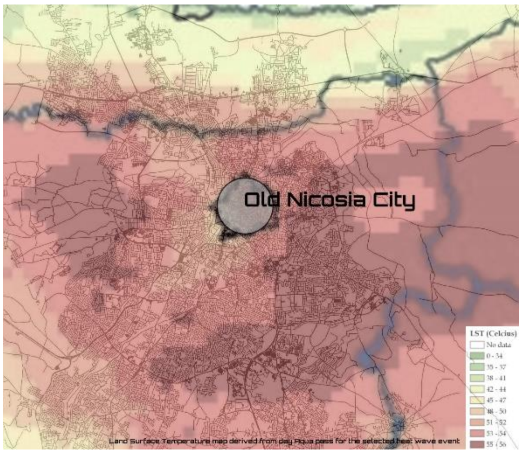


Figure 29. Temperature surface in the city of Nicosia

Figure 30. Nicosia square – draftworks.eu

4.3 Determination of the selection criteria of the plants and the vertical garden type

Plant selection depends on various criteria and the most important is the climatic conditions and the geographical location of the green wall. Also, the microclimate in specific areas significantly impacts the plants because it determines the variable light, heat and humidity. Additionally, the orientation of the building is an important criterion to choose the right plants and their survival.

In the case of the study area, the selection of plants will be based on the existing plants that are thriving in the area. In order to achieve a possible and correct selection of the plants, an analysis and overview of the area are made and more specifically the case of Jean's Nouvel building – tower 25 is presented *(figure 31, 32, 33)*. This building is located near the case study and is characterized by the way the architect incorporates nature into the building. The building vertically acts as a visual counterpoint to the horizontality of the nearby medieval walls and moat that surrounds the old section of the city as it stands as a new landmark.

Tower 25 according to the architect, is a "brise soleil" (25) which means that the plants are protecting naturally the indoor area from the sun during the summer period and simultaneously apartments, and offices admit the natural light during the winter. We can say that this building belongs to the category of green facades. As it is mentioned before, Green facades are "the systems that mostly consist of climbing plants or vines that are attached to existing walls". (16) Specifically in the Jean's Nouvel building, the architect used flowerbeds at the edge of the building or balconies to create a green shield for the building shell.

Figure 31. dezeen.com

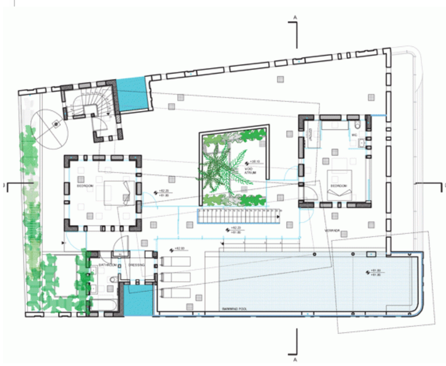


Figure 32. dezeen.com

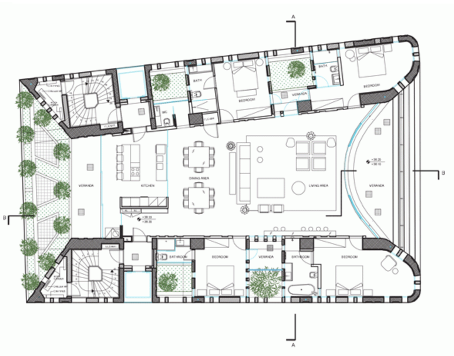


Figure 33. dezeen.com

On the southern façade –that receives the most sunlight, a vertical landscape covers approximately 80% of the building and the local plants that are supported by this living façade change seasonally *(figure 34)*. The concrete wall across the eastern and western facades is punctured by a haphazard arrangement of square openings. These openings are filled with greenery that emerges from internal gardens. The architect wanted to create a natural shield from the sun and connect nature with the people inside the building *(figure 35, 36)*. By contrast, the north façade is kept empty from plants.

Figure 34. dezeen.com

Figure 35. dezeen.com

Figure36. dezeen.com

The selection of the plants of Tower 25, seems to be successful because the plants are thriving and provide environmental benefits and aesthetic values during the past seven years. They used various Cypriote climbing and spreading plants *(figure 37, 38, 39, 40, 41, 42*) that will continually change by the cyclic movement of the seasons. Some of the plants that they planted in the building are *Bougainvillea glabra, Syagrus romanzoffiana, Strelitzia reginae, Hedera Hibernica* and *Schefflera sp.*

Figure 37. www.jeannouvel.com

Figure 38. www.jeannouvel.co

Figure 39. www.jeannouvel.com

Figure 40. www.jeannouvel.com

Figure 41. www.jeannouvel.com

Figure 42. www.jeannouvel.com

4.4 Research method, experimental design, and description

The main goal of this study is to determine whether green walls works as a natural cooling processes, especially in hot arid climates. In this context, this paper discusses through the simulation modeling procedure if green walls can be a planning strategy of reducing the urban heat island. The methodology that will be followed will be the simulation program procedure, starting with the creation of an information base and ending with results about the variation of the temperatures.

Every environmental modeling system has a function and set of traits. For this study it has been decided to use the ENVI-met simulation program. ENVI-met is a three-dimensional microclimate model program that is suitable for simulation and calculations of the climate urban areas. The typical grid of working area that is used for this study is 100m by 100m by 80m height and the main prognostic variables are wind speed and air temperatures.

Firstly, the digital map data for Eleftheria's square was obtained from the simulation program. Then, the map of the two sub-areas *(figure 43, 44)* of the study area was insert to ENVI-met and the model was created through the graphic interface that the simulation program uses. ENVI-met has its own databases like soils, plants, buildings and materials of the surfaces. In order to be created and finally to complete the model, used generic types of the databases which have been chosen according to the existing characteristics of the soil, the plants and the buildings.

Specifically, for the roads, has been used *Asphalt road* (0.9 frac emissivity), *Concrete pavements* for the pavements (0.9 frac emissivity) and buildings from *Aerated brick walls, insulation and plaster* (25cm thickness) and *Brick burned walls and plaster* (40cm thickness). Additionally, *Hedera helix* is the plant that used for the green walls and is located in front of the buildings in 4m height.

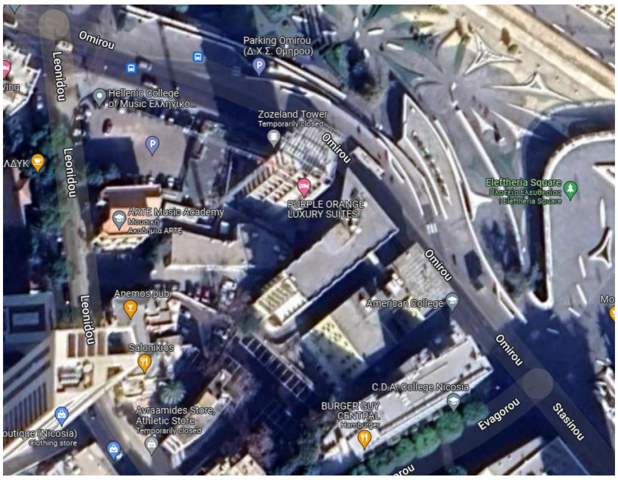


Figure 43. Case study Eleftheria's square – option A

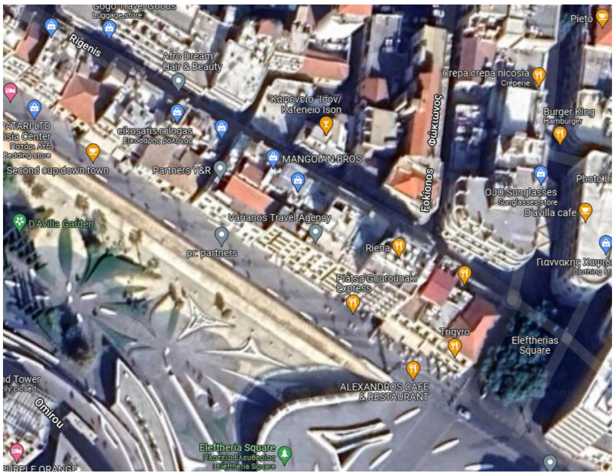


Figure 44. Case study Eleftheria's square – option B, C

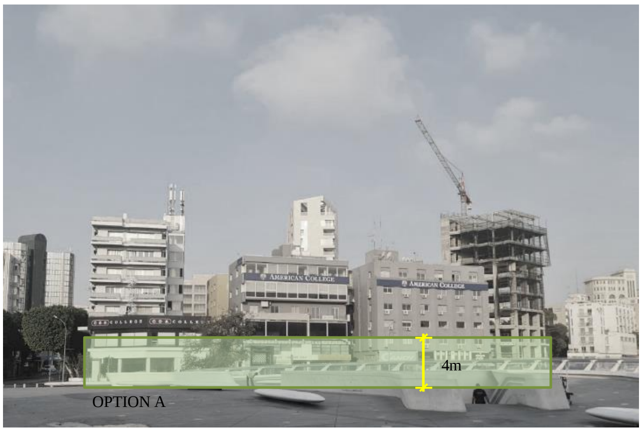


Figure 45. Case study – option A

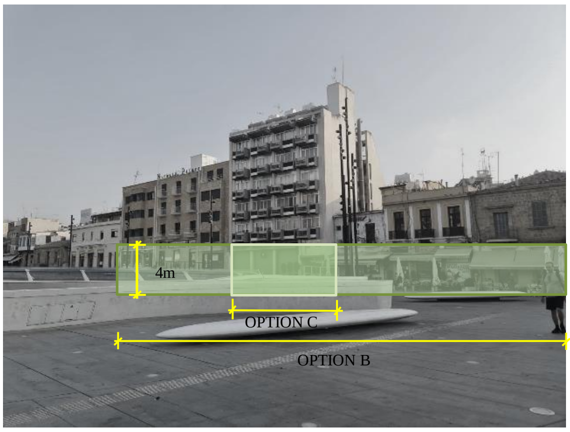
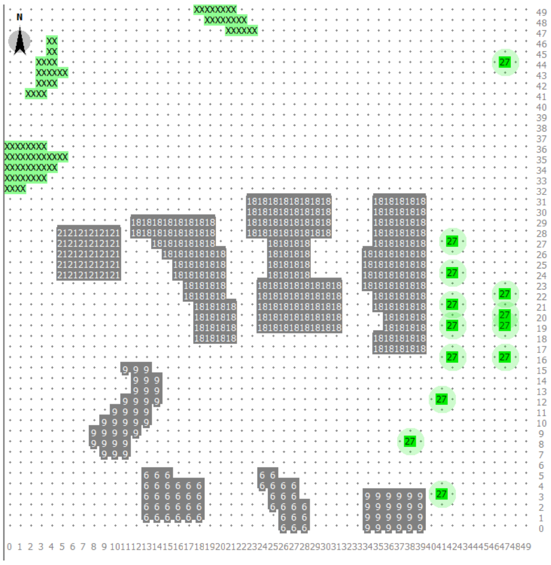


Figure 46. Case study – option B, C

The results are basic 2D information on the atmosphere and specifically for the temperatures of the area at 1.8m above the ground level. The first step of the simulation included the presentation of the accurately data of the temperatures for the model. In the second step is included changing the façade of the buildings and adding green walls as a strategy to reduce the high temperatures of the summer.



