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The Vertical Greening Envelope and its Effect on Energy Consumption Efficiency in a Residential Building, Case Study: Twin House, 6th of October City

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Vertical Greening Systems; Energy Consumption Efficiency; Green Envelope; Leaf Area Index

Abstract

Egypt has suffered from Energy problems, especially in the last 10 years, as it transformed from exporter to importer of oil and gas. [1]. The residential buildings consume over 40% of electricity. Moreover, most of this consumption is for using HVAC systems to reach the thermal comfort inside spaces, as it used non-environmental material, which led to maximizing heat gain. The study aims to measure the vertical greening envelope and its variables such as LAI and air gap effect on energy consumption. The research methodology includes reviewing the literature and methods of Vertical greening systems (VGS) and their types, plantations… Etc. and its effect on the buildings' external envelope to achieve maximum energy efficiency. A practical study was carried out by simulating one direction Town House on 6th October, Egypt, every 30° starting from the north using a design-builder simulation program. The research compared the energy consumption of the building's initial case with 12cm concrete bricks and VGS installation with a 60cm airgap. The VGS reduced energy consumption by 19.6:29% in the different installation directions, and 240° SW recorded the highest saving in the case of LAI was 2.0 and to measure the effect of LAI beside the installation orientation the LAI 2.0 compared to LAI 4.0 in 240° SW and the saving has increased to 32.3%. In the case of no airgap, the saving was 29.3% which means that the LAI and air gap distances affected the performance of VGS as the installation direction did.

1. **Introduction**

The building sector (Residential and Services) is responsible for about 33 % of the global energy consumption and one-third of total direct and indirect CO2 emissions, [2] in 2010,

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the total energy consumption was 117 EJ, and 25% of this consumption was consumed by services sub-sector, and the remaining 75% of this energy was consumed by residential sub-sector (Figure 1). Globally, most of the energy consumption is dominated by space heating and cooling. [3]

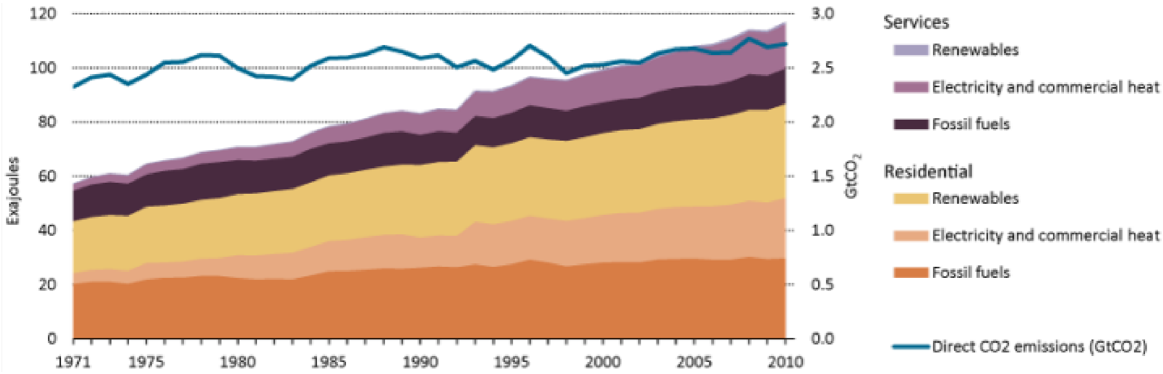

Figure 1: Global building's energy consumption by energy source and direct CO2 emissions [3]

According to that, all countries are targeting to reduce both to minimize the harm of the built environment to the natural environment through “Transition to Sustainable Buildings,” which emphasizes the necessity of implementing priorities in buildings, such as high-performance building envelopes and new strategies to address the energy consumption as 40% of energy consumption expected to be reduced by 2050 through improving the building envelopes. [2] So that, the use of green infrastructures (GI) at an urban scale and especially in buildings has been taken the priority to achieve the targeted energy consumption and CO2 emissions reduction in the built environment. [4]

