# Impact of Green Wall Facade on Residential Building Users in Hot Climates - Famagusta Case

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# ABSTRACT

Today cities have fewer green areas because of newly constructed facilities thus the surfaces of our existing and upcoming buildings should integrate more vegetation. Integrating vertical green systems is advantageous for improving aesthetic, mental health and indoor thermal comfort. The use of a well-designed and managed green surface systems provides thermal regulation for energy saving buildings with passive thermal insulation for interior spaces. The aim of this study is to find innovative and meaningful ways to increase useful vegetation by implementing them into architectural design processes. Green walls are vertical constructions that are cladded with various types of plants or other vegetation. The walls frequently have built-in watering systems since they contain living plants in them.

Integrating green surface systems will decrease energy consumption and increase thermal comfort throughout the year. With the use of Ladybug and Honeybee in Grasshopper, running with EnergyPlus, it allows us to simulate the indoor thermal levels of a residential building in North Cyprus by creating a virtual energy model of the building in Rhinoceros 3D. By running simulations, the effects of integrating green surface systems to the exterior walls of the building will be predictable. The simulation was run three times, the first was to simulate the existing building before integrating green surface systems to serve as a control, whereas the second and third were to simulate the same existing building but after integrating green surface systems to the exterior walls. The average total thermal comfort percent of Döveç Apartment 20 Building with no wall insulation, AC nor HVAC systems was around 35.8% throughout the whole year. After integrating green surface systems to all the exterior walls of the building the average was about 45%, which is a 25.7% increase in the thermal comfort felt by the users of the building.

In conclusion adding green surface systems to exterior facades of a building would increase the time spent in the thermal comfort zone of a building, which would decrease energy consumption of thermal regulating systems due to less usage of those thermal regulating systems by the users throughout the year.

**Keywords:** Vertical Green Systems, Thermal Comfort Zone, Sustainability, Residential, Karakol, Famagusta, North Cyprus, Hot Climate

# ÖZ

Bugün şehirler, yeni inşa edilen tesisler nedeniyle daha az yeşil alana sahip olduğundan, mevcut ve gelecekteki binalarımızın yüzeyleri daha fazla bitki örtüsünü entegre etmelidir. Dikey yeşil sistemleri entegre etmek, estetik, zihinsel sağlık ve iç mekan termal konforunu iyileştirmek için avantajlıdır. İyi tasarlanmış ve yönetilen yeşil yüzey sistemlerinin kullanımı, iç mekanlar için pasif ısı yalıtımı ile enerji tasarruflu binalar için ısıl düzenleme sağlar. Bu çalışmanın amacı, faydalı bitki örtüsünü mimari tasarım süreçlerine uygulayarak arttırmanın yenilikçi ve anlamlı yollarını bulmaktır. Yeşil duvarlar, çeşitli bitki türleri veya diğer bitki örtüsü ile kaplanmış dikey yapılardır. Duvarlar, içinde canlı bitkiler bulunduğundan, sıklıkla yerleşik sulama sistemlerine sahiptir.

Yeşil yüzey sistemlerinin entegre edilmesi, yıl boyunca enerji tüketimini azaltacak ve termal konforu artıracaktır. EnergyPlus ile çalışan Grasshopper'da Uğur Böceği ve Bal Arısı kullanımıyla, Rhinoceros 3D'de binanın sanal bir enerji modelini oluşturarak Kuzey Kıbrıs'taki bir konut binasının iç mekan termal seviyelerini simüle etmemizi sağlıyor. Simülasyonları çalıştırarak, yeşil yüzey sistemlerinin binanın dış duvarlarına entegre edilmesinin etkileri tahmin edilebilir olacaktır. Simülasyon üç kez çalıştırıldı, ilki yeşil yüzey sistemlerini kontrol görevi görecek şekilde entegre etmeden önce mevcut binayı simüle etmek, ikincisi ve üçüncüsü ise aynı mevcut binayı simüle etmek, ancak yeşil yüzey sistemlerini dış duvarlara entegre etmekti. Döveç Apartmanı 20'nin duvar yalıtımı, klima ve HVAC sistemleri olmayan ortalama toplam ısıl konfor yüzdesi tüm yıl boyunca %35,8 civarında gerçekleşti. Yeşil yüzey sistemlerinin binanın tüm dış duvarlarına entegre edilmesinden sonra ortalama %45'e ulaştı ve bu da bina kullanıcıları tarafından hissedilen termal konforda %25,7'lik bir artış oldu.

Sonuç olarak, bir binanın dış cephelerine yeşil yüzey sistemlerinin eklenmesi, bir binanın ısıl konfor bölgesinde geçirilen süreyi artıracak, bu da ısı düzenleyici sistemlerin yıl boyunca kullanıcılar tarafından daha az kullanılması nedeniyle enerji tüketimini azaltacaktır.

**Anahtar Kelimeler:** Dikey Yeşil Sistemler, Termal Konfor Bölgesi, Sürdürülebilirlik, Konut, Karakol, Gazimağusa, Kuzey Kıbrıs, Sıcak İklim

Dedicated to my Family, my Friends

&

Our Earth

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# INTRODUCTION

## 1.1 Background Information

The use of a well-designed and managed green surface systems provides thermal regulation for energy saving buildings with passive thermal insulation in winter seasons, natural cooling in summer seasons, for interior spaces, with sound insulating characteristics between exterior and interior spaces; These systems require maintenance three times annually with components such as felt (Pérez et al., 2011).

This thesis was purposed for those who are in practice of sustainable architecture as for these green systems to be used passively for buildings as energy saving systems and to calculate the expectations of energy saving levels, the following are essential and must be taken into account:

- The green surface system type
- Variables that affect their behavior
- Climate and weather conditions in which the vegetation of these systems will operate

## 1.2 Problem Statement

Today cities have fewer green areas because of newly constructed facilities thus the surfaces of our existing and upcoming buildings should integrate more vegetation, the loss of vegetation and green areas would lead to problems such as increased greenhouse gases in the atmosphere which leads to climate change.

Scientists and urban planners are interested in the role of vegetation in minimizing the negative consequences of urbanization because of its ability to reduce the environmental issues that come with urbanization. For example, urban greenery is thought to give a variety of social and health advantages to society, which are collectively referred to as cultural ecosystem services, hence enhancing city sustainability. The removal of pollutants from the atmosphere by urban trees and other plants, which are a regulating ecosystem function, has roused attention in recent years.

## 1.3 Aim of the Study

The aim of this study is to find innovative and meaningful ways to increase useful vegetation by implementing them into architectural design processes, thus the result will be increasing local vegetation in North Cyprus by increasing the existing vegetation in urban areas such as Famagusta by integrating green surface systems to the exterior facades of residential buildings.

## 1.4 Limitations

This thesis will focus on mid-rise residential building, between five to ten floors that is equipped with an elevator, the interior spaces of the building will be considered as an open plan building with no thermal regulating systems such as AC or HVAC systems, the building will have no thermal insulation within the walls, green surface systems will be integrated to the exterior facade of the walls from all orientations. This thesis will be focus more on the green surface system rather than the type of vegetation used to observe its effects on the thermal comfort zone of the building.

The simulation in this thesis will be simulated with EnergyPlus in Rhinoceros 3D using Ladybug and Honeybee within Grasshopper.

## 1.5 Hypothesis

Throughout the last decade, it has been proven that green walls have the potential to increase building energy efficiency. System characteristics, physical building characteristics, and local climate conditions all influence their performance. During the cooling season, studies show that, when compared to traditional walls, green facades are a 34 percent more energy efficiency and living walls are 59 percent to 66 percent more energy efficiency in the Csa (Hot-summer Mediterranean) climate (Manso et al., 2021).

Since combining architecture with vegetation creates new sustainable ways of living, green systems are to likely act as some form of insulation as green systems have been researched lately for their potential to increase the energy efficiency of a building by decreasing surface temperature and the shading provided by the foliage of vegetation. Thus, we think by integrating green surface systems to the exterior facade of all the walls of a building the vegetation will also increase the time the users of the building spend in the thermal comfort zone of that building throughout the year. Therefore, we set hypothesis 1 as:

*H1: Integrating green surface systems will decrease energy consumption and increase thermal comfort throughout the year.*

# Chapter 2

# GREEN SURFACE SYSTEMS AS A SUSTAINABLE TECHNOLOGY APPROACH

## 2.1 Green Surface Systems

The building's energy efficiency and thermal comfort are determined by how the interior environment responds to air conditioning and artificial lighting demands. By managing the transmission of thermal heat into the building, the building skin has a significant impact on the total energy consumption of the structure. Integrating green surface systems is one of the techniques, among other novel technologies, for improving a building's thermal efficiency, since they show considerable energy savings and help adapt to a warmer environment.

### 2.1.1 Vertical Green Systems

The phrase "Vertical Green System" is used to describe all types of vegetated wall surfaces. Traditional vertical green gardens have been used since before the seventeenth centuries. Vine was often used to cover pergolas, shading the building facade, or on building walls, cooling the facade during the summer in Mediterranean regions. Woody climbers were often employed as aesthetic parts of building facades in European and North American towns throughout the nineteenth century. In actuality, the term "green wall" encompasses all systems that allow for the greening of a vertical surface with a variety of plant species, as well as any methods for growing plants on, up, or within a building's wall (Manso & Castro-Gomes, 2015). Green

Facades and Living Walls are the two most common forms of vertical green systems today (Uzuhariah Abdullah et al., 2016).

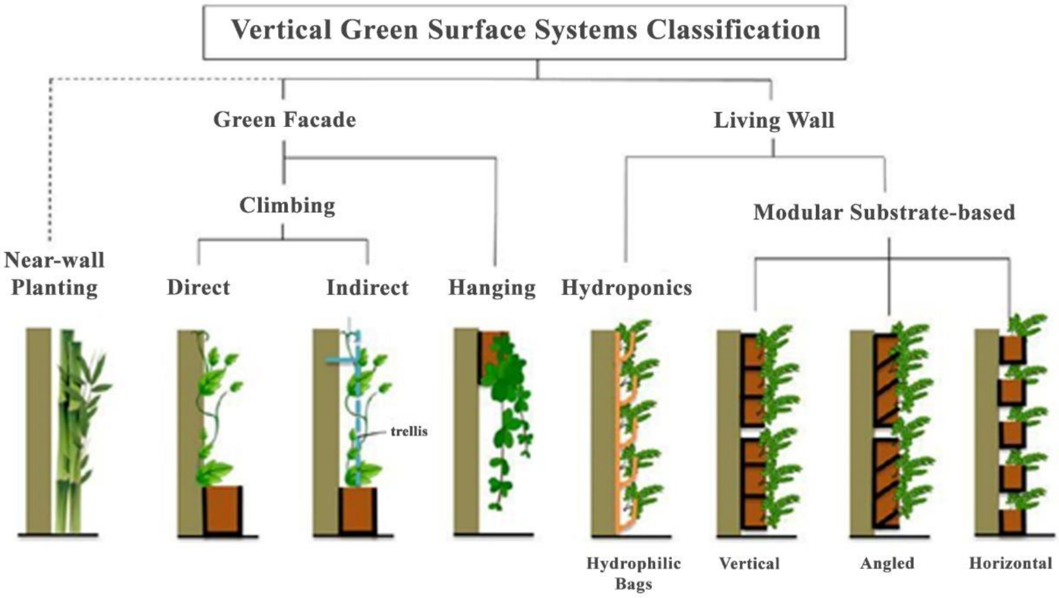


Figure 1: Vertical Greenery Systems classification (Ottelle, 2011).

- Near-Wall Planting

As the name states, near-wall planting vertical green surface is simply growing various vegetation in close proximity to the walls of the structure, this is more of a technique then it is a system as little manifested components are needed.

Figure 2: Near wall planting (Lisa Hallett Taylor).

#### 2.1.1.1 Green Facades

- Direct Climbing Green Facades

The vertical green system method, which is highly known and old-fashioned, is the wall-climbing type. Climbing plants may organically cover the walls of a structure, which is a time-consuming process. They are sometimes developed upwards with the assistance of supporting structures (Uzuhariah Abdullah et al., 2016).

Figure 3: Vertical green system, Direct Climbing Green Facade on residential buildings in Istanbul, Turkey (by Author).

- Indirect Climbing Green Facades

The indirect green facade provides a structural support for plant development (eg. trellis). This support system has various advantages, including creating an air gap between the building's surface and the vegetation, preventing plants from dropping, and increasing the system's resilience to natural elements such as rain, wind, and snow.

Figure 4: Indirect Climbing Green Facade (Green Wall SG).

* Hanging Green Facades

A common option for vertical green systems is the type of vegetation that hangs down from the structure. In comparison to the type of climbing vegetation, it may simply establish a complete vertical green facade on structures with multiple floors by planting at every story (Uzuhariah Abdullah et al., 2016).


Figure 5: Vertical green system, hanging green facade on a local store in Istanbul, Turkey (by Author).

#### 2.1.1.2 Living Walls

* Hydroponic Living Wall (Non-Substrate Based)

Vertical green systems may be constructed using a variety of methods, by using hydroponic culture systems they use less in these systems than in soil-grown plants and there are no soil pests or diseases thus making it easier to control and maintained (Kazemi et al., 2020).

Figure 6: Vertical green system, hydroponic living wall ("San Francisco Zoo vertical garden", 2021).

- Module Modular Substrate-based Living Wall

In comparison to the two pervious categories, the module type is the most recent innovation. A vertical green system needs more complex design, planning and considerations before it can be implemented. It's also the costliest way to build green walls (Uzuhariah Abdullah et al., 2016).

Module green surface systems are made out of pre-grown plants that may be utilized both inside and outside, in any environment. Suitable for new construction, retrofitting, and rehabilitation of existing structures.

Figure 7: Vertical green system, vertical substrate-based living wall, module with plants (*Schefflera Arboricola*) (Abdo et al., 2016).

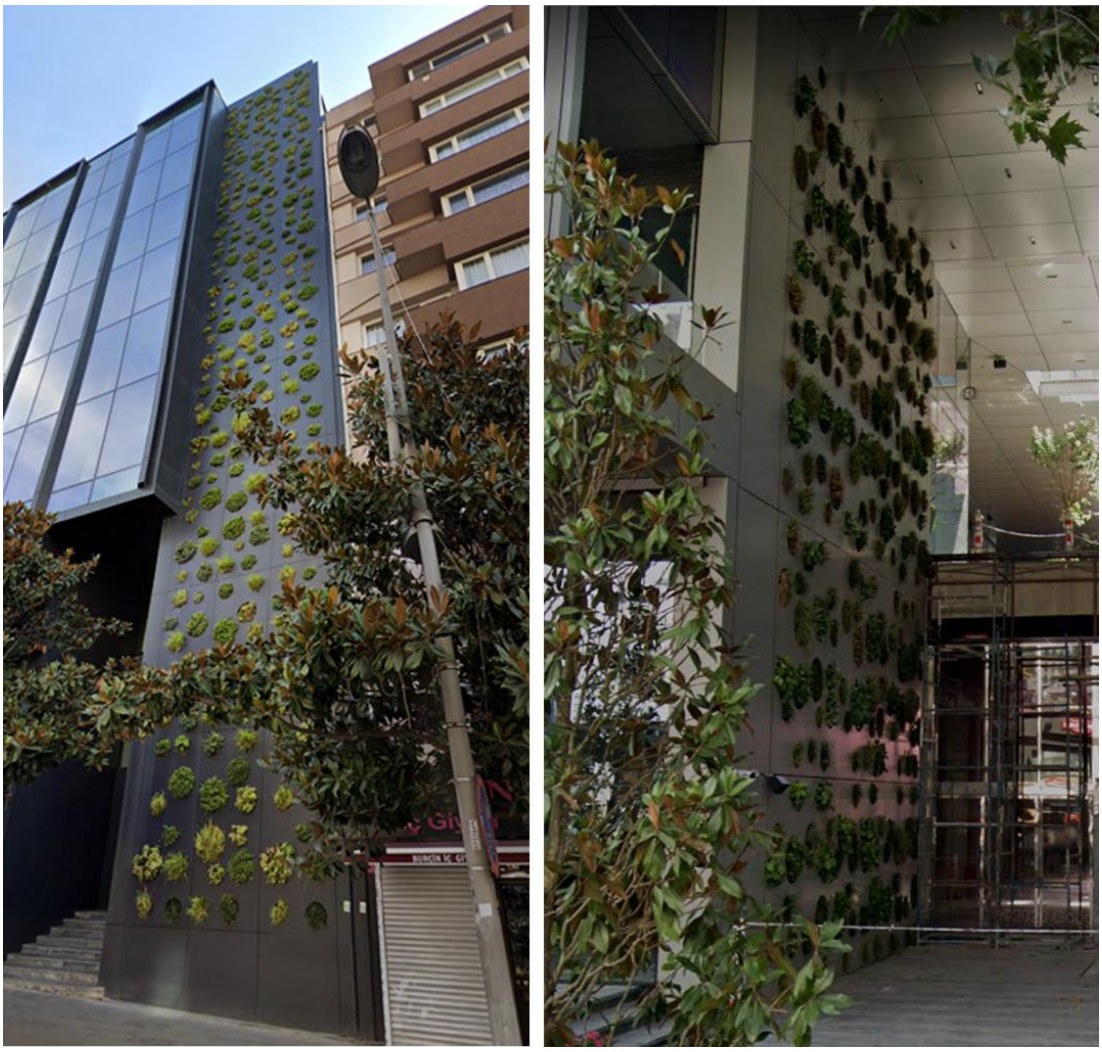

Figure 8: Vertical green system, vertical substrate-based living wall, integrated modules, Garanti BBVA in Istanbul, Turkey (by Author).

### 2.1.2 Horizontal Green Systems

Green roofs are divided into three categories: extensive, semi-intensive, and intensive. Extensive green roofs have a thin substrate layer (less than 15cm), a low initial cost, a light weight, and require little care. Because of the thin bottom layer, extensive roofs can only support a few species of plants, such as grasses, moss, and a few succulents. In circumstances when extra structural support is not required, a large green roof system is typically employed (Vijayaraghavan, 2016).

Intensive green roofs, on the other hand, have a deep substrate layer (20–200cm), a large diversity of plants, significant upkeep, a high initial investment, and are heavier. Because of the increased soil depth, a wider range of plants, including shrubs and small trees, may be grown. As a result, they often need a lot of upkeep in the form of fertilizing, weeding, and watering (Vijayaraghavan, 2016).

Because of the somewhat deep substrate layer, semi-intensive green roofs may handle tiny herbaceous plants, ground coverings, grasses, and small shrubs. These roofs demand a lot of upkeep and have a lot of capital costs. Due to construction weight constraints, expenses, and upkeep, extensive green roofs are the most frequent of the three varieties across the world (Vijayaraghavan, 2016).

An extensive green roof typically has less than 200 mm of soil or substrate, but an intense green roof might have a meter or more of substrate. An extensive green roof will likely have a shallow layer of substrate that covers a vast area, whereas an intense green roof will likely have a deeper layer of substrate that is limited to fewer sections (Figure 9).