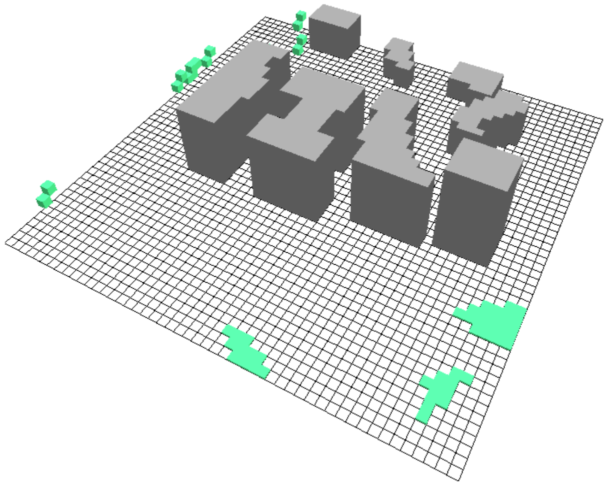
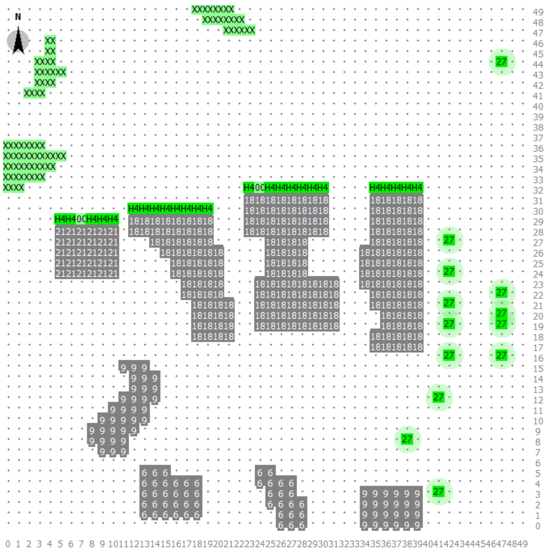


Figure 37. Case study plan – option A without green walls *Figure 48. Case study 3D – option A without green walls*



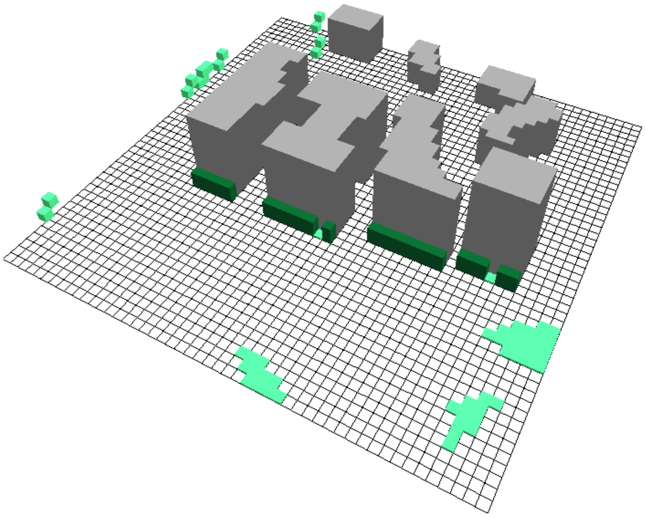


Figure 49. Case study plan – option A with green walls *Figure 50. Case study 3D – option A with green walls*

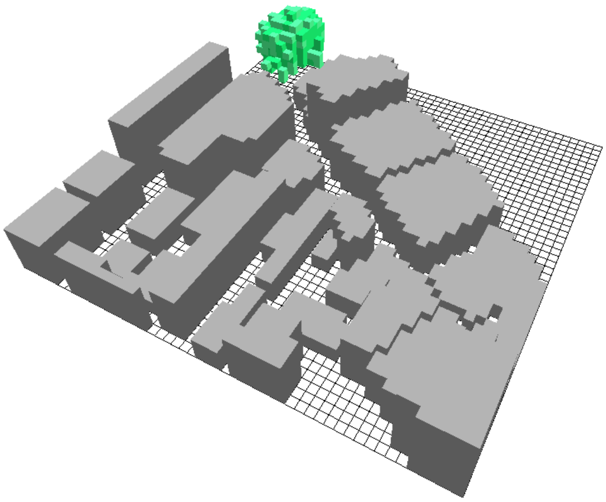


Figure 51. Case study plan – option B without green walls *Figure 52. Case study 3D – option B without green walls*

Figure 53. Case study plan – option B with green walls

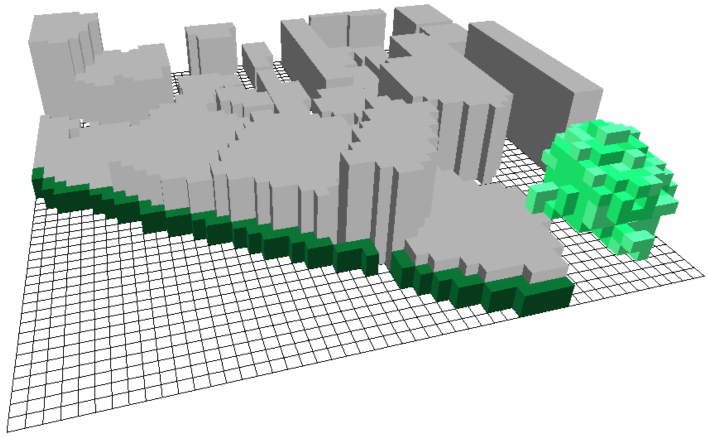


Figure 54. Case study 3D – option B with green walls

4.5 Variable descriptions

As it mentioned before, Eleftheria's square connects the historic area with the new part of the city of Nicosia. In this study, two sub-areas which are located around the square and characterized with different orientation towards, were selected for experimentation. In the first area the north façade of the buildings face Eleftheria's square while in the second area, the south façade face the square. To study the performance of the green walls, a simulation was carried out in the two areas. The results present whether the microclimate is affected by the green walls installation on the south and north elevations, respectively in each case. Also, the dates that simulation ran are 21st of March, 21st of June, 23rd of September and 21st of December.

As a first step, green walls were installed to all building facades in each study area. After the selection of the optimal orientation for green wall installation, we have been proceeded to alternative options. Specifically, in north area, green wall is installed in one building, in order to compare the results with the installation in all the façade.

Figure 55. Case study plan – option C with green walls

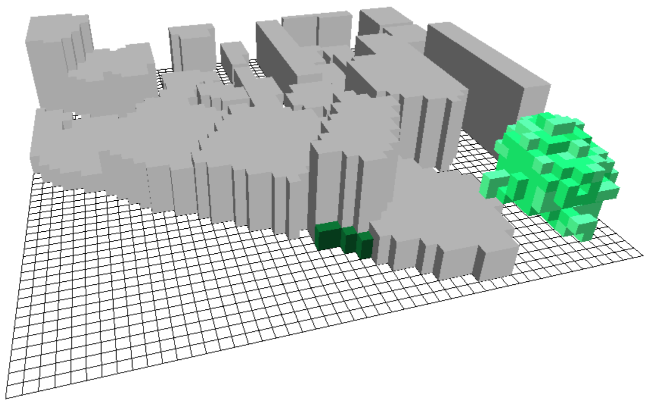


Figure 56. Case study 3D – option C with green walls

4.6 Results of the simulation analysis

In order to have measurable and comparable results, we have chosen four days of the previous year (2021) and three hours per day. The main days are the two equinoxes and the summer and winter solstice. Also, the hours that the simulation ran were nine o' clock in the morning, twelve o' clock in the noon and six o' clock in the afternoon. For each day and hour, is presented below a table data with the temperatures around the area.