According to Dover, there are two ways to implement GI techniques in building envelopes to reduce energy consumption and CO2 emissions; Green Roofs and Vertical greening systems (VGS) also; he defined the concept of VGS as growing plants on the unused space on walls. [5] As The building's envelope is considered as a thermal barrier between the exterior and interior of the building, it is considered as one of the most essential elements in achieving thermal comfort as it has a key role in reducing the energy consumption that is needed to heat and cool spaces. According to that, insulating the building envelope with natural materials such as plants is important for making a cooler building envelope which does both reducing the heat gain inside the spaces and reducing the reflected heat radiating into the surrounding environment to minimize the harmful impacts of the building and reduce the urban heat island. [6]. Vertical Greening System (VGS) plays a vital role to improve the energy performance of buildings [4] as it has many environmental, social, and economic benefits, such as the other types of green infrastructure, VGS can decrease the building’s internal temperature as it creates an air layer which is considered as an insulating layer that protects the building from the direct and reflected solar radiation [6].

There are a lot of previous studies which were interested in using VGS to increase energy saving in buildings, such as; Olivieri et al. studied the importance of the thickness of the vegetation envelope and its effect on the energy performance in a school building in a hot arid climate through using “the Green Facade Optimization” (GFO) methodology which is a parametric method to optimize the VGS effect with taking into considerations the properties of VGS components such as; growing media, irrigation system, evapotranspiration, shading impact… etc. and the results showed that the facade works as a moderately insulated façade. [7] In Larsen et al. study, they used the Energy Plus and Design-Builder software to simulate the effect of green facades, and the objective of this research was to simulate the effect of green walls by using a traditional wall and glazing element with fictitious properties like what in the green facades and the results were promising. [8] Also, Coma et al. compared the green wall thermal performance and the double-skin facades with the bare wall thermal performance in an experimental cubicle house under Mediterranean continental climatic conditions in winter [9]. The results showed that in winter, there was an enormous potential for energy saving, but in summer, there was no observed extra consumption in energy for the evergreen green wall system, and according to that, he studied both the heating and cooling effect of vegetated façade on energy saving and focused on one climate region only. [9]

Recent studies deal with the effect of the green facade in saving energy in both Mediterranean and tropical climate, but there are very limited studies that deals with the using vegetated facades in both cold semi-arid and hot arid climates as according to that the research aims to study the effect of VGS on the energy consumption in both cooling and heating loads in a different orientation to measure its effect and discovered the effect of each installation direction on the energy saving to be able to mention the best direction for Giza, Egypt which located in a hot arid climate. Thus, this paper will be focused on using a plantation to cover the buildings' walls through the following.

- Highlighting the various vertical Greening Systems (VGS) definitions and terms
- Understanding the main types of VGS
- General overview of VGS characteristics, advantages, benefits, maintenance, design consideration… Etc.
- Applying the VGS on a residential unit façade in a different orientation
- Comparing the effect of VGS on energy consumption in each orientation

2. Methods and tools

The Research used two methods to measure the effectiveness of the vertical greening system (VGS) on energy consumption; the first one is the observation study though using the inductive approach to reviewing the literature on VGS and its benefits, consideration, components, maintenance… etc. and the second one is the applied study through Computer simulation using Design-Builder, starts by defining the base case then building a geometry model, and finally set the variables of the study. The first phase of the simulation was the typical base case with a bare wall. Then the second phase was after adding a vegetated facade with a 60 cm air gap and LAI. The research analyses and compares the results of the two phases to determine the most effective installing direction according to the location and weather climate

3. The Vertical Greening Systems as A Component of Green Infrastructure

3.1. Green Infrastructure

Green Infrastructure can be defined as "Planning/strategic approaches that maintain ecological functions at the landscape scale in combination with multifunctional land uses."

