DIPLOMARBEIT

Green facades: Evaluation, impact, advantages, disadvantages and potential in a humid subtropical climate zone – Burgas, Bulgaria

unter der Leitung von

Univ.-Prof. Dipl.-Ing. Dr. techn. Ardeshir Mahdavi

E 259-3 Abteilung für Bauphysik und Bauökologie

Institut für Architekturwissenschaften

eingereicht an der

Technischen Universität Wien

Fakultät für Architektur und Raumplanung

von

Kosta Varbanov

Matrikelnr.1228010

kosta.varbanov@gmail.com

Wien, April 2019

ACKNOWLEDGEMENTS

The work on this master thesis would not have been done without the help and support of colleagues, friends, family members, and professors and assistants of the Department of Building Physics and Building Ecology.

I am especially grateful for the support and advice of my supervisor, Professor Ardeshir Mahdavi, for his assistance during all levels of this work and for knowledge that I gained thanks to his lectures throughout my master studies.

Additionally, I would like to thank Kristina Kiesel for her suggestions and her valuable support through this work. She has helped me a lot by giving me feedback and guidelines via email – which is a lot harder and more time consuming than face to face meeting. Also I would like to thank Matthias Schuss for all the help and advices.

I would like to express my deep appreciation and thanks to Farhang Tahmasebi, Elena Batueva, Milica Tomazovic, Mirjana Bucevac, Hristiana Kirova, my brother Simeon Varbanov and many others for their support and guidance.

I would also like to say thank you to Rumen Stoimenoff (head director of the Siemens Building Technologies department) in Siemens Bulgaria and George Brashnarov and Vesselka Dancheva from Nemetschek Bulgaria for the great opportunities.

ZUSAMMENFASSUNG

Die Beeinflussung des Stadtklimas durch Begrünung, ist kein neuer Ansatz und bietet erhebliche Vorteile, vor allem für die dicht verbauten städtischen Umgebungen. Pflanzen in städtischen Gebieten haben einen positiven Einfluss auf die Luftqualität und das Mikroklima sowie den Lärmpegel. Darüber hinaus kann dadurch das Außen- und Innenklima von Gebäuden verbessert werden, Treibhausgase absorbiert und in manchen Fällen können auch die Pflanzen auch als lokale Produzenten von Lebensmittel fungieren. Für die Begrünung von dichte verbauten Gebieten gibt es verschiedenste Möglichkeiten. Der am meisten verbreitete Ansatz ist das Vorsehen von Parks und Gärten bereits in der Stadtplanung. Diese Grünflächen benötigen jedoch viel Platz welche in den existierenden Städten Mangelwaren sind. Gründächer und grüne Fassaden stellen somit eine interessante Alternativen dar. Um die Wirkung und Effizienz solcher Begrünungsmaßnahmen zu beurteilen leisten Performance-Studien einen entsprechenden Beitrag.

Die vorliegende Arbeit analysiert verfügbare Berechnungs- und Simulationsmodelle und deren Anwendung in Bezug auf eine Potenzialabschätzung von grüne Dächer und Fassaden an existierenden Gebäuden in einer feuchten subtropischen Zone – Burgas, Bulgarien.

In der Literatur gibt es zum diesem Thema zahlreiche Beiträge und umfangreiche Bemühungen um die Effekte von grünen Fassaden zu modellierten , jedoch veranschaulichte die Recherche auch das Fehlen von einfachen und leichtanwendbaren Simulationsmethoden speziell für die Beurteilung von grüne Fassaden bei Sanierungskonzepten. Ein wesentlicher Schwerpunkt der Arbeit ist die exemplarische Anwendung einer einfache und dennoch adäquate Abschätzung zur Beurteilung des Einflusses von grünen Fassaden auf die durch Transmissionsverluste verursachten Heiz- und Kühlbedarfsanteile von Wohngebäuden. Auf Basis dieser Werte wurden des weiteren Abschätzungen hinsichtlich der Kostenänderung für Kühlung und Heizung sowie der resultierenden CO_2-Emissionen gemacht .

Schlagwörter:

Grüne Fassaden, Energieeffizienz, Heizung, Kühlung, Simulationsmethoden, Konstruktionen, Wärmedämmung, Kosten, Wartung, Lebenszykluskosten, Energieeinwirkung.

ABSTRACT

Greening the cities is not a new approach, and there is a significant amount of benefits, especially for dense urban surroundings. Plants in urban areas can have a positive influence on the air quality and the microclimate as well as the noise level in cities. Furthermore, the indoor and outdoor thermal comfort can be improved, greenhouse gases can be absorbed and in some cases, fresh food can be provided to the residents. There are different ways of greening highly dense cities. The most common approach is to arrange parks and gardens within the city, but these green areas need a lot of space in a city center. Two greening ideas that do not imply any extra space usage are the green roofs and the green facades. In order to test the design and the effect of such structures, scientific studies and simulations are very useful.

The current contribution examined and analyzed available calculation and simulation models with regard to green facades. The literature research showed a lot of detailed modeling concepts but the absence of simple and applicable method for green facades with focus on the evaluation of retrofitting options. As a result a simple calculation method based on U-Values and heating and cooling degree days was suggested. Heating and cooling demands for a case study building and different façade cases were calculated. Additionally costs and, and CO2 emissions with respect to used building system were estimated. The results demonstrated that the transmissions losses can be reduced by the use of green facades.

Keywords

Green facades, energy performance, heating, cooling, commercial buildings, methods of simulation, constructions, thermal insulation, cost, maintenance, life cycle cost, energy impact.

CONTENTS

ABBREVIATIONS

ACH Air changes per hour

ECS Energy Community Secretariat

EP Energy Plus

EF Existing facade

GF Green facade

LAI Leaf area index

PUC Public utility company

RR Refurbished roof

WR White roof

XPS Extruded polystyrene

NOMENCLATURE

c Specific heat capacity [$J.kg^{-1}.K^{-1}$]

d Thickness [m]

l Length [m]

U Thermal transmittance value [$W.m^{2}.K^{-1}$]

T Temperature [°C]

λ Thermal conductivity [$W.m^{-1}.K^{-1}$]

ρ Density [kg/m^{3}]

1 INTRODUCTION

1.1 Overview

The growing concerns of CO_2 and other greenhouse gas emissions, and scarcity of fossil fuels has recently made the energy efficiency of buildings a major issue. Buildings worldwide account for a surprisingly high 40 % of the global energy consumption (Krarti, 2012; Krarti, 2011; Bribian et al., 2009). Researchers all around the world are searching for ways to improve sustainability of our built environment in different ways. Some of them are focusing greening concepts for urban areas in various ways, e.g. in green roof and facades.

The use of well-designed greening systems can be an expedient tool for thermal regulation for buildings with interest in energy saving. In addition, the same system can change and improve the microclimate around (Alexandri et al., 2006) and in the building by reducing urban background noise levels from automobile traffic, railways, air traffic, and remote industrial sources (Boer et al., 2007). It will improve the biodiversity of the built environment and help to improve air quality. The main question here is how effective might the system be and what is the cost of potential improvements and what will be the cost of that saving and improvement.

In this context, the present work focuses on the evaluation and the potential of green facades in the subtropical climate of Burgas, Bulgaria. The work is divided into two main parts:

- The state of the art on research in the field of green façades, their implementation and effects will be collected. Special emphasis will be given to the simulation an evaluation of green facades.
- Evaluation of application possibilities and potential of green facades in the region of Burgas. For this purpose a cost estimation for construction and maintenance and life cycle assessment will be applied. Furthermore, the effect of these constructions on the heating and cooling energy demand will be estimated and several different scenarios will be reviewed.

1.2 Motivation

In Bulgaria, the concept of green facade and roofs is not well established and they are not as popular as in Regions like Greece, Turkey, Italy, and Spain, with similar climatic conditions (GRADAT 2017). In those Areas, the application of green facades is much more developed. So far green facades have been used in Bulgaria only in a small scale mainly on domestic projects. There is only one public building with a green facade in the whole country, which was realized in Burgas in 2017. (GRADAT 2017).

This master thesis examines the potential of green facades in Burges, Bulgaria in regards to the energy demand for heating and cooling caused by transmission losses of the façade. In Detail a simple calculation method based on heating and cooling degree days will be applied for this study on a typical case study building and different façade concepts. The results are illustrating the benefits of the green facades in terms of energy and cost savings. The presented method could make the evaluation of green façade concepts easier and maybe more popular it in the near future.

2 BACKGROUND

2.1 Green facades

A green façade, or also a living wall is a vertical arrangement of plants, covering a wall of a facade of a building, partially or completely (LIVINGWALL 2017).

Introducing vegetation plants on a building surface is not a new concept. It has been done by the Greeks and the Romans as far back as the third century BC and historically reaching the Babylonians - one of the seven wonders of ancient world includes the famous Hanging Gardens of Babylon (Figure 1) (LIVINGWALL 2017).

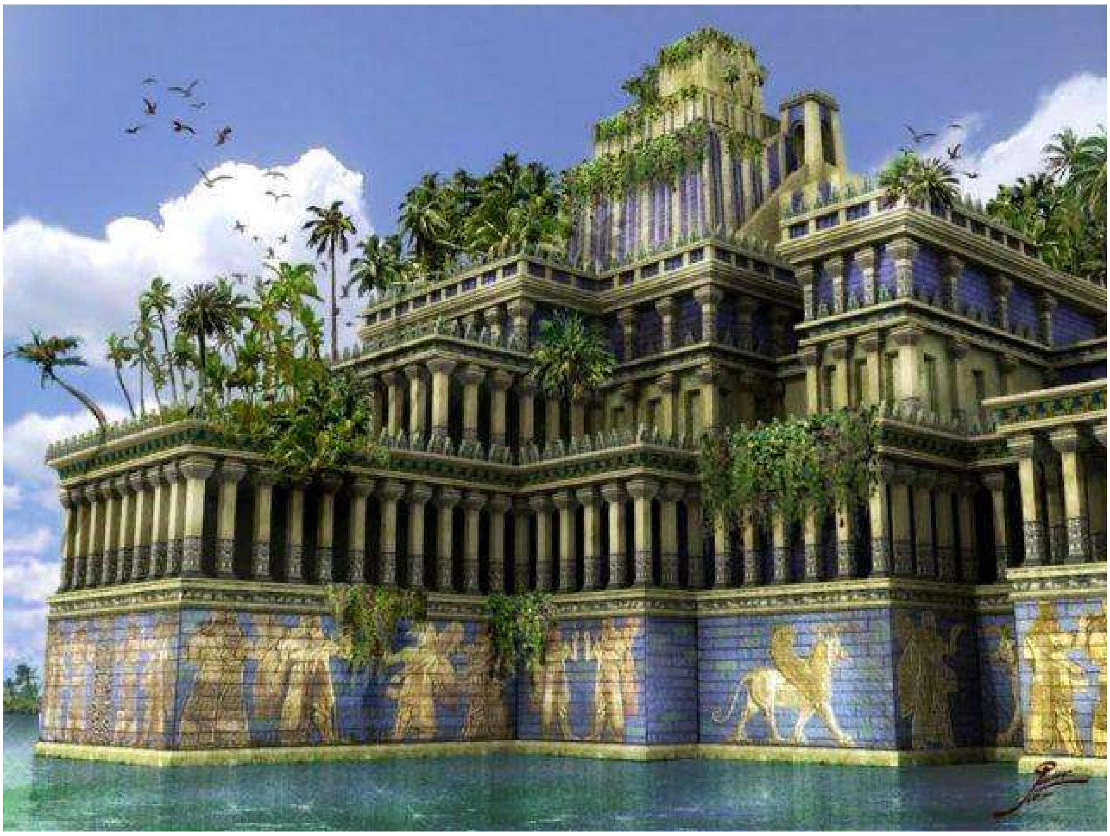


Figure 1 : The hanging gardens of Babylon (Source: LIVINGWALL 2017)

Grape arbors have been used by the Greeks on their villas for the fruits they are producing and for the shade, they are providing. Green walls are plants in vertical systems, which are attached to internal or external walls

Plants can fulfill various functions. According to Givoni (1991), plants provide places for sports and recreation, meeting establishing social contacts, isolation and escape from urban life, aesthetic enjoyment, and viewing buildings from a distance and so on. It has been proven that visual and physical contact with plants can result in health benefits. Plants can generate restorative effects leading to decreased stress, improve patient recovery rate and higher resistance to illness (Givoni, 1991). Green spaces in the living environment (focused on urban areas) can be an important environmental factor, which can influence our health (van den Berg et al., 2010).

Unfortunately though, because of increasing urbanization in the previous times, a lot of people become more and more displaced from green areas. The unstoppable force of urbanization is consuming vast quantities of natural vegetation, while they are replaced with hard and low albedo surfaces. In most urban spaces, an appreciable amount of vegetation exist, but is primarily concentrated in parks or recreational spaces. Although parks manage to lower temperatures within their vicinity, they are incapable of thermally affecting the concentrated built spaces where people live, work and spend most of their urban lives.

By placing vegetation within the built space of the urban fabric, elevated urban temperatures can decrease within the human habitats via the process of evapotranspiration from plants, and not only in the detached spaces of parks.(Alexandri et al., 2006). The higher urban temperatures within an urban environment result from surface materials with high heat absorption and heat capacity and the lack of evapotranspiration in urban areas that eventually may lead to a phenomenon known as the urban heat island (UHI) effect (Wong et al., 2009). Recently, architects and responsible agencies are trying to create green spaces around the residence area. They are searching for new configurations of green structures, which are able to reduce the urban heat island effect in the cities. According to Köhler, (2008) green strategies can be applied on different manners in urban areas. Since the outer surfaces of buildings offer a great amount of space for vegetation in urban cities, planting on roofs and walls has become one of the most innovative and rapidly developing fields in the worlds of ecology, horticulture, and the built environment (Wong et al., 2009).

The living wall and the green façade create their own microclimate, which is significantly different from surrounding conditions. This has a positive effect on both – around and inside the building. Depending on the orientation and location of the green structure and the surrounding buildings, the façade itself is a subject of great temperature variances (hot during the day and cold during the night). The temperature differences can be as different as 30 degrees Celsius at certain locations (Krusche el al., 1982; Wong, 2010). When a green facade/living wall is installed, a still standing air layer is created. This layer has the ability of thermally insulating the structure. According to Akbari et al. (2001), peak energy demand in the USA rises 2 to 4% for every 1 degree Celsius increase in air temperature. On cool days, the dense vegetation layer on the facade of the building will reduce the wind speed along the façade, which will reduce the heat loss during the cold winter days.

Another main reason these systems are used, is to be a protection from the direct ultraviolet solar radiation, lashing rain, and vandalism (graffiti) (Peck et al., 2011).

Furthermore, a green facade is also a natural air filter. The elevated temperatures in the modern urban environment, with the increasing of the vehicles on the streets, air-conditioned buildings, and industrial emissions led to rising in NOx (nitrogen oxides), Sox (Sulphur oxides), VOCs (volatile organic compounds), CO (carbon monoxide) and a lot of dust. Furthermore, they are a natural shield against lashing rain and ultraviolet solar radiation. In addition, the space between the green façade and the structural façade has a temperature-regulating effect which promotes optimum ventilation and also cleans the air.

Vegetation is widely used to reduce the noise pollution levels from busy highways, railways, and airports (van den Berg et al., 2010). It is believed that living walls are able to control the acoustics of the space around and inside the buildings. It is proven that living walls have a higher sound absorption coefficient than many standard building materials, and that they can significantly reduce the sound pollution (Wong, 2009). The improvement of the acoustics depends on the frequencies of the sound, types of the vegetation, percentage cover of the wall and the density of the plant. The living wall may contribute to a reduction of sound levels that transmit through or reflect from the structure, but the question is how much the improvements are going to be (Chang, 2010)

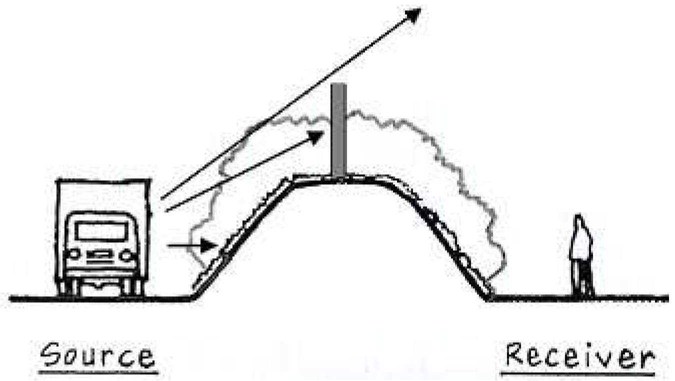


Figure 2 : Acoustifence control (Source: GENERATORNOISE 2018)

2.1.1 Advantages of the Green facades

Green facades can offer a wide range of benefits – from environmental tough financial to ascetical. Advantages provided by a green facade are not strictly attached to a given building on which the facade is installed, this structure can and will have an effect on the urban surrounding as well as. Multiple goals that green facades can accomplish, when properly designed and installed are described in the next few pages.

Reduction of the urban heat island

The reintroduction of vegetation into the urban environment promotes the natural cooling process evapotranspiration. With strategic placement of green walls, plants can create enough turbulence to break vertical airflow, which slows and cools down the air (Peck et al. 1999). The high-density urban environment, especially dark colored structure and objects (buildings, roads, walking ways etc.) absorb heat during the daytime and release it in the night. Green walls contribute to the big city environment by reducing the absorption area of the buildings and contribute by creating their own microclimate. The microclimate created around the facade is with more moisture and because of that, it feels cooler and refreshing (Figure 3).

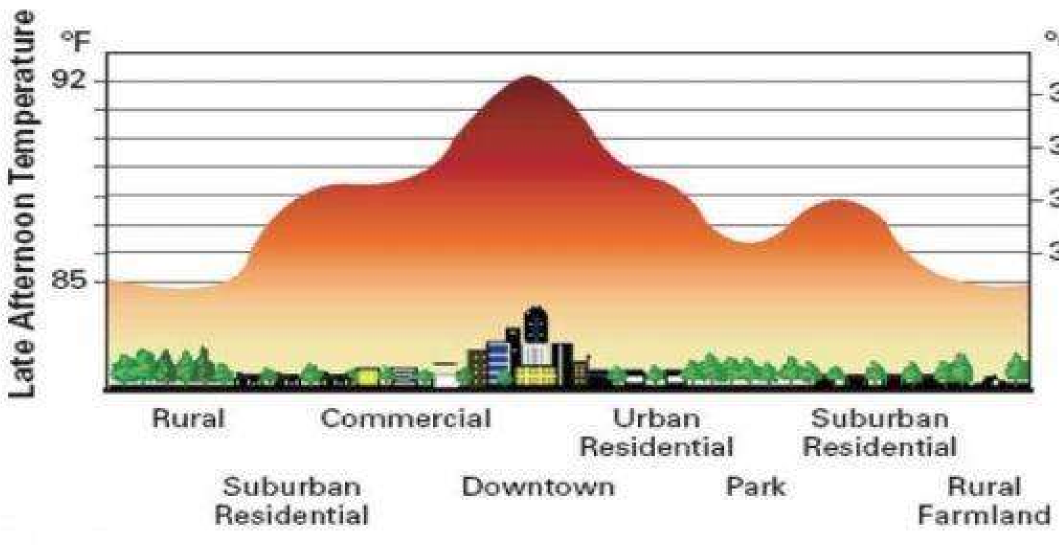


Figure 3 : Urban heat island diagram (Source: EPA US 2017)

Acoustical insulation and urban city noise absorption

Due to the thickness of the green facade and the vegetation leafs and structure, the green facade has very good acoustical properties. It absorbs the street noise unlike the concrete that tends to reflect it. It improves the sound insulation of the building, which is good for the occupants and improves the environment around the building by absorbing a good part of the traffic, trains or industry noise pollution.

Improvement of the thermal performance

A well-designed and well-executed green facade can, and will improve the thermal performance of the building. The green façade layer increases the insulation layer around the structure by adding the thickness of the plants. Leafs and the air trapped between them, and the layer between the external wall and the green structure is adding thickness to the insulation of the building envelope. The green wall also reduces the amount of solar energy absorbed by the wall, by shading it and moisturizes the air around it. Thus it lowers down the surface temperature of the building.

Protection

The green facades, when properly designed and executed are protecting the building envelope. They guard the building envelope by acting as a shield against the Sun's ultraviolet radiation. They also save funds for cleaning the facade from graffiti and vandalism.

Filtering the air and carbon dioxide reduction

Urban air pollution is linked with respiratory disease and breeding problems in people living in this areas. Green facade vegetation can trap particles of dust from the air. The living will also improve the air quality, not only with trapping dust and small airborne particles, but with cleaned the polluted air and releasing oxygen as a waste product. It is well known that plants during the process of photosynthesis use carbon dioxide from the air and release oxygen. Furthermore the vegetated facades reduce the amount of carbon dioxide in an indirect way - by reducing the amount of energy used for heating and cooling the building.

Wind reduction

Due to their nature, Green facades reduce street wind (Figure 4) and this improves the street environment. Because of its structure, the vegetated facade lowers down the wind speed and by doing that has the potential to make the street environment more comfortable.