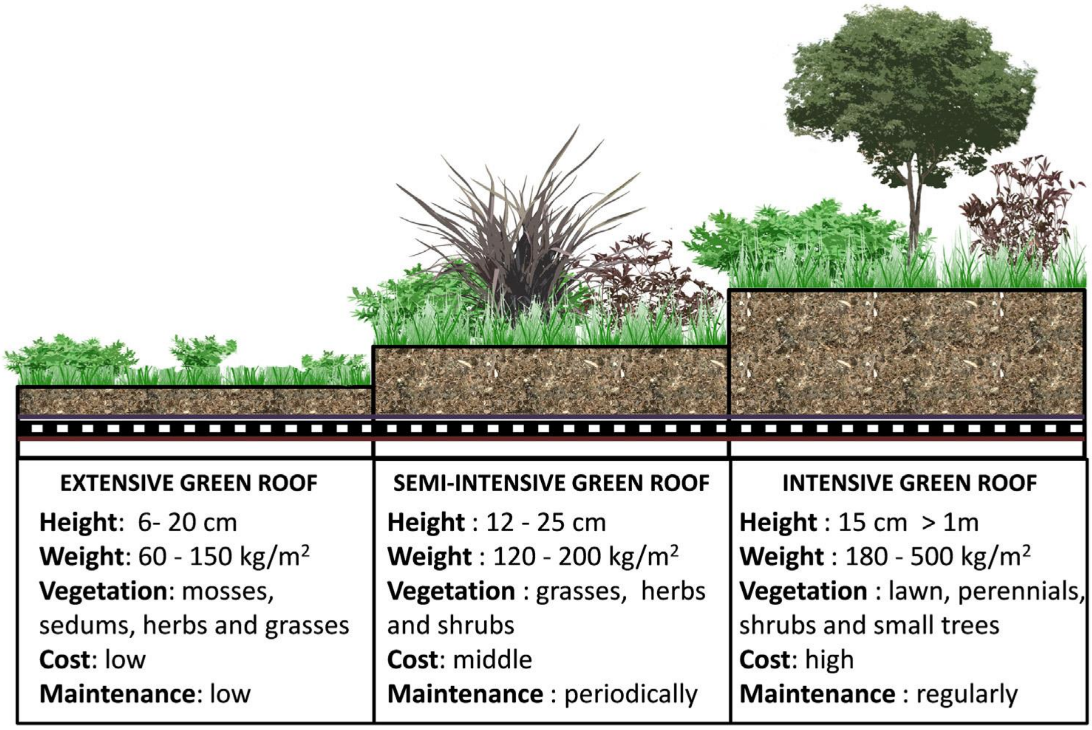


Figure 9: Green roof types (IGRA, 2008).

#### 2.1.2.1 Extensive Green Roof

Extensive green roofs require very little upkeep. They are usually not visible and are not accessible to the public. Plant species are limited to herbs, grasses, mosses, and drought-tolerant succulents like Sedum because to the lesser medium depth (15.2 cm). A sloping surface may also be used to build large green roofs.

The structure of most green roofs is similar. The roof is protected against root penetration damage by a root barrier put on top of the conventional roofing membrane. Excess water is channeled away from the roof by a drainage layer above the root bather. A filter cloth sits on top of the drainage layer, preventing silt and particle debris from clogging the drainage layer. On top of this, an optional water retention cloth can be spread, allowing more water to be kept for the benefit of the plants. Finally, a growing substrate that supports plant development is installed. The design of these components is determined by the greening project's goal and the building's load capacity (Getter & Rowe, 2006).

#### 2.1.2.2 Semi-Intensive Green Roof

Green roofs that are semi-intense (or simple intensive) are a step between extensive and intensive green roofs. On a green roof, practically any type of garden plants may be installed. From low-maintenance plants like mosses, stonecrops, or houseleeks that are popular on light-weight vast green roofs to trees that may be found on intense green roofs with thick substrate layers, there is something for everyone. Ground coverings, tiny herbaceous plants, grasses, and small shrubs are all suitable for a semi-intensive green roof. The exact composition of the plants on the roof may be changed to suit the local climate. These plants only require minimal upkeep and occasional watering in temperate climates. Irrigation is required most often when there is a lack of precipitation for an extended length of time. The amount of water given is determined by the need of the individual plants. The suggested minimum substrate thickness ranges from 12 cm for grass or herbaceous plants to 20 cm for tiny shrubs, however this can be altered. For more demanding plants, a thicker substrate is required. In comparison to extensive green roofs, semi-intensive green roofs have a stronger thermal resistance, which is one of the fundamental qualities of modern low-energy construction. The semi-intensive green roof system may support a more diverse ecosystem due to the thickness of the substrate layer. As a result, it has a greater chance of replacing built-up land than a large-scale system. It can also hold more storm water, which helps to enhance the urban water cycle (Vacek et al., 2017).

#### 2.1.2.3 Intensive Green Roof

Planting trees and bushes on an intensive green roof demands a deeper substrate of >20cm and more horticultural management. A shallow soil base of 20cm, on the other hand, may support broad green roofs with low-maintenance grass, herb, or drought-tolerant sedum plants. From the ground up, both intensive and extended kinds use the same materials and structure: root barrier, drainage, filter, water storage (rockwool), substrate, and vegetation (Jim & Tsang, 2011).

## 2.2 Green Surface System Components

Blanc's initial idea "to have nature coming back in towns" led him to draw inspiration from vegetation in high mountain environments and tropical rainforests which required low or no amount of soil. (Blanc, 2015).

His plant wall system, which can be used both indoors and outdoors, is made up of a metal frame that can be attached to walls or stand alone; a 10mm thick PVC layer that provides stiffness and waterproofing; a thin polyamide felt that transports water to the plant roots via capillary and on which the roots grow; and a variety of plants, both climbing and non-climbing, that are installed into the felt as seeds or already grown.

A watering system, which is a crucial feature of the green wall and is as basic as a plastic hose with little holes 2mm wide every 10 cm and an irrigation timer, provides water, either tap or recycled, from the top. A vertical garden, according to Blanc, makes better use of water than a standard, horizontal garden since there is less percolation in the soil and, as a result, more water is available for the vegetation (Blanc, 2015).

There are the two types of vertical green surface systems, green facades and living walls. The growth media is placed on the ground in green facade surface systems, and the plants grow vertically to cover the wall. As for living walls, the growth media can be positioned vertically on the wall's surface for the vegetation to grow on or growth media with pre-grown vegetation can be installed and maintained easier. Both of these vertical green surface systems can minimize heat flow as well as air, ambient, and surface temperatures. The following figures show how modular substrate-based living wall green surface system, and its various components, are integrated into the exterior walls of a building:

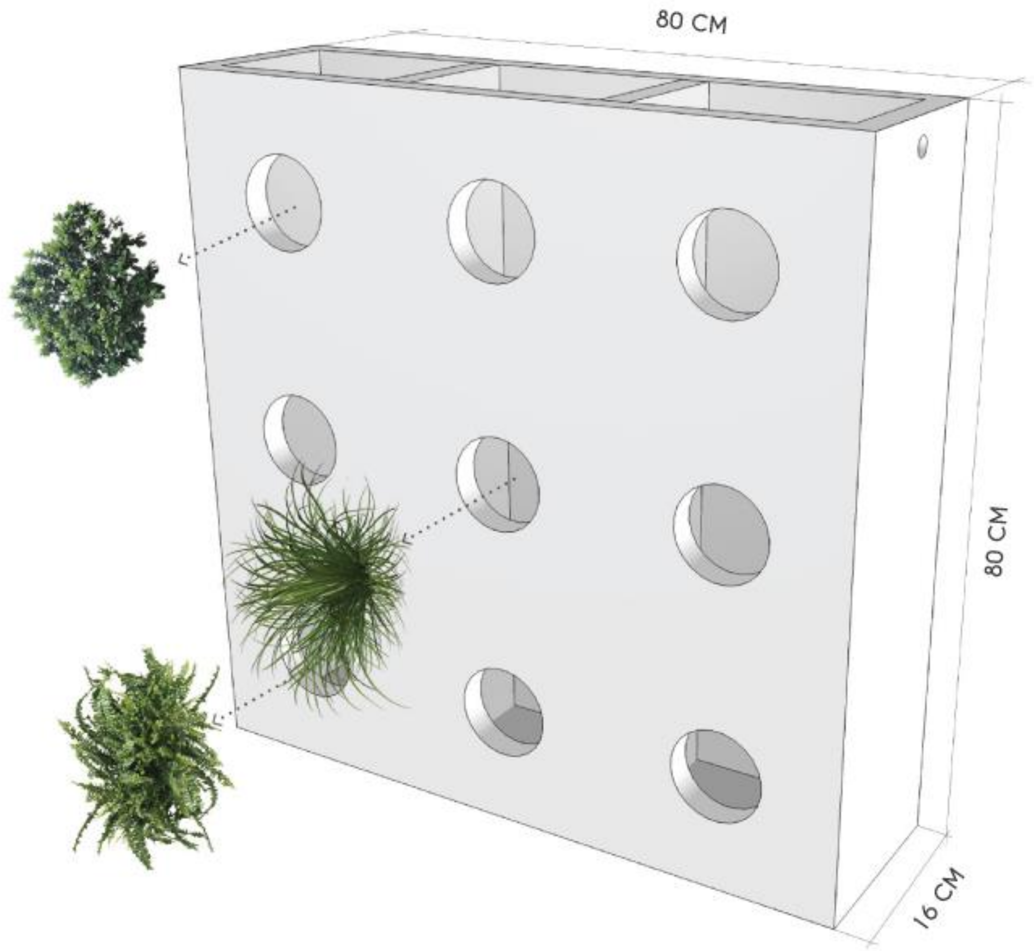


Figure 10: Modular living wall system module unit (*Preserved Greenery Como*, n.d.)

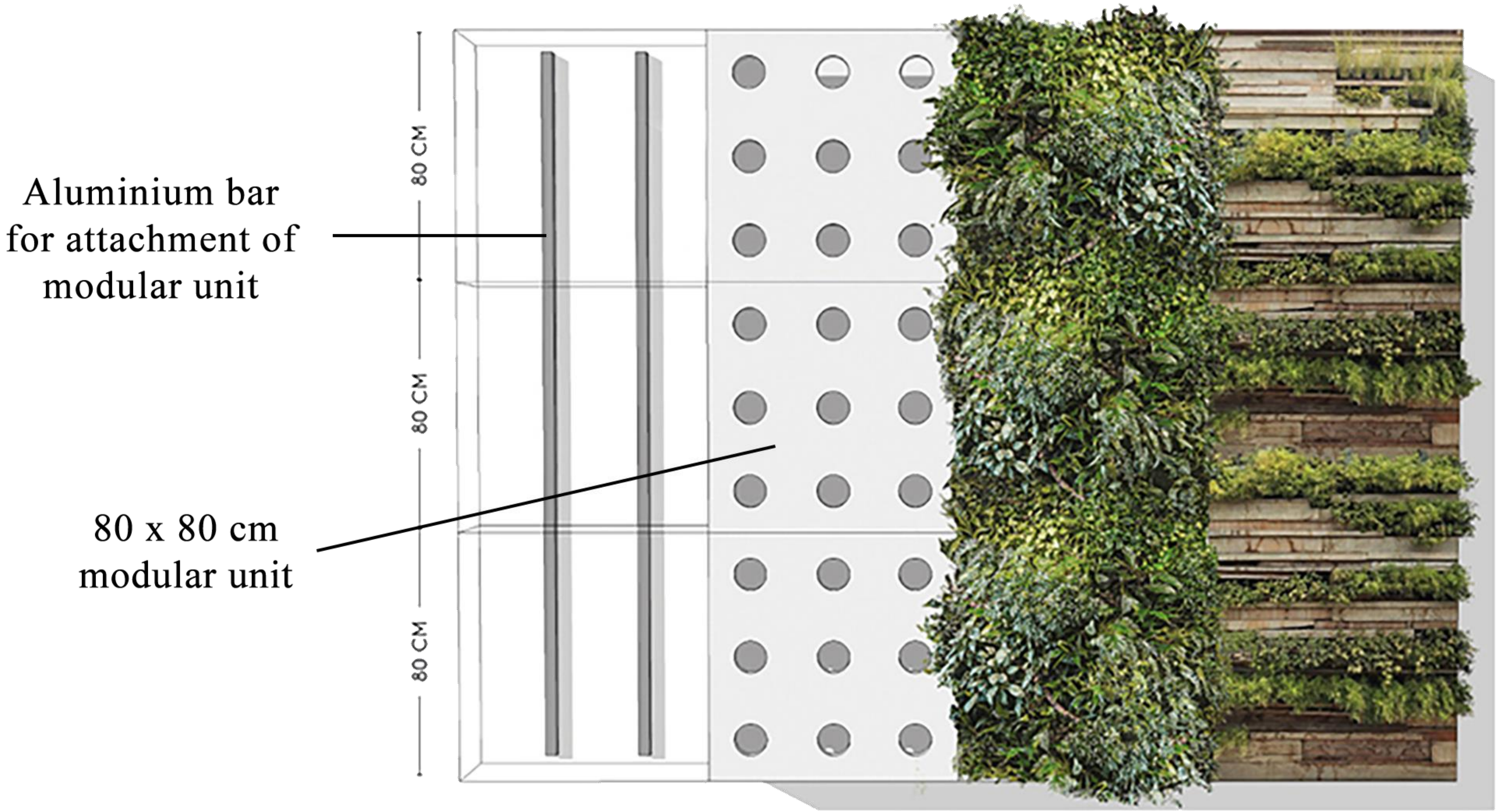


Figure 11: Modular living wall system layer breakdown (*Preserved Greenery Como*, n.d.)

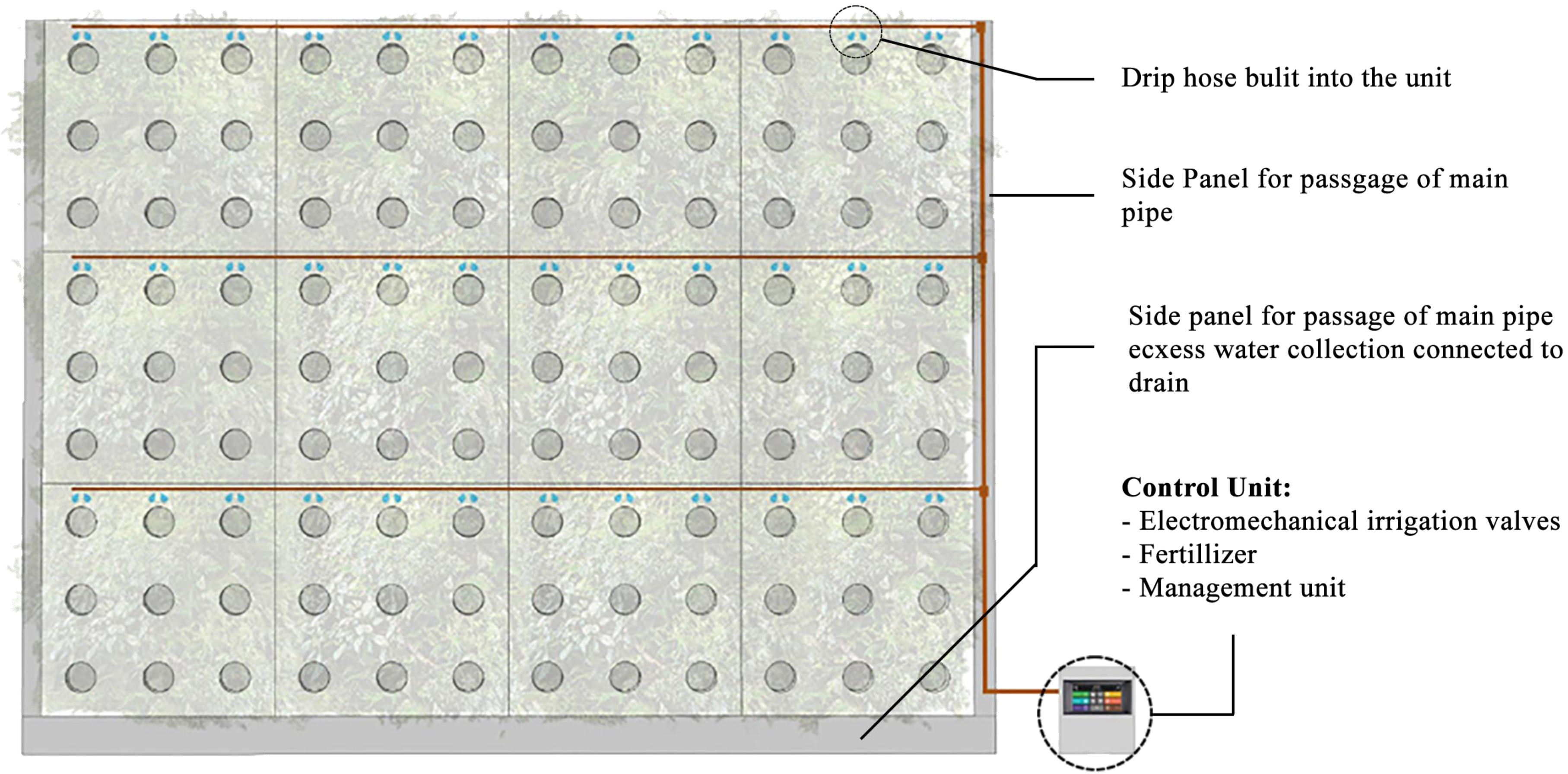


Figure 12: Modular living wall system irrigation system (*Preserved Greenery Como*, n.d.)

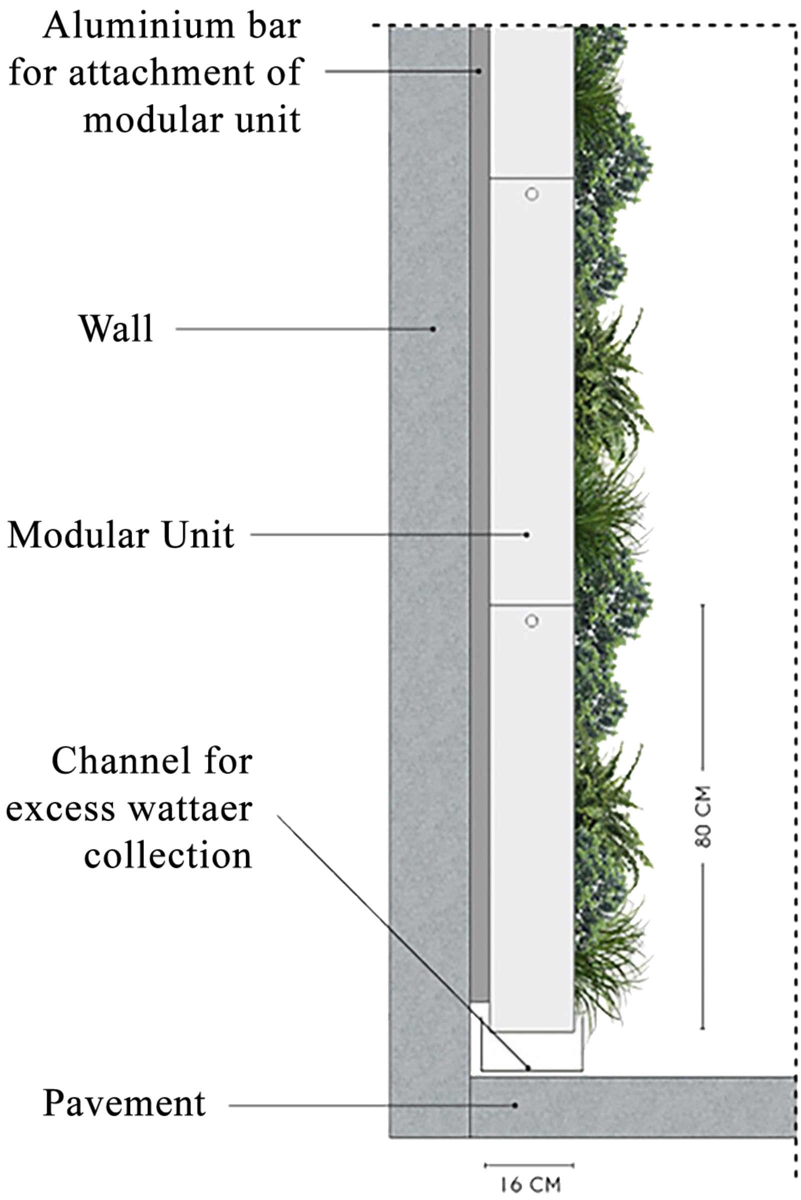


Figure 13: Modular living wall system elevation on wall section (*Preserved Greenery Como*, n.d.)