(The workshop was held in Brussels in March 2009) GI includes the established green spaces and the new sites, and it should surround and integrate the built environment also, connecting the urban area to its wider rural area. (Natural England, 2009). In 2015, Dover defined the GI as *"Green infrastructure is the sum of an area's environmental assets, including standalone elements and strategically planned and delivered networks of high-quality green spaces and other environmental features including surfaces such as pavements, car parks, driveways, roads and buildings (exterior and interior) that incorporate biodiversity and promote ecosystem services."* [5]

3.2. Vertical Greening Systems – an overview

The term green walls or Vertical greening systems (VGS) describes the vegetation that grows directly or on a separate structural system onto a building's façade. [10]. Green walls are a particularly promising component of green infrastructure (Cameron et al., 2014). They are cost-effective and, if designed properly, will require less human intervention and maintenance over their lifetime (Hunter et al., 2014; Mitsch & Jorgensen, 2003; Mitsch, 2012). While it takes 5 to 15 years for a tree to grow large enough to provide energy savings (McPherson & Rowntree, 1993), vines can cover large spaces in only a few years (Tilley, Price, Matt, & Marrow, 2012). Furthermore, green walls have small footprints compared to trees. Thus, they are a perfect solution for dense urban areas. Indirect green walls are highly robust and customizable, too, because vines can be easily trained to different support structures.

3.2.1. The use of VGS as a type of green infrastructure in building's envelope

The VGS was historically known since Babylon's Hanging Gardens were constructed in 500 BC [11], and according to populations increase. With the shortage of horizontal open spaces for plantations, the use of building facades has appeared again. Using a building's facades not only does not need a horizontal space to be installed but can also overcome all the horizontal vegetation limitations such as prevailing soil conditions, needing a land space for trees, and sub-surface infrastructure. [12, 13]. The VGS provide thermal insulation for building facades, providing shade, and acting as a wind screen and cavity wall. [14] Also, it improves indoor air quality by trapping airborne pollutants. [15] Finally, it considered an effective solution for storm water management and improved the quality of human life.

The most significant factor in the success of VGS installation is climate; if the chosen VGS system and components are suitable for the local climate conditions, higher thermal insulation and energy efficiency will be achieved. In a dry-hot climate, covering the vertical facades with vegetation affects the reducing the urban temperature. Also, in hot-humid climates, the VGS can be effective for urban temperature reduction, especially when both walls and roofs are covered with vegetation, as the greening of vertical surfaces contributes to reducing the solar radiation absorption, which leads to a higher reduction in temperature. So, the hotter and drier the climate, the higher the efficiency of the VGS as well as temperature reduction. This degree of temperature reduction can result in a significant annual saving. [16]

The massive influence of weather conditions must be considered for the potential of VGS regarding saving energy in buildings. In addition, the effect of climate on the building's thermal performance, the effect of weather on the plants' growth, and their physiological responses must also be determined. Thus, the thermal behaviour of the VGS will also depend on weather conditions, which will affect the results. According to much research, the Köppen Climate Classification System can be used to appropriately consider the climate for the vertical greening systems (Figure 2). [12]