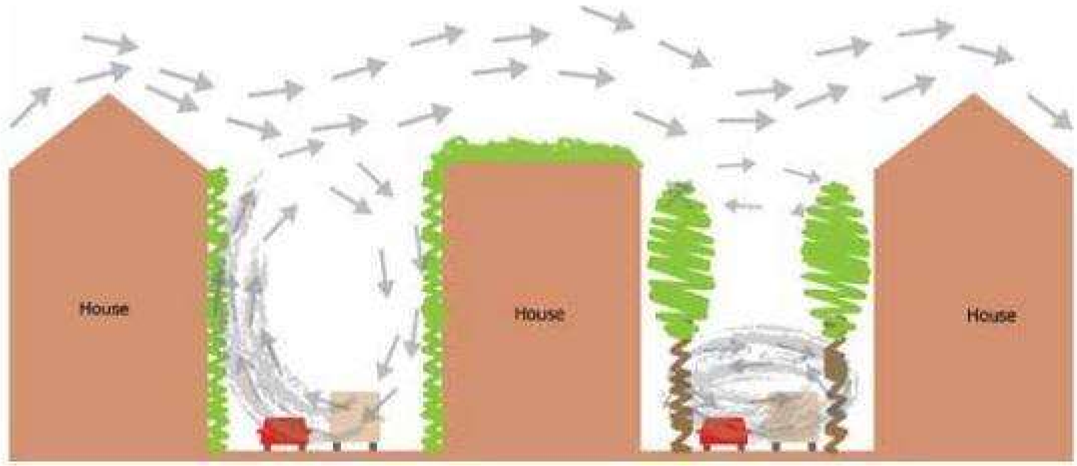


Figure 4 : Ilustration of Wind reduction effect (Source: EPA US Environmental Protection Agency)

Aesthetics

Green facades can make a regular square building interesting and better looking, as well as more comfortable for the inhabitants and others. Depending on the plants used, the type of green façade and load-claying structure - a living wall can be the pride of a city.

Economic benefits

Having a green structure on the external wall of a building will cost funds and time for the plants to grow, and will also cost money for the maintenance of the green system. But the green wall can be seen as an investment, or an update of the building and in most of the cases it pays off over time. As it was mentioned above, the green facade protects the building from the direct expositor of the Sun and other elements, which decrease the facade maintenance cost. Another major benefit is the reduction of the energy demand for heating and cooling the building. Last, but not least, having a green facade can increase the value of the property.

Fresh food source

In some cases, the green facade can be used as a fresh food source. There are many examples of that in Greece and Bulgaria, where locals have grapevine constructions attached to their external walls.

Figure 5 : Wine grapes growung on a house (Source: PIXELTOTE 2018)

2.1.2 Disadvantages of Green facades

There are many benefits in reintroducing vegetation to the surfaces of urban buildings and their related spaces but also some technical problems that might be occur during implementation. Living wall system seems to be relatively new technology, which is not sufficiently investigated, as discussed in Ottele (2011). There are no real disadvantages known for living wall systems, when well designed and installed, but still, there is a number of issues that need to be considered.

Chance of damaging the facade

The most of the damages on the walls can be done by the self-climbing ivy plants (Hedera helix and other plants). The problem can be divided into two groups – roots of the plant, damaging the foundation or the sewerage pipes and sucker root structure, damaging the external wall (when growing directly on the wall).

The first problem, where the roots of the plant can cause damage to the foundation and pipe systems of the building is less discussed in the literature, because it is not visible and that is why the main focus is actually on the second problem.

The aggressive root structure of the plant does not penetrate into the wall, but there are small cracks present at the wall, which the sucker roots can penetrate. Because of that - it can cause damage (Figure 6). If the wall is very smooth, then the adhesive (sucker) roots would separate organic acids and react with limestone materials and forms crystalline compounds. With this chemical reaction, the sucker roots can penetrate a few micrometers inside the wall (Kohler, 1993). It is important to be mentioned that the phenomenon, where the wall is penetrated a few micrometers, is not visible without a stereo microscope.

Figure 6 : Picture of façade damage caused by self climbing plants (Source: GREENSCREEN 2017)

Increased maintenance

The green facades can be designed and executed for minimum maintenance cost, but it is not possible to go without any maintenance at all. The maintenance is very important for the green facade, however, the location of the site, the weather and soil conditions may require additional irrigation and nutrients. Some plant species might provide fruits or flowers. That might require additional care and maintenance. Cables and wire-rope systems require periodic checking and of the tensions. The vegetation needs watering and trimming. Proper drainage needs to be provided.

Cost

Implementation of a green facade will cost more than just a regular facade and it will take some time until the plants grow up and start insulating the building. There are two costs which need to be considered – the construction cost and the maintenance cost.

- **Construction cost**s
  Vertical greening systems are an expensive cladding technique (Ottele, 2011).
  According to the Middelie (2009) and Perini (2011), the initial cost to build a vertical greening system is based on living wall systems is can be between 350 euro to1200 euro per square meter – depending on the country of residence, type of construction and plant species.
- **Maintenance costs**
  According to Middelie (2009) and Perini (2011) the following points are the priciest activities in the maintenance of the green facade. Irrigation management system,

the cost of using boom lifts for maintenance work, human activity costs and collection and disposal of fallen leaves are just a part of the spending which needs to be done for a proper maintenance of a green facade system.

Structural limitation

When constructing a green facade on an existing building and not only, there are some limitations, that need to be contemplated - the height of the building and the maximum high of the plant, the green structure will add at least 20 cm to the outside envelope of the building, which in many cases has to be approved by the municipality. Wind loads need to be calculated and in some cases, additional reinforcement needs to be added to the external wall in order to support the greening system. All the mentioned above limitations and difficulties are able to be solved, but it makes the green wall more expensive.

Limited choice of plants

The plant limitations are restricted by two factors – the height that needs to be covered and the climate and location of the building (which facade will be covered). The first factor – the height, is important to be considered due to the plant's height limitations. Also, it needs to be taken into account the time needed for the plant to develop certain height. Some green facade systems are designed with plants on two or more levels in order to cover more area of the facade for less time. The climate and the location of the building and facade are important for the plant selection. As it is well known, some plants like the sun and some shadows. It is crucial for the plant selection to be taken into account the local microclimate around the building.

Aesthetics

Aesthetic values of a green facade can be positive as well as negative. If the design, selection of vegetation and planning are not done correctly, the results can be devastating. There are many examples of poorly planned green facades, where the plants do not grow as they suppose. That is due bad plant selection or bad maintenance.

Figure 7 : Scrapped living wall (Source: ARCHITECTSJOURNAL 2018)

2.1.3 Green façade construction types

The construction of a green facade depends on the plants used and vice versa. The scale is a crucial factor in the designing of green facades. It can range from small, single family houses to buildings that include entire building envelope. Another critical aspect is the budget. Typically, product manufacturers only provide the material cost, but that is not the only cost in this type of product. Shipping, construction, and maintenance are also very important and in most cases, they cost more than the structure itself. The engineering requirements are also very crucial - snow, ice, wind and weight loads must be confirmed by a structural engineer before the beginning of the construction (LIVINGWALL 2017). According to GREENFACADESYSTEMS 2017, there are three main types of constructions (illustrated in Figure 8):

- **Direct facade greening** - the plants are attached directly on the façade
- **Indirect façade greening** – some construction (e.g. cable mesh, framework or ropes) is needed
- **The living wall** – a self-sufficient vertical garden attached to a wall. For this system, the plants will root in a soil or growing medium within a structural support system.

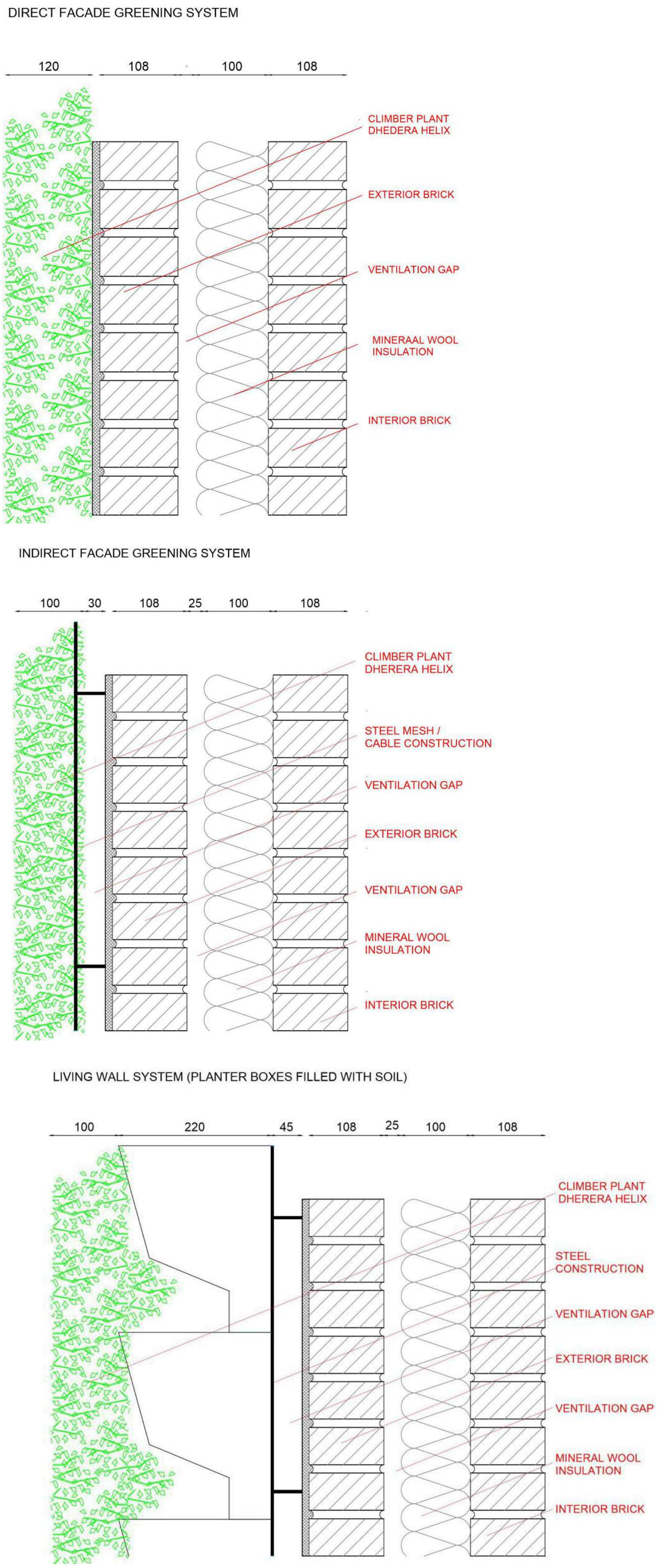


Figure 8 : Green facade systems (Figure by author)

2.1.3.1. Direct façade greening system

This is a natural, very common system in the traditional architecture. There is no construction – the climbing plans are attached directly on the façade. It is the most cost efficient and natural way of greening the building. However, there are two problems with it – the climbing roots can harm the façade and the roots which are in the ground can harm the foundation of the building. Most of the climbing plants have very strong roots, which are able to penetrate through the construction and damage the structure. It is the most cost efficient of all greening systems because it doesn't need any additional construction, and there is little maintenance required (it is only once every six months that maintenance is recommended – just cutting and forming the plans). This system is usually seen in country houses (not often used for big city projects) (GREENSCREEN 2017).

The plants used are usually from the Hedera family, Parthenocissus heterophylla or Ipomoea nil (Ottele, 2011). Figure 9 shows two examples for this façade greening system.

Figure 9 : Green facades with self-climbing plants directly to the wall (Source: GREENSCREEN 2017)

2.1.3.2. Indirect façade greening system

This is the most commonly used system. It is very similar to the direct plant system, but with a couple of differences – there is a lightweight supporting construction (cable mesh, framework or ropes/cables). The plant is climbing the lightweight construction, therefore, they are not damaging the façade. Furthermore, this type of system has greater insulating value because there is a layer (between the support construction and the façade) of trapped, not moving/slow moving air, which acts as insulation. The density of this type of green façade construction is greater than the direct façade greening system. The expenses here are more – it costs more to build and the maintenance is six times per year (once for two months). The installation cost for the indirect green façade system runs between 80 euro and 240 euro per square meter, and that depends on the construction, which is going to be used, and the manufacturer. However, this type of façade system grows much faster than the direct façade system and it is used in the dense urban areas and for large buildings (GREENSCREEN 2017).

Due to its advantages the indirect green façade is the most widely used greening system in Bulgaria. There are three types of constructions, which can be used – steel mesh construction, steel modular framework grid, and the third one are the steel cables/ropes (GREENSCREEN 2017).

The **steel cables mesh construction** consists of stainless steel cables of different diameters (between 1 and 4 mm diameter). The width of the mesh varies between 30mm and 400mm. The biggest advantage of the system is that it has very low self-weight, and at the same time it is very stable (high strength), never rusts and has low maintenance (more than 30 years' warranty). By using this kind of green façade construction, large areas can be covered very economically, and it is simple to install, which makes it cost and time effective. The square meter price is 26 Euro, and that includes the supporting ropes. Figure 10 shows different steel cable mesh constructions.

Figure 10 : Steel cables mesh construction (Source: GREENSCREEN 2017)

Another green wall construction system is a **steel modular framework grid**, which is typically mounted on the façade with bolts (each of the panels). It consists of a steel frame and the mesh which is made by welding several steel bars. It is made out of galvanized iron wire which is painted against corrosion or in some cases (depends on the manufacturer) can be PVC coated. The dimensions of the modules are usually 120cm by 300cm, but cutting is possible. The product itself is cheaper than the first solution, but when the erection delivery and maintenance of the elements is included it becomes a lot more expensive. The biggest advantage of the system is that if one of the panels breaks down – it can be changed without damaging the rest of the construction. This construction is significantly heavier than the first solution. The square meter price for the product is 29 euro not including the ropes which are supporting the construction. The lifespan of the panels is around 15 – 20 years, and rust is usually the main problem with this product (GREENSCREEN 2017).

The third solution consists of **stainless steel ropes and trodden rods or wall plugs** (Figure 11). The rods are bolted to the façade and the ropes are running through them. They can be only vertically or horizontally, or even both. Like the first one, it is easy to install but it is most commonly used for small areas. If used for bigger areas, it will become very expensive. The advantage of this system is that by using this ropes and rods some original design can be created. The prices for this type of façade construction are in the 25 to 35-euro range (it depends on the density and shapes created). The green façade structure is hard to build and also require a tough façade structure (GREENSCREEN 2017).

The solution that has been selected here is the steel cable mesh construction because it is the most commonly used in Bulgaria, and it is also the cheapest and easiest to maintain.

Figure 11 : Steel ropes and trodden roads construction (Source: GREENSCREEN 2017)

2.1.3.3. The living wall

The last type of greening systems is **the living wall system**, which is based on a different principle than the previous two types. The living wall systems consist of modular panels (Figure 12), each of them filled up with a growing medium. A heavy construction is needed to support the modular panels, as well as a watering and feeding system that is needed. All of these factors significantly increase the cost of building and maintaining this type of system. This is why the living wall system is usually seen in small external or internal projects. The area they cover is usually not very large because of its price. The cost for this construction is five to seven times more expensive than the indirect system (560 to 1200 €/m^2). The price varies depending on the construction, materials, and the manufacturer.

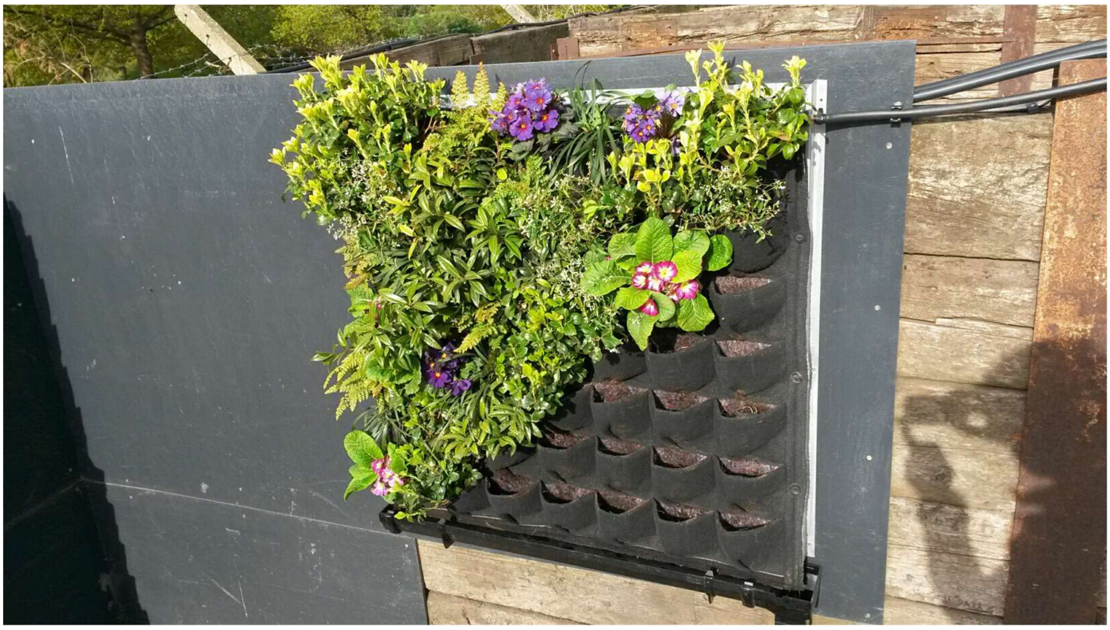


Figure 12 : Living wall System (Source: GREENSCREEN 2017)

2.1.4 Green façade plant types and selection

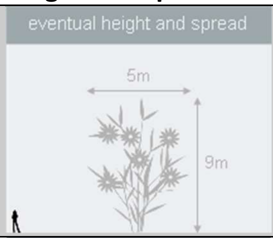
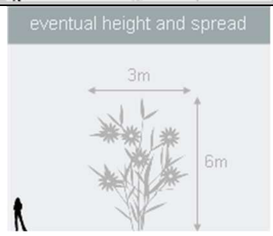
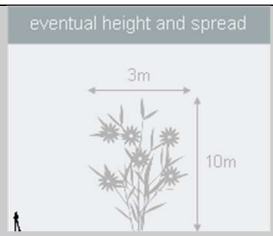
The appropriate plant selection is essential for the success of the green facade system. In addition, to determine the plant's hardiness, there are certain minimum requirements that have to be estimated in order to select the plant needed. In the subtropical climate zone, the most used plants for green facades are the Wisteria floribunda, Tecoma radicals, and the well-known Hedera helix (Table 1). The species selection criteria should be based on the local climate conditions of the site, the foliage from the ground to top, resistant to the weather (wind, snow, ice, sun), the orientation of the building they are installed on (full sun or shadow), and the growing speed.

Wisteria Floribunda or also the Japanese Wisteria usually grows around 9 meters, but there are plants over 25 - 30 meters. It is a woody deciduous twining climber plant. It needs heavy supports. Its foliage consists of shiny, dark-green, feather-like compound leaves, 10 to 30 cm in length. The Wisteria Floribunda also bears poisonous brown to velvet, bean-like seed pods 5 to 10 cm long. This plant prefers moist soils and likes the sun. It lives over 50 years (GROWINGGREEBGUIDE).

Trachelospermum as viaticum or also the Asiatic Jasmine usually grows around 6 meters, but it can reach the 10 - 12 meter barrier, with a proper support structure. It is an evergreen plant with glossy, leathery leaves and strongly scented cream-colored flowers in the summer. It needs light support. It grows very fast and it is a very dense plant. It has an oval shaped leaf, the flower is yellowish, and the fruit is pod-like with a length of 2 to 7 cm (GROWINGGREEBGUIDE).

Hedera Helix, also known as the English ivy, is a native plant for most of the parts of Europe (also native for Bulgarian seacoast). It grows around 30 meters, but there are some plants over 40 meters. Its leaves are alternate – 50 to 100 mm long with a 15 to 20 mm petiole. Its flowers are produced in the late summer, and its fruits are berry-like from purple-black to orange, relatively small – 6 to 8 mm diameter. They are very rich in nectar, and are food for many species of birds, but poisonous for humans. They provide very dense shade, which is easy to maintain. It is not a fickle plant, but it does not grow very fast – around 50 cm to 100cm per year (GROWINGGREENGUIDE 2017).

Table 1 : Different plant types and their properties (Source: GARDENIA2017)

Plant Type	**Pluses**	**Height and spread**	**Photo**
Wisteria Floribunda (Japanese Wisteria)	Grows up to 9 meters. NOT evergreen		
Trachelospermum as viaticum (Asiatic Jasmine)	Grows up to 6 meters. NOT evergreen		
Hedera Helix (English ivy)	Grows up to 30 meters. Evergreen		

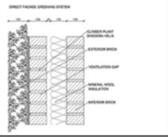
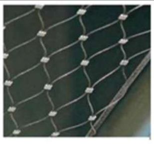
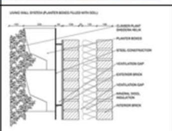
A few companies, which are designing and executing green facades, were contacted in order to ask for their opinion (LifeWall, Bionicle, ZELENAGRADINA).

To conclude, Hedera Helix is the most suitable plant to use in an urban environment with Bulgarian seacoast geographical coordinates is the Hedera Helix subs. Poetarum (the one, which is growing in the southeast Europe and southwest Asia). The main reason is that it is an evergreen climbing plant, growing up to 30 - 40 meters, has the densest shadow, and probably the most important of all – it is a native plant very common for the Bulgarian seaside climate. It is weather resistant and not pretentious at all (URBANGREENBUILDINGS).