### 2.2.1 Support Structures

The climbing plants that grow along the wall determine the direct kind of green facade. Modular living walls come in a variety of designs and sizes, series of modules make up the modular system, each of which has an interlocking mechanism on the sides that allows for bonding (Figure 14 &Figure 15).

Figure 14: Grid of trays (Tarboush, 2019).

Figure 15: Example of modular trays living wall (Tarboush, 2019).

Vessels that are modular living walls are built of polymeric materials and are distinguished by the ability to install a group of plants elements separately, each of which includes a different variety of plant in a row, giving the building's wall a unique character (Figure 16).

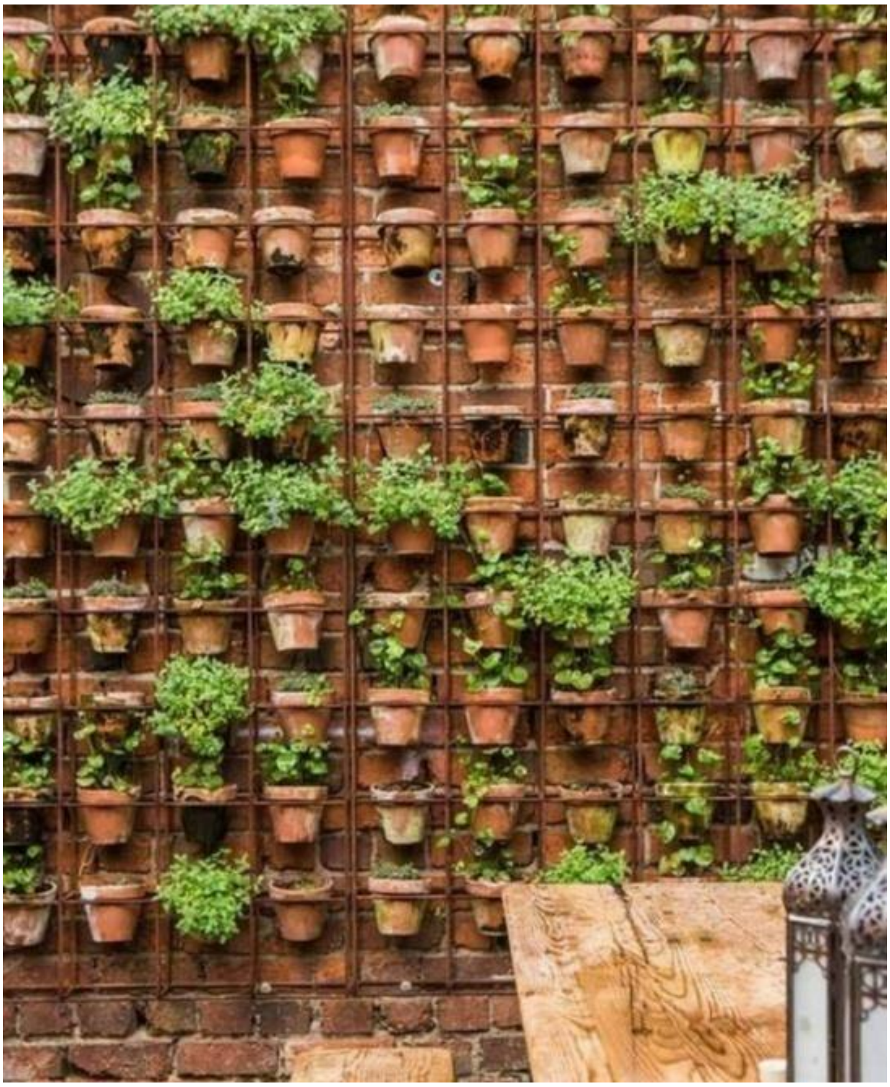

Figure 16: Example of modular vessels living wall (Tarboush, 2019).

Planter tiles that are modular living walls are made up of two parts: a flat back that is bonded to the building's wall in a vertical manner, and a front component that is used to farm plants separately (Figure 17). These tiles are constructed of light materials such as plastic or ceramics and are juxtaposed to one other (Tarboush, 2019).

Figure 17: Example of modular planter tiles living wall (Tarboush, 2019).

Flexible modular bags may be mounted to the wall or as modules and are composed of plastic material filled with growth media and the plants are placed into them (Figure 18) (Tarboush, 2019).

Figure 18: Modular flexible bags living wall (Tarboush, 2019).

### 2.2.2 Growing Media

There is no requirement for growth material in continuous living wall systems since they employ lightweight absorbent screens that are sliced into pockets and plants are individually inserted into them. Because they lack a substrate, they require a constant supply of water and nutrients. In addition to nutrients like nitrogen, this substrate aids plant development (organic matter mixed with inorganic fertilizers) (Tarboush, 2019).

### 2.2.3 Irrigation

Water is supplied to plants by an irrigation system in modular and continuous green surface systems. To encourage vegetation growth, plant nutrients can be mixed with water. Permeable screens provide water and nutrients consistently throughout the whole surface of the living wall system. Modular living wall system has an indent in the top face of the module for inserting the irrigation tube, as well as many holes in the recess of trays for gravity watering the growth medium, and holes for drainage in the bottom of the trays to enable excess water to irrigate the modules beneath (Tarboush, 2019).

Table 1: Irrigation system components

| Part Number | Part Name |
|---|---|
| A | Wall or support structure to affix irrigation rig to |
| B | Aerial |
| C | Nutrient dosing unit |
| D | Irrigation controller |
| E | WRAS approved sub-tanks (size to suit) |
| F | Filter |
| G | Flow Meter |
| H1, H2, etc. | Solenoid Valve per zone |
| i | Non-Return Valve |
| J | Magnetic Scale Inhibitor |
| K | 25/75L nutrient tanks (or to suit) |

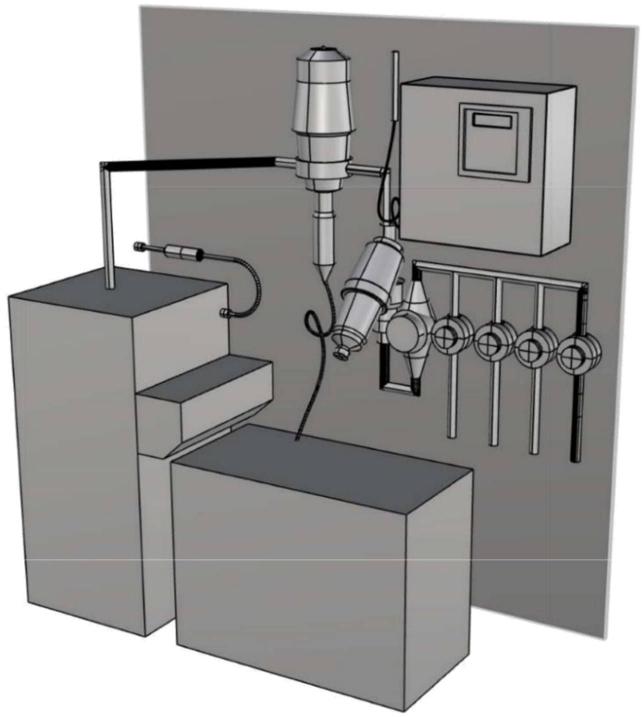

Figure 19: Irrigation System (3D Model)(Green Wall Specification and Drawings - Biotecture, n.d.)

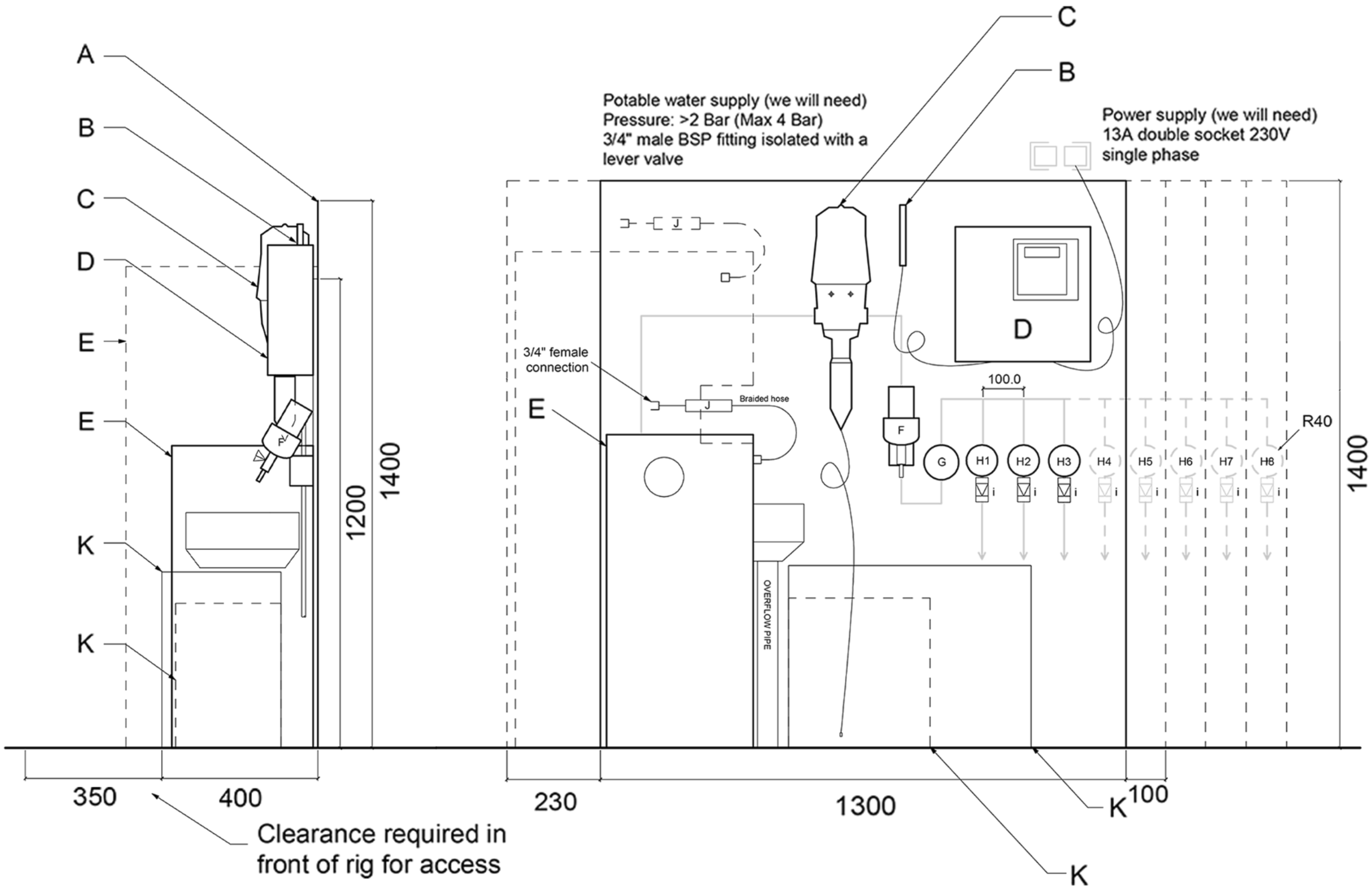


Figure 20: Irrigation System (Side View and Elevation View)(*Green Wall Specification and Drawings - Biotecture*, n.d.)

A Water Regulations Approval Scheme (WRAS) approved break tank of sufficient size to store 24 hours of irrigation water supply. Pumping will be done with a dependable pump set that can give the proper pressure to all drop points. Water will be supplied from the pump via a ring main and header pipe by segmented solenoid valves, with control provided by an automated system (*About the Uk's Leading Living Wall Company* - *Biotecture*, n.d.).

- Break tank

An unpressurized and closed water tank, with an air gap that ensures zero backflow into the system made of high-density polyethylene with inbuilt submersible pump, certified by WRAS.

- Irrigation fittings

Wall/array fittings are all barbed, with couplers, elbows, and T pieces with non-return valves if needed.

- Water feed pipework and irrigation pipework

Low-density polyethylene (LDPE) water feed pipe 20/25mm (pipe diameter varies according to the distance between the plant room and the living wall).

- Dripline

Round polypropylene dripline with a 16mm diameter and flat pressure compensating drippers with a dripper flow rate of 1.6 l/h. Dripline is secured to the carrier rails by injection molded polypropylene clips that are exclusive to Dripline. Rigid PVC extrusion cover strip, fastened to irrigation lines with proprietary clips, to improve aesthetic appearance and offer solar protection to minimize solar gain to the dripline.

### 2.2.4 Vegetation

Wall flora is made up of a variety of plant groupings, including lichens, which are frequently brightly colored and textured and have a characteristic patina. Plants on walls may be split into four categories:

#### 2.2.4.1 Self-Climbing Vegetation

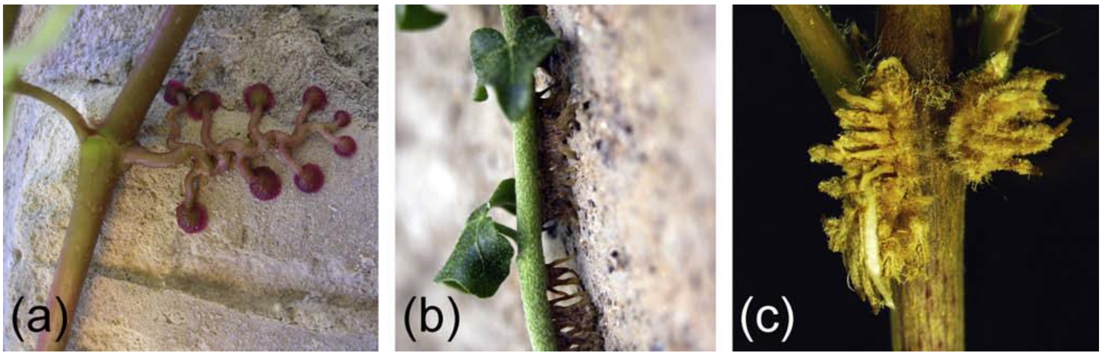


Figure 21: Climbing plants (Steinbrecher et al., 2010).

a) Attachment Structures

Within the Vitaceae family, Parthenocissus tricuspidata is a tendril-bearer. The attachment pads that were evaluated were about a year old, fully lignified, and growing on a plastered wall (Figure 21a) (Steinbrecher et al., 2010).

b) Internodal Attachment Roots

Hedera helix is a woody root climber that belongs to the Araliaceae family. Internodal portions of the plant growing on the bark of Celtis occidentalis were about 2 cm long (Figure 21b) (Steinbrecher et al., 2010).

c) Nodal Attachment Roots

The trumpet vine (C radicans) is a woody root climber in the Bignoniaceae family that is endemic to southeastern US forests. Their connection roots can only be found at the nodes. Every root contains thick root hairs that interlock to form clusters (Figure 21c) (Steinbrecher et al., 2010).

#### 2.2.4.2 Trellis Climbing Vegetation

Trellis is a structure for training trees and climbing plants. It's commonly made out of crisscrossed long, narrow wood or metal slats that create square or diamond-shaped gaps. Trellises can also be created out of any open structure that serves the same purpose, such as untrimmed branches loosely fastened or weaved together. Screens made of latticed trellises are popular.

Despite the fact that vines vary greatly in size, shape, and evolutionary origin, they have historically been classed based on their mechanism of attachment. Recent advancements in attachment mechanics knowledge (Isnard & Silk, 2009).

a) Scrambling Plants

Many climbers don't need specific equipment and instead grow unusually long shoots that drape and rest on the structure they're climbing. With enough development, they can eventually climb a suitable support with only a little help from the gardener.

Rambling or climbing roses are a sort of scrambling plant that requires tying onto supports at times but may cover enormous areas due to its prolific growth. Many rambling roses have thorns that let them latch onto things and are commonly grown over trees.

Figure 22: Scrambling roots of climbing roses *(Rosa Setigera Michx)* ("Barony Rosendal - Wikipedia", 2021).

b) Twining & Tendril Climbers

To sustain themselves, these climbers wrap shoots, leaves, and leaf-stalks around stems, wires, poles, and pillars. These unique shoots basically connect the plant to the support without the need for intervention, albeit they will require some supervision in terms of growth direction.

Figure 23: Twining stem of hop (*Humulus lupulus*) (Isnard & Silk, 2009).

## 2.3 Advantage of Integrating Green Surface Systems

Green surface systems have a number of advantages, including improved aesthetics and noise reduction. They can also act as "additional insulation" for the structure's envelope. The evergreen plant cover reduces the wind flow across the building facade in the winter. Furthermore, the thick plant foliage insulates heat radiation from the external walls, preventing the structure from cooling down. Only 5-30% of the energy from the sun that falls on the leaves is absorbed by the leaf. Others might be reflected, converted to heat, or utilized in photosynthesis or evapotranspiration (Rakhshandehroo et al., 2015).

### 2.3.1 Indoor Advantages

Thermal comfort, according to ISO 7730, refers to the overall thermal sensation and degree of discomfort in a given setting. Thermal comfort may also be characterized as a mental state that is linked to psychological terms. To evaluate thermal comfort sense, the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) were used (Elsadek et al., 2019a).

#### 2.3.1.1 Building Thermal Levels

It is described by the ASHRAE as “the state of mind where one is satisfied with the current existing environment”. According to the definition above, comfort is a state of mind rather than a state of situation. In summary, it is the temperature range in which the user of the space is comfortable without the need for artificial heating and cooling. Various research on green facades and green roofs have investigated their thermal performance using on-site measurements or simulation models. Green facades have a great potential to intercept solar radiation, according to the findings of the spring and summer campaigns (de Jesus et al., 2017).

#### 2.3.1.2 Acoustics

Vegetation can also act as a noise barrier as the irregular foliage of the vegetation help to scatter the incoming unwanted sound waves. According to a (Pérez et al., 2016), green walls, which are meant to be covered with flora, can significantly reduce the amount of noise that penetrates buildings, modular green surface system lowered sound levels by 15 decibels in lab experiments (dB).

#### 2.3.1.3 Air Quality

Natural ventilation capability of green surface systems and their impact on mechanical ventilation system’s energy consumption by lowering intake of fresh air requirements. Calculation of facade capacity, which determines the $CO_2$ reduction of interior air by photosynthesis, which results in a reduced mechanical system outflow air flow rate, as well as the number and power of fans required to circulate inside air into the facade cavity (Parhizkar et al., n.d.).