North Façade

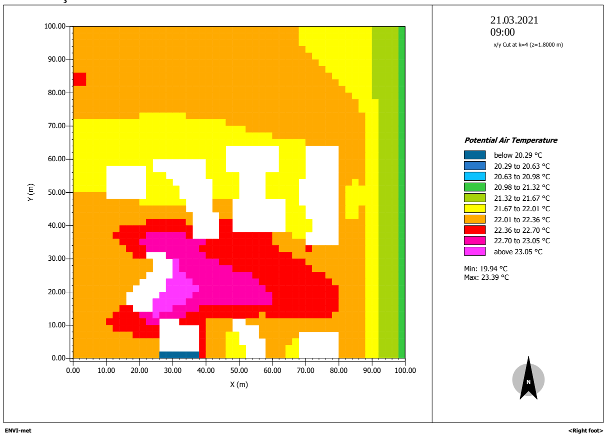


Table 2

North Façade – Green wall

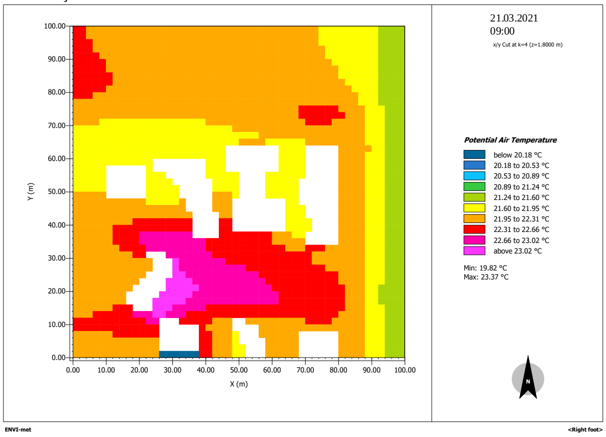


Table 3

North Façade

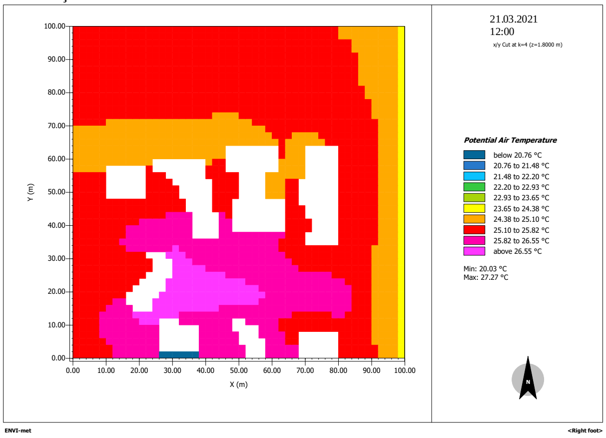


Table 4

North Façade – Green wall

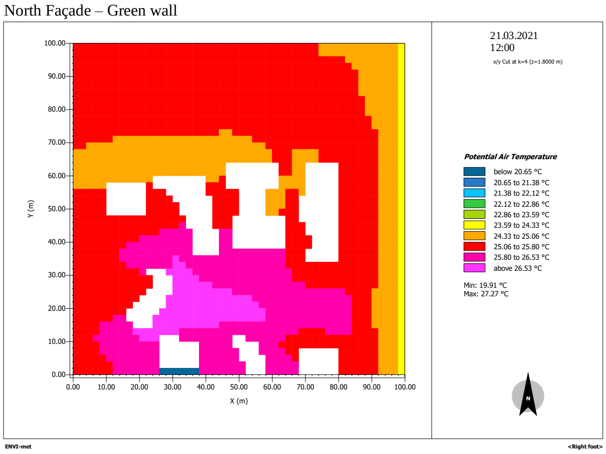


Table 5

North Façade

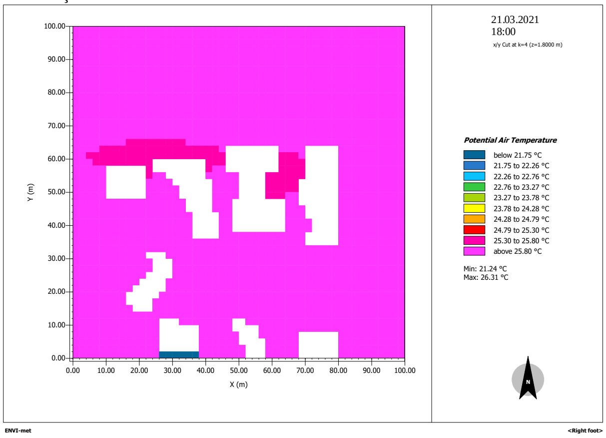


Table 6

North Façade – Green wall

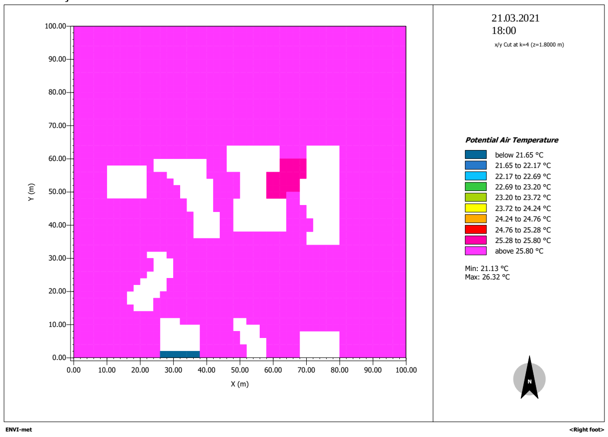


Table 7

South Façade

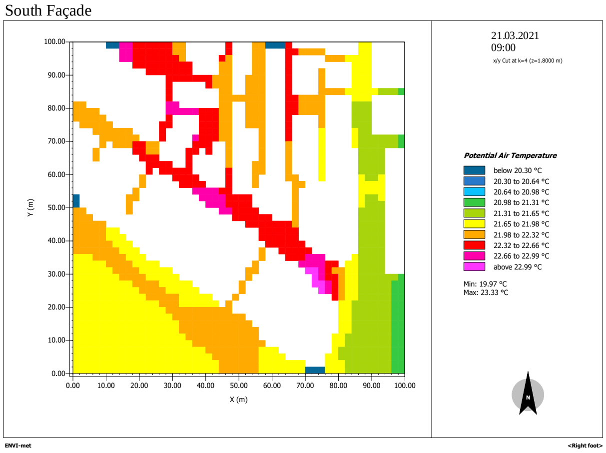


Table 8

South Façade – Green wall

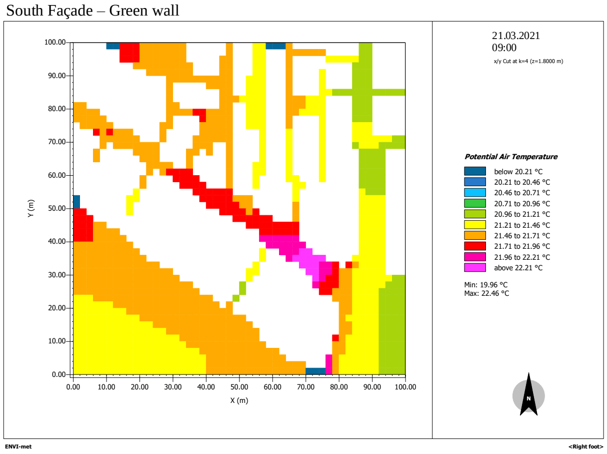


Table 9

South Façade

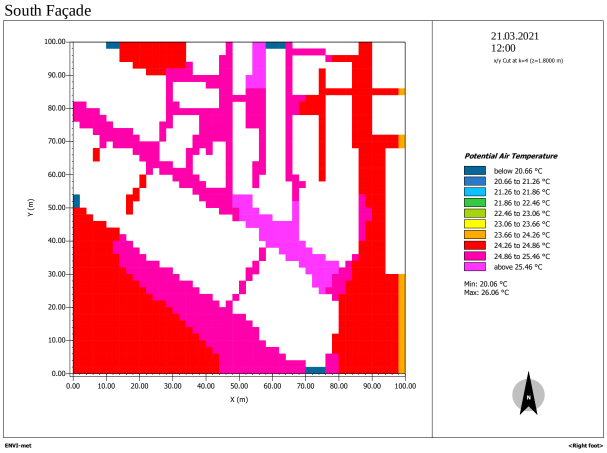


Table 10

South Façade – Green wall

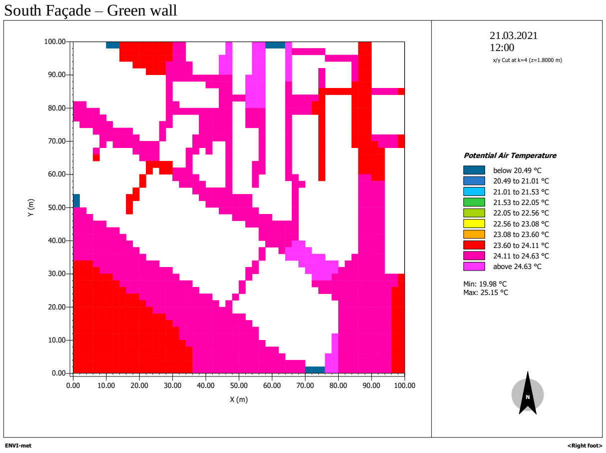


Table 11

South Façade

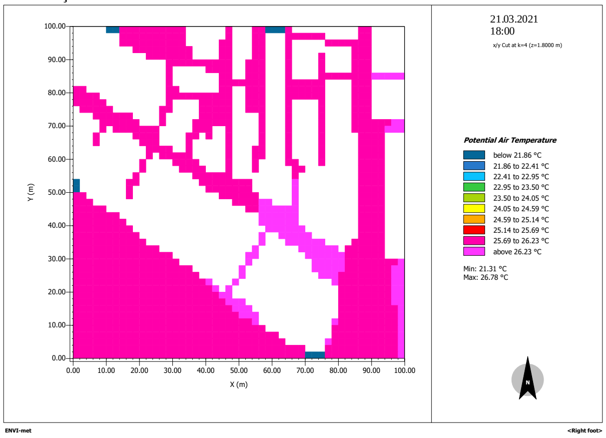


Table 12

South Façade – Green wall

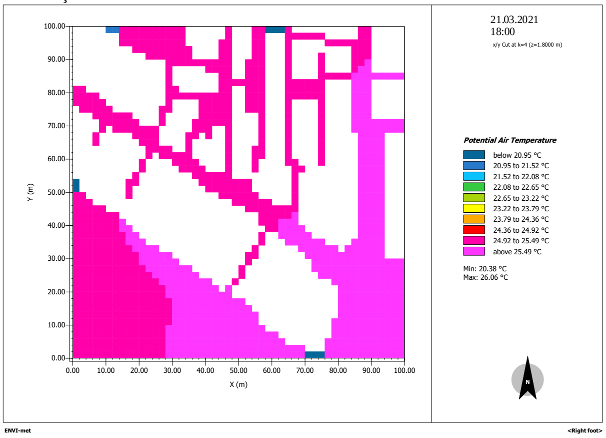


Table 13

North Façade

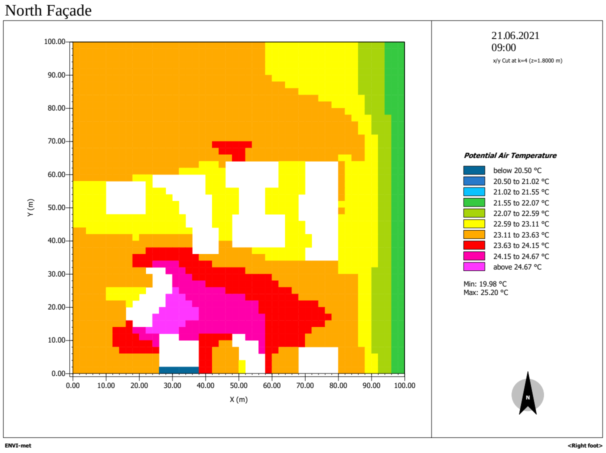


Table 14

North Façade – Green wall

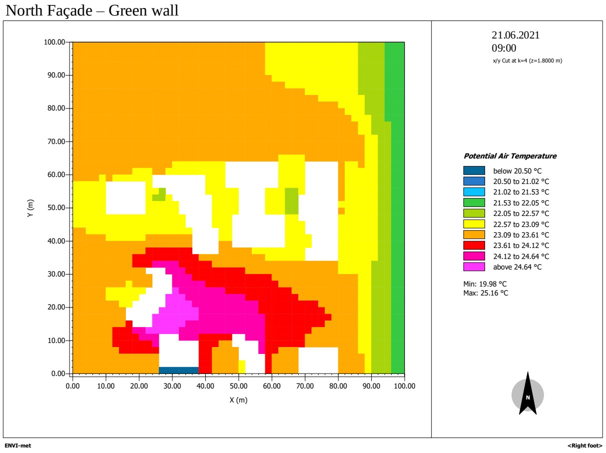


Table 15

North Façade

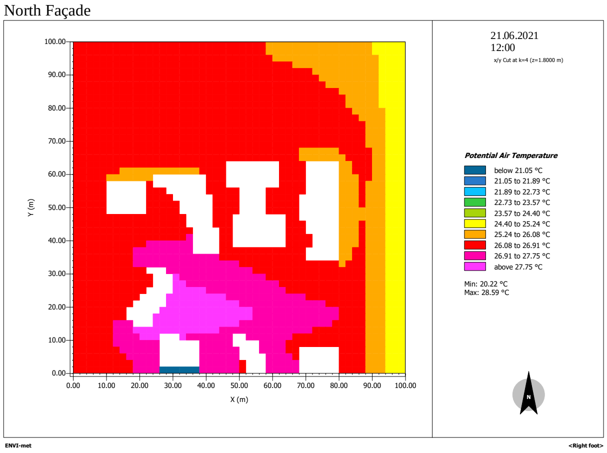


Table 16

North Façade – Green wall

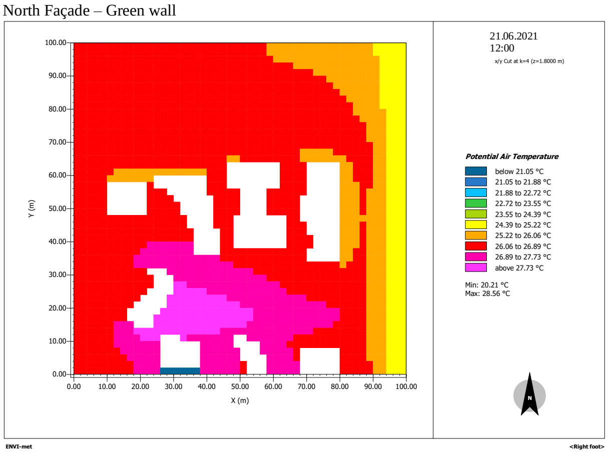


Table 17