2.1.5 Green façade Costs

Since prices are changing, a table will be introduced, where instead of Euros the prices will be estimated with points (Table 2). This table will be used for better understanding and more accurate comparison between the different products. The prices will be converted into a scale from 0 to 5, where 0 is the lowest price, and it means that it costs nothing, and 5 is the highest price.

Table 2 : Different façade types and their properties (Source: by the Author)

Facades construction types							
Type	**Construction**	**Example**	**Plants**	**Pro**	**Con**	**Costs (1 starts very low...5 stars very high)**	**Maintenance (1 star very low...5 stars very high)**
Direct	No construction		Usually the Ivy plant family	Very cheap and natural way of greening the building	Roots can harm the façade, no need for additional construction.	★	★
Indirect	Steel cables mesh construction		It depends on the construction (the height). It can be theoretically any climbing plant.	Has very low self-weight and at the same time is very stable (high strength), never rusts and has low maintenance, very economically and it is easy to install	It is not modular so it can not be "prefabricated".	★★★	★★
	Steel modular framework grid		It depends on the construction (the height). It can be theoretically any climbing plant.	If one of the panels brakes down – it can be changed	Not very flexible, can not make different shapes.	★★★	★★★
	Steel ropes and trodden rods or wall plugs		It depends on the construction (the height). It can be theoretically any climbing plant.	Original design can be created	Hard to build and also require a tough façade structure	★★★	★★
Living wall	Modular panels		It depends on the construction and the pots sizes. It can be theoretically any plant.	Easy to change the panels if the plant dies. Fast to cover the façade and have an "instant green façade"	Very expensive and heavy construction.	★★★★★	★★★★★

2.1.6 Sustainability of green facades and green walls

Whenever we think about green facades and the related environment, we think actually about present moment (our current generation). Green facades have a lifespan of over 50 years when properly maintained. This means that the future generation will also be able to enjoy the beauty and functionality of the structure. To build a green façade it is necessary to take into account the manufacturing of the supporting structure, which can have a negative environmental effect.

The sustainable structure can be described as a design and construction supporting human health and at the same time is in a harmony with nature. Sustainable refers to the property of a material, building section or construction that indicates whether or not sustain demands are met for affecting the air, water, and soil qualities, for influencing the health and well-being of living organisms, for use or raw materials and energy, and even for scenic and spatial aspects, as well as for creating waste and nuisance (Dobbelsteen, 2001; Hendiriks, 2001).

2.1.7 The Influence of green facades and green walls on the thermal performance of a building

So far have been examined the effects and the benefits of the plant layer on the thermal performance. However, the effect of the plant layer on the building energy consumption is an open field of study. There are studies which are examining the effects of vegetation (in most cases trees and climbing plants) on heating and cooling loads and the energy efficiency of buildings, using the method of energy simulations.

The most prominent studies are reviewed below.

A study by Huang (1987) investigated the effect of trees on the buildings energy consumption, highest cooling loads, and energy cost by stimulating the use of energy in a typical air-conditioned, one-story wood frame house located on sites with different amounts of tree area coverage in four different hot climates. The results of the simulation showed that annual energy cooling requirements were reduced with an 11 – 18 % energy use reduction for 10 % tree-covered sites, a 27 – 43 % reduction for 25 % tree covered sites, and a 33 – 53 % reduction for 30 % tree-covered sites.

Another study by McPherson (1988) inspected how the vegetation on a building could affect the wind and sun in order to reduce the heating and cooling costs. For the purpose of the study the energy use for four different climate zones (Wisconsin, Utah, Arizona, and Florida) in a single-story building was simulated. The researchers were examining multiple parameters, such as orientation of the building, shading factors of the plants, and wind speeds. The shading effects of trees reduced the space cooling cost by 53 - 61 % and peak cooling load by 32 - 49 % in temperate and hot climates. However, in cold climates, with major heating requirements, reducing the solar exposure of the building with trees in winter increased the energy cost by 21 - 24 %. On the other hand, the wind reduction effect allowed for lower building air infiltration and decreased heating loads by 9 – 11 % in cold climates but increased cooling loads by 17 - 23 % in hot climates.

The energy savings in building with green walls were evaluated in a couple of studies precisely. For example, Di (1999) measured a 28 % decline in the peak cooling load through a west-facing wall of a building covered with thick ivy plant on a clear summer day. Also, a study by Price (2010), who developed a mathematical model based on his experimental findings to evaluate energy savings in low-rise buildings with plant-covered trellises, discovered that building cooling load could be reduced by a maximum of 28 %.

A study by Kontoleon (2010) using a one-dimensional thermal resistance model to analyze the effect of green facade on energy performance in a one-story brick house in Thessaloniki, Greece, found that the plant layer can reduce building cooling load by 5 % for the north-facing wall, 18 % for the east-facing wall, 8 % for the south-facing wall, and 20 % for the west-facing wall.

Also parametric study by Wong (2009), which simulated the energy performance of a hypothetical 10-story office building in Singapore with various degrees of plant facade coverage, showed a significant cooling load reduction of 74 % in a building with a 100% opaque facade fully covered with vegetation, a cooling load reduction of 10 % in a building with a 50 % opaque facade fully covered with vegetation and 50% glazing, and a cooling reduction of 32 % in a fully glazed building with a curtain wall facade fully covered with vegetation. A more wide-ranging method to estimate the performance of vegetated facades is to use mathematical models rather than only experiments. Such models should be able to dynamically simulate the effect of plants on the facade thermal performance for variable plant characteristics, facade properties, building orientations, and weather conditions.

Several mathematical models of ground vegetation canopy were developed in the field of climatology (Deardorff, 1978; Zhang, 1997) and were later modified to simulate the thermal performance of plants in green roofs (Alexandri, 2007; Djedjig, 2012; Sailor, 2008). The model of green facades developed by Susorova (2013a,b) presents an improvement over previous models by computing plant physiological processes including evapotranspiration and radiative and convective heat exchange between the plant layer, the facade, the surrounding environment, and the ground and using individual plant characteristics inputs (e.g., leaf absorptivity, typical leaf dimension, LAI, radiation attenuation coefficient, and leaf stomatal conductance) and weather data to simulate the impacts of vegetated walls on facade thermal performance. A few new thermal models of green walls were recently developed by Malys (2014) and Olivieri (2014a,b).

The impact of wall plants on building energy demand was analyzed by creating a green façade mathematical model (soil not included) (Susorova, 2013a,b). The study’s objectives were used to estimate the energy use decrease in buildings with green facades and to examine the effects of various parameters on building energy efficiency. That will also contain weather conditions, climate zones, facade orientation, wall types, and differences of the plant types. Annual energy simulations were done to find energy use decrease due to the vegetation layer. The annual energy use in two air-conditioned thermal zones were compared— the first with a bare and the second with a vegetated façade — located in the hot climate of Phoenix.

A thermal zone in this context is an indoor room with a constant temperature maintained at the thermal comfort level, which is done because of the mechanical heating, mechanical cooling, and ventilation. Each thermal zone was 6 m wide, 6 m deep, and 2.75 m high and had an adiabatic floor, ceiling, and three interior walls. Heat transfer between the defined thermal zone and the exterior occurred only through the single exterior wall, which was left bare in the first model and covered with a plant layer in the second model. Energy use in the tested buildings was analyzed for a range of parameters, including building occupancy type (office and residential), zone geometry (one and two exterior walls), exterior wall opaqueness (100 % opaque and 60 % opaque + 40 % glazing), facade orientation (north, east, south, and west), exterior wall assembly type (brick wall with and without insulation and metal stud wall with and without insulation), and plant LAI.

Annual cooling energy use was reduced by an average of 1 - 33 %, 2 - 55 %, and 2 - 66 %. Total energy consumption was reduced by an average of 0.3 - 2.7 % for 1, 0.6 - 4.4 % for 2, and 0.2 - 5.4 % for 3. The highest total energy reduction of 6.2 % corresponding to an annual cooling energy reduction of 34.6 % was achieved in a residential thermal zone with one east-facing opaque exterior wall made of an uninsulated brick material, covered with a dense plant layer.

Between two reviewed building types, the energy use decrease in the residential thermal zones was more than that of the office zones. This is explained by the different types - office and residential buildings in their schedule of operation, people occupancy, and lighting and equipment loads. Office buildings typically have internal heat gains generated by office equipment, lighting, and high occupant density, while residential buildings have heat gains and losses because of the exterior envelope. Heat conduction through exterior walls is a major contributor to cooling loads in residential buildings. Any thermal improvements to exterior envelopes produce noticeable building cooling energy reduction.

The part of the building covered with green façade directly affects the reduction in energy consumption. The maximum energy improvements occurred in thermal zones that had two opaque exterior walls covered with vegetation. The energy savings effect of the plant layer decreased moderately for thermal zones whose exterior walls contained glazing that reduced the fraction of the plant cover to 60 %. The facade orientation plays a critical role in achieving energy savings, which is explained by the facade receiving a different amount of solar radiation depending on the latitude, solar angle, and elevation of the location of the building. The highest energy reduction, due to the plant layer on the facade in Phoenix, occurred for east and south facades. Another important factor had the materials used in the exterior walls behind the green façade. Among the thermal zones with four different external walls assemblies, the highest energy use reduction was reached in the zones with exterior brick walls without insulation. The energy improvements were high when the thermal resistance of the original exterior walls was low and occurred mainly on walls with less or none insulation. The improvements to well-insulated exterior walls were marginal. The most energy savings showed up in the thermal zones, whose exterior walls were covered with a very dense plant layer.

In conclusion, green walls can improve and increase cooling energy savings in buildings, but the reduction in energy use varies depending on the environmental factors and the shape of the building and materials that the structure is made of. It shouldn't be expected that green facades can be the whole solution of reducing building energy consumption. However, the greatest reduction in cooling loads and energy consumption can be reached with the use of green facades on buildings combined with other energy-efficiency measures like high quality thermal insulation.

2.2 Thermal resistance of green façades

The reduction of surface and air temperatures on the external walls covered by green facades, lead to reduced heat flux through the opaque facade. Several studies estimated that mean instantaneous heat flux reduction due to the plant layer can vary and reach 10 % (Susorova, 2014), 75 % (Hoyano, 1988), and 70 - 80 % (Mazzali, 2013), depending on the experiments' weather conditions, solar radiation intensity on the wall, and plant layer characteristics.

The effect of the green façade on heat conduction through facades could be estimated by utilizing a metric of "effective thermal resistance." This could also be used to compare the results with those of other insulating materials. The effective R-value of bare and vegetated facades is calculated, as the temperature gradient between the indoor and the outdoor surfaces, divided by the dynamic heat flux through the wall (Figure 13).

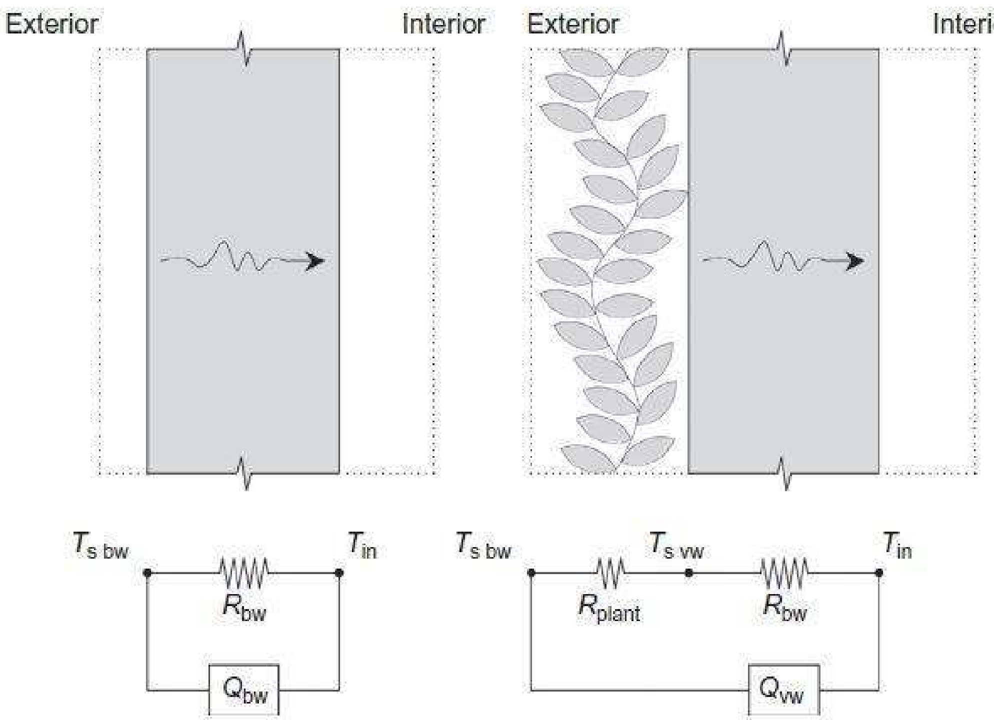


Figure 13 : Ilustartion of the model used for a R-value calculation(Sourse: Eco-efficient materials for mutigating building cooling neers)

The decrease in heat flux through the facade caused by the green facade, due to shading and evapotranspiration, raises the thermal resistance of the exterior wall. If instantaneous surface temperatures and heat flux through the exterior wall is known, effective R-values of a plant layer can then be calculated for any weather conditions, plant characteristics, and facade material properties. This concept can be shown through the analogy of an electric circuit diagram where thermal resistances are shown as resistors in series, a temperature gradient is analogous to voltage, and heat flux is analogous to current (Figure 13). From the heat flux through the facade, one can find the instantaneous effective thermal resistances of the bare facade R-by:

$$R\mathrm{bw} = \frac{\mathrm{Ts\ bw} - \mathrm{Tin}}{\mathrm{Qbw}} \quad (1)$$

Where Ts bw is the bare facade external surface temperature, Tin is the internal surface temperature, and Qbw is the heat flux through the exterior wall [W/m^2]. The immediate effective thermal resistance of the vegetated facade R-vw, which includes the bare wall and a green façade layer, is calculated as

$$Rvw = \mathrm{Rbw}\frac{Qbw}{Qvw} = \frac{Ts\,bw{-}Wi}{Qvw} \tag{2}$$

where Qvw is the heat flux through the wall with the green façade [W/m^2]. Knowing the effective thermal resistances of the façade with and without vegetation, the instantaneous effective thermal resistance of the plant layer R-plant can be estimated as

$$R\ plant = Rvw - Rbw \tag{3}$$

2.2.1 Calculation and simulation

Several authors have done simulations in order to examine the thermal behavior of VGS (vertically greenery systems) on buildings. In this section a review of these studies, specifying parameters studied, main assumptions of the model, if the model was validated or not, and finally main conclusions, is presented.

In order to examine the effects of irradiance and wind reductions on the energy performance of similar residences located in different climates in the United States, McPherson created a computer simulation. Irradiance reductions from vegetation were modelled using Shadow Pattern Simulation software (SPS), which simulates shade cast from plants on buildings, and MICROPAS, a microcomputer based energy analysis program. The studied parameters were solar irradiance and wind reductions and the energy performance of the building. The main assumptions were:

- windows shading coefficient
- air change rate
- occupancy
- uniform shade from plants

No validation was conducted, and the main conclusions were 21 % increase for heating in cold climates (great influence of south and east facade) and 53 % decrease for cooling in warm climates (big influence of the roof and west facade). For the wind speed, the study concluded that wind reductions were generally beneficial in cold climates, but greenery should not block solar access to south- and east-facing surfaces. In temperate climates, wind reduction lowered annual heating costs by 8 %, but increased annual cooling costs by 11 %.

In Holm a dynamic model, simulating the thermal effects of green facades on external walls using Dynamic Energy Response of buildings system (DEROB), was created. For the simulation, the building mass (high or low), the orientation (equator or west), the season (summer or winter), the climate (hot arid, hot humid, Mediterranean) and the exterior temperature were considered. Indoor temperatures were calculated without considering the vegetation properties (assumptions). The model was validated with data from four winter and summer days, and the main conclusions are summarized in Figure 14. It can be observed that the most pronounced beneficial thermal effect is obtained by leaf cover on the outside walls of low mass in hot-arid climates. On the other hand, the beneficial effect on high-mass buildings in the simulated Mediterranean climate was negligible. In most cases, the improvement produced such acceptable indoor climates that no artificial heating or cooling was required.

Building mass	Orientation	Season	Climate	Outdoor temp. (°C)	Indoor temp. without leaf-cover (°C)	Indoor temp. with leaf-cover (°C)	Effect of leaf-cover
High	Equator	Summer	Hot–arid	21 - 31	19 - 25	19 - 24	Maximum lowered by 1 K
High	Equator	Winter	Hot–arid	7 - 18	15 - 22	15 - 22	Minimum raised by 1 K
High	West	Summer	Hot–arid	21 - 31	19 - 26	19 - 25	Maximum lowered by 1 K
High	West	Winter	Hot–arid	7 - 18	15 - 21	15 - 20	Maximum lowered by 1 K
Low	Equator	Summer	Hot–arid	21 - 31	18 - 33	18 - 28	Maximum lowered by 1 K Indoor cooler than outdoor Acceptable indoor climate
Low	Equator	Winter	Hot–arid	7 - 18	10 - 30	12 - 27	Maximum lowered by 3 K Minimum raised by 2 K Acceptable indoor climate
Low	West	Summer	Hot–arid	21 - 31	17 - 34	18 - 30	Maximum lowered by 4 K Minimum raised by 1 K Indoor cooler than outdoor
High	Equator	Summer	Mediterranean	17 - 26	18 - 24	18 - 24	No significant difference
High	Equator	Winter	Mediterranean	10 - 17	14 - 19	15 - 19	Minimum raised by 1 K
High	West	Summer	Mediterranean	17 - 26	18 - 27	18 - 25	Maximum lowered by 2 K Acceptable indoor climate
High	West	Winter	Mediterranean	10 - 17	10 - 17	15 - 19	Maximum raised by 2 K Minimum raised by 5 K Acceptable indoor climate
High	Equator	Summer	Hot–humid	22 - 32	19 - 26	19 - 24	Maximum lowered by 2 K Acceptable indoor climate
High	Equator	Winter	Hot–humid	12 - 25	17 -22	17 - 22	No difference Acceptable indoor climate
High	West	Summer	Hot–humid	22 - 32	19 - 26	19 - 25	Maximum lowered by 2 K Acceptable indoor climate
High	West	Winter	Hot–humid	12 - 25	17 - 22	17 - 21	Maximum lowered by 1 K Acceptable indoor climate

Figure 14 : The effect on indoor temperature by leaf-covered exterior walls (Source: Holm D.)

Di and Wang recorded data, during two summers, on a west-facing facade of a two-story structure covered with thick ivy plant. Conductive heat transfer mechanisms and energy use reduction were also analyzed theoretically to determine the basis for the cooling effect of the green façade. The main conclusions that were made were that there was no leaf layers overlap, the leaf temperature was uniform and the ivy plant had negligible thermal capacity. The main assumption were reductions of 28 % for peak-cooling loads transferred through the wall in summer days and heat gains reduction by solar radiation absorption (40 % of the energy absorbed by leaves is lost by convection, 42 % by transpiration, and the rest by long-wave radiation to the environment).

Stec developed a simulation model, built by using Simulink, in order to define the thermal performance of a double skin façade with vegetated layer. Stec have used a laboratory test facility with lamps in order to validate the simulation process. The output plant's leaves temperatures were compared with the measured ones. According to Stec, difficulties were met with defining the properties of the plant. Thus, transmission was measured in the lab experiment. The absorption and reflection coefficients were taken from an agricultural literature reference. These results proved that plants work more effectively as a shading system than artificial blinds. Temperature of each layer of the double skin façade has been lower for the case with plants than with blinds. The temperature rise of the plant was about twice lower than for the blinds. Also, the temperature of the plant didn't exceeded the temperature of 35 °C, when blinds were able to exceed 55 °C. Furthermore, installation of plants in the double skin façade improved the cooling capacity by almost 20 %. A similar result was noticed for the energy consumption of the cooling system.

Alexandri and Jones studied the thermal effect of covering the building envelope with vegetation on the microclimate in the built environment, for various climates and urban canyon geometries. A two-dimensional, prognostic (dynamic) micro-scale model has been created and programmed in C++, showing the heat and mass transfer in a typical urban canyon (Figure 15). The geometry of the vegetation (roofs and walls), canyon geometry and orientation, and wind direction were the main studied aspects. The façade system and the plants species was not specified. The first main conclusion was that there is an important and working potential for lowering urban temperatures when the building envelope is covered with vegetation. Moreover, it can be concluded that the hotter and drier a climate is, the greater the effect of vegetation on urban temperatures. In general when covering with vegetation, the larger the amount of solar radiation a surface receives, the larger its temperature decreases. For all the examined climates, vegetated facades have a stronger effect than green roofs inside the canyon. Nonetheless, green roofs have a greater effect at the roof level and, consequently, at the urban scale. In hot climates, energy savings from 32 % to 100 % for cooling were calculated.