#### 2.3.1.4 Psychological Effects

Green surface systems create a sense of serenity as users find vegetation calm and relaxing. The participants seemed to like the natural qualities of a green setting, which contributed to a relaxing impact. Because people have an instinctive need for woods, vegetation, and urban green areas, several explanations support the benefits of observing them (Elsadek et al., 2019b).

### 2.3.2 Outdoor Advantages

Rapid urban expansion has resulted in a rise in urban heat island, traffic noise, and air pollution. The use of green surface system as part of vertical gardening has emerged as an intriguing concept for developing urban greenery infrastructure. It permits plants to cover the outside of a structure, forming a secondary skin. The most major benefit of passive building design technology is improved building thermal performance (Elgizawy, 2016).

#### 2.3.2.1 Wall Protection

The protection provided by green surface systems slows the degradation of the wall caused by UV radiation, and other elements. This impact is visible in green surface systems such as living walls, where continuous supporting layers provide additional protective function (Perini & Rosasco, 2013).

#### 2.3.2.2 Urban Temperatures

Green surface systems help decrease the Urban Heat Island Effect (UHIE) on urban areas. Urban Heat Island is a city that is noticeably warmer than the rural regions surrounding it; scientists refer to this phenomenon as the Urban Heat Island Effect to avoid confusion with global warming. Excessive urban expansion is one of the primary reasons Urban Heat Island thrives, and green surface systems are a popular option for 'cooling' cities and lowering Urban Heat Island (Tzortzi -julia Georgi & Sophocleous, n.d.).

#### 2.3.2.3 Biodiversity

Green surface systems have been shown to improve biodiversity on a local scale, with even simple flora ensembles offering a habitat for invertebrates and nesting, as well as food and shelter options for urban ornithology. In theory, technological advancements imply that living walls may be designed to mimic natural ecosystems and provide more opportunities for biodiversity enhancement. Green walls can help cities sustain biodiversity at a landscape scale by serving as a "corridor" or "stepping stone" for mobility and dispersal. In the face of growing disturbances and unpredictable variations, a well-connected network controlled at a landscape size will strengthen the stability of urban biodiversity (Collins et al., 2017).

## 2.4 Disadvantage of Integrating Green Surface Systems

Although there are several advantages to returning plants to the surfaces of building structures and their associated areas, there are certain technological challenges that must be overcome. Green surface systems are a relatively new technology that has received little research.

### 2.4.1 Green Surface System Installation

Although the installation of a green system is particularly energy efficient, green systems have difficulty maintaining vegetation sustainability. In order to cover the entire surface area, certain climbing plants require assistance throughout their development. Climbing plants may also damage the building's surface because their roots penetrate the fractures and erode the surface. To avoid this, putting the vegetation at different elevations on the surface so that their burden is spread evenly and failing plants would solve the problem. Some variants of modular living wall systems allow for individual module disassembly. The other varieties have a front cover that may be removed for green wall maintenance or plant replacement. living wall systems that are modular are easier to install, maintain, and replace. Continuous living wall systems allow for a wider choice of plants to be used in the creation of the green wall and are often lighter than modular living wall systems (Tarboush, 2019).

### 2.4.2 Green Surface System Maintenance

<u>Maintenance of vertical greening systems</u>

Because they are living systems, all green surface systems require some level of upkeep. The amount of upkeep a user is willing to undertake is a key design consideration that might influence the type of system and plant species used.

- Green facades

Hedera or/and vines are commonly used in green facades, and they may grow in either ground soil or planter boxes, with varied watering and fertilizer requirements according to the site. Because of the site's location and circumstances, a typically strong or non-dependent vine species may require more watering and nutrients. Some plant species will be deciduous, and others may produce an abundance of fruits or flowers, necessitating more care and upkeep.

- Living wall systems

Living wall systems often require more intense maintenance than green facades due to the diversity and density of plant life. A few criteria for maintenance are listed below.

- Vegetation that has evolved in nutrient-poor habitats will require more attention than those that have developed in nutrient-rich ones.
- Regular pruning (long-term maintenance) is necessary for living wall systems, and the level of care required will vary depending on the kind of living wall system and the vegetation employed.
- Plant species replacement as they die, as well as selection of the appropriate plant species (Figure 24a)

Panels must be replaced due to degradation (Figure 24b). When the felt layers are ripped or damaged, it is required to replace the panels for various systems, such as feeling layers.

Figure 24: (a) (left) felt layer with dead plants (b) (right) substrate with tears, degrading felt layer and water leakage (Tarboush, 2019).

- Plants that are not evergreen may wilt in the winter, which is not a pleasant sight (Figure 25). As a result, it is critical to select the appropriate plant species for the climate.


Figure 25: Living wall panels degradation, Islington, North-London (Tarboush, 2019).

### 2.4.3 Irrigation Systems

Irrigation's main goal is to keep plant root zones at optimal water levels. The practical difficulty that all irrigation scheduling techniques face is determining how much water and fertilizers should be delivered to the soil and when. The deployment of any efficient water management system demands a regular assessment of precisely what plant species require. Establishing proper irrigation and nutrition levels are vital components of living things that should be maintained at all times. Otherwise, it may cause issues by failing to remember to service and operate. Irrigation systems are energy-intensive and are based on the deployment of a self-automated system for continuous monitoring of the moisture regime inside the root zone (Tarboush, 2019).

### 2.4.4 Birds and Insects

Architects all around the globe are creating green buildings, whether it's in terms of sustainable construction, ecologically friendly operations, or simply being green in appearance. Biophilia is a wide term that refers to a desire to link humans with the environment, and it may lead to some inventive and imaginative ideas. However, we are now seeing that actually greening the planet — by covering building walls and roofs with flora — has certain unintended consequences. Pest species have been identified on green roofs, but there is little study on the subject, particularly in terms of comparative studies. The 2015 research by Quispe and Fenoglio was one of the first to quantify pest species on green roofs in compared to ground level habitat. As the number of green roofs grows, it's critical to understand how they'll affect the abundance of pest species in metropolitan areas. The presence of pests on vertical and horizontal green systems affects the provision of ecosystem services as well. If the plants on green surface systems have a high pest burden, it might affect the systems' functionality and long-term durability. Increased pest management via increasing beneficial insects is thought to be linked to increasing insect diversity in urban environments. However, according to Quispe and Fenoglio's (2015) research, owing to the height of buildings, some parasitoids may be unable to exploit food resources on green roofs. More study is needed to discover how pest-predator interactions and the quantity of insect herbivores on green roofs are affected by green roofs (Grimshaw-Surette, 2016).

# Chapter 3

# EVALUATION OF A RESIDENTIAL BUILDING IN KARAKOL, FAMAGUSTA

## 3.1 Döveç Apartment 20 Building

A typical mid-rise residential apartment building constructed by Döveç Construction in 2008. The building is neighbored by other residential buildings of various heights within the quiet district of Karakol (*Döveç Construction - Döveç*, n.d.).

Figure 26: Döveç Apartment 20 in Karakol district (by Author).

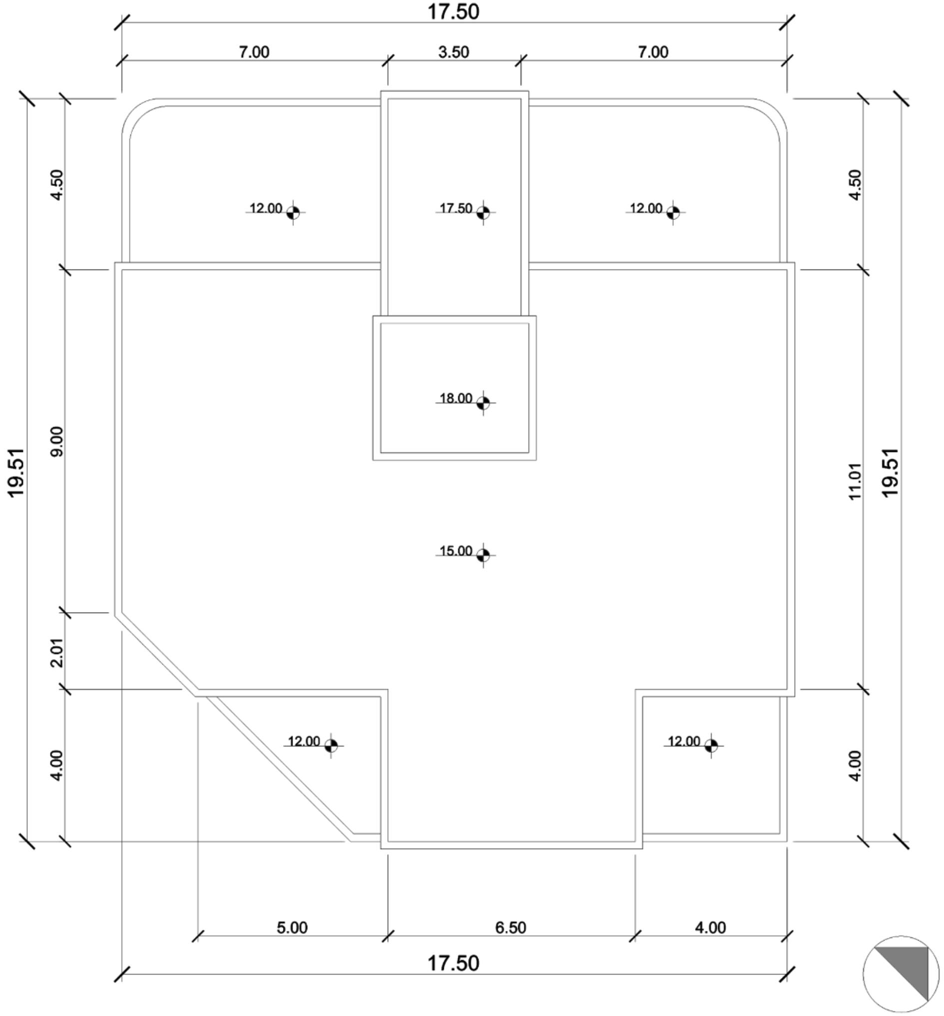


Figure 27: Top view plan of Döveç Apartment 20 Building (by Author).


Figure 28: North elevations of Döveç Apartment 20 Building (Left: North West) (Right: North East) (by Author).


Figure 29: South elevations of Döveç Apartment 20 Building (Left: South West) (Right: South East) (by Author).

### 3.1.1 Location


Figure 30: Google Earth satellite image of Cyprus indicating Famagusta’s location (*Google Earth*, n.d.)

The building is located north of Osman Fazil Polat Pasha Mosque, in the district of Karakol in Famagusta, North Cyprus.


Figure 31: Google Earth satellite of Karakol district site image (*Google Earth*, n.d.)

### 3.1.2 Orientation

Döveç Apartment 20 building faces North West towards one of the streets in the district of Karakol.

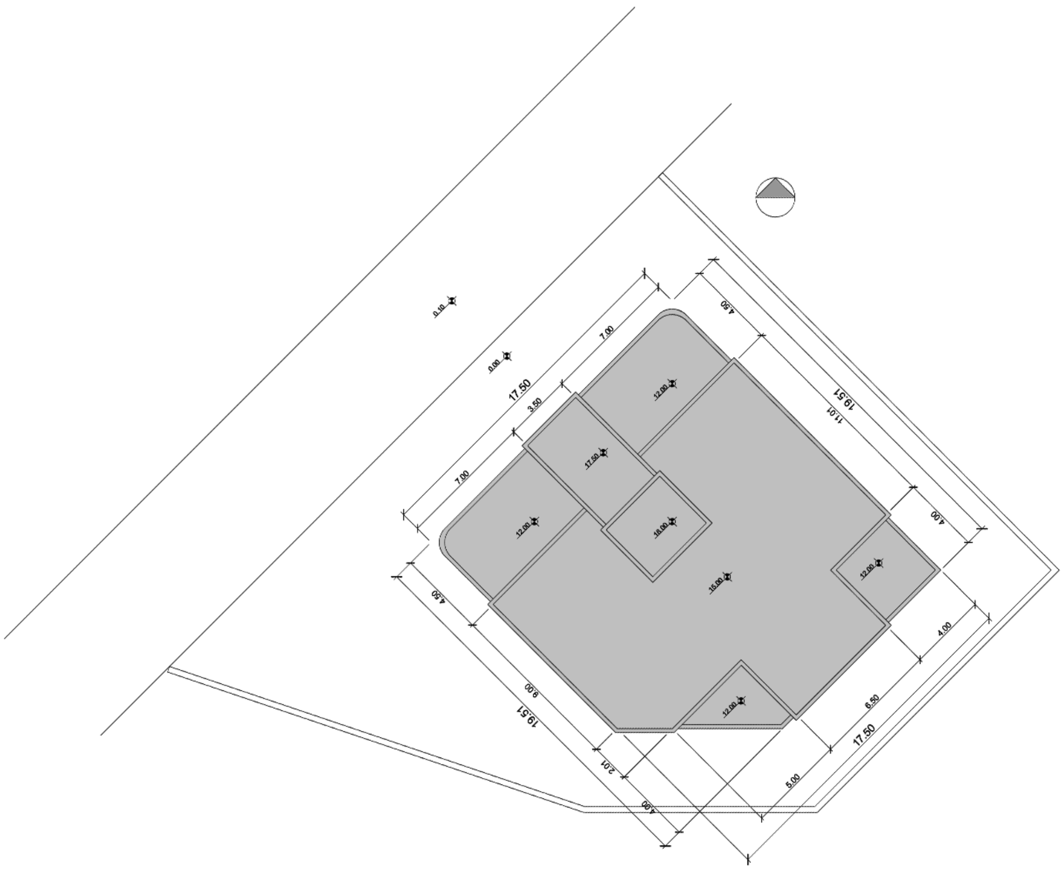

Figure 32: Building orientation in Karakol, Famagusta (on Site Plan) (by Author).

### 3.1.3 Local Wind & Ventilation

Annually the average hourly wind speed in Famagusta varies significantly during each season. From November 9 to April 2, 4.8 months are windier where the speed of wind would be more than 9.5 m/h. In February the speed of wind would reach around 11.4 m/h from April 2 to November 9, the period lasted 7.2 months. September is the calmest month in Famagusta, where the speed of wind is 7.5 m/h.

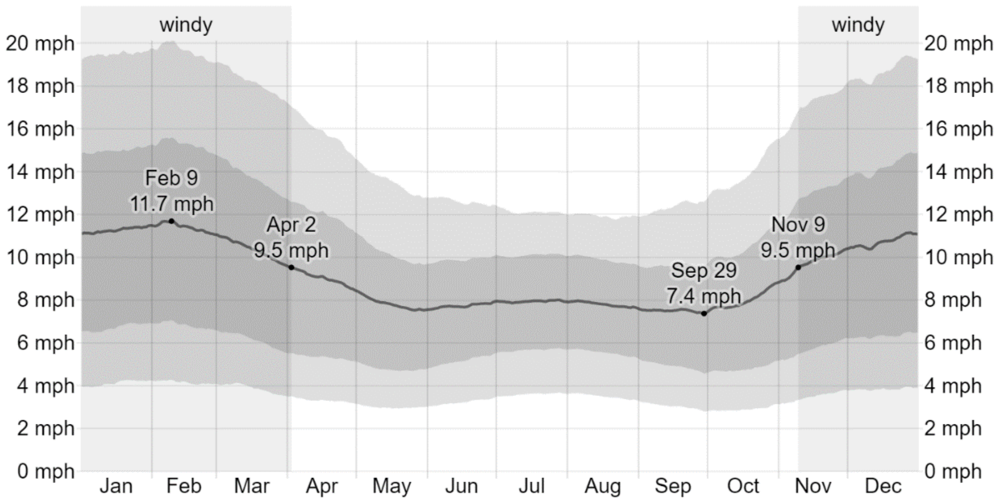


Figure 33: Average Wind Speed in Famagusta (Famagusta Climate, Weather By Month, Average Temperature (Cyprus) - Weather Spark, n.d.)

For 8 months, the prevailing winds come from the west, for the rest of the remaining 3 months the prevailing winds come from the north.

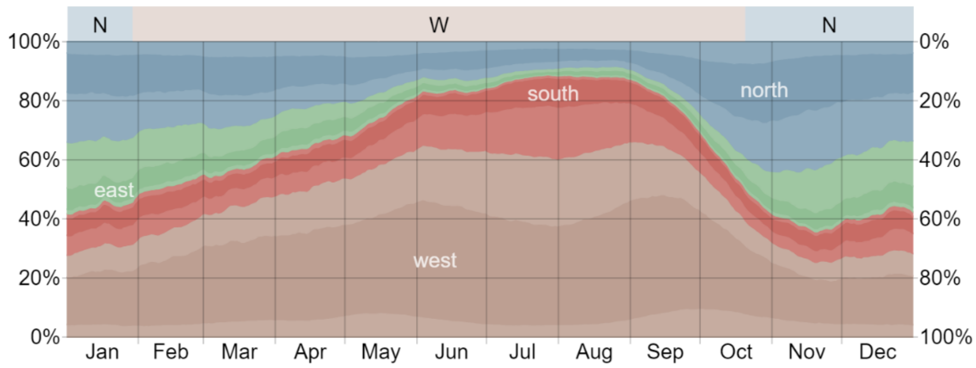


Figure 34: Wind Direction in Famagusta (*Famagusta Climate, Weather By Month, Average Temperature (Cyprus) - Weather Spark*, n.d.)

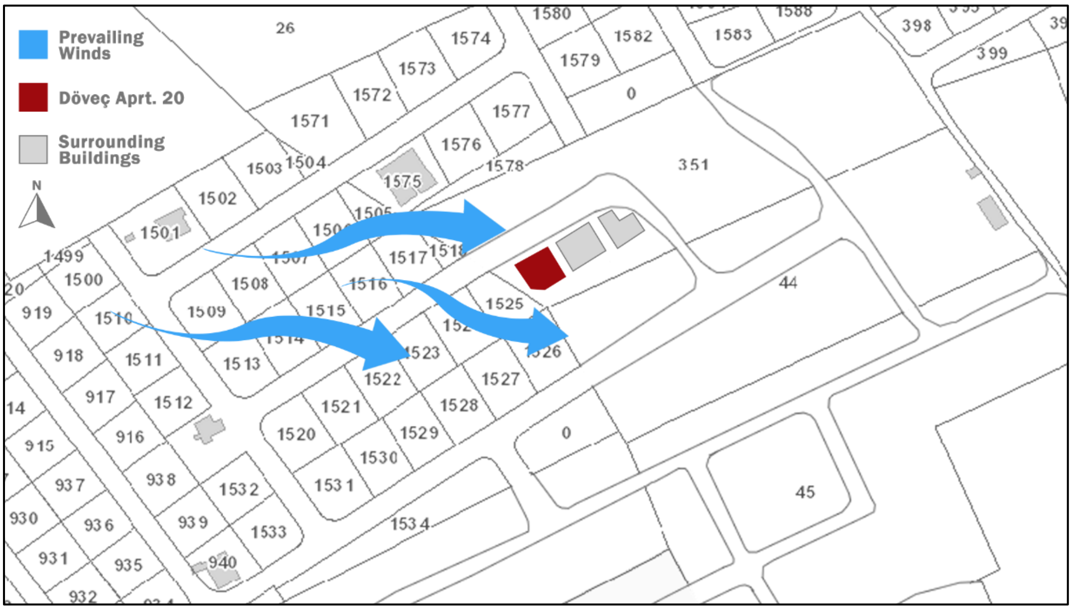


Figure 35: Wind Direction in Karakol, Famagusta (on Site Plan)

### 3.1.4 Temperature

The following figure shows the hourly outdoor temperature of Karakol district (in degrees Celsius) with temperatures ranging from 3 to 35 degrees Celsius for every month throughout the year.