North Façade

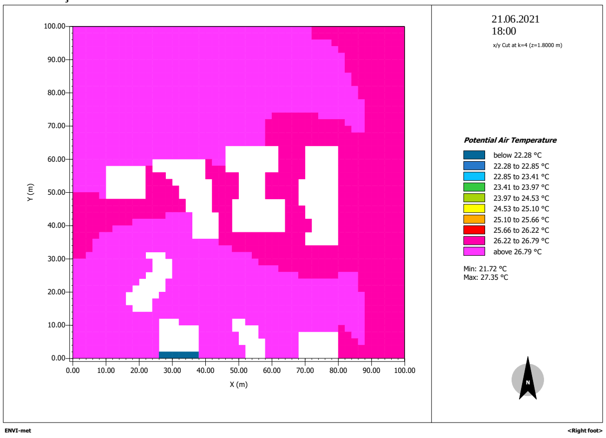


Table 18

North Façade – Green wall

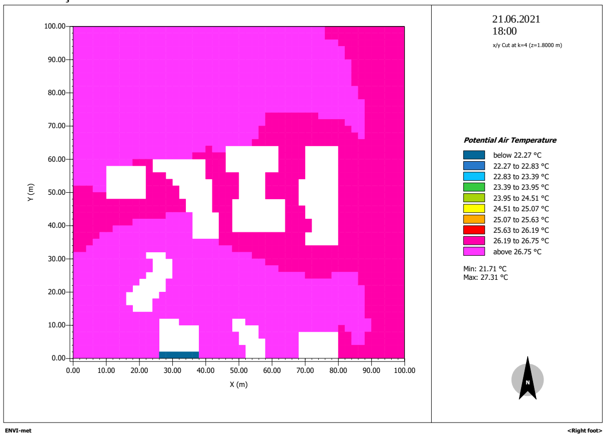


Table 19

South Façade

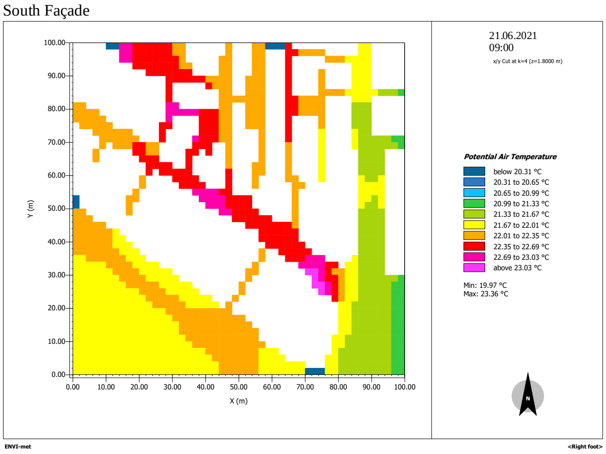


Table 20

South Façade – Green wall

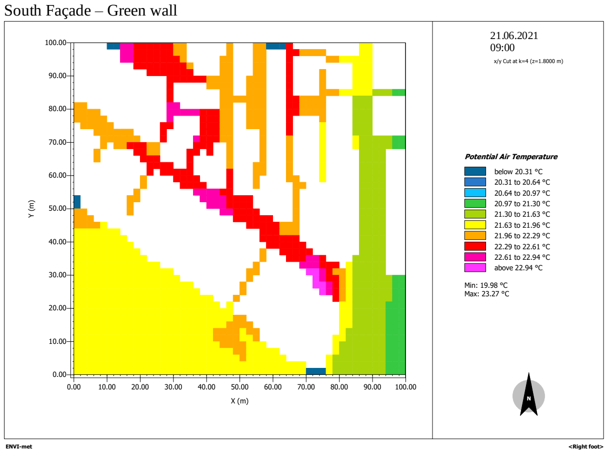


Table 21

South Façade

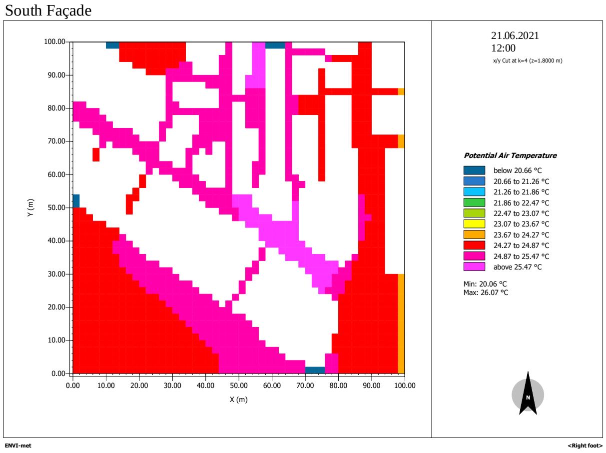


Table 22

South Façade – Green wall

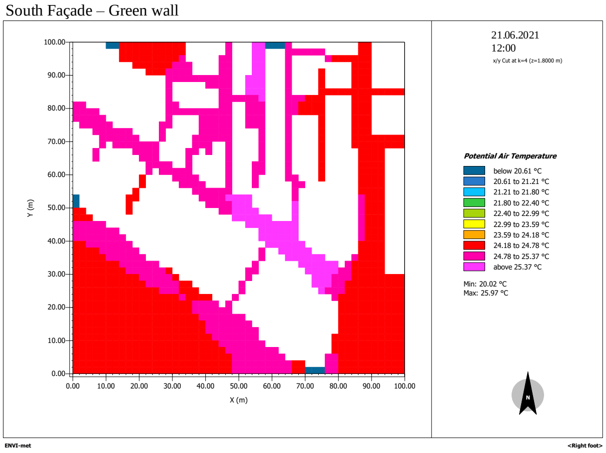


Table 23

South Façade

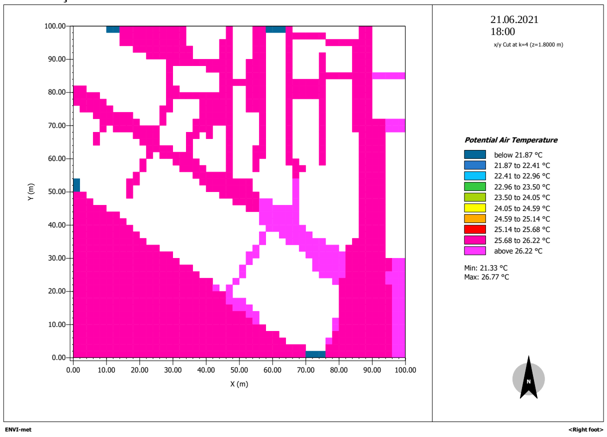


Table 24

South Façade – Green wall

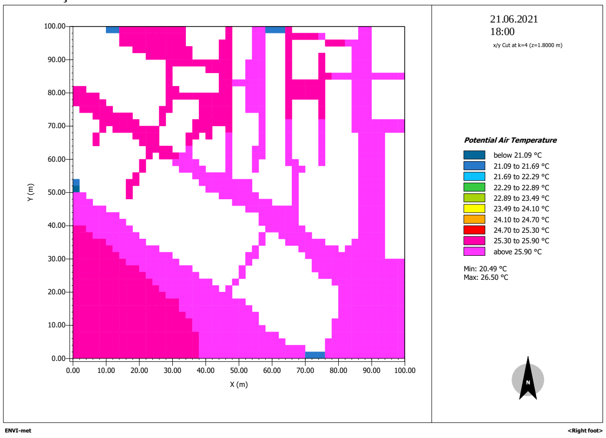


Table 25

North Façade

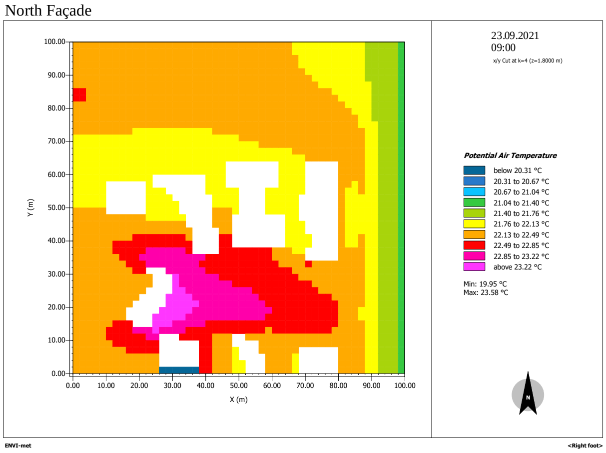


Table 26

North Façade – Green wall

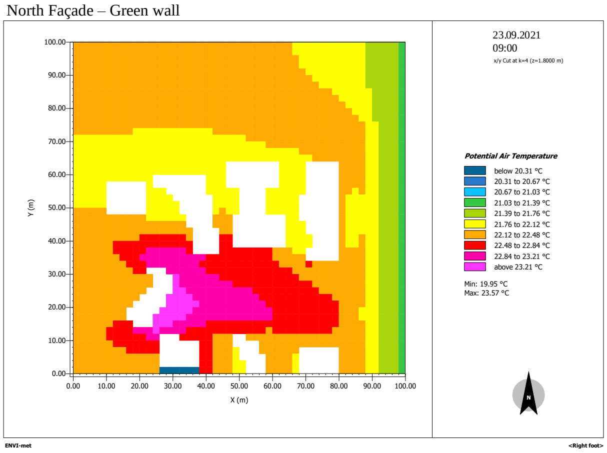


Table 27

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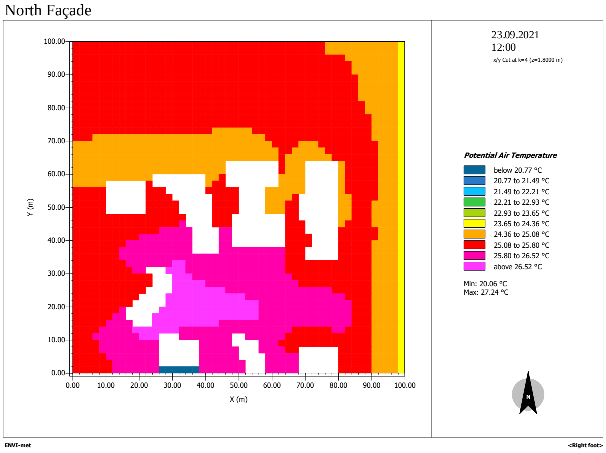

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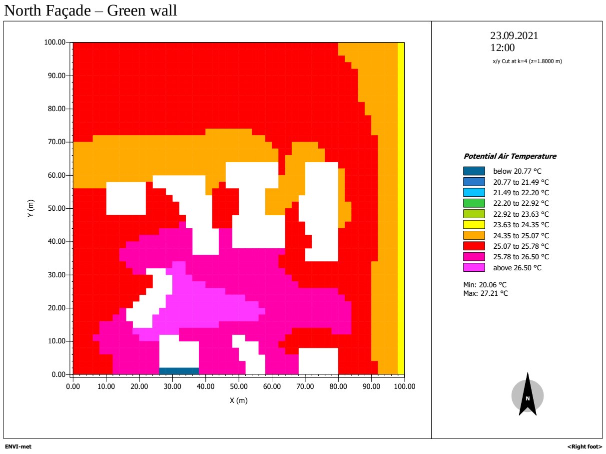

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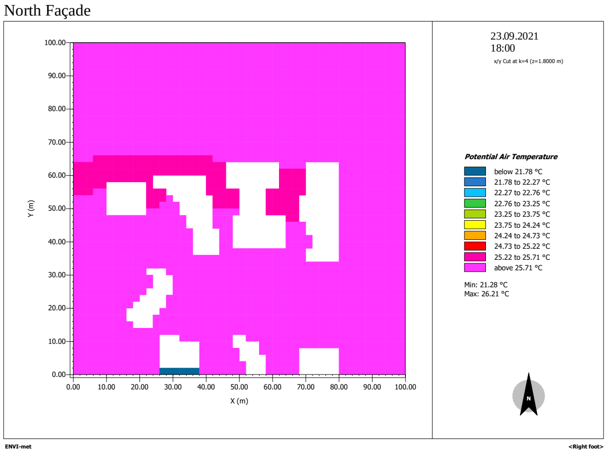
North Façade



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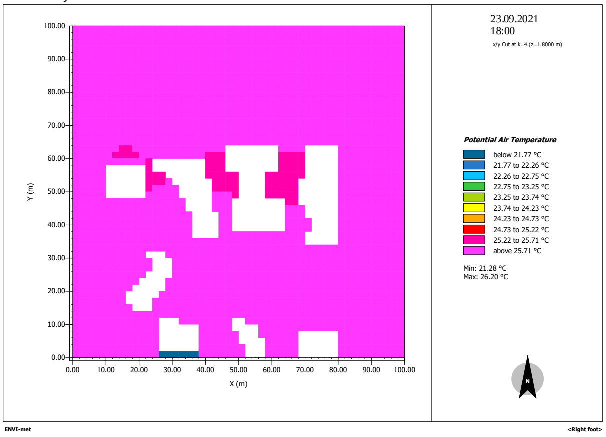
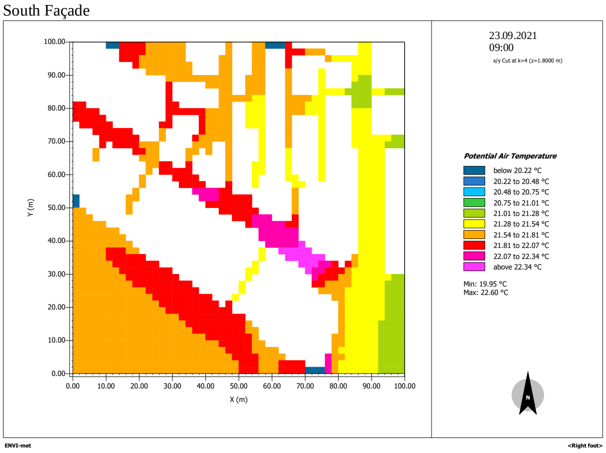