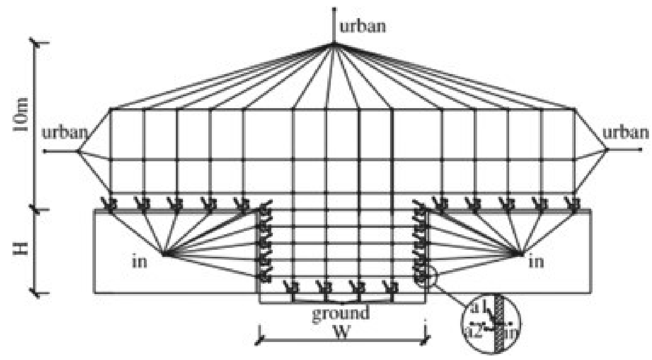


Figure 15 : Two-dimensional canyon model (Sourse: Alexandri E.)

The objective of the research of Wong et al. was to simulate the effects of green facades on the temperature and energy consumption of buildings. Thermal analysis simulations (TAS) were performed to regulate the effects of vegetation on thermal comfort and energy consumption (Figure 16). Additionally, a thermal calculation of the envelope thermal transfer value to obtain their effects on the thermal performance of the building envelope was done. For the calculation some data from previous research about green roofs were used (turf, substrate, LAI, plant species, etc.), assuming the same conditions for vegetated facades. Green facades, for these simulations different plant coverages to a hypothetical building were given.

One of the main conclusions was that the shadow effect is closely related to the density of the foliage, which was related to the LAI of the fern species used (Boston Fern (Nephrolepis exaltata)). In the conclusions, it was found that the key behind shading is thicker greenery. Moreover, reductions between 10 % and 31 % energy cooling load were calculated due to the effect of greenery.

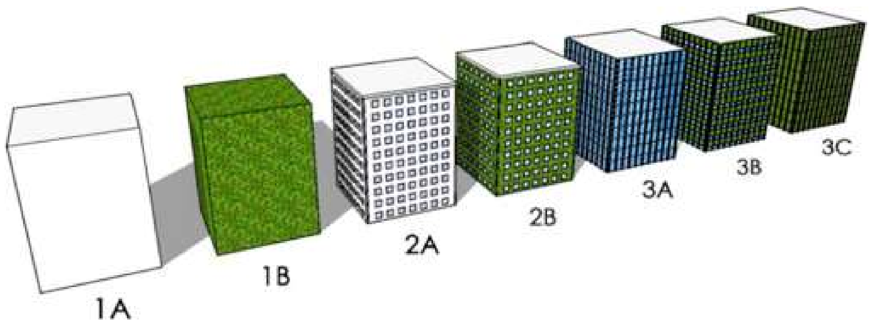


Figure 16 : Scenario 1 (left), 2 (centre) and 3 (right) of TAS simulations (Sourse: Wong NH)

Kontoleon and Eumorfopoulou studied the effect of the orientation and proportion (covering percentage) of a vegetated façade layer on the thermal performance of a building. In this paper the main objective was the study of the influence of a 5 cm insulation layer in the façade wall of a theoretical building (Figure 17). Furthermore, a 25 cm vegetation layer, with an estimated thermal conductance value of 2 W/m^2, was added to the calculations in order to simulate its outcome on the thermal behavior of the building. Surface and indoor temperatures as well as energy requirements for a set point of 20 °C were the main parameters calculated. Results showed that vegetation had a crucial influence by the absorption of great amounts of solar energy. The exterior/interior surface reductions calculated were 1.73/0.65 °K for the north façade, 10.53/2.04 °K for the east façade, 6.46/1.06 °K for the south façade and 16.85/3.27 °K for the west façade. This effect implied cooling load reductions of 4.65 % for the north, 18.17 % for the east, 7.60 % for the south and 20.08 % for the west.

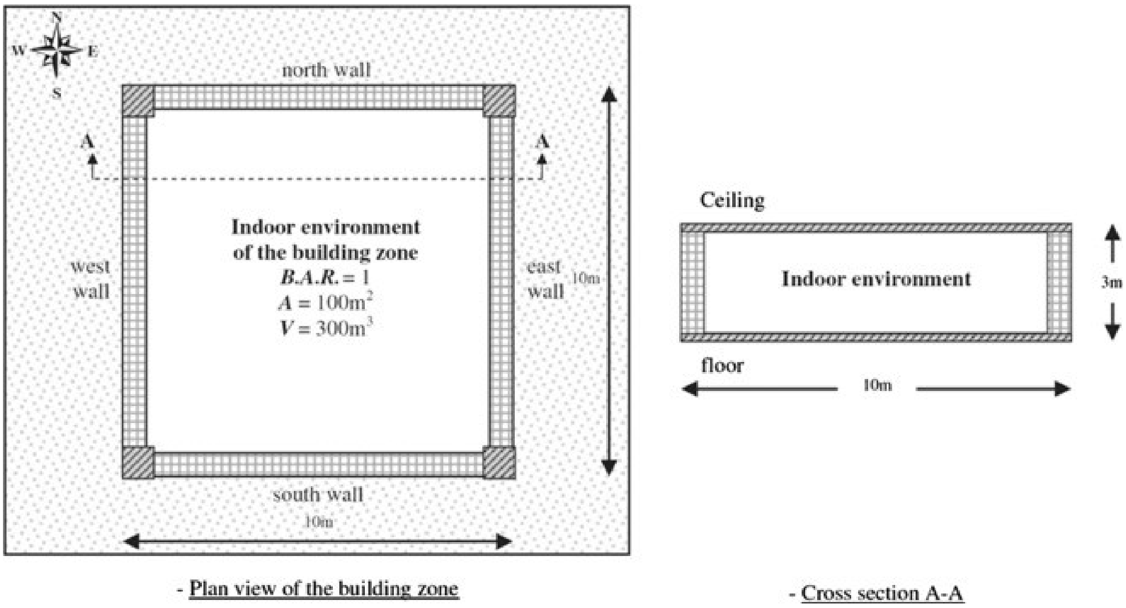


Figure 17 : Schematic representation of the analysed building zone (Sourse: Kontoleon K.)

Jim and He developed a thermodynamics transmission model to simulate heat flux and temperature variations of vertical greenery ecosystems. The studied parameters were global solar radiation, diffuse solar radiation and seasonal heat flux. In order to validate the simulation a little experiment, composed by four green wall units (50 x 85 x 35 cm) oriented, two to the north and two more to the south, was carried out. The modules were placed 15 cm in front of the railing of the roof, and this 15 cm air gap was open. The results showed that when global solar radiation and temperature of the south control wall had reached maximum values, the south green walls had recorded reductions up to 8.83 °K.

Susurova et al. developed a mathematic model to simulate the thermal performance of vegetated exterior façades. Data collection for validation took place over 3 days in a south traditional green façade (Parthenicissus tricuspidata) at the Illinois Institute of Technology in Chicago. The idea of the study was to consider the variable plant characteristics in the simulations, because according to the authors, previous studies only considered aspects such as the façade properties, building orientations or weather conditions. However, due to the lack of data related to the vegetation and the difficulty to obtain it, several assumptions were carried out (leaf absorptivity coefficient, radiation attenuation coefficient, etc.). The main conclusions from the simulation process were that solar radiation, façade orientation, and air temperature were more influential over the green façade thermal behavior than the air relative humidity, wind speed or the plant parameters. On sunny days, a plant layer on a brick façade was estimated to reduce its exterior surface temperature by 0.7 - 13.1 °K, to reduce the heat flux through the exterior wall by 2 - 33 W/m^2 and provide an effective R-value of 0 - 0.71 (m^2K)/W, depending primarily on the wall orientation, the leaf area index, and the radiation attenuation coefficient.

In Table 3 the reviewed literature on simulations about VGS is organized and the main features and conclusions are summarized. Because simulations allow working with a wide range of different climates, so as not to complicate the summary table, in this case studies have not been classified by climatic zones. Only the differentiation among green walls and green façades, and their typologies, has been considered.

From the nine simulation studies analyzed, three did not specify what typology of façade was considered, four referred to green façades, three to traditional green façades and one more was a green double-skin façade, and finally two studies concerning green walls were found.

About the plant species – there were specified in the three simulations in which the constructive system was not specified. With respect to the four simulations about Green Façades, two of them used ivy plants, an evergreen plant, and two more used Boston ivy plant, a deciduous plant, although being deciduous or evergreen did not affect the main conclusions because the cooling period was considered mainly in these four studies (summer).

Regarding the two green walls simulations, similar to the studies of real or experimental vegetated facades, species are very varied, but mainly shrubs and herbaceous plants well adapted to the local climatic conditions.

With reference to the mathematical models and software used, great variability and little continuity between consecutive studies can be observed. The most analyzed parameters were surface temperature and environment temperatures, the heat flow through the wall, and the energy savings achieved. In general a great difficulty to characterize the vegetation in an objective way can be seen, which results in a large number of assumptions used by the authors in order to conduct their simulations. This fact highlights the importance of carrying out further research on the plant properties in different climates. Indeed the large list of assumptions also questions the necessity of actually knowing in detail all the physiological properties of plants (absorption of radiation, transpiration, stomatal opening, etc.). With regard to the models' validation, except one study which employed data from two consecutive summers, it can be observed that usually the periods of the data collection were too short, between 4 and 12 days; even in some of the found studies the models used were not validated with real data.

Regarding the main conclusions from the simulation studies on VGS, it can be generally stated that VGS are an effective tool for energy savings during the cooling period in warm temperate (C) and arid (B) climates, with reductions between 5 % and 50 %, the most frequent being between 20 % and 30 %, taking special consideration of the West façade orientation influence. Only one of these simulation studies provided a conclusion regarding the increase in energy consumption for heating (21 %), being one of the reviewed studies in which neither the green system nor the plant species was specified. These lonely negative data about these systems during the heating period suggests that further studies should be carried out during the rest of the year (winter, spring and autumn) and that it will be necessary to evaluate their thermal behavior for all year.

Comparing the different VGS systems, are visible in Table 3, it seems that Green Façades are the most efficient in reducing power consumption during cooling periods but the fact that there are only a few simulations on Green Walls does not allow actually confirming this statement.

Table 3 : Simulations: Related papers; Main characteristics and findings (Source: Perez G.)

Plant species	Model/software	Parameters	Validation	Main assumptions
None	MICROPAS - SPS Shadow Pattern Simulation	Solar irradiance reductions/ Wind reductions/Energy performance	no	Windows shading coefficient/air change rate/occupancy /uniform shade
None	DEROB — Dynamic energy response of buildings	Indoor temperatures	4 days	Plants properties were not considered
None	Two-dimensional prognostic (dynamic) micro-scale model Cþ þ	Temperatures and energy savings	No	Properties of the plant
Hereda	Mathematical model	Conductive heat transfer/ energy use reduction	2 summers	No overlap of the leaf layers/ Uniform leaf temperature/Negligible thermal capacity
Hereda	Simulink	Heat exchange between layers	Lab experiment	Properties of the plant
Parthenocissus tricuspidata	PCW — thermalnetwork model	Temperatures and energy savings	No	Plant thermal conductance
Boston ivy Parthenocissus tricuspidata	Mathematical model	Surface temperatures/Heat flux through the exterior wall	4 days	Leaf absorptivity coefficient, radiation attenuation coefficient, typical stomacal conductance, etc.
Nephrolepis exaltat/ /Ophiopogon japonicus/ Tradescantia spathacea	TAS simulations	Temperatures and energy savings	No	Shading coefficient, greenery coverage
Euphorbia x lomi "salmon"	Thermodynamics transmission model (TIM)	Heat flux transmission/ Temperature variations	12 days	Not explained

In 1989 Holm, from the University of Pretoria studied thermal gain management by means of Leaf Cover on External Walls using a thermal simulation model. While his study excluded the consideration of evaporative cooling, Holm does consider all other parameters relevant to the thermal effect of vegetated walls and validated his model on vegetated walls, finding the correlation coefficient to be over 0.93. His simulation results indicated an average of 5 °C of reduction for the interior temperature of the simulated buildings. The limitations of his simulation became visible, when he concluded that vegetated walls would be almost ineffective in Mediterranean climates. His simulation was conducted on a series of DEROB (dynamic energy response of buildings) system of programs, which required the use of a mainframe computer.

In 1998, Bruse and Fleer from the Climatology research group at the University of the Ruhr in Germany studied simulated surface–plant–air interactions inside urban environments with a three-dimensional numerical model. A highly detailed work of mathematics and physics, this article presented a very useful differentiation between two often confused or assumed identical cooling mechanisms of plants: evaporation and transpiration. Evaporation is defined as phase change to vapor, of liquid water on the surface of vegetation, whereas transpiration is phase change through the leaves. As such, their models took into account different energy impacts of dew on the surface of plants and of water within the plant having to overcome stomatal resistance to vapor diffusion. The model also took into account the upwards or downwards direction of the incoming shortwave and longwave thermal radiation fluxes. Finally, turbulence caused by the sharing of air flow by vegetation and thermal stratification is defined as is its dissipation.

In 1999, Liao and Niu from the Hong Kong Polytechnic University studied the thermal function of ivy-covered walls and presented the key factors which modulated the influence vegetation can have on the surface behind it. This mathematical method modeled the impact of the density of the greenery, the ratio of vegetation area to the wall surface and the geometrical characteristics of the supporting material. While the model is simplified, the results of the simulation indicated that ivy coverings on walls can significantly reduce the heat flux through the walls they cover. In addition to being conclusive and providing an indication about the way forward, it offers a detailed list of variables relevant to a detailed heat balance equation for the leaf and the surrounding air.

In 2000, Takakura, Kitade and Goto from the Nagasaki University and the University of Tokyo explored the cooling effect of greenery cover over a building. They presented the results of the development and validation of a simulation model and discussed its accuracy in comparison to measured results. It was a one-dimensional non-steady state model developed on CSMP software and was very simplified compared to other simulation models.

While it did predict quite well the thermal behavior of the reference section which was not vegetated, it was only somewhat satisfactory in predicting the behavior of the vegetated model. The correct trends were observed, but the effect of evaporative cooling was overestimated by the authors. Nonetheless, this field-validated simulation model did allow the authors to confirm the leaf area index, which ultimately equates to the shading ratio of the surface and evaporative cooling as the most important cooling mechanisms affecting their model. The authors concluded that increased refinement of variables, like some of the others studies mentioned, would yield more accurate prediction.

Bass and Baskaran from Environment Canada and the National Research Council, respectively, evaluated rooftop and vertical gardens as an adaptation strategy for urban areas in 2003. In it, experiments on vertical shading used shrubs to create a screen rather than a fine façade. The shrubs kept the wall surface behind it at an average of 26.8 °C while the bare wall saw average temperatures of 43 °C. In a separate chapter, the authors then used the software Visual DOE (DOE-2.IE-W83) to develop an approximate energy model allowing them to quantify the impact on cooling energy use. Given that the software did not allow them to 14 directly input a green roof and a green wall as a feature, they used alternative inputs to represent the vegetation. As such, they increased the R-Values of the envelope and increased the shading factor, but they could not replicate evaporative cooling. Results showed even without evaporative cooling, cooling energy could be reduced by 23 %.

In 2004, Carver, Unger, and Parks from the Southern Illinois University used energy modeling to quantify savings from urban shade trees. The software studied only uses the shading effect of trees based on their dimensions and foliage density, effectively ignoring evaporative cooling. Nonetheless, the study presented useful references which indicated that shading an air conditioning unit’s evaporator is very advantageous and that shading on the west side of a home is preferential. In the case of mature trees, the validation of the simulation software showed that it produced results that were accurate within 19 %. Oddly enough, the authors explained that the software under-predicted the influence of young trees by 96 % because they could not accurately identify the size of the canopies and as such used over-conservative estimates.

In 2005, Stec, Van Paassen and Mariaz from the Technical University of Delft in the Netherlands took a different approach to integrating vegetation in building façade in which they modeled a double skin façade with plants inside of it. The double skin was not green, but rather made of glass and the reference building used blinds to control the illumination and heat transmission levels. However, the mathematical model in the experiment saw plants (a creeping vine species) being installed within the double skin façades cavity instead of the blinds to perform the same functions. The results of the validated model offered striking similarities to Green Facades in terms of temperature reduction. Effectively, while the blinds would reach a temperature of over 55 °C, the temperature of the plants would never exceed 35 °C. Interestingly, the plant's capacity to dissipate solar radiation resulted in a reduction of the cooling capacity of approximately 20 % and a reduction of cooling energy consumption of also 20 %.

In 2008 Eleftheria and Jones from Cardiff University used energy modeling to quantify the temperature decrease in urban canyons due to green walls and green roofs in a number of diverse climates. They built and programmed in C++ two-dimensional, dynamic micro-scale models to represent and quantify the thermal activity of urban canyons. Of interest, the authors 15 created a different number of canyons with variations based on urban geometry, orientation and levels of vegetation covering. They applied each of those models to 9 different climates from around the world. Their findings indicated that cooling load reductions of between 32 – 100 % are possible. Those findings assumed that the buildings were entirely covered with vegetation, which is unrealistic. The results for urban canyons also assumed those conditions when presenting optimal reductions and indicated that in hot-arid climates, a reduction of up to 11.3 °C at ground level. Beyond the lack of realism, the results did show trends and patterns which indicated what climates and canyon geometry can benefit the most from the vegetative cover on the walls and roofs.

In 2009, Wong et al. from the National University of Singapore presented discoveries focusing on the impact of vegetated walls on indoor radiant temperature and also on energy consumption of building cooling systems. While the study was specific to Singapore and also focused on a single type of building, it is one of the only studies based on an energy model developed using software called TAS from EDSL. The software was used to grossly determine the impact of the vegetation based on shading and on the reduced conductance of the assembly. The vertical greenery system used in the model was based on a living wall design. The results predicted that significant cooling energy savings, on the magnitude of 74 %, were achievable when the entirety of the building was covered. While it fell short of being a comprehensive and field-validated study, it nonetheless quantified the theoretical impact.

In 2010, Kontoleon and Eumorfopoulou, from the Aristotle University of Thessaloniki in Greece explored the effect of the orientation and proportion of a plant-covered wall layer on the indoor thermal conditions. The authors wanted to refine the understanding the two parameters found in the title by using a thermal network model to conduct simulation and comparison of different configurations. The article was essentially a mathematical demonstration of the conclusions generated by a number of field studies. Of interest, the authors assigned a U-Value of 2 W/(m^2K) to the foliage once it is fully developed. Also, the authors greatly simplified the interactions between incident shortwave solar radiation and the vegetation. As such, they concluded that in general terms about 20% of the solar energy was reflected while the remaining 80% was deemed absorbed and dissipated by the plant's biological mechanism. The authors 16 included photosynthesis, evaporation, transpiration, and breathing of the plants in the absorbed value used in their model.

A study by Ottele, which measured thermal properties of English ivy on a wall in a controlled environment using a hot-box apparatus, discovered that the plant thermal resistance is approximately 0.18 (m^2K)/W (Ottele, 2011). However, experiments done in controlled environments are significantly differ from field measurements. In the field measurements the weather conditions might constantly change throughout a day or even week. These findings were confirmed with a study by Susorova that calculated the effective thermal resistance of a green facades vegetated layer using a model of a vegetated facade that dynamically accounts for changing weather conditions (Susorova, 2013a,b). Plant thermal resistance calculated using week-long experimental data for Chicago varied throughout the day and reached a maximum of 0.14 (m^2K)/W. It shows that the plant layer reduced conductive heat transfer by as much as an additional 10 cm layer of brick or 0.5 cm layer of expanded polystyrene insulation for this climate and for these conditions (ASHRAE Handbook Fundamentals, 2009; Straube, 2005).

Plant effective thermal resistance is the highest when the plant layer covers external walls made of materials with high solar absorptivity (e.g., dark brick walls). Such material surfaces can heat to higher temperatures due to a larger fraction of absorbed solar radiation and when external wall assembly has little or no thermal insulation. The plant thermal insulation effect is less pronounced for reflective and lightly colored facade materials with low solar absorptivity and for well-insulated exterior walls.

While plant elements, such as leaves and stems, have some thermal value (e.g., thermal conductivity of fresh leaves is 0.37 - 0.41 W/(m·K) for Citrus lemon, 0.36 - 0.38 W/(m·K) for Arbutus menziesii, 0.32 - 0.36 W/(m·K) for Eucalyptus globulus, and 0.55 - 0.56 W/(m·K) for Peperomia obtusifoliol), it is insignificant in comparison with the thermal insulation of the whole plant layer (Hays, 1975).

2.2.2 Heating and cooling degree day method

The heating and cooling degree day is simple and well-established approach for estimation of energy requirements, which is based on outdoor air temperature measurements (ASHRAE 2001; Matzarakis and Balafoutis 2004; Christenson et al. 2006). The influence of ambient air temperature fluctuations on energy consumption is directly affecting to the degree-days and has been examined by various researchers (Sailor 2001; Valor et al. 2001; Pardo et al. 2002).

Heating degree-days (HDDs) are calculated by simple subtractions of the outdoor temperature from the base temperature, taking into account only positive values. The base temperature is considered as the outdoor temperature above which there is no need for a building to be heated. Likewise, cooling degree-days (CDDs) are calculated from temperatures above the base temperature. In this case, a base temperature is considered as the outdoor temperature below which a building needs no cooling. The calculation of degree-days can be carried out by a number of ways and timescales (CIBSE 2006) as it appears:

- Mean degree hours, calculated from the hourly temperature record
- Using daily maximum and minimum temperatures
- Using mean daily temperatures
- Direct calculation of monthly degree days from mean monthly temperature and the monthly standard deviation

Studies on energy efficiency in buildings are focusing on weather-related energy consumption. Guntermann (1982) introduced a degree-day formula that can be applied for both industrial and commercial building calculation purposes. The nowadays degree-day method, which is used mainly for residential buildings, uses the peak design heat loss divided by the design temperature difference. McMaster and Wilhelm (1997) in their paper refer that heat units, expressed in growing degree-days (GDDs). These degree-days are frequently used to define the timing of biological processes. Different methods for the calculation of GDD have been proposed (Gilmore and Rogers 1958; Cross and Zuber 1972; Klepper et al. 1984; Russelle et al. 1984; Perry et al. 1986).