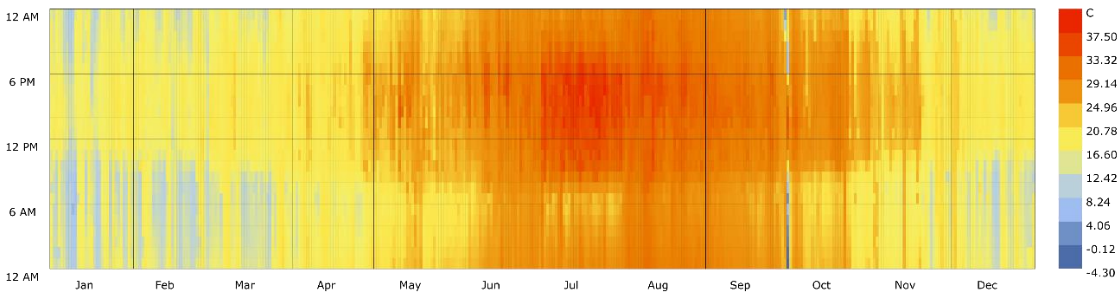


Figure 36: Hourly Dry Bulb Temperature of Karakol, Famagusta (C) (by Author)

## 3.2 Residential Apartment Buildings of Karakol District

- Building Regulation

According to the findings of research articles about environmental control and climatic design in Famagusta, there are no formal construction standards, norms, or recommendations in this city for building controls.

- Building Heights

Only some portions of some of the buildings receive direct sunlight during the day, some neighboring building would only receive sunlight in the morning and/or evening due to bad distancing between buildings in Karakol and their unfortunate orientation and height.

- Roof Construction

Building with flat roofs allow for more direct entrance of the sun's rays, resulting in an overheated living area in the summer, which is inappropriate for this hot-humid environment.

- External Wall Material

Brick makes up the majority of the external wall materials in these structures. It was also discovered that there was no insulation in the building's walls, resulting in a significant rise in energy use.

- Construction Details

Moisture was also found to impact the contact points, resulting in an increase in heat transfer.

- Wall thickness and Material

Energy consumption is affected by the thickness of these structures walls as seen in Figure 37. Most of Karakol structures' walls are roughly 25 cm thick brick walls (60 percent).

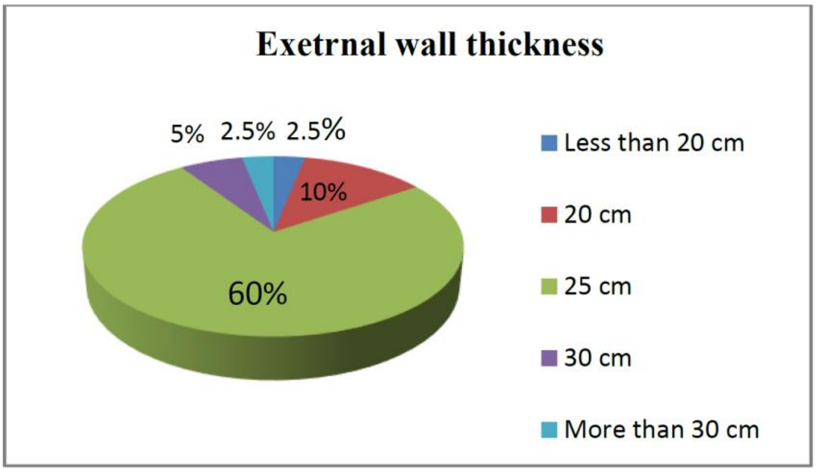


Figure 37: Karakol wall thickness pie chart (Rahbarianyazd & Raswol, 2018)

- Glazing Type

The buildings in the Karakol area have double glazing, which decreases the consumption of energy since it would escape from the room during heating or cooling. This aspect will decrease the energy and cost consumption of these structures on a monthly basis.

- Shading

Most of the buildings on the south facade lack any shading mechanisms or awnings, allowing the sun's rays to directly penetrate the structure at specific hours throughout the summer. Therefore, the apartments will be excessively hot for the tenants, necessitating the use of AC for cooling, resulting in a rise in energy expenses.

## 3.3 Summary

The case used for this study was Döveç Apartment 20 building a typical mid-rise residential apartment building constructed by Döveç Construction in 2008 located north of Osman Fazil Polat Pasha Mosque, facing North West towards one of the streets in the district of Karakol in Famagusta, North Cyprus, with prevailing winds coming from the west and wind speeds ranging from 9.5 m/h to 11.4 m/h with temperatures ranging from 3 to 35 degrees Celsius throughout the year.

# Chapter 4

# ANALYSIS AND FINDINGS OF A VIRTUAL SIMULATION OF GREEN SURFACE SYSTEMS ON A MID-RISE RESIDENTIAL BUILDING

## 4.1 Analysis Method and Software

- Rhinoceros 3D

Rhinoceros uses NURBS based geometry which creates precise mathematical surfaces and curves to graphically represent 3D models, it's a 3D graphics application by Robert McNeel & Associtesites (*Rhino - About McNeel*, n.d.).

- Grasshopper

Grasshopper is a plugin made for Rhinoceros 3D by David Rutten at Robert McNeel & Associates, which visually represents generative inputs by using various components (*Grasshopper - Algorithmic Modeling for Rhino*, n.d.).

- EnergyPlus

EnergyPlus provides the capability to engineers to virtually simulate building factors such as energy, lighting, heating, ventilation, cooling, etc. (*EnergyPlus*, n.d.).

- Ladybug

In Grasshopper and Dynamo, Ladybug imports standard EnergyPlus Weather files (.EPW). It offers a choice of 2D and 3D interactive climatic visualizations to aid decision-making during the design stage. Solar radiation assessments, view analysis, sunlight-hours simulations, and other tools help Ladybug evaluate early design possibilities (*Ladybug Tools | Ladybug*, n.d.).

- Honeybee

Honeybee supports extensive daylighting and thermodynamic modeling. It develops, executes, and visualizes the daylight simulations. It does so by connecting computer aided designs to digital simulation engines (*Ladybug Tools | Honeybee*, n.d.).

## 4.2 Thermal Comfort Simulation

The simulation is done with EnergyPlus which is an analytical computer-based procedure that assists architects and other building designers in evaluating a structure's energy performance and making required design changes before construction.

### 4.2.1 Simulation Setup

With the use of Ladybug and Honeybee in Grasshopper, running with EnergyPlus, it allows us to simulate the indoor thermal levels of a residential building in North Cyprus by creating a virtual energy model of the building in Rhinoceros 3D. With this simulation, we are able to predict the effects of integrating a green surface system to the exterior walls of the building (Figure 38).

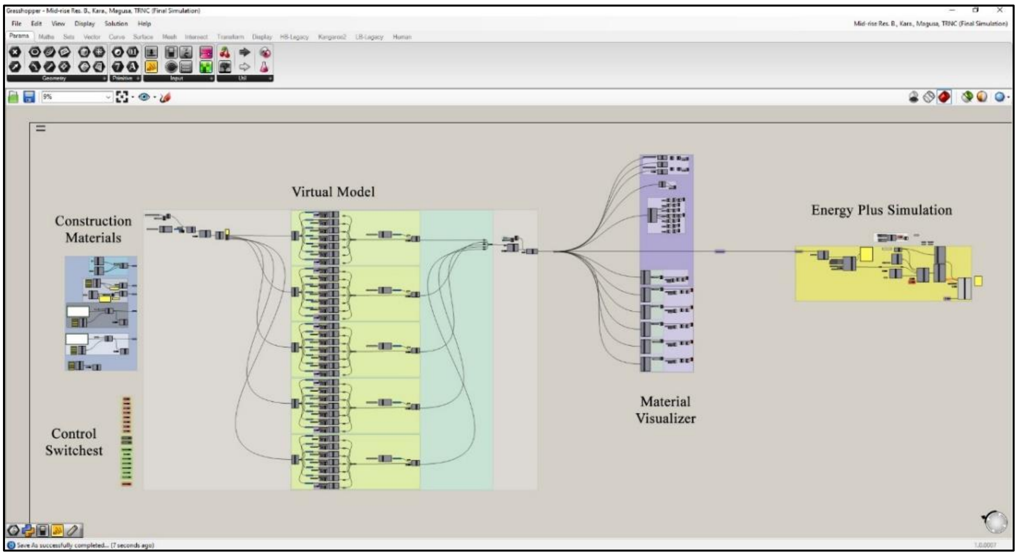


Figure 38: Window of Grasshopper showing the setup of the simulation (by Author)

Figure 39: Döveç Apartment 20 in Karakol district after green surface system integration (by Author).

Due to Grasshopper’s generative algorithms designing the exact building would complicate the simulation, for that reason, a simple version of the building was generated while still retaining the correct dimensions of the existing building.

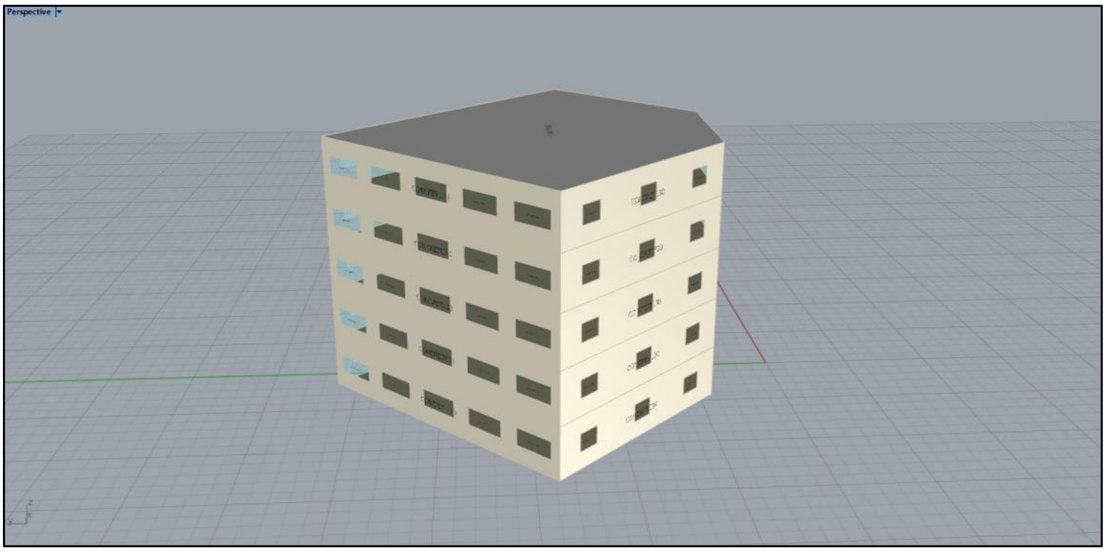

Figure 40: Virtual model of Döveç Apartment 20 generated by Grasshopper in Rhinoceros 3D (without Green Surface Systems) (by Author).

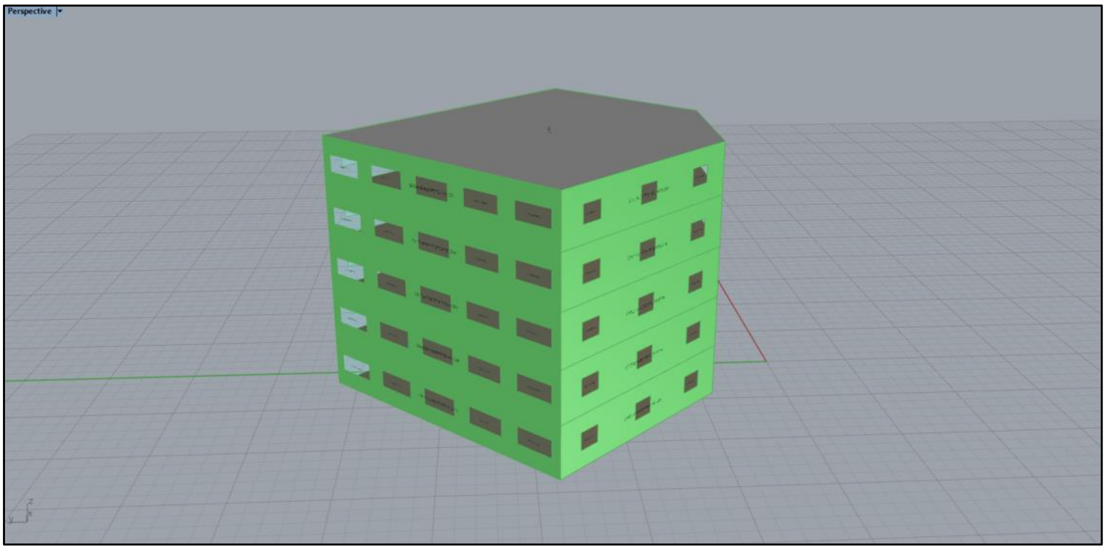

Figure 41: Virtual model of Döveç Apartment 20 generated by Grasshopper in Rhinoceros 3D (with Green Surface Sytems) (by Author).

### 4.2.2 EnergyPlus Materials & Constructions

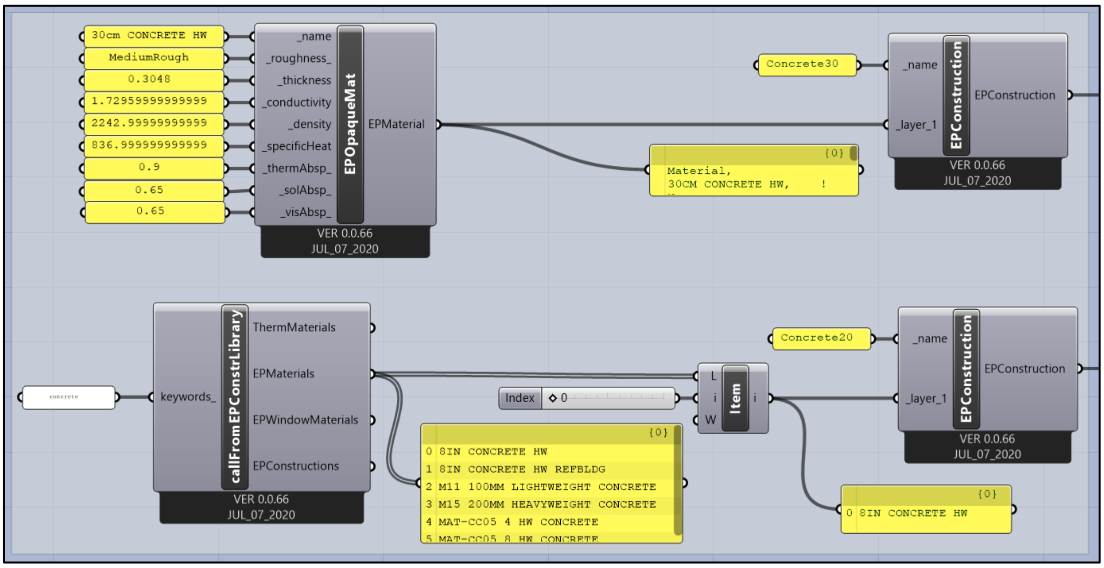


Figure 42: Wall EnergyPlus Constructions in Grasshopper (by Author).

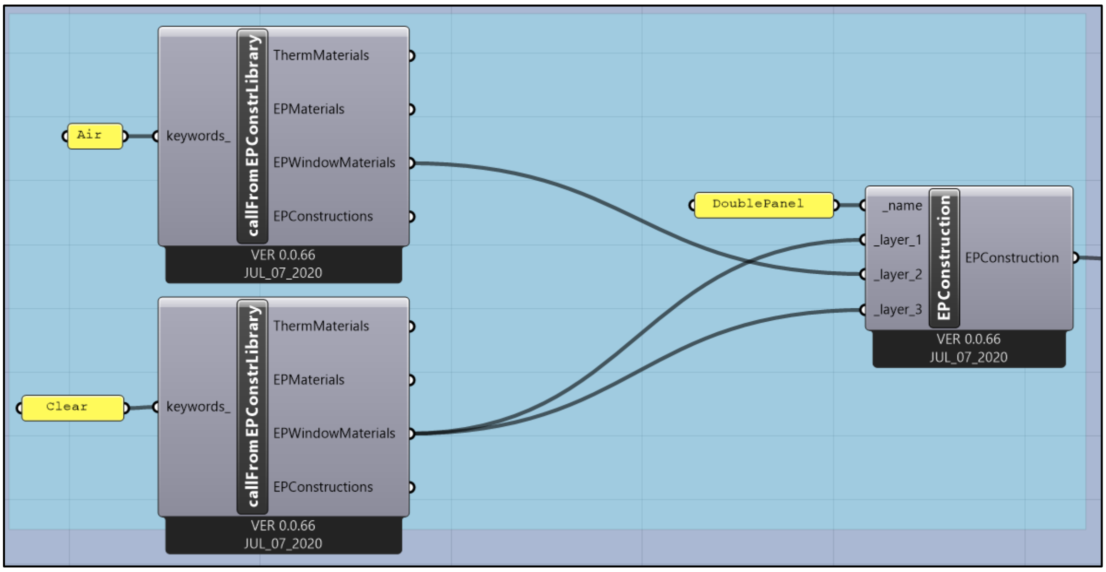

Figure 43: Double Panel Window EnergyPlus Construction input in Grasshopper (by Author).

The properties of this material have been prepared for green surface systems; it also demonstrates how to input any of the custom types of EnergyPlus materials into Honeybee to be run with an energy simulation (Figure 44 & Figure 45).

The green surface systems material properties in Grasshopper were inputted as 0.2 m for the height of the plants, a value of 1 for the (dimensionless) leaf area index, 0.22 for the (dimensionless) leaf reflectivity and 0.95 for the leaf emissivity with a minimum stomatal resistance of 180 s/m for the vegetation layer. As for the soil layer the roughness was medium rough, a thickness of 0.1 m, 0.35 W/m-K conductivity of dry soil, the density of the dry soil was 1100 kg/m3, with the specific heat of dry soil of 1200 J/kg-K, a rate of 0.9 for thermal absorptance, 0.7 for solar absorptance and 0.75 for visible absorptance, the Volumetric Moisture Content of the Soil Layer (VMCSL) had a value of 0.3 for saturation VMCSL, 0.01 for residual VMCSL and 0.1 for the initial VMCSL.