Table 31

South Façade



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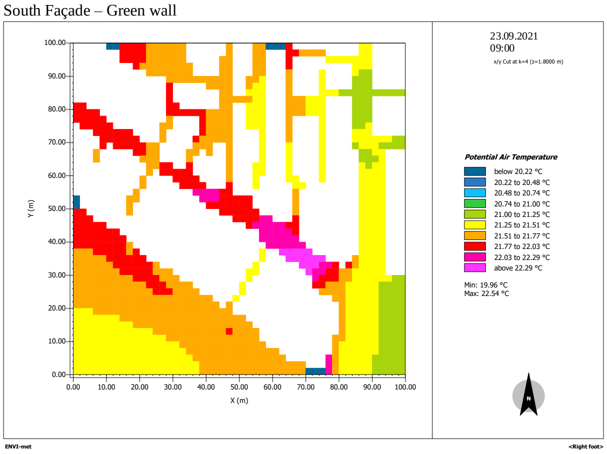

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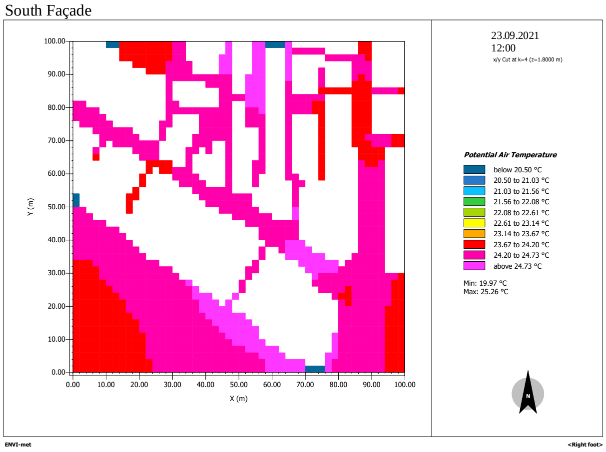

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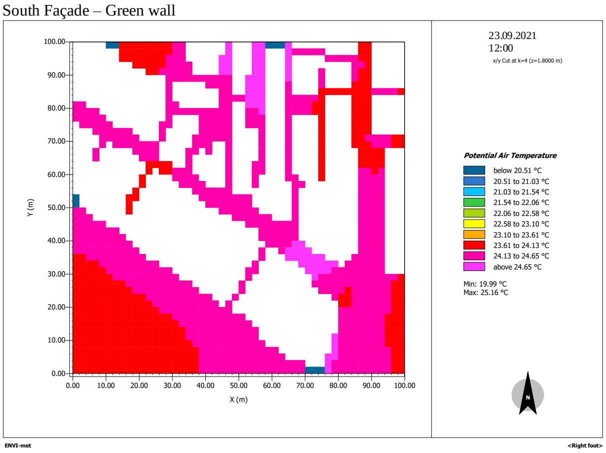

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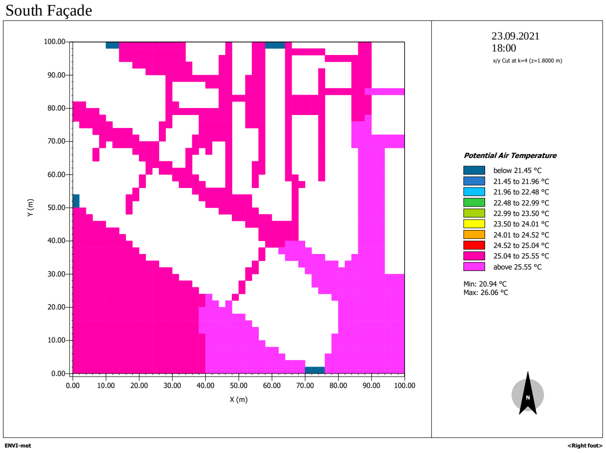

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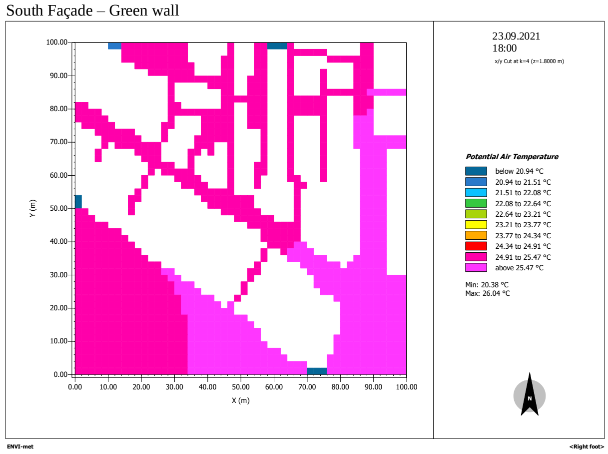

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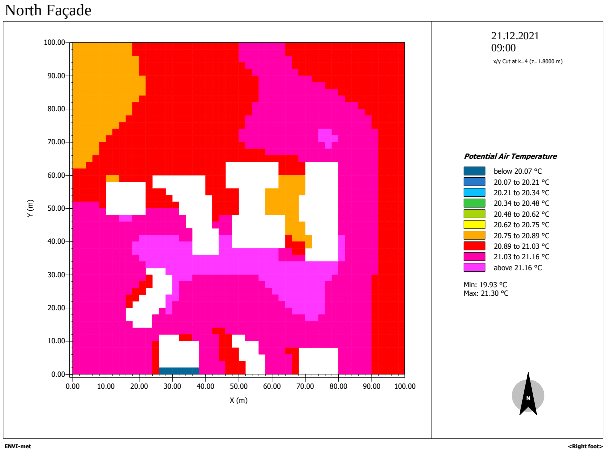
North Façade



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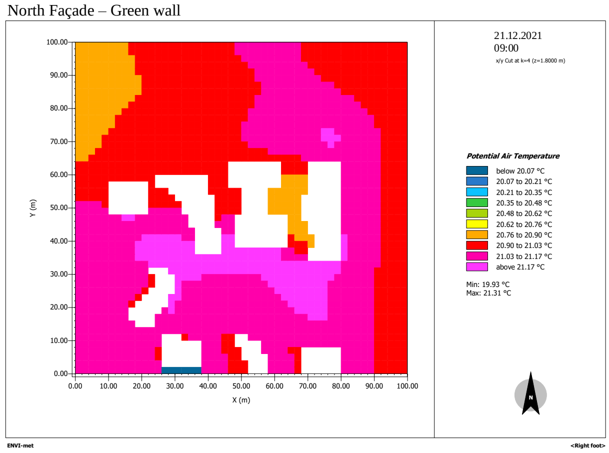

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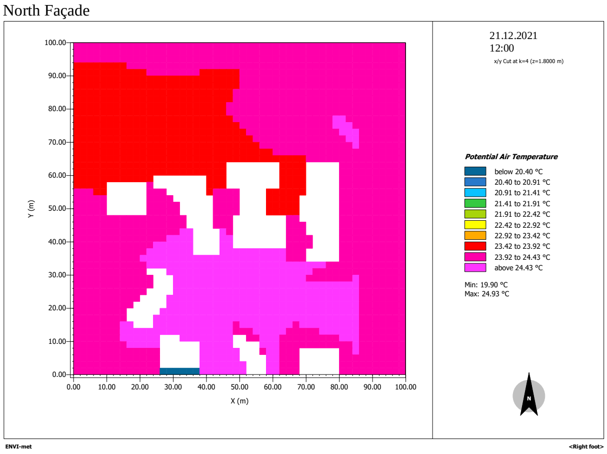

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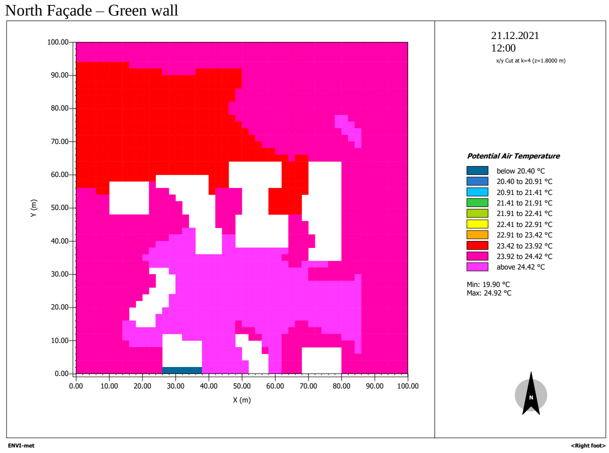

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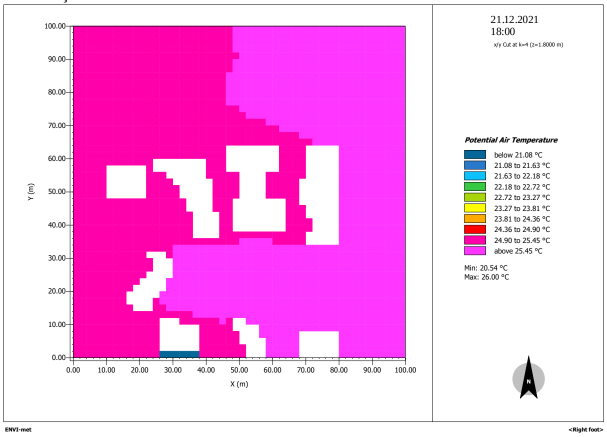

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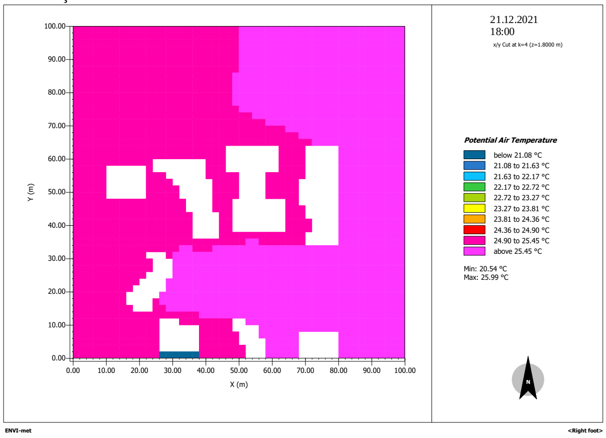

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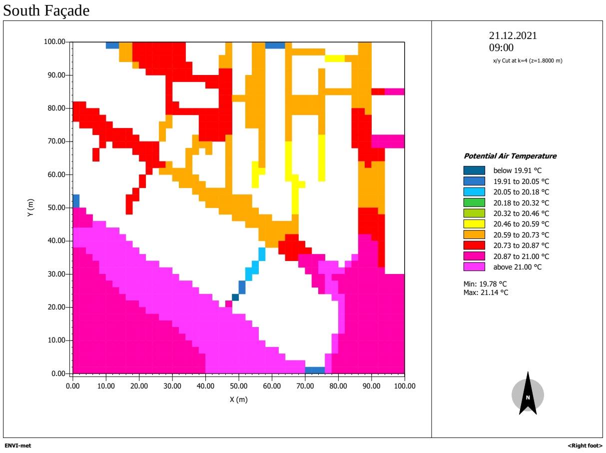

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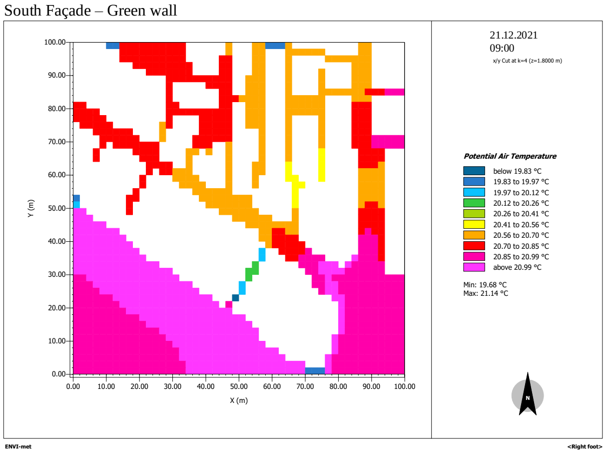