Martinaitis (1998) presents a method for the degree-day calculation, by means of the proposed cumulative air temperature duration function for the heating season, by additionally setting the temperature, which determines the limits of the heating season in this function. The results of calculations received under the current climate conditions have been compared with the actual data. The degree-days calculated on the basis of such functions, while analyzing the modes of operation of microclimate conditioning systems and simulating energy requirements for them, are very close to real climate conditions. The method proved to be acceptable and useful in solving energy consumption problems related to the building's life cycle.

Christenson et al. (2006) examined the effect of climate warming on degree-days and building's energy demand in Switzerland. They developed a procedure to estimate HDD and CDD from monthly temperature data that tested and applied to four representative Swiss locations. The findings showed that weather data currently used for building design increasingly lead to an overestimation of heating, and underestimation of cooling demand in buildings and, thus, periodic adaptation and consideration of local modifications, such as urban or topographic effects on temperature are required.

Lowry (1977) discussed the problem of empirical estimation of urban effects on climate. He suggested a working model, where the measured values of weather elements for a given weather type, time period, and station are taken to be linear sums of three components: the "background climate;" the effects of "local landscape," which is the departure of an observed value from background climate, due to landscape effects, such as topography and shorelines; and the effects of "local urbanization," which is the departure of the observed value from background climate, due to urban effects.

Concretely, Tselepidaki et al. (1994), in order to study the variability of the ambient temperature distribution in an urban environment, and the representativeness of a given station, calculated the CDD for three different meteorological stations located in the Greater Athens area (GAA). They proposed that it is possible to calculate the mean daily ambient temperature as a function of the maximum and minimum ambient temperature, using a linear regression formula.

Matzarakis and Balafoutis (2004) calculated HDD by using daily maximum and minimum air temperature and then compared with an experimentally determined base air temperature equal to 14 °C, according to their estimations. These calculations are based on daily weather data from 40 meteorological stations, belonging to the Hellenic National Weather Service.

Papakostas and Kyriakis (2005) determined and presented heating and cooling degree hours for the two main cities in Greece, namely Athens and Thessaloniki, using hourly dry bulb temperature records from the meteorological stations of the National Observatory of Athens and of the Aristotle University of Thessaloniki.

Stathopoulou et al. (2005) studied the relationship between midday land surface temperatures derived from satellite data and mean daily air temperature observations recorded at two standard meteorological stations in Athens City, Greece. The relationship was further used for the calculation of CDD.

Gelegenis (2009) developed a simplified second-degree expression for the approximate estimation of annual HDD to various base temperatures. The only data needed for the application of this relation are the degree-day value to some reference base temperature and the mean annual temperature of the location.

Papakostas et al. (2010) presented in their study the annual values of HDD and CDD for two typical base temperatures, namely 15 °C for heating and 24 °C for cooling, and for the two main cities of Greece (Athens and Thessaloniki), from 1983 to 2002. For the calculations, hourly dry bulb temperature records from the meteorological stations of the National Observatory of Athens and of the Aristotle University of Thessaloniki are used. The decade average (1983 - 1992 and 1993 - 2002) values of the HDD and CDD of the two examined cities are compared, for various base temperatures. The results showed that the average value of HDD of Athens for the decade 1993 - 2002, depending on the base temperature, is decreased from 8 to 22 % compared to the corresponding value for the decade 1983 - 1992. Similarly, the reduction in the Thessaloniki case is found in the range 4.5 - 9.5 %. The difference in the average value of CDD of the decades is more pronounced, the increase ranging from 25 to 69 % for Athens and from 10 to 21 % for Thessaloniki. In order to evaluate the effect of these changes on the energy requirements for heating and cooling of a typical residential building, the latter was calculated using the variable base degree-day method and the data sets of the two decades. The results showed a reduction of the heating energy demand by 11.5 and 5 % and an increase of the cooling energy demand by 26 and 10 %, for Athens and Thessaloniki, respectively.

2.3 Burgas – location and climate

Burgas, sometimes spelled as Burgas, is the second-largest city on the Bulgarian Black Sea coast and the fourth largest city in Bulgaria. Its populations around 211 000 inhabitants, while in the urban areas live around 315 000 people. It is the capital of the Burgas Province and it is an important industrial, transport and tourist center. The city is surrounded by the Burgas three lakes – located at the westernmost point of the city. The city Burgas has a humid subtropical climate with no dry season and also with maritime and continental influences (National Statistical Institute – Bulgaria).

Figure 18 : Map of Bulgaria (Source: METEO, National Institute of Meteorology and Hydrology – BAS)

2.3.1 Climate

Table 4 shows the temperatures, precipitation, humidity and mean monthly sunshine hours in Burgas. It gives a basic idea of the weather conditions of this region. The data shown here is taken from National Institute of Meteorology and Hydrology – BAS and it is a summary data since the year of 2000 until now. On average the warmest month is August and coldest month is January. The total precipitation averages 598 mm and the annual sunshine average is 2468 hours. More detailed data will be shown below, where the daily average temperatures of the year 2015 will be extracted, analyzed and used in the heating and cooling degree calculation.

Table 4 : Climate data for Burgas, Bulgaria (Source: METEO, National Institute of Meteorology and Hydrology – BAS)

Climate Data for Burgas, Bulgaria													
Month	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May.**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**Year.**
Record High	20	23	28	32	35	42.8	41.3	42	38	34	27	24	42
Average High	7.1	8.8	11.6	15.7	21.8	26.6	29.2	29	24.6	19.1	14.1	8.2	18
Daily Mean	4	5.2	8.4	12.0	17.5	22.1	24.5	24.5	20.1	15.2	10.2	4.8	14
Average Low	0.5	1.7	4.4	8.2	13.2	17.5	19.8	19.9	15.6	11.2	6.5	1.9	10
Record Low	-17.8	-14	-12	-4	2	9	14	14	3	-2	-9	-19	17.8
Sunshine hours	105	121	163	196	266	290	322	320	241	183	126	106	2468

Due to the location between three lakes and the Black See the air there is humid. The relative humidity is as high as 85% in the winter months and around 70% in the summer.

2.3.2 Housing stock and energy consumption in Bulgaria

According to the National Statistical Institute in Bulgaria currently are living 7 369 431 people who are living in 3 006 376 different households - this makes 2.4 people per household. Around ¾ of the people or 73.3 % of the households are living in the cities, which is 2 203 007. Around 84% of the households are 90 m^2 and 96.6 % of it is private, just 3.4 % is state-owned property. According to the National Statistics Institute (NSI), more than 50 % of the households are buildings before 1970 and 83.6 % of them are buildings before 1990, which makes them very energy inefficient. On Figure 19 is shown the structure of the housing stock by period of construction until 2011. As it is visible, most of the living spaces are built before 1970 and are in the villages. Those apartment buildings or houses are very poorly insulated, or do not have any insulation at all, therefore it is very difficult to adequately heat them in the winter or cool them in the summer (National Institute of Population and Housing Census in the Republic of Bulgaria).

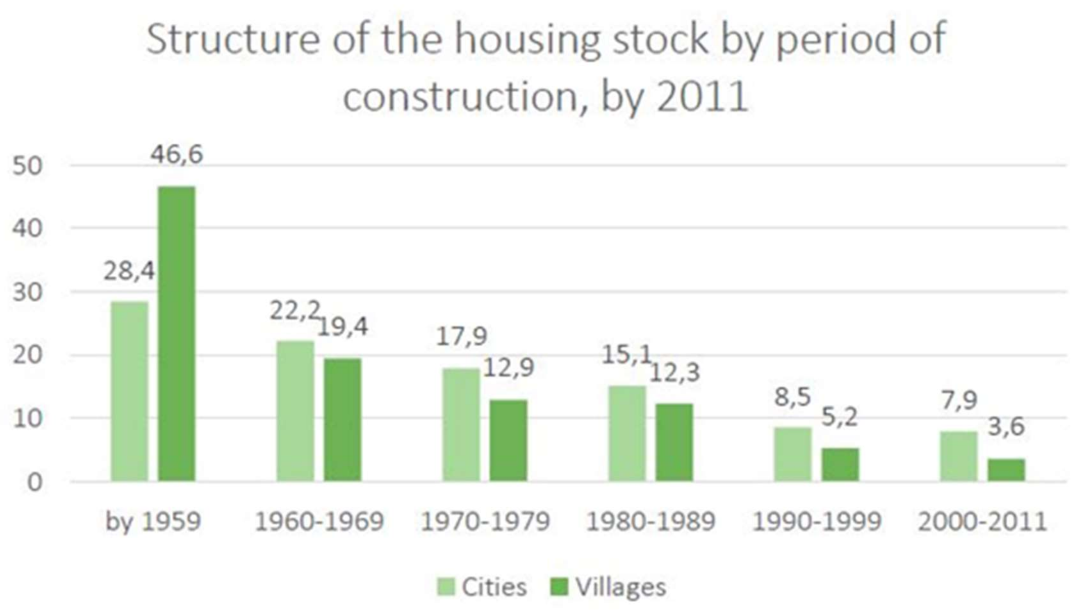


Figure 19 : Structure of the housing stock in Bulgaria (Source: "National situation in the field of fuel poverty" (NSI, National Statistics Institute))

2.3.3 Energy consumption and CO_2 emission in Bulgaria

Despite the fact that Bulgaria has the lowest energy prices in the European Union, the low-income groups have problems with the affordability, not only because of the low income, but mostly because of the inefficient dwellings and upward rebalancing of energy prices. According to the National Statistical Institute for 40 % of the final energy consumption of the households, around 32 % comes from primitive biomass, 9 % from coal, 16 % from district heating and just 2 % from gas. This is highly inefficient and the resulting answer to the high costs for primary energy. The electricity consumption has increased in the past few years, due to the fact that many district heating users changed their heating sources to electrical, in order to keep the energy bills low. This led to a decrease of the district heating users and made the district distribution cost for those who remaining higher and bills unpredictable. A big problem is the undeveloped and unfinished gas supply network. Unlike the electricity prices, the gas prices in Bulgaria are the highest in EU. This is due to this fact that many users who were using gas switched to electricity (NSI, National Statistics Institute).

In Figure 20 shows the energy consumption of households in Bulgarian in the period 2000-2010 which is more or less constant and about two times less than the average in the European Union. During the 2008 - 2009 there is a small reduction in the energy consumption of the households due to the economic crisis in Bulgaria and. Since 2009 the intensity of the private energy consumptions starts growing back upwards (NSI, National Statistics Institute).

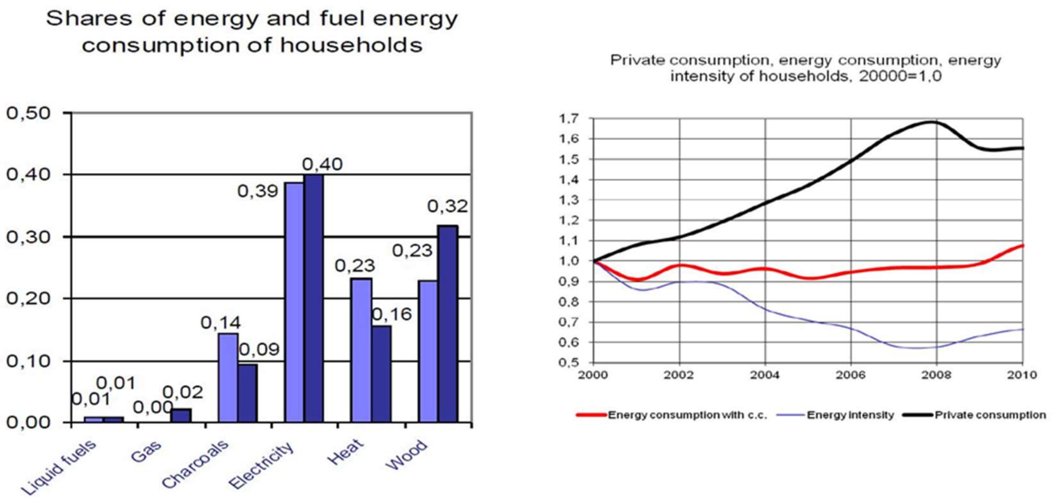


Figure 20 : Shares of energy and fuel consumption of a household in Bulgaria (Source: "National situation in the field of fuel poverty" (Source: NSI, National Statistics Institute))

According to the National Statistical Institute, the average energy consumption in an average household in Bulgaria is as it is shown in the diagram below (Figure 21). Around 50 % of the energy consumption is spent for heating, 19 % for water heating and 15 % for cooling, 10 % for small electrical appliances and 6 % for cooking. That makes around 65 % in total for heating and cooling (NSI, National Statistics Institute).

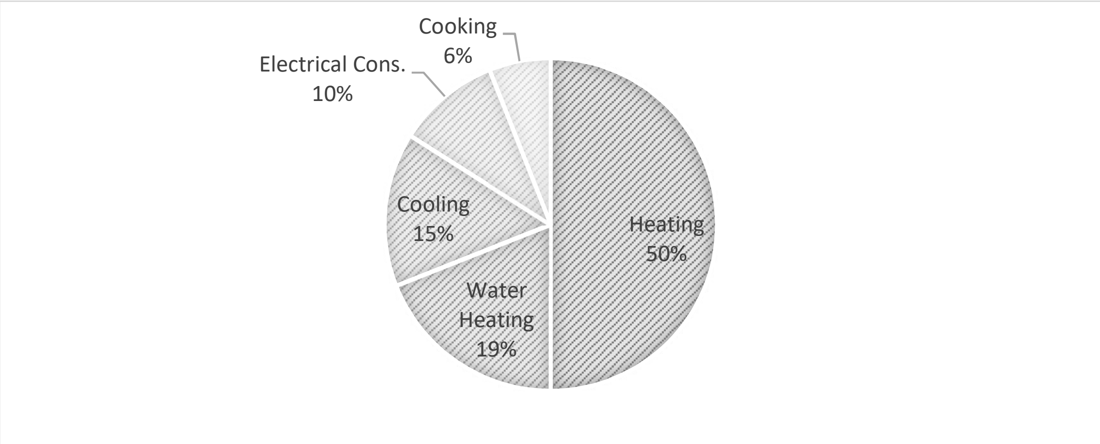


Figure 21 : Energy consumption in a household in Bulgaria (Source: NSI, National Statistics Institute)

Many buildings nowadays in Bulgaria (and all around the globe) transform one type of energy to another in order to fulfill their energy demands, usually heating demands. The most effective way is to have a central system, which will do that for a city, city block or a building but that is not always possible. The effectiveness of the system also depends on the type of fuel used, as well as on the system in general. In Table 5 is shown the most common fuels and systems of heating used. The problem is that these numbers are available only in lab conditions. In the different systems, the values will be different because of the way the systems are designed. The humidity of the air is a factor, but it will not be considered due to the calculation method. The numbers in Table 5 will be taken as it is (NSI, National Statistics Institute).

Table 5 : Energy content per unit of fossil fuels

Type of fossil fuels	**Energy content per unit**	
1 kg of anthracite (4% moisture content)	36 MJ	10 kWh
1 kg coal (5-10% moisture content)	37 MJ	10.3 kWh
1m3 of natural gas	39 MJ	10.8 kWh
1 liter of gasoline	34 MJ	9.4 kWh
1 liter of diesel fuel	40 MJ	11.1 kWh
1 liter of fuel oil	44 MJ	12.2 kWh

As it is stated above the production of one kWh of electricity or any other energy can be made by using different sources. Each of these sources can be defined by a factor that indicates the amount of CO_2 released into the atmosphere in order to produce 1kWh of electrical energy. Some of the sources of energy, which is globally used are coal, oil, natural gas, municipal waste, enriched uranium (for nuclear power plants) and others. Every nation has a mix of power plants that use different energy sources and that is the reason for the different values of CO_2-Emissons (g/kWh) for every country. The numbers below (Figure 22) are calculated for Bulgaria where the mix of fuels used for making the electrical energy is giving 683 grams of CO2 for kWh (NSI, National Statistics Institute).

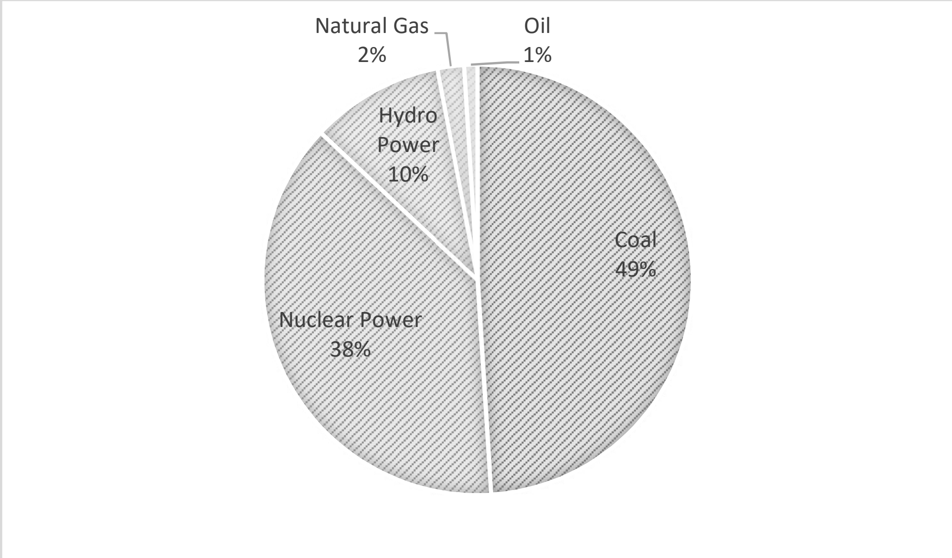


Figure 22: Electrical energy mix in Bulgaria (Source: NSI, National Statistics Institute)

Table 6 : CO_2 emissions per kWh of fossil fuel

Type of fossil fuels	**CO_2 emissions per kWh**
Anthracite (4% moisture content)	354 g/kWh
Coal (5-10% moisture content)	364 g/kWh
Natural gas	202 g/kWh
Gasoline	283 g/kWh
Diesel fuel	311 g/kWh
Central heating (Produced in Bulgaria)	290 g/kWh
Electrical energy (Produced in Bulgaria)	819 g/kWh

2.3.4 Energy prices

Traditionally in the small cities and villages, the heat source for the homes is firewood and coal because they are cheap and commonly used for very long time. In the bigger cities, the situation is slightly different – there is central heating available in some of the cities, there is gas heating available in some of the cities and the electrical energy heating. Those heating sources are used for heating over 98 % of the homes in the bigger cities around the country. In Burgas, the most common heating energy sources are central heating, electrical heating, and gas heating, but many people are switching to electrical energy, because the air-conditioner can be used as a heating unit in the winter and a cooling unit in the summer (NSI, National Statistics Institute).

Table 7 : Average prices of different heat sources in Bulgaria for the year of 2017 (Source: NSI, National Statistics Institute)

heat sources	**Prices**	**Primary energy demand factor**
Central Heating	0.05225 €/kWh	1.3
Gas heating	0.04963 €/kWh	1.1
Electrical heating	0.07959 €/kWh	3.0
Firewood heating	0.04037 €/kWh	1.05
Coal heating	0.03543 €/kWh	1.2

2.4 Thermal comfort

According to the ANSI/ASHRAE Standard 55-2010, thermal comfort is defined as ”that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation”. The thermal comfort is the comfort of the occupants' satisfaction of the surrounding thermal conditions and it is an essential factor when designing a structure that will be occupied by people (ANSI/ASHRAE 2010).

The thermal insulation of a building is one of the requirements for improvement of the indoor climate and the energy consumption. By increasing the temperature in the building in the winter months and decreasing it in the summer, the thermal comfort in the building is improved.

For reaching and sustaining the comfort temperature in a building with low level of thermal insulation – more energy will be needed due to thermal bridges of the structure. If a body in a room has a different surface temperature than the surroundings, heat transfer will happen – from the warmer body to the colder surroundings. High vertical temperature differences more than 3 degrees Celsius should be avoided. Air velocity and relative humidity are also key factors for the thermal comfort. Table 8 shows the requirements of air temperature, walls and floors temperature, relative humidity and air velocity. As it is visible in the diagram below (Figure 23) the thermal comfort is difficult to measure and even more difficult to achieve because it is highly subjective and it is different from a person to person (ANSI/ASHRAE 2010).