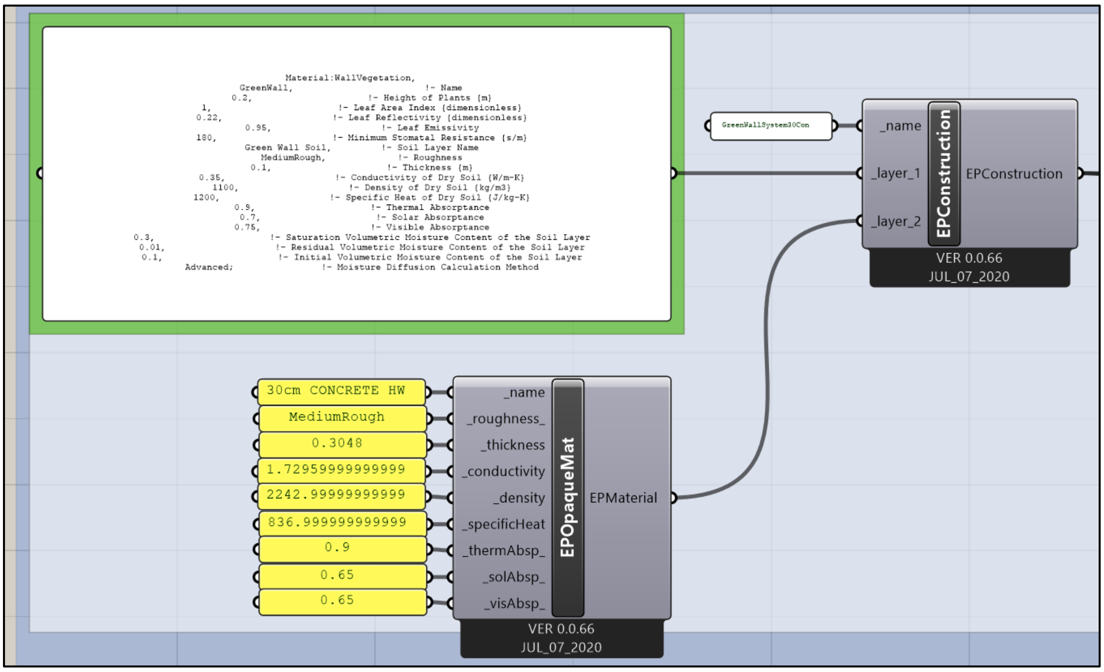


Figure 44: Modular Living Wall System EnergyPlus Construction in Grasshopper (by Author).

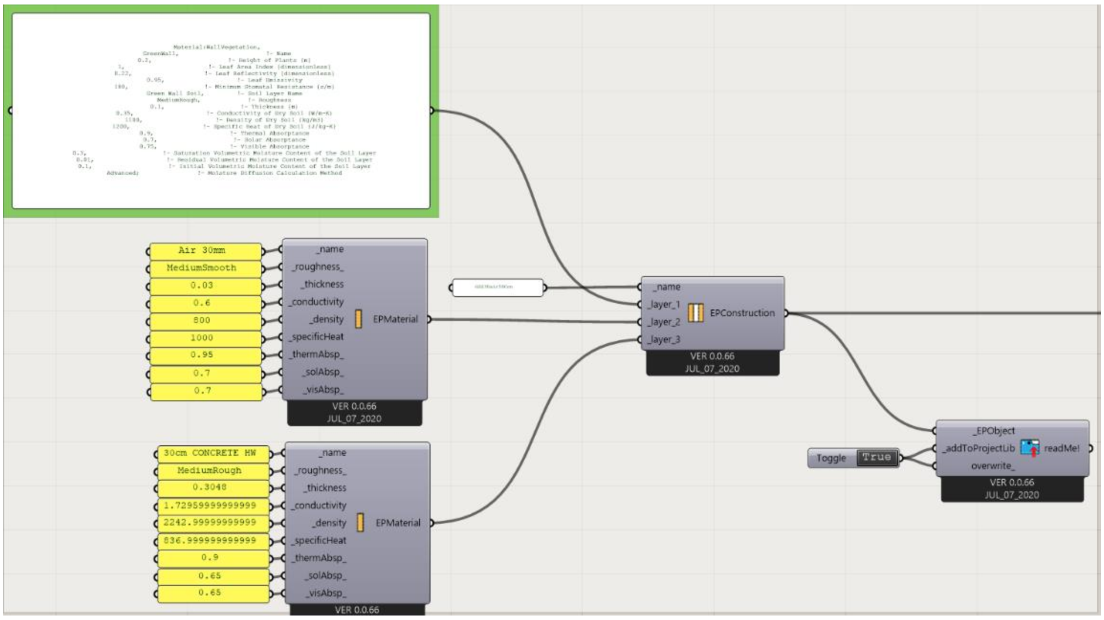


Figure 45: Indirect Green Facade System (with air gap) EnergyPlus Construction in Grasshopper (by Author).

## 4.3 Main Thermal Findings

The simulation was run three times, the first was to simulate the existing building before integrating green surface systems to serve as a control, whereas the second and third were to simulate the same existing building but after integrating green surface systems to the exterior walls. The simulations take into account the fact that the windows will be opened and closed throughout the day for natural ventilation, the windows will be opened when the indoor temperature is between 20 to 35 degrees Celsius (thermal comfort) and the outdoor temperature is between 15 and 30 degrees Celsius throughout the year. For the climate, the simulations use a weather data file that was collected from the ladybug's weather file database for Famagusta (Epwmap, n.d.).

The total thermal comfort percent with no wall insulation, AC nor HVAC (Heating, ventilation, and air conditioning) systems for floors 0, 1, 2, 3 and 4 were about 35.6%, 38%, 38.1%, 36.9% and 32.7% respectively, making the average total thermal comfort percent around 35.8% throughout the whole year. After integrating modular living walls to all the exterior walls of the building, the percentages of floors 0, 1, 2, 3 and 4 were about 37.3%, 50.3%, 54.5%, 48.1% and 36.9% respectively, which averages to about 45%, and after integrating indirect green facades, the percentages of floors 0, 1, 2, 3 and 4 were about 37.1%, 49.5%, 54.2%, 47.7% and 36.7% respectively, which averages to about 45.1%, which is a 25.7% increase in the thermal comfort felt by the users of the building.

### 4.3.1 Simulation 1

In simulation 1 the building was originally oriented to intercardinal directions, the analysis period was from the 1st of January at hour 1:00 to the 31st of December at hour 24:00. The following two figures are the results of the simulation (Figure 46,Figure 47).

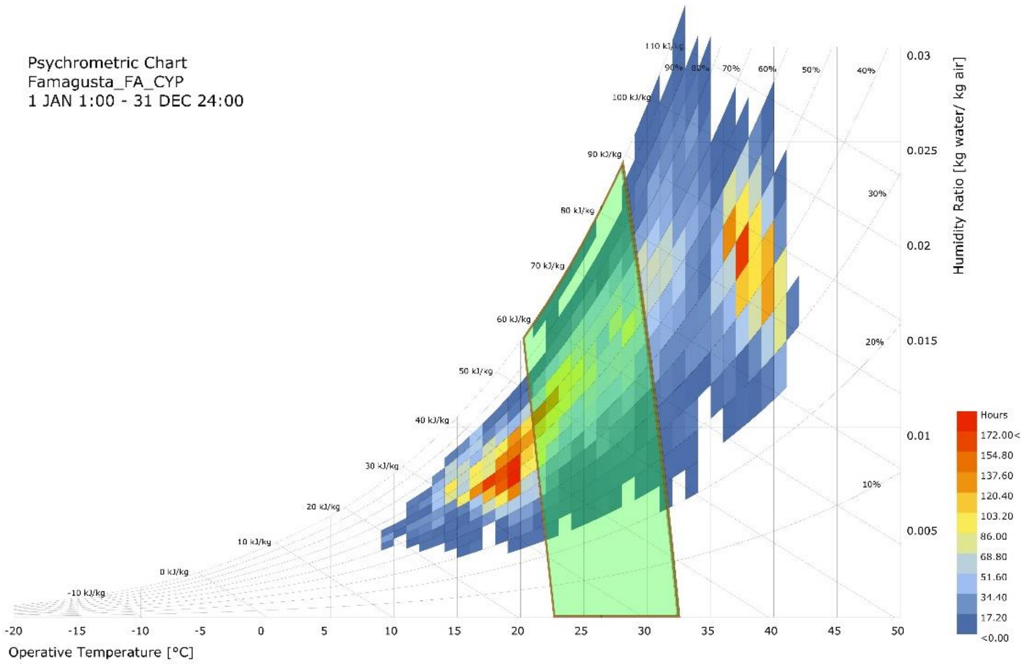


Figure 46: EnergyPlus psychrometric chart showing the annual comfort zone for simulation 1.

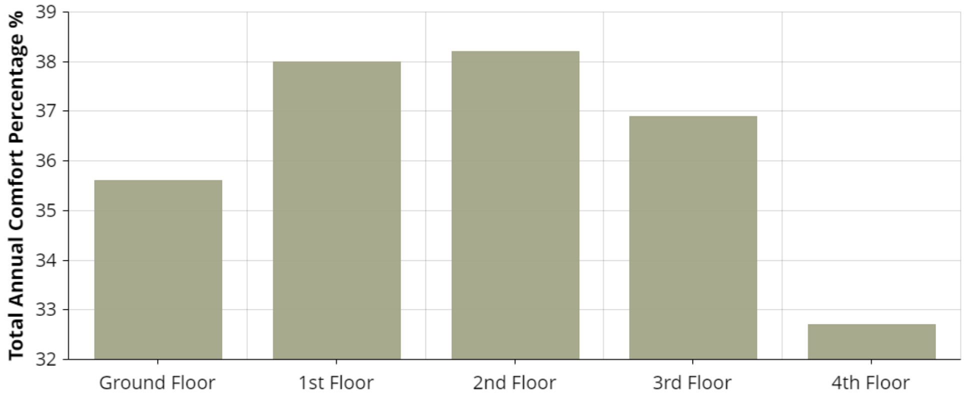


Figure 47: EnergyPlus, simulation 1 results showing total annual comfort percentages for each floor.

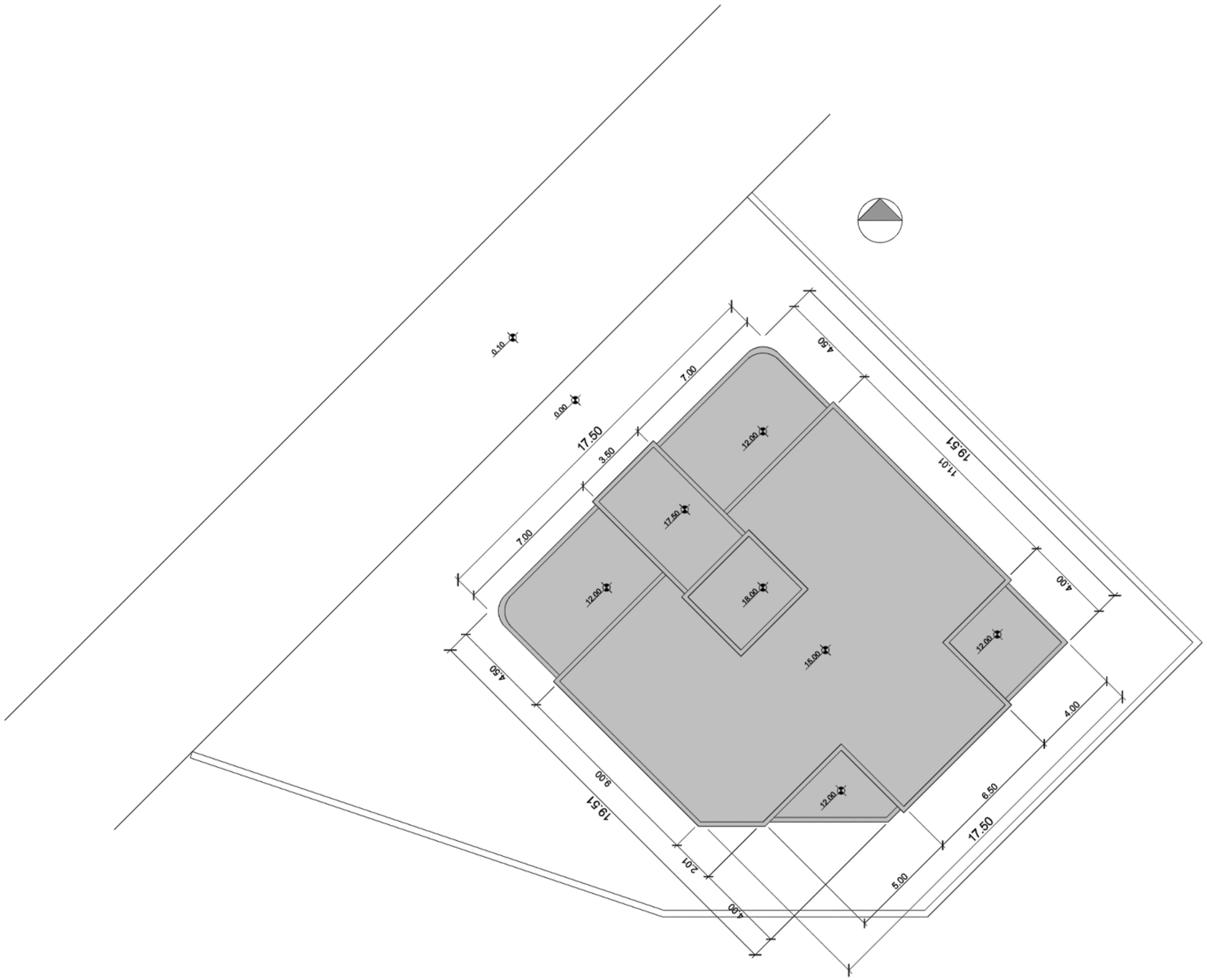

Figure 48: Building orientation in Karakol, Famagusta with no green surface system (by Author).

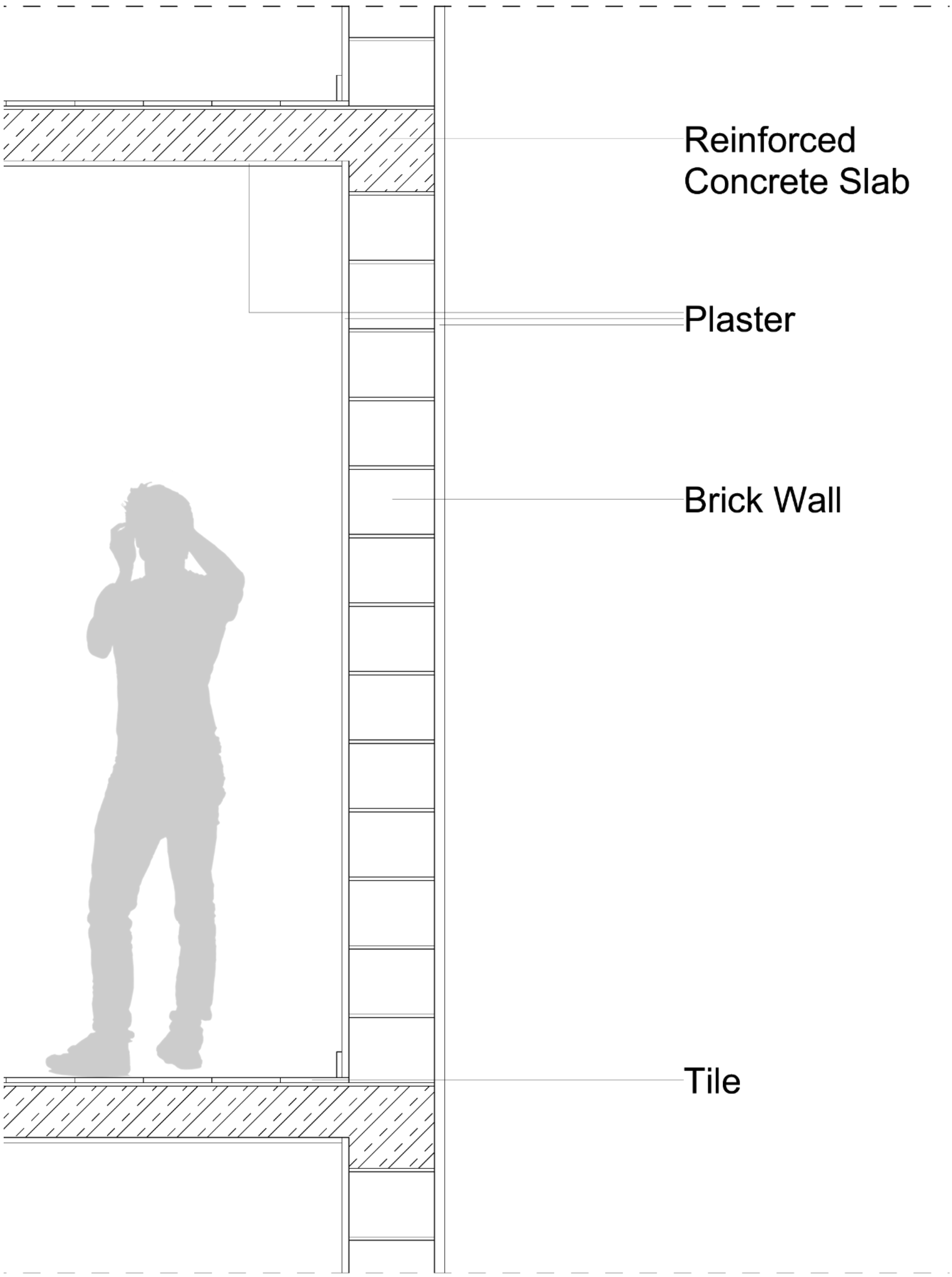


Figure 49: Wall Detail with no green surface system (by Author).

### 4.3.2 Simulation 2

Simulation 2 follows all factors of simulation 1 with green walls integrated, analysis period was from the 1st of January at hour 1:00 to the 31st of December at hour 24:00. The following two figures are the results of the simulation (Figure 50Figure 51).

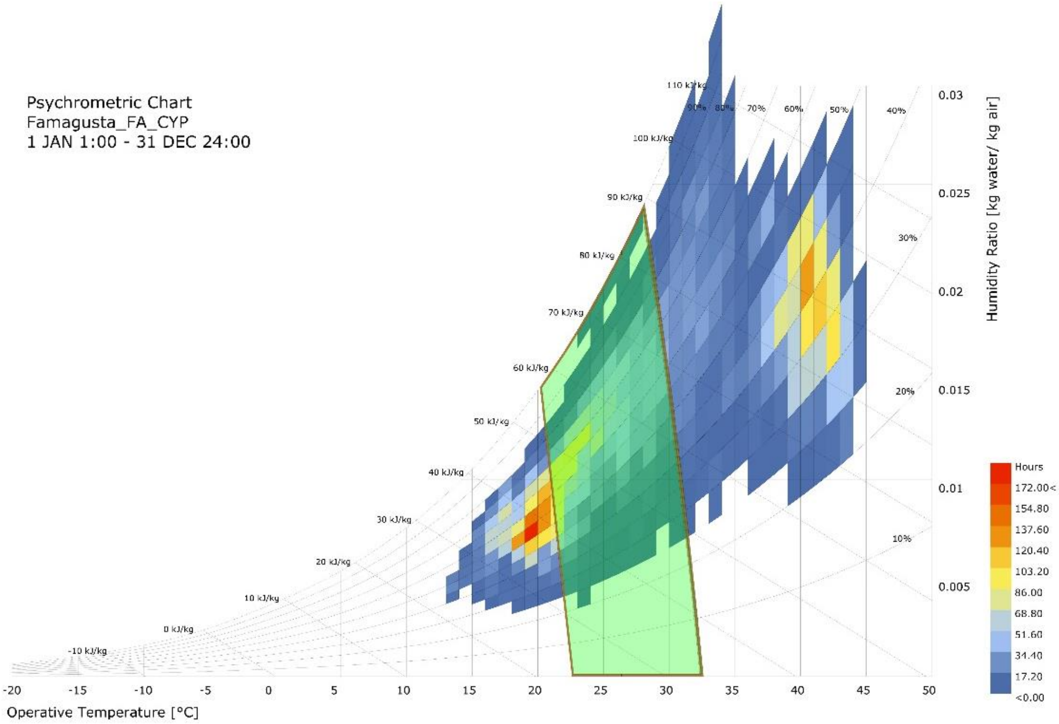


Figure 50: EnergyPlus psychrometric chart showing the annual comfort zone for simulation 2.