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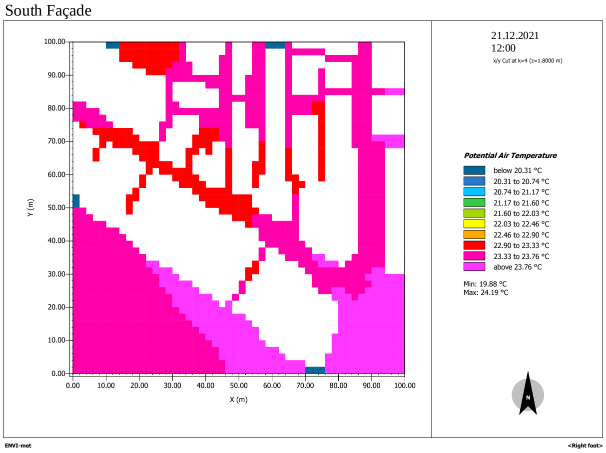

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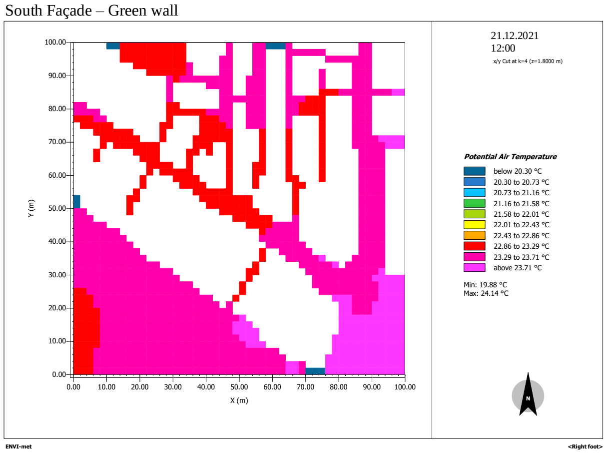

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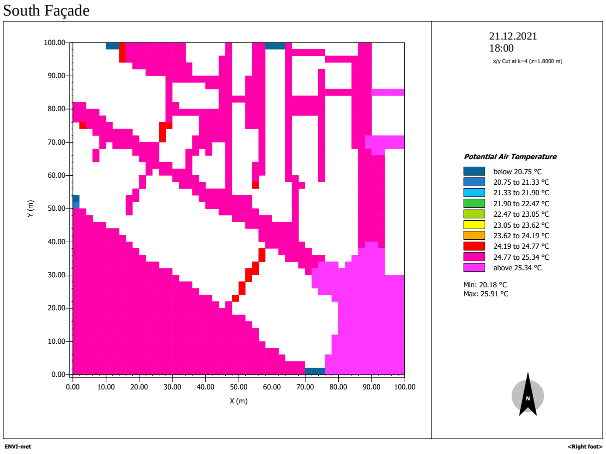

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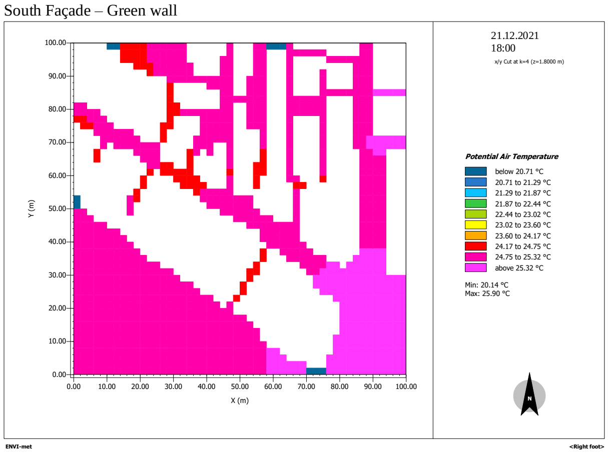

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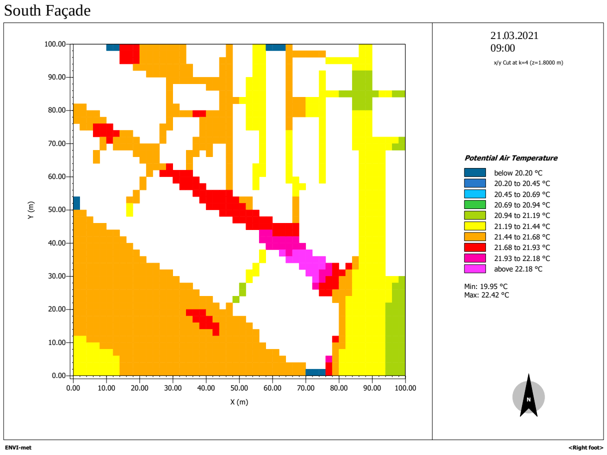

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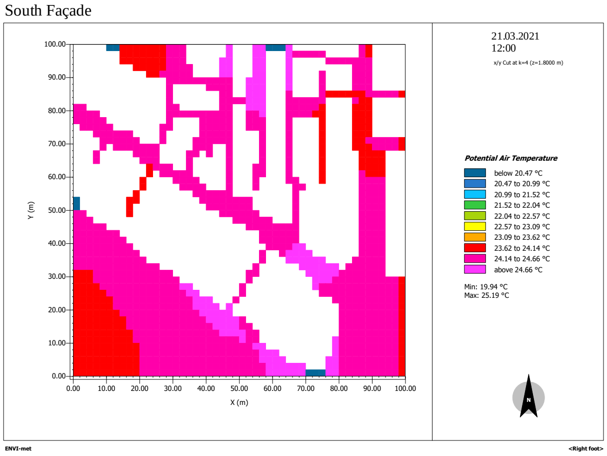

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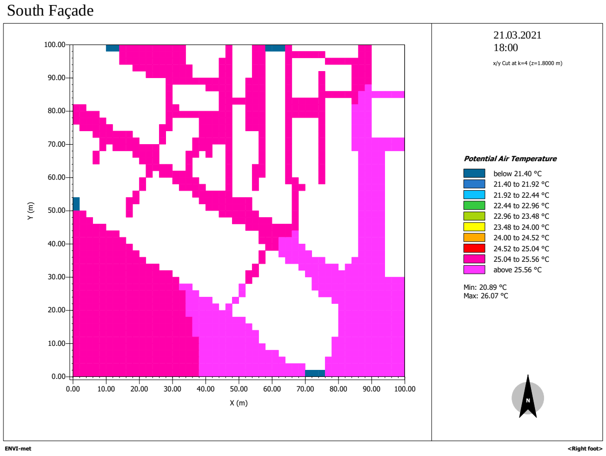

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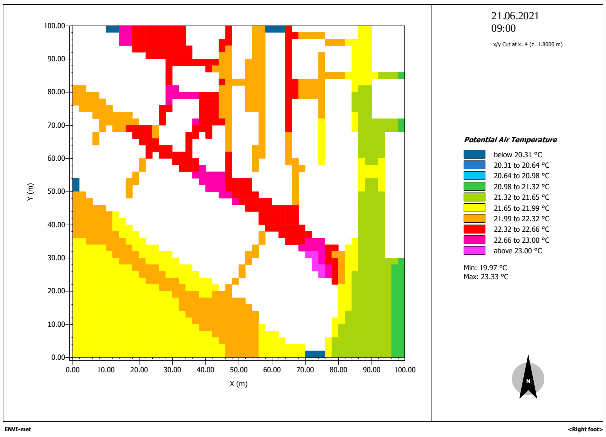

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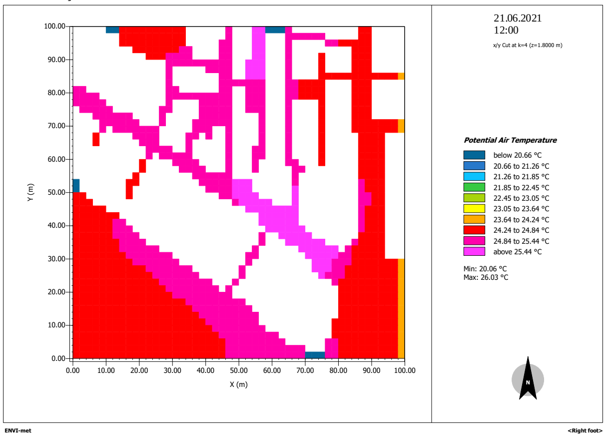

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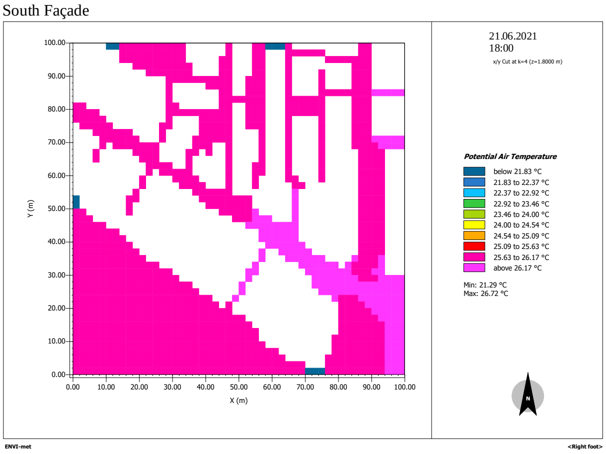

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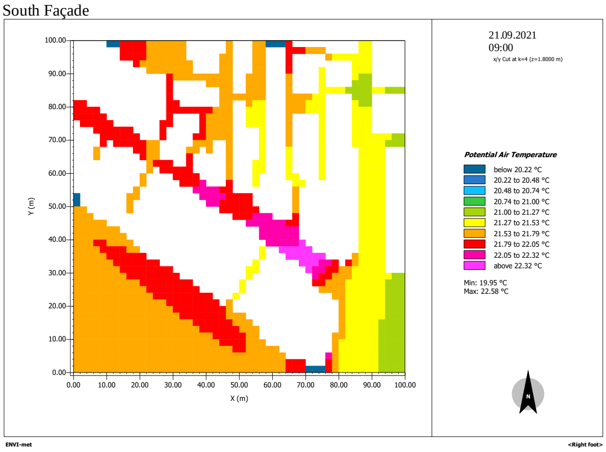

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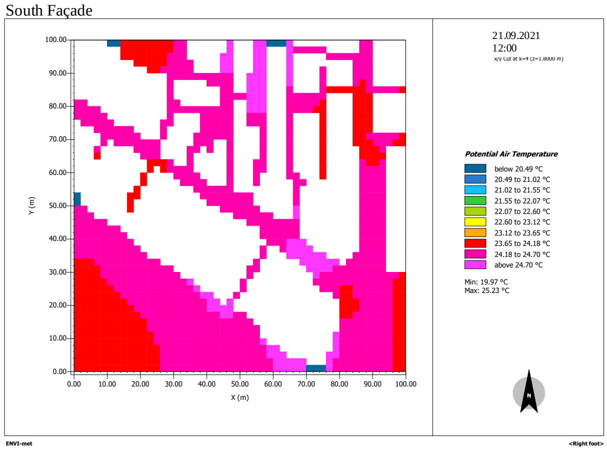

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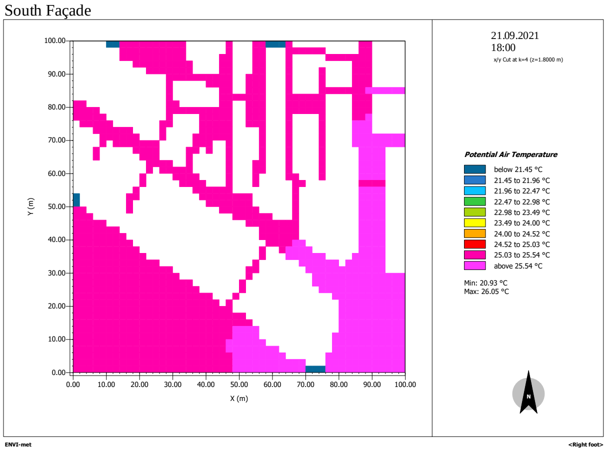