Table 8 : Bulgarian comfort standards2017 (Source: NSI, National Statistics Institute)

Room	**Temperature**	**Temp. diff. Walls and floors**	**Relative Humidity**	**Air velocity**
Living room	21	Less than 3 degrees	Summer: 30 – 70 % Winter: < 50 %	Summer: < 0.25 m/s Winter: < 0.15
Bedroom	18			
Bathroom	22			
Toilets	18			
Staircases	16			

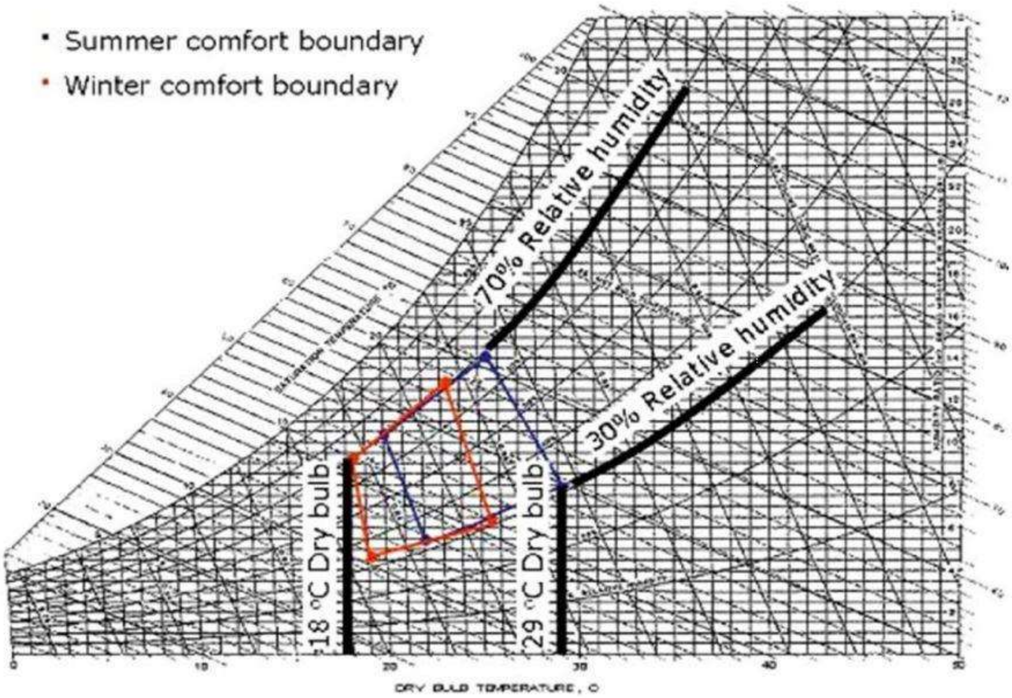


Figure 23 : ASHRAE Standards (Source: ASHRAE book)

3 METHODOLOGY

This chapter presents the methods used for the exploration of green facades potential in the region of Burgas - Bulgaria.

3.1 Modeling method and used data

Different methodologies have been carried out by the researchers in order to investigate the thermal behaviors of green facades and their contribution to reducing the cooling and heating loads in buildings. Those Methodologies were based on theoretical analysis such as field investigation, case study analyses and analyzing the different simulations.

Researches did investigate many parameters that could influence the performance of green facade like: planting density and type, climate and building location.

Those methods have been analyzed in this work in order to find a simple and adequate way of calculating the energy savings due to the application of green façade. As mentioned above, heating and cooling degree days are used to calculate the needed heating and cooling through the year at a given location. Than a couple of steps will be performed in order to understand how much energy will be saved if using green façade as an “external” insulation layer and then to examine which type of heating and cooling will be the most cost effective. At the end of the chapter a life cycle assessment will be performed.

At first the cooling degree days and heating degree days for Burgas, Bulgaria will be calculated based on the daily values of mean air temperature. For heating degree days a threshold of 18 degrees and for cooling degree days a threshold of 25 degrees Celsius have been used. The calculation is data from a local weather station, located at the airport of the city of Burgas just 10 km from the city center. In a next step annual energy consumption for heating and cooling will be calculated in consideration of the overall building losses. That is going to be the U-value of the biding before adding the green façade on top of the existing façade.

Third – the U-value of the façade will be calculated. The R-value of the green façade itself will be taken from the case studies in chapter 2.2.1 where it was calculated and calibrated.

Last but not least the annual cooling energy consumption and annual heating energy consumption needs to be compared. In order to do that they need to be transformed into primary energy consumption.

Based on the previous methodologies’ pros and cons, the methodology to be used is the heating and cooling degree day methodology. The degree day approach is based on the fact that the need of buildings in energy is directly proportional to a difference between mean daily temperature of ambient air and indoor temperature. The indoor temperature is the temperature of below or above which there is a need to spend energy to create comfortable conditions. The temperature data for of the city of Burgas, Bulgaria will be used as a demonstrative case for the calculation of cooling degree days and heating degree days.

3.2 Heating and cooling degree day calculation

At first, the weather data for the city of Burgas was taken from METEO, National Institute of Meteorology and Hydrology – BAS.

As it was mentioned above, there are several different methods of finding the effect of green facades on the thermal energy model of a building. In this case, a relatively simple energy calculation will be performed, based on the heating degree day and the cooling degree day, regarding the availability of the data and the integrating period. The most accurate heating and cooling degree day calculation are by using the hourly data of the outdoor temperature (Ti) and integrating it directly by using the base temperature. Equations (4) and (5) are going to formulate the daily values for the heating degree days and the cooling degree days by just using the hourly measures of the air temperature

$$HDD = \frac{\sum_{i=1}^{k} \quad Thb - T}{24} \qquad \text{if } (Thb - Ti) > 0,\ 0 \leq k \leq 1 \tag{4}$$

$$CDD = \frac{\sum_{i=1}^{k} \quad Ti - Tcb}{24} \qquad \text{if } (Ti - Tcb) > 0,\ 0 \leq k \leq 1 \tag{5}$$

Where Thb is the heating degree day (HDD) base temperature and Tcb is the cooling degree day (CDD) base temperature, Ti is the air temperature. For each month of the year the daily values are added, that way the monthly values of the CDD and HDD is found. The base temperature for the heating degree days is set to 18 degrees Celsius and for the cooling degree days is 26 degrees Celsius. The choice of these temperatures is based on data from the National Energy Agency of Bulgaria.

Table 9 : Heating and cooling degree days for the year of 2015

	Date	Month Number	MAX Temp.	Mean Te	HDD	CDD	MIN Temp
January	1.1.2015	1,00	-2	-4,5	22,5	-29,5	-7
	2.1.2015	1,00	4	-2,5	20,5	-27,5	-9
	3.1.2015	1,00	7	2,5	15,5	-22,5	-2
	4.1.2015	1,00	5	2	16	-23	-1
	5.1.2015	1,00	6	1,5	16,5	-23,5	-3
	6.1.2015	1,00	3	-1	19	-26	-5
	7.1.2015	1,00	-6	-8	26	-33	-10
	8.1.2015	1,00	-3	-7	25	-32	-11
	9.1.2015	1,00	1	-4,5	22,5	-29,5	-10
	10.1.2015	1,00	5	1,5	16,5	-23,5	-2
	11.1.2015	1,00	6	4,5	13,5	-20,5	3
	12.1.2015	1,00	4	2	16	-23	0
	13.1.2015	1,00	7	2,5	15,5	-22,5	-2
	14.1.2015	1,00	6	0,5	17,5	-24,5	-5
	15.1.2015	1,00	7	2,5	15,5	-22,5	-2
	16.1.2015	1,00	7	3,5	14,5	-21,5	0
	17.1.2015	1,00	4	1,5	16,5	-23,5	-1
	18.1.2015	1,00	7	3,5	14,5	-21,5	0
	19.1.2015	1,00	5	4	14	-21	3
	20.1.2015	1,00	7	6	12	-19	5
	21.1.2015	1,00	5	5	13	-20	5
	22.1.2015	1,00	7	5,5	12,5	-19,5	4
	23.1.2015	1,00	8	6	12	-19	4
	24.1.2015	1,00	9	6,5	11,5	-18,5	4
	25.1.2015	1,00	5	5,5	12,5	-19,5	6
	26.1.2015	1,00	6	5	13	-20	4
	27.1.2015	1,00	6	4,5	13,5	-20,5	3
	28.1.2015	1,00	4	3,5	14,5	-21,5	3
	29.1.2015	1,00	6	4,5	13,5	-20,5	3
	30.1.2015	1,00	6	4,5	13,5	-20,5	3
	31.1.2015	1,00	7	7	11	-18	7

Because of the big amount of numbers and information, the data had to be organized and put together in a table. By using Microsoft Excel 2016, all the sensor readings were systematically arranged and by using the formula (4) and formula (5), they were calculated in Excel. At first, the mean daily temperature was calculated by adding all hourly readings together and dividing them by 24 hours. The result is mean temperature for each day of the year. The maximum and minimum daily temperatures were added, in order to calculate heating and cooling degree days, formulas (4) and (5) were used to do that.

Table 10 : Heating and cooling degree days for the year of 2015

Month Number	Month	AvgTemperatures	HDD	CDD
1	January	2,2	490	0
2	February	3,7	401	0
3	March	7,0	340,5	0
4	April	11,7	193,5	0
5	May	19,0	6	0
6	June	24,1	0	12
7	July	26,3	0	42,5
8	August	27,3	0	71
9	September	20,5	10,5	3,5
10	October	14,1	122,5	0
11	November	12,1	178	0
12	December	5,8	377,5	0
			HDD	**CDD**
		Total:	**2119,5**	**129**

On table 9 is shown the raw wheather data from January 2015. After the calculations, it is possible to see, that the total heating degree days are 490 and the total cooling degree days are 0. As it is visible in table 10, for the year of 2015, there are only 4 months with cooling degree days and 9 months with heating degree days.

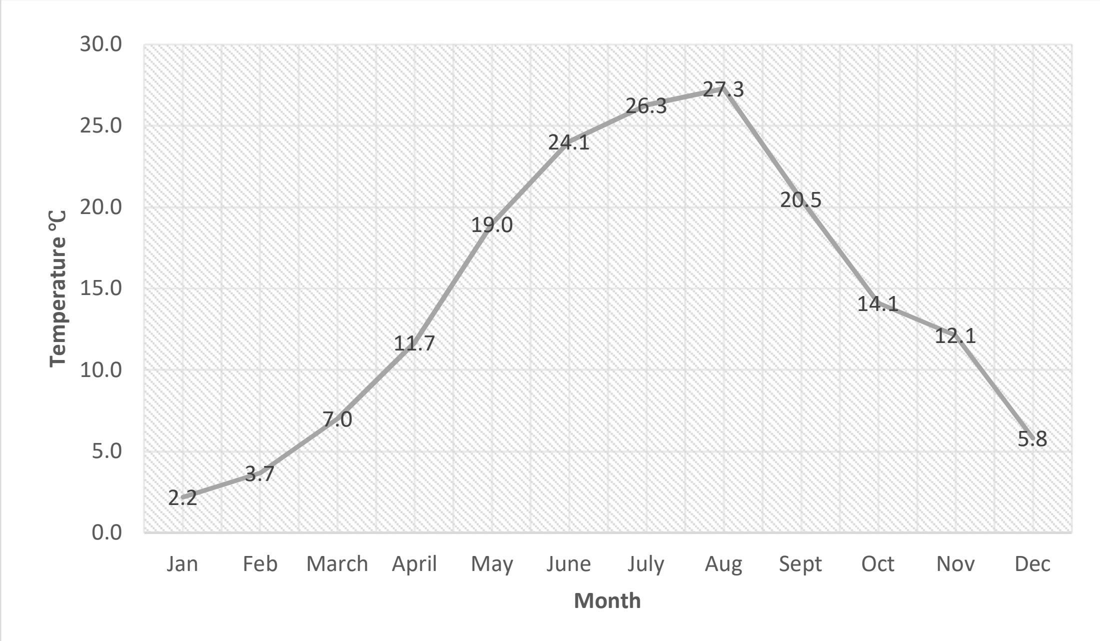


Figure 24: Average monthly temperatures in 2015 in Burgas, Bulgaria

3.2.1 Use case building

For the estimation of heating and cooling demand influence of green façade a hypothetical typical residential apartment building was used. It is 15 m by 20 m, which is equal to a total area of 300 m^2 (two apartments per floor). It is 6 stories high with 2.6 m clear height per floor (40 cm for the floor slabs and suspended sealing) - 18 meters total height. The apartment building is made from prefabricated panes back in the 1960s, 1970s and 1980s.

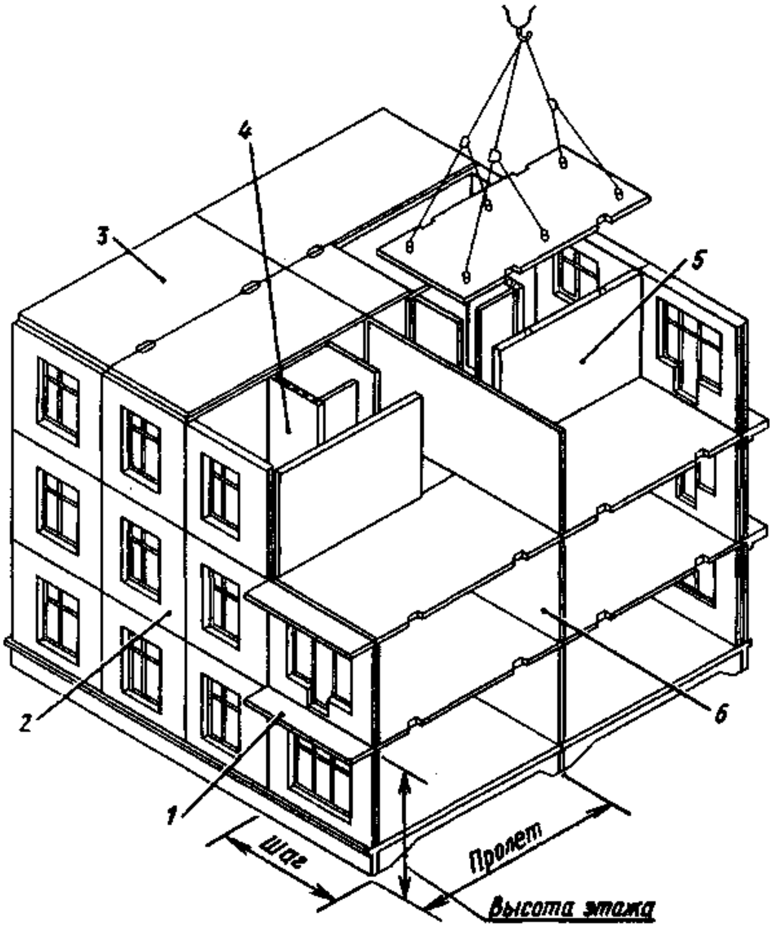


Figure 25 : Typical Bulgarian panel building housing construction build in the 60's (Source: Sandacite)

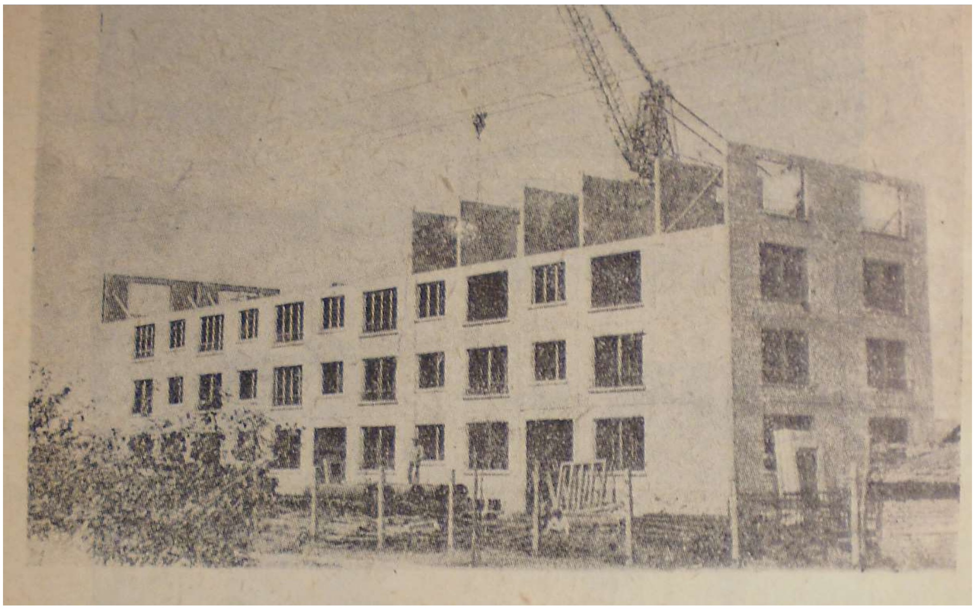


Figure 26 : The first panel building in Bulgaria - photo from 1958 (Source: Sandacite)

3.3 Evaluation of Green façade potential in terms of energy demand

An energy estimation will be calculated for 4 different façade constructions. The scenarios varying in terms of insulation and the application of a green facade. The first scenario is the base case and represents a building were the walls are not additionally insulated. The external wall in this case is made of a 140 mm reinforced concrete panel. The second scenario will be the external wall with 8 cm polystyrene insulation. The external wall in this case will be made out of 140 mm reinforced concrete + 80 mm polystyrene insulation. The third will be the external wall with a green façade only. The forth considers a green façade and polystyrene insulation. In the cases the green facades are virtually applied with estimation of the R-value in accordance to the discovered values from the literature research before. As it is visible in section 2.2 there are many studies about the thermal behavior of green facades. In this study a simplified modeling with R-values only is used instead of a detailed simulation of the green façade and their thermal behavior. In detail it is assumed that the plant layer added to the structure will be 10cm thick. According to Ottele, this vegetated layer has a R-value from 0.14 to 0.17 [m^2K/W]. In this case a R-value of 0.149 [m^2K/W] is going to be used.

Table 11 shows the different scenarios (wall types) with the calculated U-values of the walls.

Table 11 : Simulation scenarios (external wall types) and U-Values

Wall type	**140 mm reinforced concrete**	**80 mm polystyrene insulation**	**100 mm vegetation**	**U-value**
Base case (BC)	Yes	No	No	1.942 W/(m^2K)
Base case + insulation (I-min)	Yes	Yes	No	0.398 W/(m^2K)
Base case + vegetation (GW)	Yes	No	Yes	1.506 W/(m^2K)
Base case + insulation + vegetation (I-max)	Yes	Yes	Yes	0.375 W/(m^2K)

It is assumed that the building is inhabited all year around and continuously heated or cooled during the cold or warm periods. Table 12 presents the main geometry values of the case study building used for the study.

Table 12 : Main geometry values of the use case Building

	Value
Width of the building	15 m
Length of the building	20 m
Height per floor	3 m
Floors	6
Area	300 m^2

Three different building system scenarios will be evaluated for each simulation scenario. The building will be heated with natural gas, central (district) heating and electricity (split units) and will be cooled with air conditioners (split units).

Building System Scenario 1 (BSS1): The building is heated with natural gas and cooled with electrical power (split units). The coefficient of efficiency μ for the natural gas is equal to 0.9.

Building System Scenario 2 (BSS2): The building is heated with central heating and cooled with electrical power (split units). In this case the heating source is district heating and the coefficient of the efficiency is equal to 0.8. That value is different from city to city and actually from address to address due to the heating energy lost in transportation.

Building System Scenario 3 (BSS3): The building is heated with electrical power and cooled with electrical power (split units). The coefficient of efficiency μ is equal to 1 (the maximum) because all the electrical energy can be transformed into heat and the lost due to transport is so little that it is not considered.

For all building system scenarios the heating and cooling energy consumption are transformed into primary energy by formula number (5). This transformation has to be done in order to be able to compare the two energies. In this case electrical energy, natural gas energy and central heating. From the 2015 Order number 7 factor table the conversion factor for gas, central heating and electricity were taken. Gas – 1.1, central heating – 1.3 and electrical energy – 3.0.

3.4 Life cycle comparison of green façades

In this master thesis, the all three living wall systems will be taken into account for the life cycle analyses. The main goal is to define the impact of the raw materials, fabrication, transportation, operation, maintenance, and disposal for the two greening systems compared with a bare wall façade.

Case used for the life cycle comparison:

1. bare wall (without any green surface) will be used as a basis for all measurements
2. green façade with self-climbing plant directly on the wall
3. green façade with self-climbing plant supported by a structure (indirectly to the wall)

3.4.1 Functional unit

At first, the in this product comparison, the functional unit of the comparison will be set. According to the ISO 14040, "the functional unit is a measure of the studied system". The functional unit must be defined, so that the different green façade system while comparison will provide the same services, for a similar duration. As said above the greening systems will be compared with a bare wall. The functional unit in this life cycle analysis will be performed for 1 m^2 of the wall, which will include all the wall layers and materials. The transportation distances will be set from the providers to the companies to Burgas from Plovdiv (the second biggest city in Bulgaria) and that is 252 km. On the figure below it is shown the different layers of the two different green façade solutions, which are going to be compared to the bare wall structure. The bare wall has the same layers as the facades below without the greening system – internal brick, 100 mm of glass wool insulation, 25 mm of air cavity and an external brick, smoothen with cement on the external surface. The first investigated green façade is a direct green façade system. The system consists of a bare wall + 120 mm of vegetation. The second one, on the other hand, consists of the bare wall + 30 mm of air cavity + steel supporting construction and 100 mm of vegetation (as shown in the Figure 28 below).