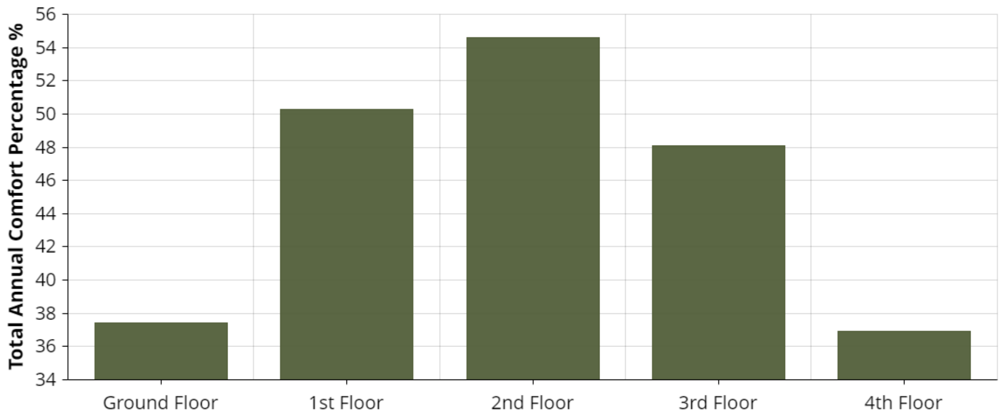


Figure 51: EnergyPlus, simulation 2 results showing total annual comfort percentages for each floor.

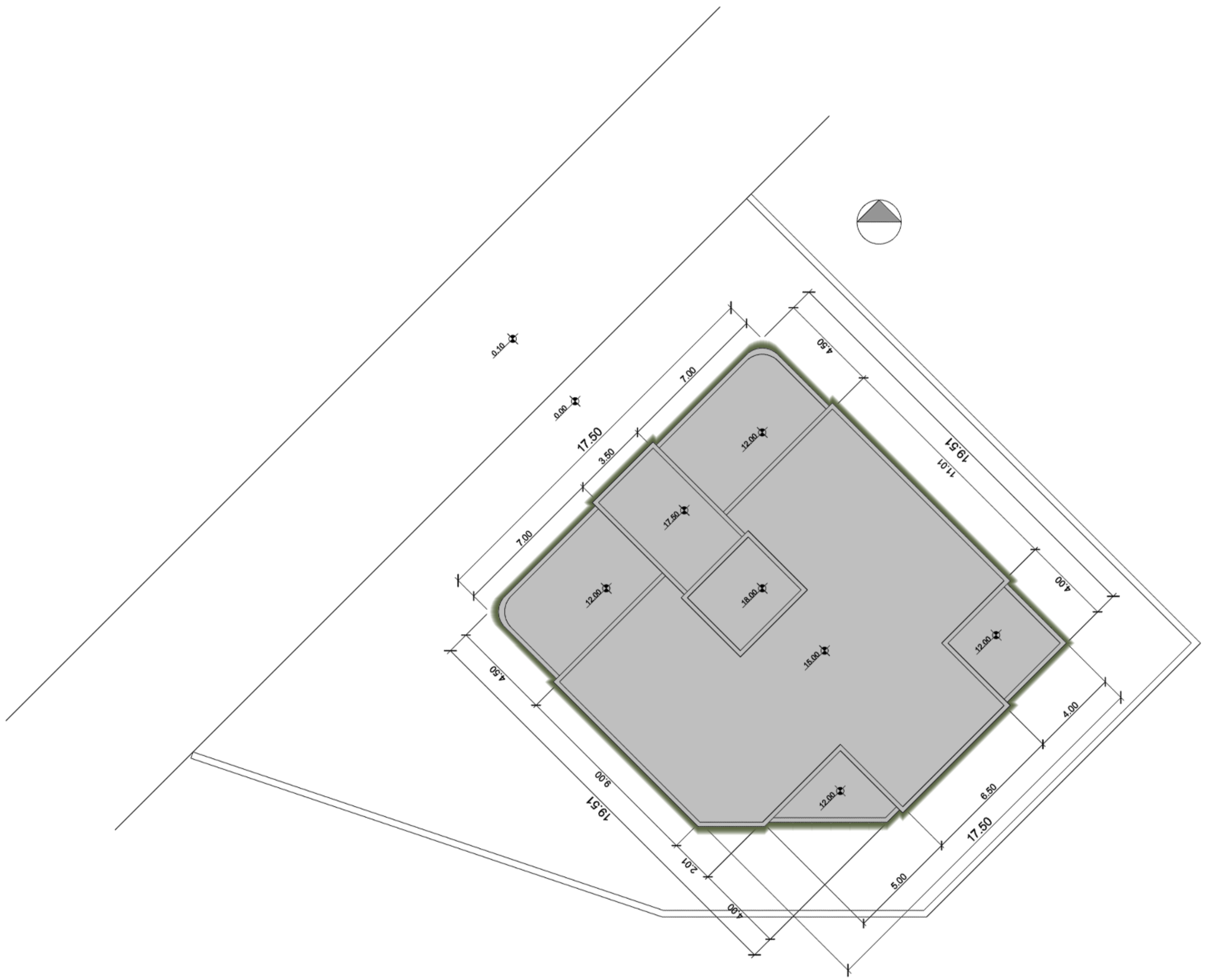


Figure 52: Building orientation in Karakol, Famagusta with modular living wall system (by Author).

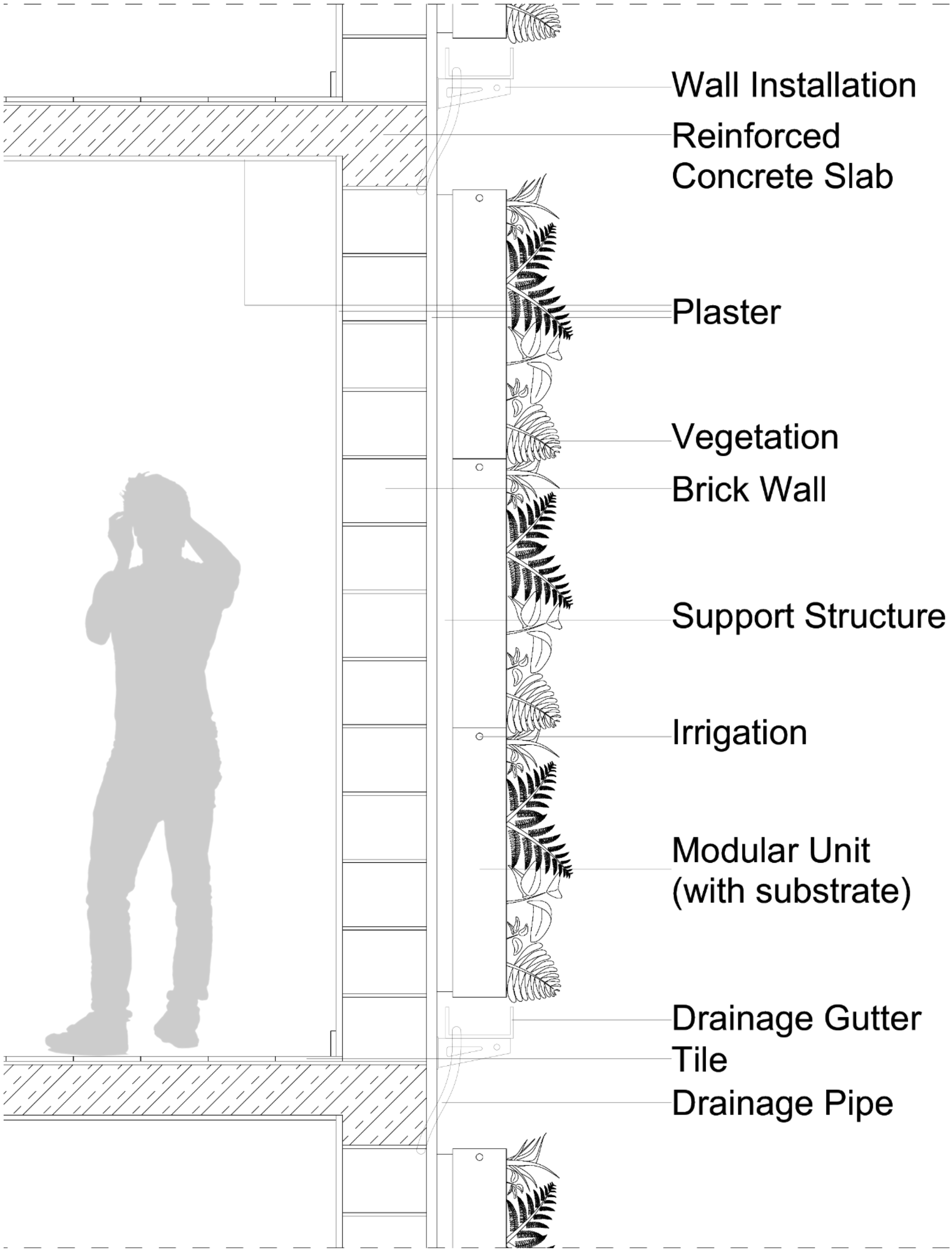


Figure 53: Wall Detail with modular living wall system (by Author).

### 4.3.3 Simulation 3

Simulation 3 follows all factors of simulation 1 with green facades systems integrated, analysis period was from the 1st of January at hour 1:00 to the 31st of December at hour 24:00. The following two figures are the results of the simulation (Figure 54Figure 55).

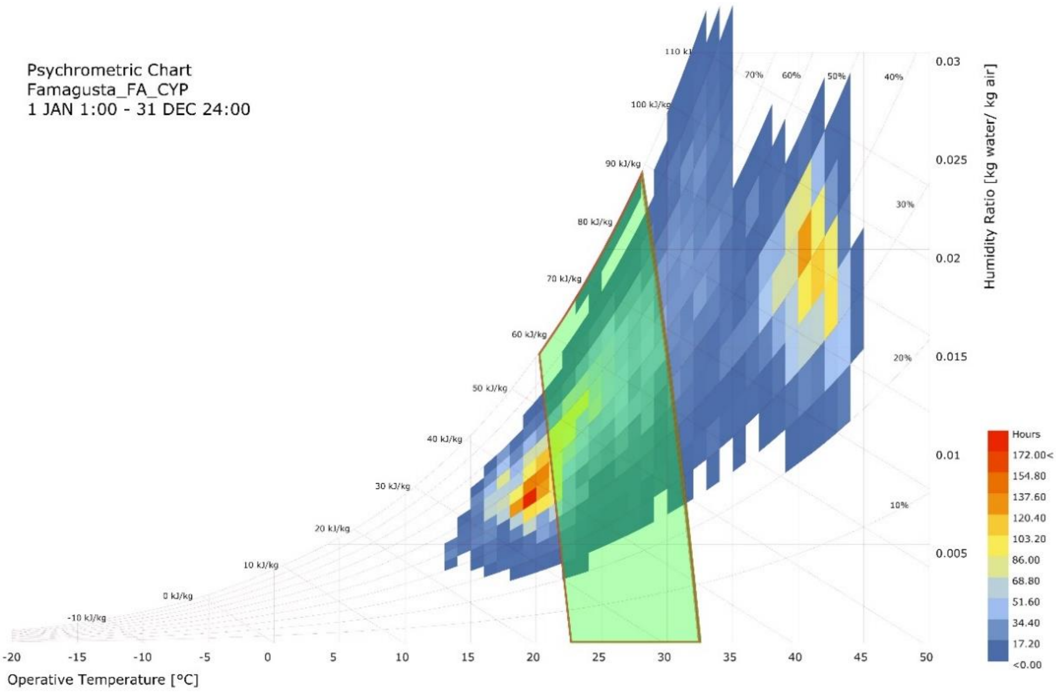


Figure 54: EnergyPlus psychrometric chart showing the annual comfort zone for simulation 3.

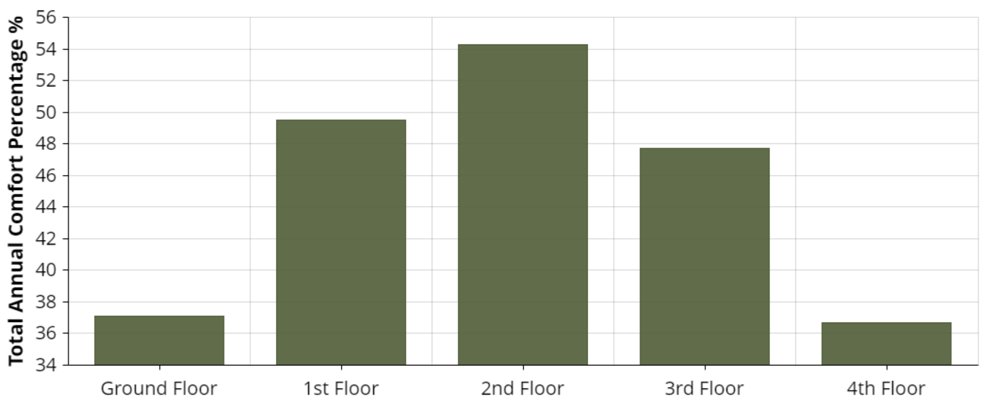


Figure 55: EnergyPlus, simulation 3 results showing total annual comfort percentages for each floor.

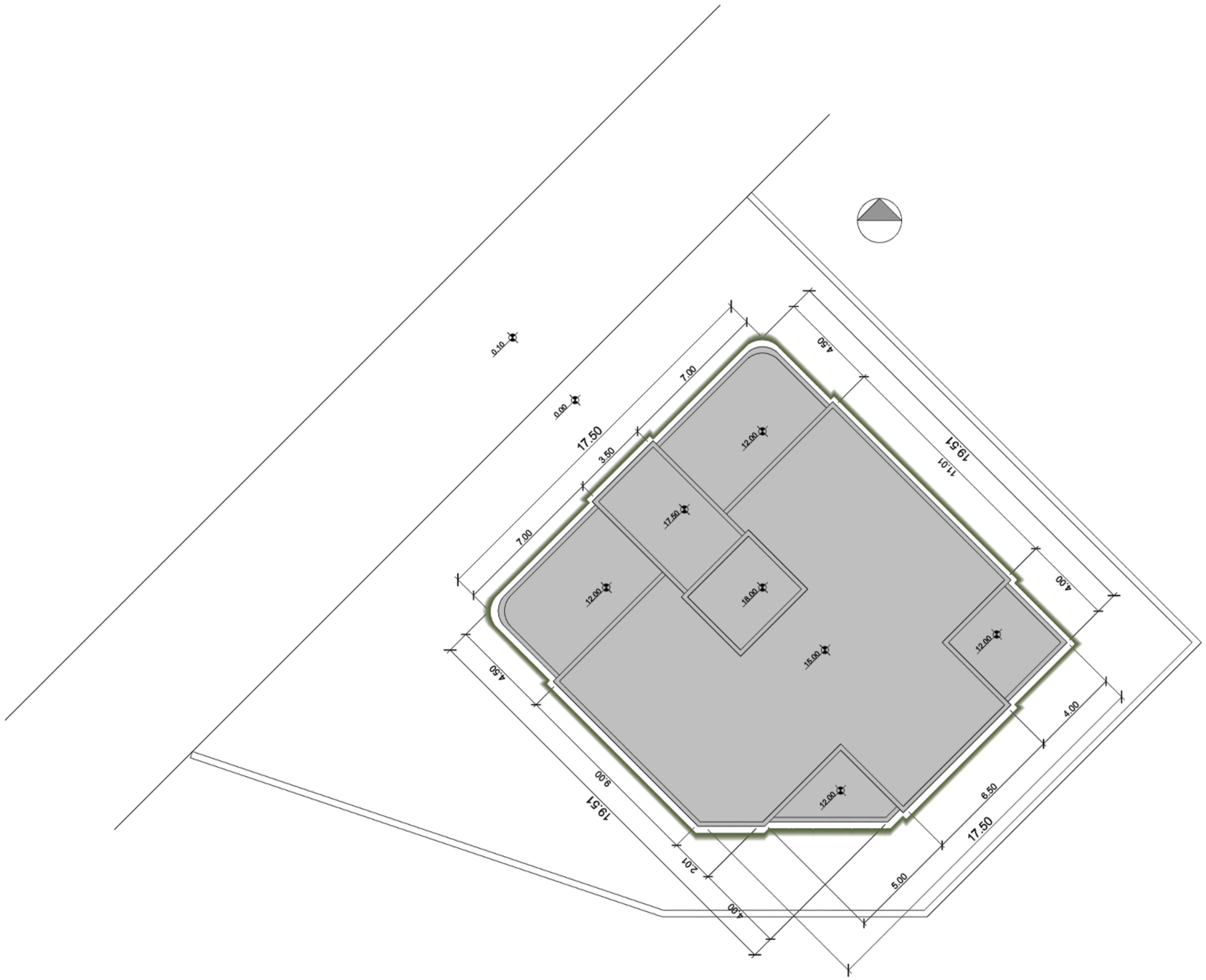


Figure 56: Building orientation in Karakol, Famagusta with indirect green facade system (by Author).