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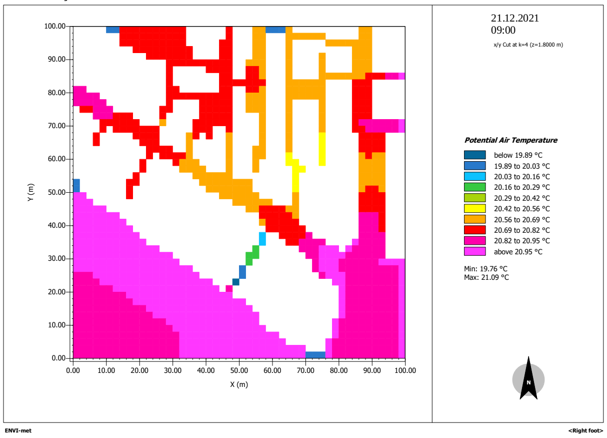

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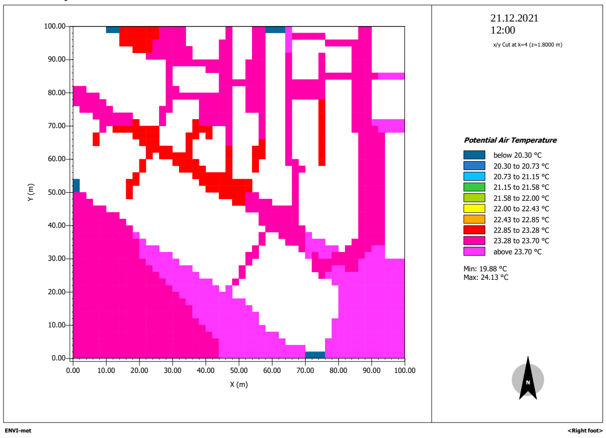

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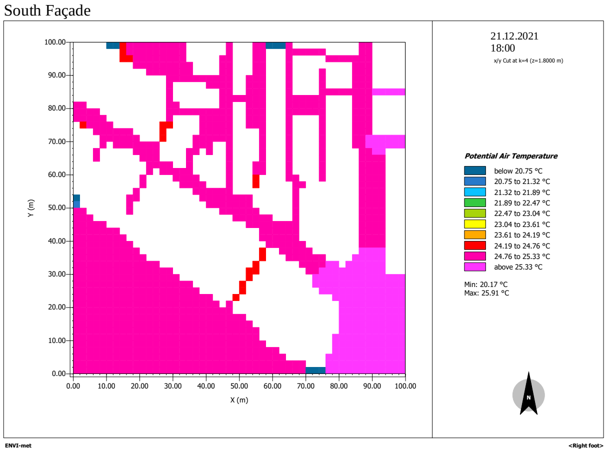


Table 61

The whole simulation process, shows that during the morning, there is a greater variation of temperatures on the different areas around the buildings, with or without the green walls. As the day progresses, the temperature fluctuations decrease. As a result of this, is the creation of a uniform temperature at the human eye level. During the summer and spring months, there is a greater variation in temperatures from midday to the evening, in contrast to the winter and autumn months where the variation appears to be lower.

During the summer period, the highest temperatures are observed, firstly at the dense buildable areas and secondary at the road areas due to the asphalt. Also, as we can see through the diagrams, the green areas reduce the high temperatures approximately up to 2ºC. During the winter months, the highest temperatures are observed at the asphalt road areas and the lowest at the dense buildable areas. Green areas during this period do not seem to create particular differences on temperatures.

At the first area where is proposed the installation of green walls on the north façade of the building, the results showed few variations on temperatures. Specifically, at March the reduction of the temperature because of the green wall was 0.06 ºC, on June was 0.02 ºC, on September 0.02 ºC and finally on December the temperatures were the same. The temperature differences in the two cases, have been calculated from the whole area but as shown on the diagrams, the reduction is achieved at the front area of the buildings elevation that have been installed the green walls.

The simulation process was achieved as well in the northern area of the case study. In this case, it is proposed to install green walls on the southern elevations of the buildings that face the square. The results of this proposal showed temperature reduction 0.58 ºC on March, 0.22 ºC on June, 0.12 ºC on September and 0.05 ºC on December. According to the results, the greatest decrease in temperature is observed during the afternoon hours in the area where the green walls were installed.

After the simulation of the two areas where we have installed green walls on all the buildings facades, we have been proceeding the option of installing green wall on one building façade. Specifically, in the case of north area where the results were optimal, we installed green wall in one building façade. The results for this proposal showed temperature reduction from the simulation without the green walls but the average temperatures were higher than the case of the installation of green walls on all building's façade. Specifically, in March, with this option we have 0.09 ºC higher temperature than in option b, in June, 0.19 ºC, in September 0.10 ºC and in December 0.01 ºC. According to the results, we have reduction of the temperature at the area even with the installation of the green walls on one building.

In conclusion, the installation of green walls on the southern facades of the buildings can show optimal results in comparison to the installation on the northern facades. Through this simulation it is clear that green wall is an important strategy to reduce high temperatures during the summer season.

Chapter 5: Comparison

This chapter is presenting the comparison of the results of the simulation of Eleftheria's square and the monitoring of green wall at The Cyprus Institute. Firstly, in both cases the green walls have been installed on the south façade of the buildings and temperature data was taken near the proposal and around the area.

5.1 Compare the results of the two case studies

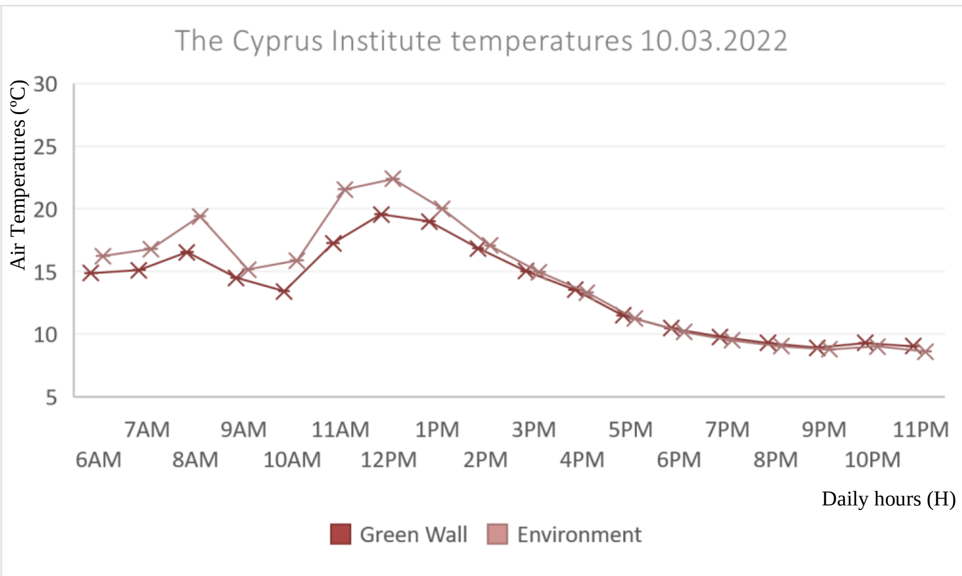
In this chapter is presented the results of the comparison for the two case studies. In order to compare the results of the case studies, we collected data for the 4 months March, June, September and December, the 10th day for each month. For the comparison we needed to collect data behind and next to green walls in both cases. The data that was analyzed and presented is the air temperature at 1.20m height above the ground level.

In general, the temperature variation is greater to The Cyprus Institute results than in Eleftheria's square, except for the results of June. The temperatures behind the green wall, are almost always reduced compared to temperatures next to the green wall. During the afternoon hours, higher temperatures are observed behind the green wall compared to next to it. This is a result of the accumulation of the temperatures of the midday.

Generally, green walls in both cases are reducing the temperatures during the year. Specifically, for March the reduction in the case of The Cyprus Institute is 0.84 ºC and in Eleftheria's square, 0.012 ºC. During the summer period – in June, the reduction was 0.016 ºC for The Cyprus Institute and 0.004 ºC for Eleftheria's square. In September the reduction for The Cyprus Institute is 1.36 ºC and for Eleftheria's square is 0.005 ºC. Finally, in December the results showed a temperature reduction 1.06 ºC for The Cyprus Institute and 0.016 ºC.

Apart from the fact that green walls can create ideal temperature conditions, this comparison lead us to two main conclusions. Green walls are a protective shell for building surfaces as they prevent direct solar radiation during the summer. As a result of this, is a reduction of indoor temperatures.

Also, another important conclusion is that green walls can be a strategy for the reduction of the high temperatures both in urban areas and in open areas surrounded by nature. In urban areas the effect of green walls is smaller in comparison to an open space. In my opinion we should enrich urban areas with more green walls and green areas in order to have better results.



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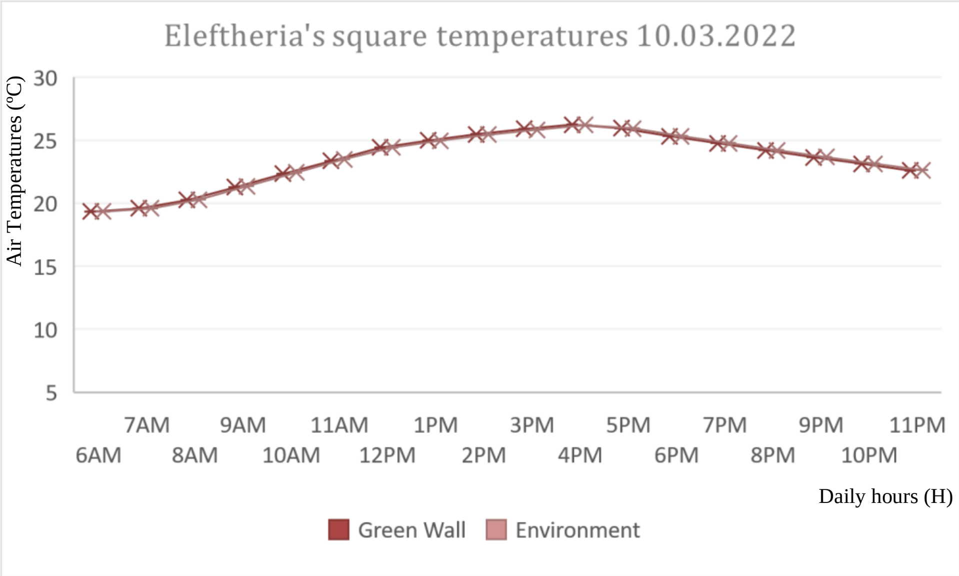

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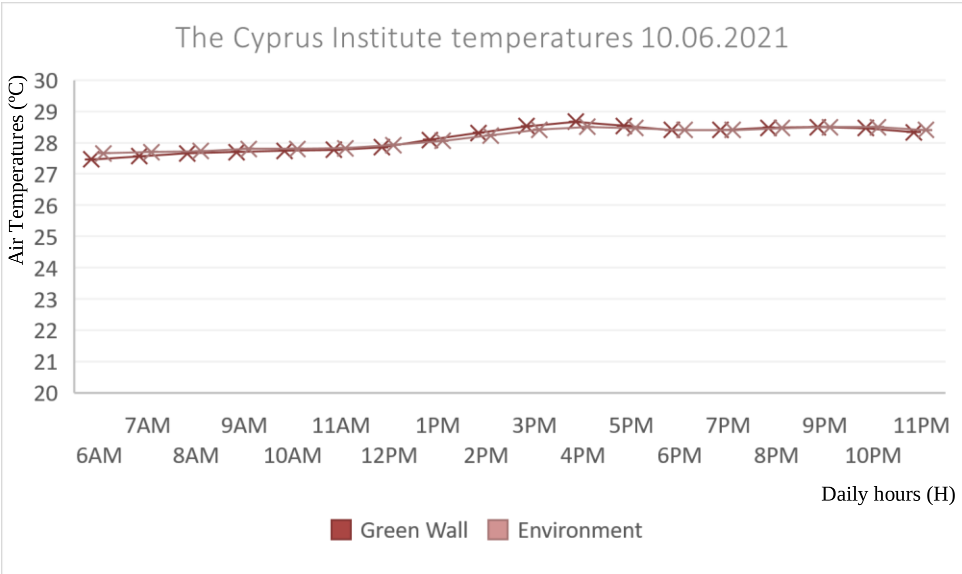