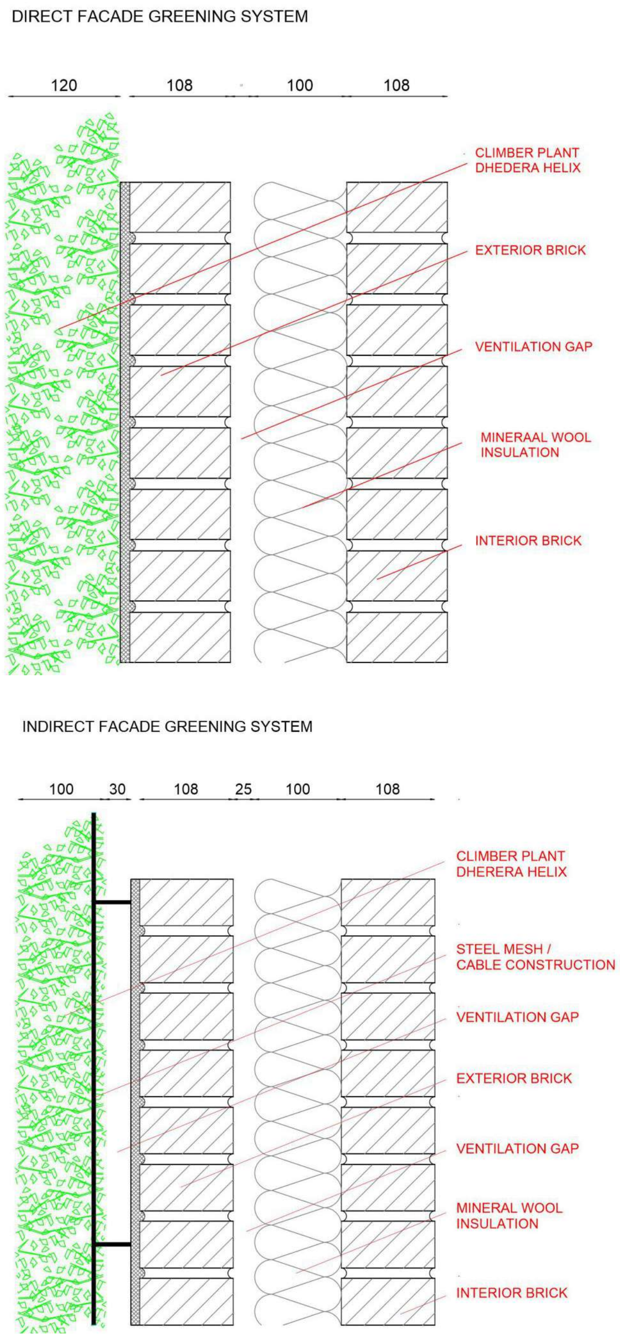


Figure 27 : External wall types (Figure by author)

The results of the life cycle analysis are noted, as the accumulation of the environmental impact over the life of the structure. In order to be as correct as possible, all the maintenance activity, replacements and repairs need to be described. At the end of the assumption, the limitations and the data used in the lifecycle analyses will be discussed.

Data inventory

In order to make a comparison between the three external wall types it is needed to know their structure and materials they are made out of. Table 13 shows that the bare wall (a regular brick wall) is made out of two layers of bricks (internal and external), 100mm of glass wool insulation and an air gap (50 mm wide between the glass wool insulation and the external layer of bricks). The second type (the direct green façade) is based on the first type, but with added vegetation layer. The third type (indirect green façade) is also based on the bare wall with added the structural support layer of the vegetation layer and the vegetation layer itself.

Table 13 : Cases used for life cycle comparison

Components	**1.Bare wall**	**2.Direct green façade**	**3. Indirect green façade**
Internal masonry	Brick (clay)	Brick (clay)	Brick (clay)
Glass wool insulation	100 mm	100 mm	100 mm
Air cavity	50 mm	50 mm	50 mm
External masonry	Brick (clay)	Brick (clay)	Brick (clay)
Air cavity	-	-	50 mm
Structural support	-	-	Steel mesh
Vegetation	-	Hedera helix	Hedera helix

Assumptions

The service life for the analysis is assumed for the duration of 50 years. The life expectancy of the conventional bare wall is assumed to be 50 years, as well as for the facades covered directly and indirectly with climbing plants (Dunnett and Kingsbury, 2004). The life expectancy for the vegetation is 50 years as well as the life expectancy of the steel mesh supporting structure. The green façade system is going to be watered with a self-automated system and due to the complicity of it, the system is not doing to be included in the life cycle analyses. It is also assumed, that each of the plants will need an average of 2 liters of water per day and the Hedera helix is going to be planted with a distance of 250 mm from each other. That means that each linear meter of green façade is going to consist 4 plans, which will need 2 liters per water a day in average. It has to be taken into account that the plants will be supplied with nutrients for their faster growth and this is going to be ones a month.

For both of the green facades, recycling and reuse after the end of the lifespan are going to be performed.

Bare wall material weight, transportation and service life of the component.

Table 14 : Bare wall material weight, transport, and life

Components	**Material**	**Weight (kg/m²)**	**Distance (km)**	**Service life (years)**
Internal masonry	Brick (clay)	155	62	50
Insulation	Mineral wool	4.3	190	50
Air cavity	Cavity	-	-	-
External masonry	Brick (clay)	155	80	50
Mortar	Sand cement water	84	15	50

Direct green facade material weight, transportation and service life of component

Table 15 : Bare wall with direct green facade construction - weight, transport, and life

Components	**Material**	**Weight (kg/m²)**	**Distance (km)**	**Service life (years)**
Internal masonry	Brick (clay)	155	62	50
Insulation	Mineral wool	4.3	190	50
Air cavity	Cavity	-	-	-
External masonry	Brick (clay)	155	80	50
Mortar	Sand cement water	84	15	50
Vegetation	Hedera helix	5.5	30	50

Indirect green facade material weight, transportation and service life of component

Table 16 : Bare wall with indirect facade - weight, transport, and life

Components	**Material**	**Weight (kg/m²)**	**Distance (km)**	**Service life (years)**
Internal masonry	Brick (clay)	155	62	50
Insulation	Mineral wool	4.3	190	50
Air cavity	Cavity	-	-	-
External masonry	Brick (clay)	155	80	50
Mortar	Sand cement water	84	15	50
Air cavity	Cavity	-	-	-
Bolts	Stainless steel	0.015	18	-
Spacer brackets	Stainless steel	0.045	18	-
Structural support	Stainless steel mesh	1.55	18	-
Vegetation	Hedera helix	2.7	30	50

4 RESULTS

Trying to have more and larger green areas in the cities is not a new approach, and there is a significant amount of benefits, especially for larger urban environments where most of the materials used are concrete, steel and glass. Plants in urban areas can have a positive influence on the air quality and the microclimate as well as the noise level in cities. Because of plants - the indoor and outdoor thermal comfort can be improved, greenhouse gases can be absorbed and in some cases, fresh food can be provided for the residents. There are different ways of greening highly dense cities. The most common way is build parks and gardens within the city, but these green areas need a lot of space. The two greening ways that do not imply any extra space usage are the green roofs and the green facades.

The energy saving potential of different façade with and without vegetation was examined by the use of simplified U-Value and heating and cooling degree based calculation. The used case study building will be heated 8 months in the year and cooled for 4 months. The total heating degree days for the year will be 2119.5 and the total of the cooling degree days will be 129.

Four different cases were used for the different façade types – bare case -BC (a wall without any insulation which is just a hypothetical case, because it is not legal to build without insulation in Bulgaria), bare wall with 8 cm polystyrene insulation – I-min (the absolute minimum insulation for a building in Bulgaria), bare wall with green façade - GF and bare wall with 8 cm polystyrene insulation and the green façade structure – I-max. In order to illustrate and show the performance of the building with and without the green façade the cooling and heating loads were calculated. Depending on the wall type (BC, I-min, GF or I-max) the U-value of the envelope of the building would be different it can variate 1.942 $W/(m^2K)$, 0.398 $W/(m^2K)$, 1.506 $W/(m^2K)$ and 0.375 $W/(m^2K)$. Additionally to the façade types three different cases for heating the structures were used (natural gas - BSS1, district heating - BSS2 and electrical power heating - BSS3). The differences in terms of energy are significant when green facades are applied. Additionally, result from a first lifecycle analyses are presented.

Table 17 shows the annual heat loss attributable to conduction through opaque building envelope components.

Table 17: Annual heat loss attributable to conduction through opaque building envelope components.

Façade Type	Heat loss [kWh]	Heat loss per m² [kWh/m²]
BC	134245	74.6
I-min	51778	28.8
GW	110958	61.6
I-max	50550	28.1

The cooling degree days are much less than the heating degree days. Hence related annual cooling demand (see table 18) is much lower compared to the heating loss through opaque building envelope components.

Table 18: Annual cooling demand attributable to conduction through opaque building envelope components.

Façade Type	Cooling demand [kWh]	Cooling demand per m² [kWh/m²]
BC	8170	4.5
I-min	3151	1.8
GW	6753	3.8
I-max	3076	1.7

Table 19 presents the annual heat loss and cooling demand attributable to conduction through opaque building envelope components.

Table 19: Annual heat loss and cooling demand attributable to conduction through opaque building envelope components in the heating and cooling season.

Façade Type	Heat loss and cooling demand [kWh]	Heat loss and cooling demand per m² [kWh/m²]
BC	142415	79.1
I-min	54929	30.5
GW	117711	65.4
I-max	53626	29.8

4.2 Energy saving results

Green walls can contribute towards cooling energy savings in buildings, but the reduction in energy use greatly varies depending on multiple environmental factors and building geometry and materials. It is not expected that green walls are the whole solution to reducing building energy consumption, but it is a step towards that. However, the greatest reduction in cooling loads and energy consumption can be achieved when the use of green walls in buildings is combined with other energy-efficiency measures like thermal insulation. As it is visible from the table and the charsc below, that the energy and money savings are well proven. The differentness between the BS (Building Scenarios) is coming from the different types of heating. On the other hand the differences between the façade types is because of their insulation properties, where the BC case is the worst performing case, because there is no insulation at all and the I-max is the best performing case, where the façade is equipped with 8 cm of polystyrene insulation and 10 cm of vegetation. In the table 20 below it is also visible that annual heat losses attributable to conduction through opaque building envelope components with base case façade type is around 5 times more expensive and produces around 5 times more CO_2 than the I-max façade type. It is also visible that the difference between the I-min and the GW quite big. Having in mind that these results are based on estimations and things like humidity and wind resistance were not taken into consideration.

Table 20: Annual heat loss and cooling demand attributable to conduction through opaque building envelope components, related cost and CO_2 emissions for all facade types and BSS cases.

Façade Type	**Heat loss per m²** [kWh/m²]	**Cost** [€/m²]	**CO_2** [kg/m²]
Building System Scenario 1			
BC	82.0	4.1	16.6
I-min	31.6	1.6	6.4
GW	67.8	3.4	13.7
I-max	30.9	1.5	6.2
Building System Scenario 2			
BC	97.0	5.1	28.1
I-min	37.4	2.0	10.8
GW	80.4	4.2	23.2
I-max	36.5	1.9	10.6
Building System Scenario 3			
BC	223.7	17.8	183.2
I-min	86.3	6.9	70.7
GW	184.9	14.7	151.5
I-max	84.3	6.7	69.0

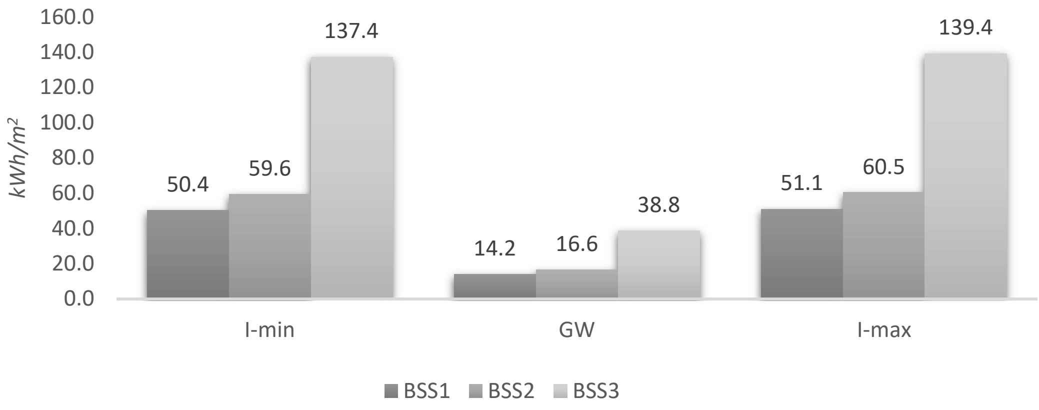


Figure 28 : Yearly energy savings in kWh/m² for the different building scenarios and façade types compared to the Base Case.

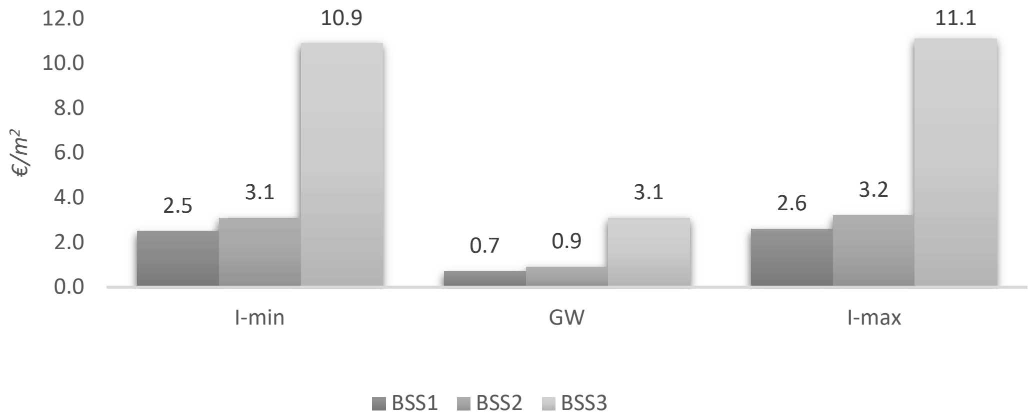


Figure 29 : Yearly cost savings in €/m² for the different building scenarios and façade types compared to the Base Case.

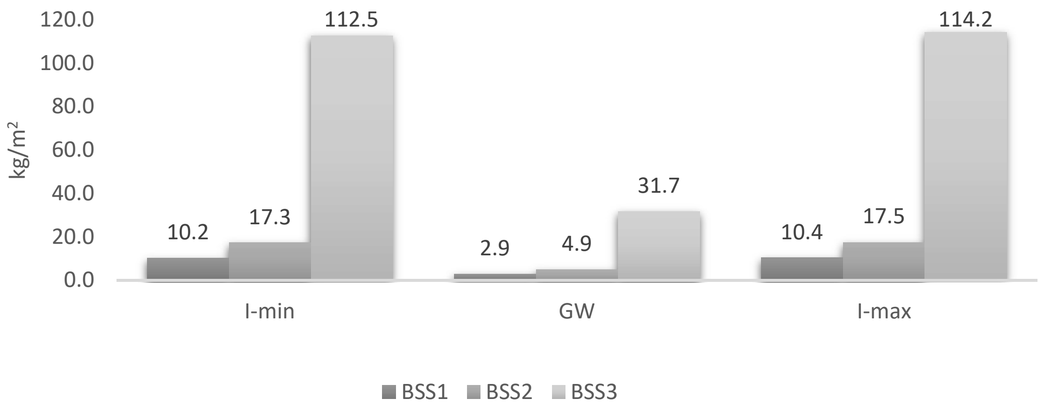


Figure 30: Yearly CO_2 emissions savings in kg/m² for the different building scenarios and façade types compared to the Base Case.

4.3 Concept evaluation of direct and indirect green facades based on lifecycle analyses

After performing the evaluation of lifecycle analysis for direct green façade and indirect green façades, the results are going to be discussed. Global warming, human toxicity, and water toxicity are the environmental profiles that are going to be showing the results. As it is visible below, there is a substantial difference between the indirect greening system and the bare wall. The direct greening system has almost the same results as the bare wall, since the only difference from the bare was is having vegetation on top. That means that the supporting structure makes the difference.

Both of the facades showed almost the same results and as we have mentioned before, the only difference is due to the supporting materials. The indirect greening system has a higher impact profile from the direct greening system, because of the use of stainless steel for supporting system. Since the stainless steel is a high-quality material, it could be used for more than the mentioned period of 50 years. Due to this fact, the environmental burden of the indirect green façade structure can be lowered down.

The benefits that can be extracted from the green walls depend on the growth rate of the plants used. In this case for the direct and indirect systems, the full covering of the façade will take more than 10 years depends on the climate, building and the system used (for direct façade construction takes longer than the indirect one). According to Bellomo, 2003, the vertical growth of Hedera Helix is between 0.5 m a year to 1.2 – 1.5 m a year.

5 GENERAL EVALUATION OF GREEN FACADES IN BULGARIAN CLIMATE ZONE

The integration of vegetation in the architecture in the last years has evolved conceptually from a primarily aesthetic design and gardening, to a "vegetated architecture" where the vegetation is a functional element of the building. The idea now is that the green façade has specific functions for the building in relation to energy aspects, acoustic protection, etc.

Facade greening can be a good contribution to urban air and not only. This fact is already known, but not often seen in Bulgaria and around many other countries the world. In addition to creating visual comfort and insulating the urban heat island effect, a vertical vegetation cover could lower the temperature of a facade wall (in the hot and dry summer days), leading to reduced power consumption in air-conditioning and lower outside temperatures (around the façade). Time lag in temperature increase reflected that a vegetated cladding could reduce the potential impact of solar heat that continued to affect the indoor space after sunset. With a vigorous green cover on a facade wall, residents could be benefited by a cooler flat and cheaper electricity bill in addition to the ecological issues of the vertical green panels.

In general, the use of well-designed and managed green facade, can be a useful tool to achieve a passive thermal control of buildings, with the consequent energy saving. This can happened in four ways, often related to each other - thermal insulation, interaction with solar radiation (shade), evaporative cooling, and variation of the wind on the building. The parameters commanding these mechanisms are summarized in Table 18.

Table 21 : Parameters that affect the operation of the plant on the building façade

	Temperature reduction	**Shading and insulation**	**Evaporative cooling**	**Variation of the wind on the building**
Facades	-Density of the vegetation -Effect of the wind -Modification of the air space -Density, moisture content and color	Density of vegetation Number of layers	Type of plant Exposure Climate (dry/humid) Wind speed Moisture of the substrate	Foliage density and penetrability Orientation of the façade Direction and wind speed

There is another important potential of lowering urban temperatures when the building envelope is covered with vegetation. It can be concluded that the hotter and drier a climate is, the greater the effect of vegetation on urban temperatures (because the green façade is moisturizing the air). However, it has been pointed out that also humid climates can benefit from green surfaces, especially when both walls and roofs are covered with vegetation. Green facades benefits can be divided into two scales: public benefit scale and private benefits scale.

Starting with the green facades public benefits:

Table 22 : Green facades public benefits

Area of Impact	**Description**	**Benefits**
Reduce Urban Heat Island Effect	The temperature raise in urban areas caused by the vegetation with pavements, buildings and other structures necessary to accommodate results in the conversion of sunlight to heat. Vegetation cools buildings and the surrounding area through the processes of shading, reducing reflected heat and evapotranspiration. Slows down the wind around the building and also absorbs the noise.	Promotes natural cooling Processes -Reduces ambient temperature in urban Areas -Breaks vertical air flow which then cools the air as it slows down -Shading surfaces/people -Slows down the wind speed and lowers down the noise. That way it makes the streets more comfortable.
Improved Exterior Air Quality	Elevated temperatures in modern urban environments with increasing numbers of vehicles, air conditioners and industrial emissions have led to a rise in nitrogen oxides (NOx), sulphur oxides (SOx), volatile organic compounds (VOCs), carbon monoxide (CO) and particulate matter.	-Captures airborne pollutants and atmospheric deposition on leaf surfaces. -Filters noxious gases and particulate matter. -Moisturizes the air
Aesthetic Improvement	Green walls provide aesthetic variation in an environment in which people carry out their daily activities. Numerous studies have linked the presence of plants to improved human health and mental wellbeing.	-Creates visual interest -Hides / obscures unsightly features -Increases property values -Provides interesting freestanding structural elements -Protects the buildings from vandalism (graffiti)

Following with the Green facades private benefits:

Table 23 : Green facades private benefits

Area of Impact	**Description**	**Benefits**
Improved Energy Efficiency	Improves thermal insulation capacity. The extent of the savings depends on factors such as climate, distance from sides of buildings, building envelope and density of plant coverage. This can impact both the cooling and heating.	- Traps a layer of air within the plant mass - Limits movement of heat through thick vegetation mass. - Reduces ambient temperature via shading and plant processes of evapotranspiration. - May create a buffer against the wind during the winter months - Interior applications may reduce energy associated with heating and cooling outdoor air for indoor use.
Building Structure Protection	Buildings are exposed to the weathering elements and over time some of the organic construction materials may begin to break down, as a result of contraction and expansion shifts due to freeze thaw cycles and UV exposure	-Protects exterior finishes from UV radiation, the elements, and temperature Fluctuations that wear down materials. - May benefit the seal or air tightness of doors, windows, and cladding by decreasing the effect of wind pressure.
Improved Indoor Air Quality	For interior projects, green walls are able to filter contaminates that are regularly flushed out of buildings through traditional ventilation systems. The filtration is performed by plants, and in the case of bio filtration, micro-organisms.	- Captures airborne pollutants such as dust and pollen. -Filters noxious gases and other building elements
Noise Reduction	The growing media in living wall systems will contribute to a reduction of sound levels that transmit through or reflect from the living wall system. Factors that influence noise reduction includes the depth of the growing media, the materials used as structural components of the living wall system, and the overall coverage.	
LEED	Green walls contribute directly to achieving credits, or contribute to earning credits when used with other sustainable building elements.	
Marketing	Improved aesthetics may help to market a project and provide valuable amenity space	

Green walls are a key component of living architecture and they will become increasingly important fixtures in our cities in the years to come. Green wall technologies provide a wide range of options for designers who are interested in using the building envelope to accomplish multiple objectives and to provide new free standing design features on the interior and exterior of buildings. The use of plants to alleviate the urban heat island effect and to improve the quality of the surrounding environment is becoming a key design consideration in modern building developments, where facades vegetation is emerging as an element of architectural composition and design to take into account the architecture and urbanism today, given the improved environmental effects which it produces.