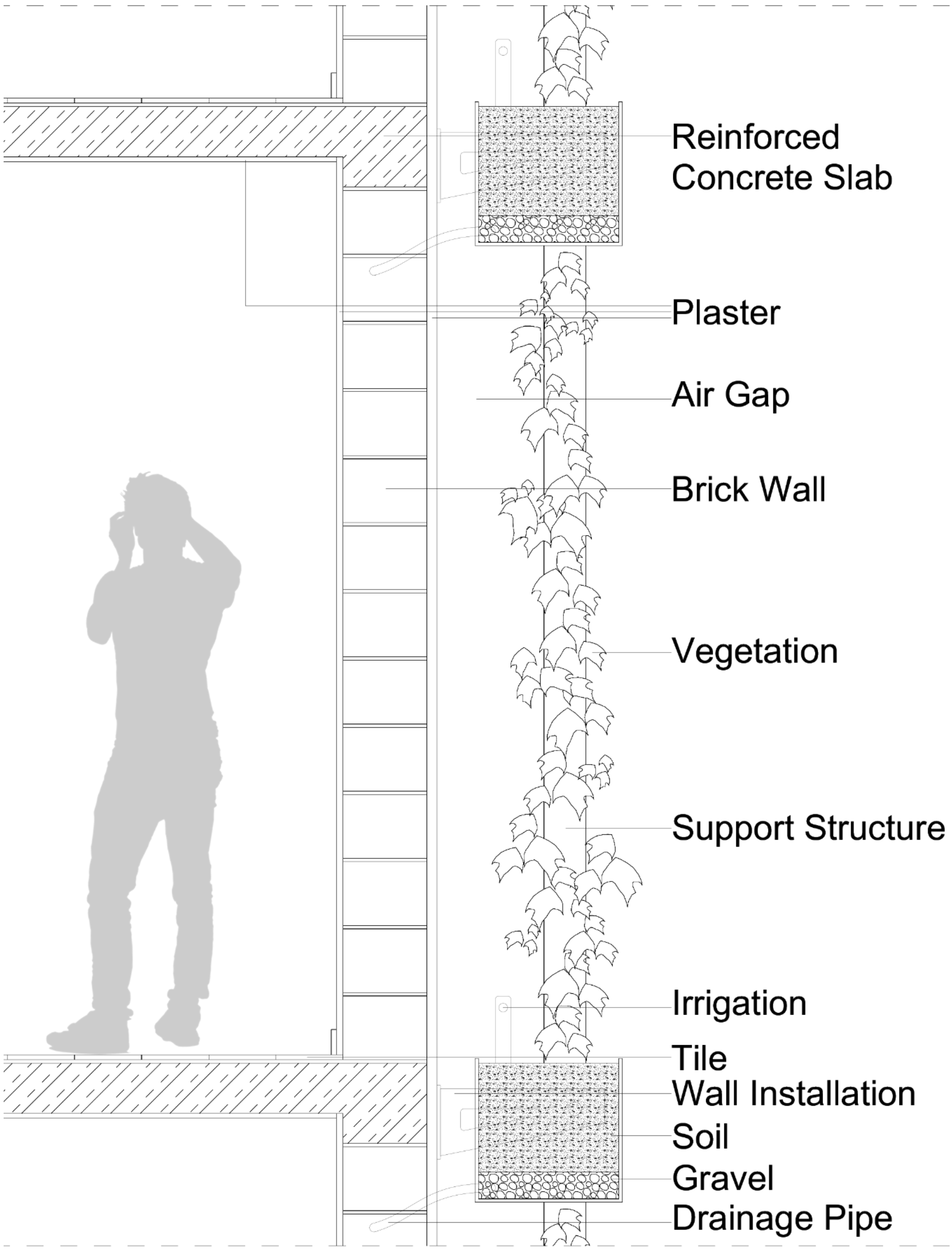


Figure 57: Wall Detail with indirect green facade system (by Author).

### 4.3.4 Simulation Result Comparison

In simulation 1 where the building was oriented to the intercardinal directions with no green surface systems integrated the total thermal comfort zone of the building throughout the year was around 35.8%, which tells us that the users of that building only are thermally comfortable for about 35.8% of the year, where in simulation 2 after integrating modular living wall systems to all exterior walls of the building the annual total thermal comfort zone increased to around 45%, and similarly simulation 3 after integrating indirect green facade systems the annual total thermal comfort zone increased to around 45.1%, meaning that after integrating green surface systems the users of the building were more thermally comfortable because they experienced comfortable temperatures for about 45% of the year.

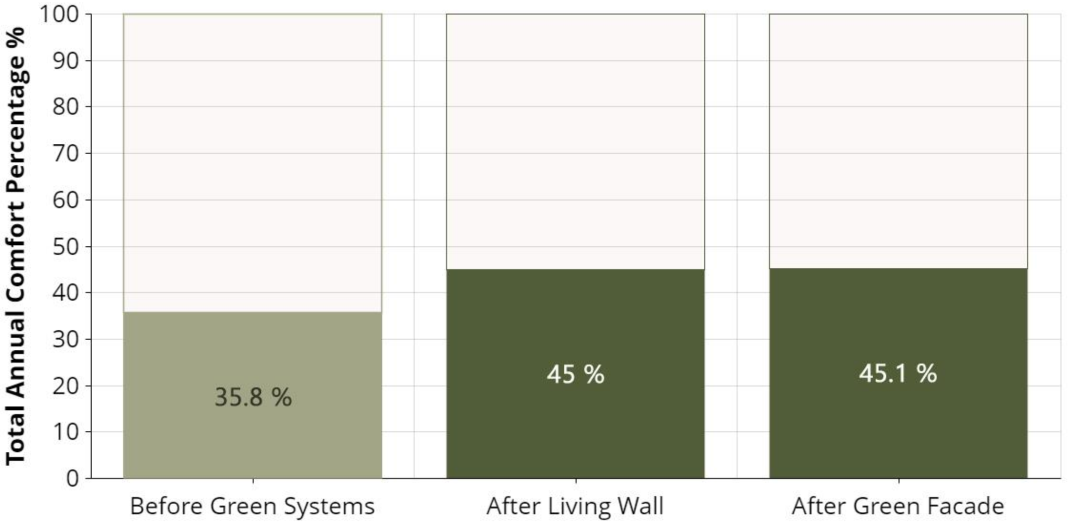


Figure 58: Comparison of total annual thermal comfort percentages before and after the integration of green surface systems (GSS).

As shown in the figure above the average total thermal comfort percent of Döveç Apartment 20 Building with no wall insulation, AC nor HVAC (Heating, ventilation, and air conditioning) systems was around 35.8% throughout the whole year. After integrating green surface systems to all the exterior walls of the building the average was about 45% and 45.1%, which is a 25.7% increase in the thermal comfort felt by the users of the building.

## 4.4 Summary

The simulation is done with the use of Ladybug and Honeybee in Grasshopper, a plugin of Rhinoceros 3D, running with EnergyPlus, it allows us to simulate the indoor thermal levels of a residential building in North Cyprus by creating a virtual energy model of the building. With this simulation, we are able to predict the effects of integrating a green surface system to the exterior walls of the building. The simulation was run three times, the first was to simulate the existing building before integrating green surface systems to serve as a control, whereas the second (Modular Living Wall System) and third (Indirect Green Facade system) were to simulate the same existing building but after integrating green surface systems to the exterior walls. The simulations take into account the fact that the windows will be opened and closed throughout the day for natural ventilation, the windows will be opened when the indoor temperature is between 20 to 35 degrees Celsius (thermal comfort) and the outdoor temperature is between 15 and 30 degrees Celsius throughout the year. For the climate, the simulations use a weather data file that was collected from the ladybug's weather file database for Famagusta. The average total thermal comfort percent of Döveç Apartment 20 Building with no wall insulation, AC nor HVAC (Heating, ventilation, and air conditioning) systems was around 35.8% throughout the whole year. After integrating green surface systems to all the exterior walls of the building the average was about 45% and 45.1%, which is a 25.7% increase in the thermal comfort felt by the users of the building.

The following table shows the final total average percentages of thermal comfort throughout the entire year for the whole building:

Table 2: Total thermal comfort percentages throughout the year.

| | Total thermal comfort percentage |
|---|---|
| Before integrating Green Surface Systems | 35.8 % |
| After integrating Living Wall System | 45 % |
| After integrating Green Facade System | 45.1 % |

# Chapter 5

# CONCLUSION

## 5.1 Implications

The purpose of this thesis was to find if green surface systems would help increase the internal thermal comfort of mid-rise residential buildings in Karakol district of Famagusta, North Cyprus to help future architects and building designers create more green spaces in North Cyprus and to increase the number of eco-friendly green buildings in Famagusta both for tourism and living purposes. The thesis recorded factors from an existing building, Döveç Apartment 20 Building which is the case study of this thesis, and the local environment to simulate what would happen if green surface systems were integrated to a mid-rise residential building in Karakol district of Famagusta, North Cyprus. To achieve the goal of this study the EnergyPlus component in Grasshopper was run inside Rhinoceros 3D using Ladybug and Honeybee. In the course of the study, the simulation was run three times and gave thermal results of what the annual total thermal comfort percentages were before and after integrating green surface systems to the exterior walls of building.

In conclusion adding green surface systems to exterior facades of a building would increase the time spent in the thermal comfort zone of a building, as the green surface systems would act as a thermal insulator for the building because the UV rays from the sun are either absorbed and used in the vegetation for photosynthesis or reflected back off the plant foliage. Resulting in a decrease energy consumption of thermal regulating systems due to less usage of those thermal regulating systems by the users throughout the year.

In doing so working towards our goal of increasing local vegetation and green spaces would slowly be achieved, which would help the mental health of the users of the buildings as vegetation provides spiritual and cultural experiences to some people, and the foliage would help maintain the exterior walls of the building, by increasing the square meters of local vegetation covering facades and surfaces around Karakol district in Famagusta of North Cyprus.

## 5.2 Recommendations

Future researchers could evaluate the economic benefits of integrating green surface systems to the exterior facade of buildings. In finding the costs of the integration of green surface systems future architects and building designers could easily evaluate the feasibility and the affordability of green surface systems as a means of saving energy as well as finances. Additionally, researchers could look into the acoustic benefits of integrating green surface systems, as it would likely increase noise insulation due to the foliage of the plants covering the facades. The ever-growing industry of mankind does provide to the society, but at the cost of pollutants especially in the form of noise. Unwanted sounds could create negative work environment for office buildings and discomfort for elder users with sensitive hearing or younger users in their academic terms. Researchers could also create a survey to understand the psychological benefits that vegetation would provide to users who would enjoy being around vegetation as it provides a sense of calm and relaxation. Vegetation provides a healthier and happier environment for user and helps increase positive mental health due to nature and plants being another source of life the users could connect spiritually and mentally.

# REFERENCES

Abdo, P., Huynh, B. P., Avakian, V., Nguyen, T., Gammon, J., Torpy, F. R., & Irga, P. J. (2016). Measurement of air flow through a green-wall module.

About the Uk's Leading Living Wall Company - Biotecture. (n.d.). Retrieved January 21, 2022, from https://www.biotecture.uk.com/about-us/

Al-Kayiem, H. H. (n.d.). Greenery Systems.

Blanc, P. (2015). The Vertical Garden: From Nature to the City. W.W. Norton, 2012.

Collins, R., Schaafsma, M., & Hudson, M. D. (2017). The value of green walls to urban biodiversity. Land Use Policy, 64, 114–123. https://doi.org/10.1016/j.landusepol.2017.02.025

de Jesus, M. P., Lourenço, J. M., Arce, R. M., & Macias, M. (2017, July 1). Green façades and in situ measurements of outdoor building thermal behaviour. Building and Environment. Elsevier Ltd. https://doi.org/10.1016/j.buildenv.2017.03.041

Djongyang, N., Tchinda, R., & Njomo, D. (2010). Thermal comfort: A review paper. Renewable and Sustainable Energy Reviews. Elsevier Ltd. https://doi.org/10.1016/j.rser.2010.07.040

Döveç Construction - Döveç. (n.d.). Retrieved January 20, 2022, from https://dovecconstruction.com/en/dovec-construction/

Elgizawy, E. M. (2016). The Effect of Green Facades in Landscape Ecology. Procedia Environmental Sciences, 34, 119–130. https://doi.org/10.1016/j.proenv.2016.04.012

Elsadek, M., Liu, B., & Lian, Z. (2019). Green façades: Their contribution to stress recovery and well-being in high-density cities. Urban Forestry and Urban Greening, 46. https://doi.org/10.1016/j.ufug.2019.126446


Elsadek, M., Liu, B., & Lian, Z. (2019). Green façades: Their contribution to stress recovery and well-being in high-density cities. Urban Forestry and Urban Greening, 46. https://doi.org/10.1016/j.ufug.2019.126446

EnergyPlus. (n.d.). Retrieved January 20, 2022, from https://energyplus.net/

epwmap. (n.d.). Retrieved January 22, 2022, from https://www.ladybug.tools/epwmap/

Famagusta Climate, Weather By Month, Average Temperature (Cyprus) - Weather Spark. (n.d.). Retrieved January 20, 2022, from https://weatherspark.com/y/97693/Average-Weather-in-Famagusta-Cyprus-Year-Round

Galagoda, R. U., Jayasinghe, G. Y., Halwatura, R. U., & Rupasinghe, H. T. (2018). The impact of urban green infrastructure as a sustainable approach towards tropical micro-climatic changes and human thermal comfort. Urban Forestry and Urban Greening, 34, 1–9. https://doi.org/10.1016/j.ufug.2018.05.008

Getter, K. L., & Rowe, D. B. (2006). The Role of Extensive Green Roofs in Sustainable Development. HORTSCIENCE (Vol. 41).

Google Earth. (n.d.). Retrieved January 20, 2022, from https://earth.google.com/web/@35.1340101,33.9275164,11.57816814a,1575.26956852d,35y,360h,0t,0r

Grasshopper - algorithmic modeling for Rhino. (n.d.). Retrieved January 18, 2022, from https://www.grasshopper3d.com/

Green Wall Specification and Drawings - Biotecture. (n.d.). Retrieved January 22, 2022, from https://www.biotecture.uk.com/design-and-specify/specifications-and-compliance/specifications-and-drawings/

Grimshaw-Surette, H. (2016). A Comparison of Native and Novel Ecosystems: Green Roof Impacts on Plant Growth and Pest Abundance.

Hydra - Sharing made easy! (n.d.). Retrieved January 22, 2022, from https://hydrashare.github.io/hydra/index.html

Isnard, S., & Silk, W. K. (2009, July). Moving with climbing plants from Charles Darwin's time into the 21st century. American Journal of Botany. https://doi.org/10.3732/ajb.0900045

Jim, C. Y., & Tsang, S. W. (2011). Ecological energetics of tropical intensive green roof. Energy and Buildings, 43(10), 2696–2704. https://doi.org/10.1016/j.enbuild.2011.06.018

Kazemi, F., Rabbani, M., & Jozay, M. (2020). Investigating the plant and air-quality performances of an internal green wall system under hydroponic conditions. Journal of Environmental Management, 275. https://doi.org/10.1016/j.jenvman.2020.111230

Ladybug Tools | Honeybee. (n.d.). Retrieved January 20, 2022, from https://www.ladybug.tools/honeybee.html

Ladybug Tools | Ladybug. (n.d.). Retrieved January 20, 2022, from https://www.ladybug.tools/ladybug.html

Manso, M., & Castro-Gomes, J. (2015). Green wall systems: A review of their characteristics. Renewable and Sustainable Energy Reviews. Elsevier Ltd. https://doi.org/10.1016/j.rser.2014.07.203

Manso, M., Castro-Gomes, J., Paulo, B., Bentes, I., & Teixeira, C. A. (2018). Life cycle analysis of a new modular greening system. Science of the Total Environment, 627, 1146–1153. https://doi.org/10.1016/j.scitotenv.2018.01.198

Manso, M., Teotónio, I., Silva, C. M., & Cruz, C. O. (2021, January 1). Green roof and green wall benefits and costs: A review of the quantitative evidence. Renewable and Sustainable Energy Reviews. Elsevier Ltd. https://doi.org/10.1016/j.rser.2020.110111

Parhizkar, H., Khoraskani, R. A., & Tahbaz, M. (n.d.). Green façade system for indoor air purification.

Peng, L. L. H., Jiang, Z., Yang, X., Wang, Q., He, Y., & Chen, S. S. (2020). Energy savings of block-scale facade greening for different urban forms. Applied Energy, 279. https://doi.org/10.1016/j.apenergy.2020.115844

Pérez, G., Rincón, L., Vila, A., González, J. M., & Cabeza, L. F. (2011). Behaviour of green facades in Mediterranean Continental climate. Energy Conversion and Management, 52(4), 1861–1867. https://doi.org/10.1016/j.enconman.2010.11.008

Pérez, G., Coma, J., Barreneche, C., De Gracia, A., Urrestarazu, M., Burés, S., & Cabeza, L. F. (2016). Acoustic insulation capacity of Vertical Greenery Systems for buildings. Applied Acoustics, 110, 218–226. https://doi.org/10.1016/j.apacoust.2016.03.040

Pérez, G., Coma, J., Sol, S., & Cabeza, L. F. (2017). Green facade for energy savings in buildings: The influence of leaf area index and facade orientation on the shadow effect. Applied Energy, 187, 424–437. https://doi.org/10.1016/j.apenergy.2016.11.055

Perini, K., & Rosasco, P. (2013). Cost-benefit analysis for green façades and living wall systems. Building and Environment, 70, 110–121. https://doi.org/10.1016/j.buildenv.2013.08.012

Preserved greenery como. (n.d.). Retrieved February 8, 2022, from http://marlosrl.it/en/

Rahbarianyazd, R., & Raswol, L. (2018). Evaluating energy consumption in terms of climatic factors: A case study of Karakol residential apartments, Famagusta, North Cyprus. Journal of Contemporary Urban Affairs, 2(1), 45–54. https://doi.org/10.25034/ijcua.2018.3658

Rakhshandehroo, M., Mohd Yusof, M. J., & Deghati Najd, M. (2015). Green Façade (Vertical Greening): Benefits and Threats. Applied Mechanics and Materials, 747, 12–15. https://doi.org/10.4028/www.scientific.net/amm.747.12

Rhino - About McNeel. (n.d.). Retrieved January 18, 2022, from https://www.rhino3d.com/mcneel/about/

Roaf, S., Brotas, L., & Nicol, F. (2015, May 4). Counting the costs of comfort. Building Research and Information. Routledge. https://doi.org/10.1080/09613218.2014.998948

Safikhani, T., Abdullah, A. M., Ossen, D. R., & Baharvand, M. (2014). Thermal impacts of vertical greenery systems. Environmental and Climate Technologies, 14(1), 5–11. https://doi.org/10.1515/rtuect-2014-0007

Steinbrecher, T., Danninger, E., Harder, D., Speck, T., Kraft, O., & Schwaiger, R. (2010). Quantifying the attachment strength of climbing plants: A new approach. Acta Biomaterialia, 6(4), 1497–1504. https://doi.org/10.1016/j.actbio.2009.10.003

Sulaiman1, M. K. A. M., Jamil1, M., Zain1, M. F. M., Kuttler2, W., & Shahidan3, M. F. (2013). SusTED'13) Faculty of Design & Architecture. 43400 UPM Serdang.

Tarboush, O. (2019). LIVING WALLS AND GREEN FACADES: A STUDY IN NICOSIA A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY.

Tzortzi -julia Georgi, N., & Sophocleous, J. (n.d.). The Green Wall as sustainable tool in Mediterranean cities: The case study of Limassol, Cyprus. Retrieved from http://www.nup.ac.cy

Uzuhariah Abdullah, A., Ossen, D., & Sadeghian, M. M. (2016). A Review on Green Wall, Classification and Function Related papers Vert ical Greenery Syst ems (VGS) for energy saving in buildings: A review Julià Coma, Ingrid Mart orell T he Int egrat ion of Veget at ion in Archit ect ure, Vert ical and Horizont al Greened Surfaces Adriano Magliocco A review of energy charact erist ic of vert ical greenery syst ems A Review on Green Wall, Classification and Function. Retrieved from www.ijsrst.com

Vacek, P., Struhala, K., & Matějka, L. (2017). Life-cycle study on semi intensive green roofs. Journal of Cleaner Production, 154, 203–213. https://doi.org/10.1016/j.jclepro.2017.03.188

Vijayaraghavan, K. (2016, May 1). Green roofs: A critical review on the role of components, benefits, limitations and trends. Renewable and Sustainable Energy Reviews. Elsevier Ltd. https://doi.org/10.1016/j.rser.2015.12.119

Zarandi, M. M. (2018). A comparative study on details of green walls in different climates. Pourmousa / Environmental Resources Research (Vol. 6).