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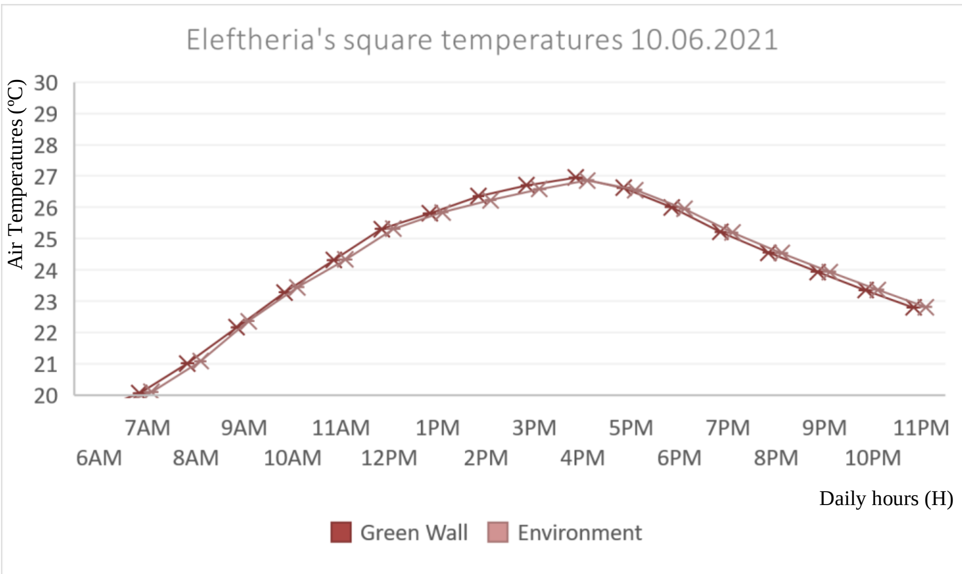

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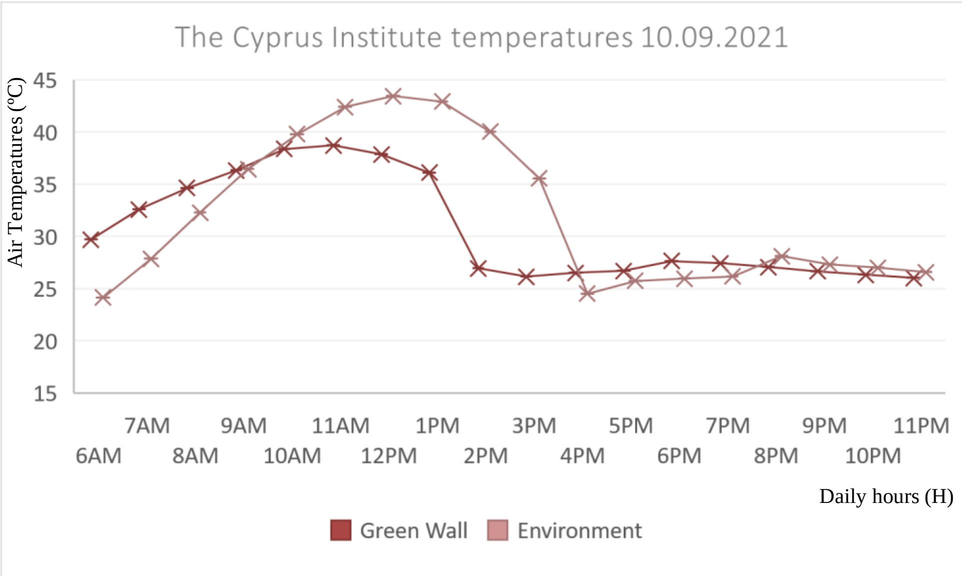

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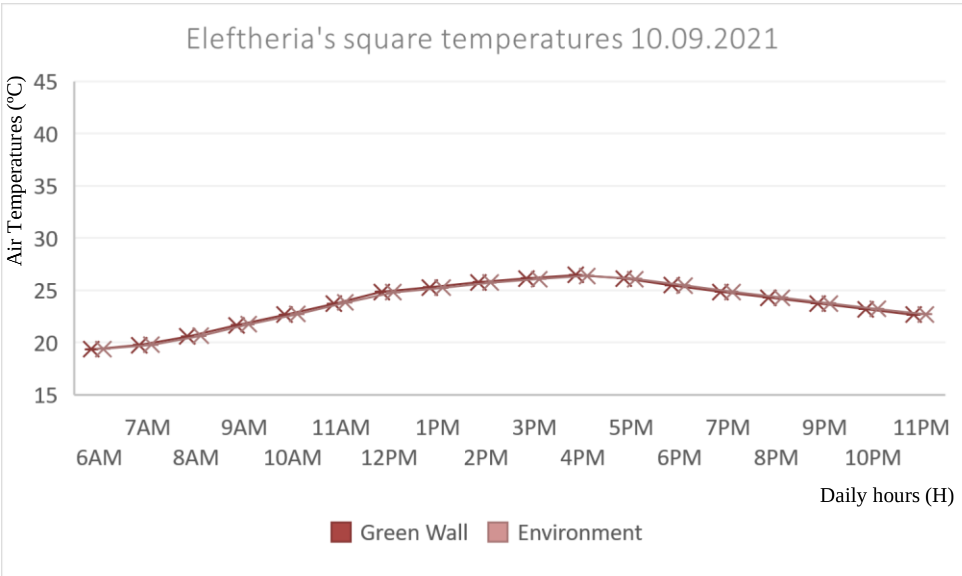

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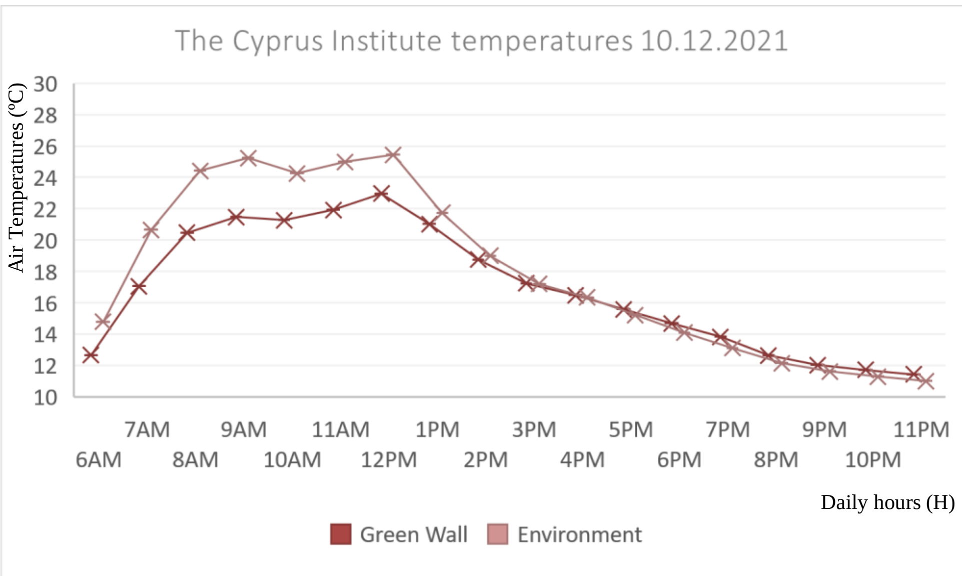

Table 68

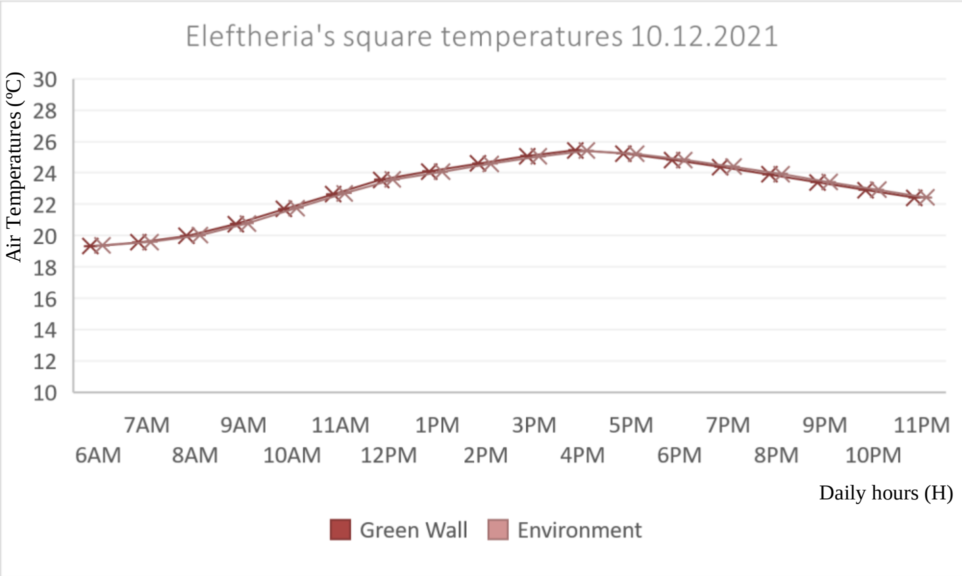
Eleftheria's square temperatures 10.12.2021
Air Temperatures (ºC)
30
28
26
24
22
20
18
16
14
12
10
7AM
9AM
11AM
1PM
3PM
5PM
7PM
9PM
11PM
6AM
8AM
10AM
12PM
2PM
4PM
6PM
8PM
10PM
Daily hours (H)
Green Wall
Environment

Table 69

Chapter 6: Summary, Conclusions and Recommendations

6.1 Summarize the results

In this study it has been identified that the installation of green walls, improve the microclimate of an area and promote thermal comfort. Specifically, it is confirmed that greening an urban area by the strategy of green walls, results a desire temperature reduction during the summer period. Additionally, during the winter season, is not observed any changes in temperatures. Green walls are important design tools for improving living conditions and providing a better environment for our growing cities.

The orientation of the installation of green walls, seems to determine how much it affects the change of the microclimate. The simulation results showed that the installation in south facades, can reduce the temperatures approximately 0.50ºC and in north facades approximately 0.05ºC during the summer period. The simulation process showed that green walls which proposed to install on south facades, are more effective than those which are proposed on north facades.

In addition to orientation, an important consideration for the effectiveness of green walls is also the surrounding area. Comparing the two case study results, we noticed that when the area is consisted by building volumes, the effect on the temperature is lower than on the case where the area is an open space with trees. So, it is important to follow strategies of greening the whole urban areas in order to achieve maximum desired results for a better living condition.

6.2 Recommendations for the case study

The application of green walls on south facades of the historical buildings in Eleftheria's square, will improve the air quality of the area. If the system of green wall implemented and adapted to all buildings in the urban area of the square of the city of Nicosia, the results will be the noticeable decrease in urban heat island. Also, green walls will create a healthy environment with fresh air and thermal comfort.

6.3 Proposals for future research

The research done for this thesis has brought to light a variety of subjects that would benefit from more study. Firstly, we propose to simulate also the east and west elevations of the buildings of Eleftheria's square, in order to investigate the overall contribution of green walls for the thermal comfort and to compare the results for each façade. Also, it would be good to use different types of planting to investigate if, what and how they affect to the microclimate of the area. Another subject that should be studied is to find ways to reduce the temperature build-up behind the green walls during the afternoon hours with different types of green wall and plants.

Finally, we propose through the simulation to calculate the dynamics of microclimate and to include in the results the main variables as wind speed and direction, humidity and the radiative fluxes. In order to observe the difference in the contribution of green walls according to the season, it must be include in the results the different variables so that the results are more substantiated since thermal comfort is the result of many variables.

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