Extending the plant or greenery onto the building façade has shown potential in improving air quality and reducing surface temperature in the built environment. The changes of carbon dioxide, carbon monoxide, temperature and relative humidity are found to be significant according to area with and without green walls. Recommendations There are several suggestions that are recommended to be implemented in designing for green facades as to improve the ambient and thermal condition. Plants and vegetation should be introduced extensively yet carefully on the building façade in the urban area. Selection of plants should consider their natural supporting mechanism and adaptability harsh environment. Plants and vegetation implemented on the urban façade should be located accordingly as to receive full sunlight in the highest amount of time possible.

Maintenance of plants introduced on the vertical plane in the urban area should be considered, as the plants will need sufficient watering and also regular trimming to prevent hazards. High relative humidity will offset thermal comfort especially when the temperature is high and no wind to overcome heat discomfort. Therefore it is important to consider the location of the green wall in enclosed areas, as it will affect the temperature as well as humidity.

6 Conclusion

The aim of this master thesis was to examine the application possibility and energy reduction of green façades on existing buildings in the local climate in Burgas, Bulgaria. Green facades as structures can be made out of different constructions and “greening material”, three different types of green facades were examined and compared to select the one, which is fitting best to the Bulgarian climate and building types. Then the local energy situation was examined and the type of fuels used for heating were compared. The prices for heating and cooling were extracted together with the resulting primary energy demand estimate differences in energy demands and costs between normal and green facades. The environmental impact of the different energy sources was considered based on related CO_2 emissions.

The application of green façade improves increases the thermal insulation of the façade and has the capability to improve the building's thermal performance. In detail, four different façade setups were examined (bare wall, bare wall with 8 cm polystyrene insulation, bare wall with vegetation layer and bare wall with the polystyrene insulation and vegetation layer). Also three different types of heating were reviewed and compared. The calculation results showed clearly that the lowest energy consumption for heating and cooling occurs for the case with thermal insulation and green façade. The differences of annual heat loss attributable to conduction through opaque building envelope components for a building insulated with 8 cm of polystyrene or with 8 cm of polystyrene and green facade were not very significant. The obtained results showed that green facade could reduce the energy demand in a considerable but much lower amount that a thermal insulation layer (8 cm EPS).

Due to its materials properties the green façade concept also offers additional advantages. Some of them are protection from graffiti, facade protection from the UV light coming from the sun, wind speed reduction and noise reduction. Green facades, when well designed and well maintained can increase the property value and decrease the property costs. However, when planning to equip green façade existing building it is crucial to check the plaster or prepare them for the additional load of the green structure.

This research was using a simply energy consumption calculation based on heating and cooling degree days and considered the transmission loses of opaque elements only. Future research could additionally analyze the impact of a green facade on building performance in combination with green roofs.

7 LIST OF FIGURES

8 LIST OF TABLES

REFERENCES

Akbari H., Matthews D., Seto D. 2012. *The long-term effect of increasing the albedo of urban areas.*

Akbari H, Rose LS (2001a) *Characterizing the fabric of the urban environment: a case study of metropolitan Chicago, Illinois.* Lawrence Berkeley National Laboratory Report LBNL-49275, Berkeley, CA

Akbari H, Rose LS (2001b) *Characterizing the fabric of the urban environment: a case study of Salt Lake City, Utah.* Lawrence Berkeley National Laboratory Report No. LBNL-47851, Berkeley, CA

Alaidroos A., Krarti M., 2015. *Optimal design of residential building envelope systems in the Kingdom of Saudi Arabia*. Energy and Buildings

Alexandri, E., Jones, P. 2008. *Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. Building and Environment* 43(4) 480-493.

Alexandri, E.; Jones, P. *Developing a one-dimensional heat and mass transfer algorithm for describing the effect of green roof on the built environment: Comparison with experimental results.* Build. Environ. 2007, 42, 2835–2849.

Alexandri, E., Jones, P., (2006) *Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates*

American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. (ASHRAE). (2007). ASHRAE Handbook: *Heating, Ventilation & Air-Conditioning Applications.* Atlanta: ASHRAE Inc.

Bass, B., & Baskaran, B. (2003). *Evaluating rooftop and vertical gardens as an adaptation strategy for urban areas. Ottawa: National Research Council l- Institute for Research in Construction.*

Boer, den, L, Schroten a., 2007. *Traffic noise reduction in Europe, Report of CE Delft.*

Bribian, I.Z.; Uson, A.A.; Scarpellini, S., 2009:. *Life cycle assessment in buildings: State-of-the-art and simplifyed LCA methodology as a complement for building certification Ignacio.* Build. Environ. 44: 2510-2520

Bruse, M., & Fleer, H. (1998). *Simulating surface–plant–air interactions inside urban environments with a three-dimensional numerical model. Environmental Modeling and Software,* 373-384.

Burklein, C. (2012, January 9). *Sustainable travel: Vienna is home to the first hotel with a zero energy balance.*

Carver, A., Unger, D., & Parks, C. (2004). *Modeling energy savings from urban shade trees: An assessment of the CITYgreen energy conservation module.* Environmental Management, 650-655.

Carver, C. S. (1998). *Resilience and thriving: Issues, models, and linkages.* Journal of Social Issues, 54, 245-266.

Chang, W., Nazaroff, W., Price, P., Sohn, M., & Gadgil, A. (2005). *Analyzing a database of residential air leakage in the United States.* Atmospheric Environment, 3445-3455.

Cheng, C., Cheung, K., & Chu, L. (2010). *Thermal performance of a vegetated cladding system on façade walls.* Building and Environment, 1779-1787.

Christenson, S. L. (2006). School completion. In G. Bear, and K. Minke (Eds.), *Children's needs III*

Christenson, S. L., & Anderson, A. R. (2002). Commentary: *The centrality of the learning context for students' academic enabler skills.* School Psychology Review, 31(3), 378 – 393.

Djedjig, R.; Ouldboukhitine, S.; Bélarbi, R.; Bozonnet, E. *Development and validation of a coupled heat and mass transfer model for green roofs*. Int. Commun. Heat Mass Transf. 2012, 39, 752–761.

Dobbelsteen, van den, A., Alberts, K., 2001. *Milleu effecten van bouwmaterialen, duurzaam omgaan met grondstof.*

Eleftheria, A., & Jones, P. (2008). *Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates.* Building and Environment, 480-493.

Eumorfopoulou, E. A. and K. J. Kontoleon. 2009. *Experimental approach to the contribution of plant-covered walls to the thermal behavior of building envelopes*. Building and Environment 44: 1024-1038.

Ismail, M. 2013 *Quiet environment: Acoustics of vertical green wall systems of the Islamic urban form.* Frontiers of Architectural Research, 2 (2): 162-177.

Francis, R., Lorimer, J. 2011 Urban reconciliation ecology: *The potential of living roofs and walls.* Journal of Environmental Management, 93 (6): 1429 – 1437.

Gelegenis JJ (2009) *A simplified quadratic expression for the approximate estimation of heating degree-days to any base temperature*. Appl Energy 86:1986–1994

Hays, H. 1975. "The Marketing and Storage of Food Grains in Northern Nigeria." *Samaru Miscellaneous Papers* no. 50, Ahmadu Bello University, Zaria, Nigeria.

Hermy M., Schauvliege M. & Tijskens G.; Groenbeheer – een verhaal met toekomst; Velt i.s.m. afdeling Bos & Groen, Berchem, 2005

Hendriks, P. H. J. (1999). *Why share knowledge? The influence of ICT on the motivation for knowledge sharing.* Knowledge and Process Management, 6(2), 91-100.

Holm D., "Thermal improvement by means of leaf cover on external walls – a simulation model" Energy Build, 14 (1989), pp. 19-30

Huang, Y. and R. A. Walkling, 1987, *Target abnormal returns associated with acquisition announcements: Payment, acquisition form and managerial resistance.* Journal of Financial Economics 19, 329-349

O'DEA, K., and HOLM, J. 1985. *Rate of starch hydrolysis in vitro as a predictor for metabolic responses to complex carbohydrate in vivo*. Am. J. Clin Nutr. 34:1991-1993.

Jim, C.Y., *"Estimating heat flux transmission of vertical greenery ecosystem"* Ecol Eng, 37 (2011), pp. 1112-1122

Kontoleon, K., & Eumorfopoulou, E. (2010). *The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone.* Building and Environment, 1287-1303.

Krusche P. & M., Althaus D. & Gabriel I.; *Ökologisches Bauen – Herausgegeben vom Umweltbundesamt;* Bauverlag GmbH, Wiesbaden & Berlin, 1982

Köhler, D. B., *Zusammenhänge zwischen Bindung, Erkundung und Autonomie*

Kolokotroni, M., Zhang, Y., & Watkins, R., 2007. *The London Heat Island and building cooling design.* Solar Energy, Vol. 81, No. 1, pp. 102– 110.

Kolokotroni, M., Davies, M., Croxford, B., Bhuiyan, S., & Mavrogianni, A. 2010. *A validated methodology for the prediction of heating and cooling energy demand for buildings within the Urban Heat Island:* Case-study of London. Solar Energy, Vol. 84, No. 12, pp. 2246–2255.

Krarti, M., "*Optimal Insulation for Ice Rink Floors*", Energy and Buildings, In Press, Available online 25 September, (2015)

Krarti, M., and A. Hernandez-Guerrero, *"Energy efficiency optimization of new and existing office buildings in Guanajuato, Mexico",* Sustainable Cities and Society, 17, 132-140, (2015).

Liao, Z., & Niu, J. (1999). *Study on the thermal function of ivy-covered walls.* Hong Kong: The Hong Kong Polytechnic University.

Liao SJ., *Beyond perturbation: introduction to the homotopy analysis method,* Boca Raton: Chapman & Hall/CRC Press, (2003)

Marini C, De Santis F, Sacco S, Russo T, Olivieri L, et al. (2005) *Contribution of atrial fibrillation to incidence and outcome of ischemic stroke: Results from a population-based study.* Stroke 36: 1115-9.

Matzarakis, A. Balafoutis, C. (2004). *Heating Degree-Days over Greece as an Index of Energy Consumption.* International Journal of Climatology, 24: 1817–1828

Mazzai, U., Peron, F., Romagnoni, P., Pulselli, R., Basianoni, S. 2013 *Experimental investigation on the energy performance of Living Walls in a temperature climate.* Building and Environment, 64: 57 – 66.

McPherson JM. 1988. *Voluntary affiliation: a structural approach. In Continuities in Structural Inquiry,* ed. PM Blau, RK Merton, pp. 325–52. London: Sage

McPherson, E. G., *"Impact of vegetation on residential heating and cooling"* Energy Build, 12 (1988), pp. 41-51

Middelie, G., 2009. *Minor steedelijke beplanting.*

Martinaitis V., (1998), *Analytic calculation of degree-days for the regulated heating season*.

Niu, Z. and Wang, C., *A one-step optimal homotopy analysis method for nonlinear differential equations, Communications in Nonlinear Science and Numerical Simulation*, 15, (2010), 2026 - 2036.

Olofsson T., Lamberts R. (2004). *Rating the energy performance of buildings.*

Ottele, M., Perini, K., Fraaij, A., L., A., Haas, E., M., Raiteri, R. 2011 *Comparative life cycle analysis for green facades and living wall systems. Energy and Buildings*, 43 (12): 3419-3429.

Ottelé, M., Mir, M.A., Fraaij, A.L.A., Bohemen, H.D., E.M. Haas. (2011). *An experimental approach to investigate the thermal behavior of vertical greened façades of buildings.* Submitted to Journal of Urban Ecosystems 2011

Papakostas K, Kyriakis N (2005) *Heating and cooling degree-hours for Athens and Thessaloniki, Greece*. Renew Energy 30:1873–1880

Papakostas K, Mavromatis T, Kyriakis N (2010) *Impact of the ambient temperature rise on the energy consumption for heating and cooling in residential buildings of Greece.* Renew Energy 35:1376–1379

Pardo, A., Meneu V. & Valor E. (2002). *Temperature and seasonality influences on Spanish electricity load.* Energy Economics 24: 55-70.

Perini, K. Ottele, *Greening the building envelope, façade greening and living wall systems*

Perini, K., Ottele, M., Fraaij, A. L. A., Haas, E. M., Raiteri, R. 2011 *Vertical greening systems and the effect on air flow and temperature on the building envelope.* Building and Environment, 46 (11): 2287-2294. Internet.

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

Peck, S. W. and C. Callaghan (1999). *Greenbacks from Green Roofs:* Forging a New Industry in Canada, CMHC/SCHL.

Perini, K., Rosasco, P. 2013 *Cost-benefit analyses for green facades and living wall systems.* Building and Environment, 70: 110-121.

Perini, K., 2013 *Retrofitting with vegetation recent building heritage applying a design tool – the case study of a school building.* Frontiers of Architectural Research 2 (3) 267-277.

Pirez, G., Rinkon, L., Vila, A., Gonzalez, J., Cabeza, L.2011 *Behavior of green facades in Mediterranean Continental climate.* Energy Conversion and Management, 52 (4): 1862-1867

Perez, G., Rincon, L., Vila, A., Gonzalez, J., Cabeza, L. *Energy efficiency of green roofs and green facades in Mediterranean Continental climate.*

Peck, S. W. and C. Callaghan (1999). *Greenbacks from Green Roofs:* Forging a New Industry in Canada, CMHC/SCHL

Peck, S. W., M. Kuhn, et al. (2003). *Design Guidelines for Green Roofs, Ontario Association of Architects*; CMHC.

Poolman JT, Peeters CC, van den Dobbelsteen GP. *The history of pneumococcal conjugate vaccine development: dose selection.* Expert Rev Vaccines. 2013;12(12):1379–94.

Sobrino,J. A., Jiménez-Muñoz, J. A**.,** L. *Paolini Land surface temperature retrieval from LANDSAT TM 5 Remote Sensing of Environment*, 90 (2004), pp. 434-440

Sailor, D.J.; Elley, T.B.; Gibson, M. *Exploring the building energy impacts of greenroof design decisions—A modeling study of buildings in four distinct climates*. J. Build. Phys. 2011, 35, 372–391.

Sailor, D.J. & Muñoz J.R. (1997). *Sensitivity of electricity and natural gas consumption to the climate in the USA - Methodology, and results for eight states.* Energy 22: 987-998

Sailor, D.J. (2001). *Relating residential and commercial sector electricity loads to climate – evaluating state level sensitivities and vulnerabilities.* Energy 26: 645-657.

Sullivan, B., J. Lischkoff, John F. Straube, and M. VanDusen. *"CMHC Exterior Insulation and Finish System (EIFS) Best Practise Guide."* CMHC, Ottawa, ON, 2004.

Straube, John F. *"Moisture Properties of Plaster and Stucco for Strawbale Buildings."* Canada Mortgage and Housing Corporation, June 2000.

Stec, W., Van Paassen, A., & Maziarz, A. (2005). *Modeling the double skin façade with plants.* Energy and Buildings, 419-427.

Susorova, I., Angulo, M., Bahrami, P., Stephens, B. 2013 *A model of vegetated exterior facades for evaluations of wall thermal performance.* Building and Environment 67: 1-13.

Takakura, T., Kitade, S., & Goto, E. (2000). *The cooling effect of greenery cover over a building.* Energy and Buildings, 1-6.13

Valor, E., Meneu V. & Caselles V. (2001). Daily *air temperature and electricity load in Spain.* J Appl Meteor 40: 1413-1421.

Wong N.H. et al.; *Acoustics evaluation of vertical greenery systems for building walls;* Building and Environment, 2010, 45: p. 411-420

Wong, N., H., Tan, A., Y., K., Chen, Y., Sekar, K., Tan, P., Y., Chan, D., Chiang, K., Wong, N., W. 2010 *Thermal Evaluation of vertical greenery systems for building walls.* Building and Environment, 45 (3): 663-672.

Wong, N., Tan, A., Tan, P., & NC, W. (2009). Energy *simulation of vertical greenery systems.* Energy and Buildings, 1401-1408.

Wong, N.H., Kwang Tan, A.Y. Tan, P.Y.,Chiang, *"Energy Simulation of Vertical Greenery Systems,"* Energy and Buildings 41 (2009) 1401–1408.

Wong, N.H., Kwang Tan, A.Y. Tan, P.Y.,Chiang, *"Thermal Evaluation of Vertical Greenery Systems for Building Walls,"* Building and Environment 45: 3 (2010a) 663–672.

Wong, N.H., Kwang Tan, A.Y. Tan, P.Y.,Chiang,, *"Acoustics Evaluation of Vertical Greenery Systems for Building Walls,"* Building and Environment 45: 2 (2010b) 411–420.

Wong, N.H., A.Y. Kwang Tan, P.Y. Tan, A. Sia, and N.C. Wong, *"Perception Studies of Vertical Greenery Systems in Singapore,"* Journal of Urban Planning and Development 136: 4 (2010c) 330–338.

Wong, N.H., A.Y. Kwang Tan, P.Y, *"Acoustics evaluation of vertical greenery systems for building walls,"* Build Environ, 45 (2010), pp. 411-420

Wong, N.H., *"Cooling effect of ivy on a wall* Exp Heat Transfer", 12 (3) (1999), pp. 235-245

Yang, H., Kang, J., Choi, M. 2012 *Acoustic effects of green roof systems on a low-profile structure at street level.* Building and Environment, 50: 44 – 55.

U.S. Government Printing Office February 26, 2009, Energy Efficiency in Buildings: Hearing Before the Committee on Energy and Natural Resources, United States Senate, One Hundred Eleventh Congress, First Session, to Provide Recommendations for Reducing Energy Consumption in Buildings

David Bodansky, "Appendix: Energy Units," in The Energy Source Book, Ruth Howes and Anthony Fainberg, editors (New York: American Institute of Physics, 1991).

Handbook of Chemistry and Physics, 77th Edition, 1996-1997, David R. Lide, editor-in-chief (Boca Raton: CRC Press, 1996).

U.S. Department of Energy, Annual Energy Review 1995, Energy Information Administration Report DOE/EIA-0384(95) (Washington, D.C.: U.S. DOE, 1996).

Organization for Economic Co-operation and Development, International Energy Agency, Energy Balances of OECD Countries 1992-1993 (Paris: OECD, 1995).

U.S. Department of Energy, International Energy Annual 1993, Energy Information Administration Report DOE/EIA-0219(93) (Washington, D.C.: U.S. DOE, 1995).

Energy In a Finite World, A Global Systems Analysis, W. Häfele, Program Leader, Report by the Energy Systems Program Group of the International Institute for Applied Systems Analysis (IIASA) (Cambridge, MA: Ballinger, 1981).

GRADAT, 2016. Newsletter about buildings in Bulgarian Cities *http://infrastructure.bg/news/2017/04/26/2960526_zeleni_fasadi_i_detski_ploshtadki_vurhu_pokriva_na/* Accessed 2016.

WEATHERUNDERGROUND, 2016. Weather website https://www.wunderground.com/history/airport/LBBG/2017/9/16/DailyHistory.html Accessed 2016. Accessed 2016.

GROWINGGREENGUIDE, 2016. The University of Melbourne Project http://www.growinggreenguide.org/technical-guide/construction-and-installation/green-walls/ Accessed 2016.

URBANGREENBUILDINGS, 2016. Green Building Association www.urbangreenbuildings.com Accessed 2016.

GREENFACADESYSTEMS, 2016. GFS Architectural Systems http://www.greenfacadesystems.com/wall-panel-systems/4557035882 Accessed 2016.

ZELENAGRADINA, 2016. Website for gardening accessories https://zelena-gradina.com/index.html Accessed 2016.

GARDEN, 2016 National Gardening Association https://garden.org/plants/ Accessed 2016.

APS, American Physical Society sites http://www.aps.org/publications/journals/index.cfm Accessed 2016.

NSI, National Statistics Institute http://www.nsi.bg/bg/node/15000 Accessed 2016.

METEO, National Institute of Meteorology and Hydrology – BAS http://www.meteo.bg/node/13 Accessed 2016.

GREENSCREEN, 2017. Website with green facades information. www.greenscreen.com Accessed 2017.

GARDENIA, 2017. Website with plant information. www.gardenia.net Accessed 2017.

Sandacite, 2017. Website with information about panel buildings. www.sandacite.bg Accessed 2018

GENERATORNOISE, 2018. Website with information about acoustics in Cities. www.acusticblok.com Accessed 2018

PIXELTOTE, 2018. Website with free image downloads. www.pixeltote.com Accessed 2018

ARCHITECTSJOURNAL, 2018. Website with information about different architectural events and news. www.architectsjurnal.co.uk Accessed 2018