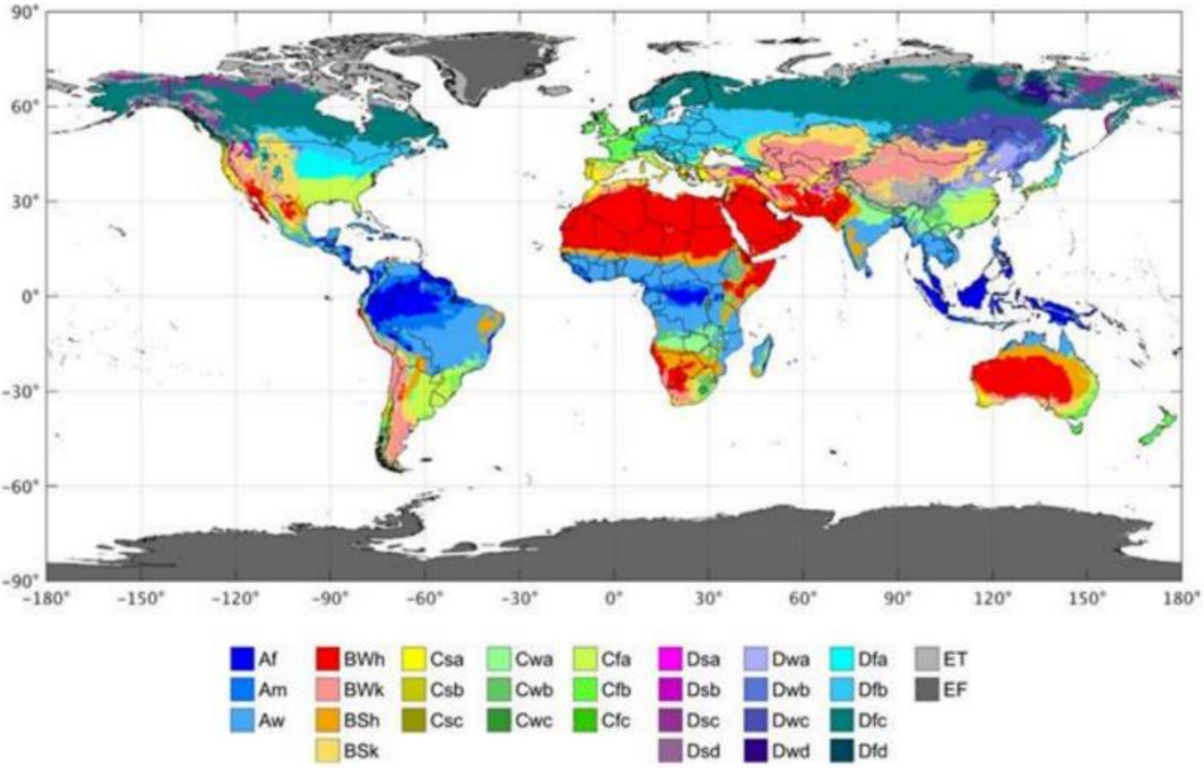

Figure 2: The Köppen Climate Classification System, period (1980-2016)

3.2.2. Types of Vertical Greening Systems

The VGS is diverse in form, and its definitions have been based on VGS design and the type of used plants. Till now, there is no established standardization for VGS designs and their variations like green roofs, but a lot of researchers provided classifications of VGS but with several overlaps based on VGS characteristics:

- Köhler (2008) and Dunnett and Kingsbury (2008) classified VGS into two groups: Living Walls (LW) and Green Facades (GF), which are based on the type of vegetation used in the systems.
- Ottelé et al. (2011) classified VGS as direct and indirect systems based on having/having not an air gap between the chosen system and the building's façade [15]
- Pérez et al. provided a classification of VGS that is divided into two systems: intensive system and extensive system, which shows both new and traditional developed systems, and they classified VGS as shown in (Table 1). [13]
- Manso and Castro-Gomes (2015) classified VGS based on construction characteristics, as shown in (Figure 3). [8]
- Dover (2015) used Ottele et al. (2011)'s classification based on having a direct or indirect connection between the chosen system and the building's façade and vegetation characteristics. [15]
- Sadeghian (2016) classified the VGS into three groups; wall climbing, hanging down, and modular green walls, based on growing media, construction, and vegetation characteristics. [16]

Table 1: Classification of VGS for building's Façade [13]

	Extensive System		**Intensive System**
Green Facades (GFS)	Traditional Green Facades		--------
	Double-Skin Green facade (Green Curtain)	Modular Trellis	--------
		Wired Mesh	--------
			Perimeter Flowerpots
Living Walls (LWS)	--------	--------	Panels
	--------	--------	Vegetated Mat

As the focus of this thesis is mainly based more on vegetation characteristics, the leaf area index of the plants, and planting design than the VGS construction features, the thesis has adopted the Dover, 2015 classification (Figure 4), which divided the VGS plantation in to:

- Direct VGS (direct green wall) in which plants are fixed and grown directly to the wall or climbers attached directly to the wall and rooted on the ground
- Indirect VGS (indirect green wall) in which the plants are grown on a supporting vegetation structure that is attached to the wall without any direct contact between the wall surface and vegetation

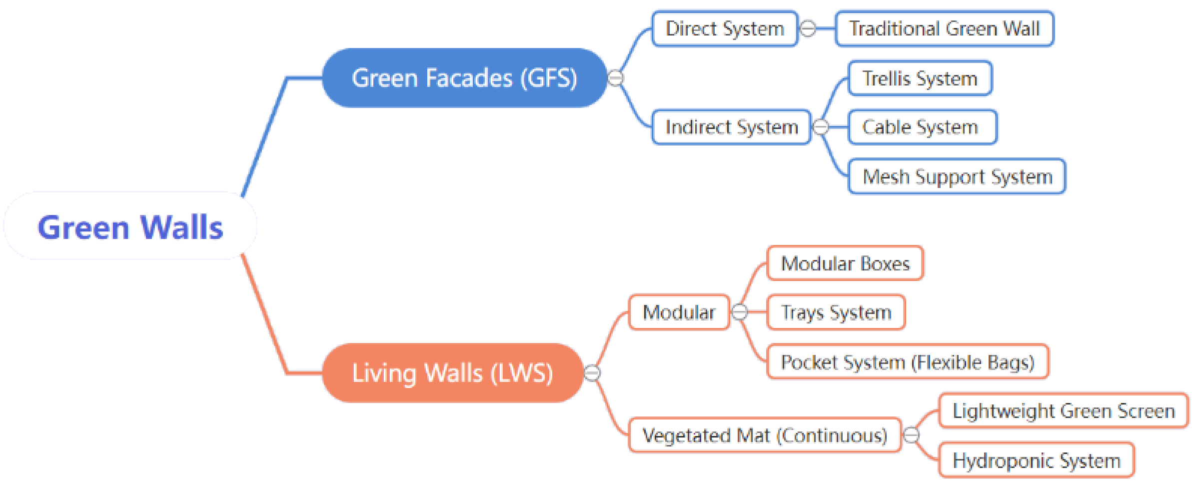

Figure 3: Manso and Castro-Gomes VGS Classification [11]

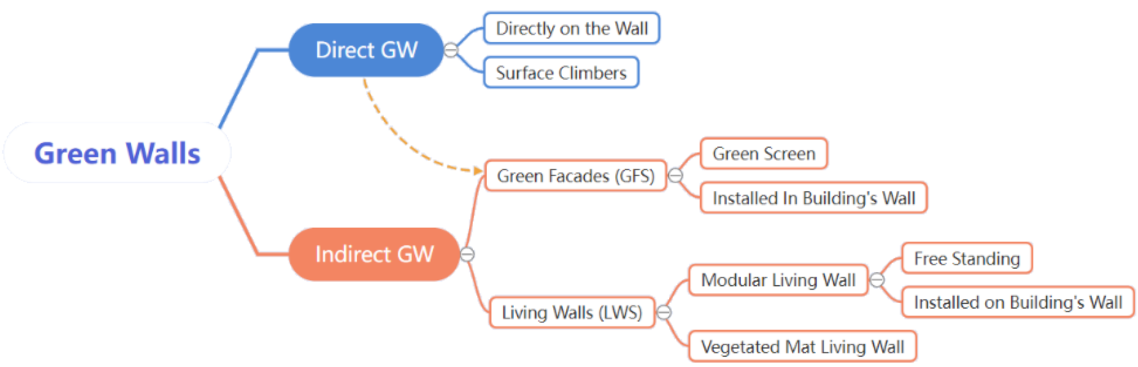

Figure 4: Green Walls Dover's Classification [5]

Based on the above classification, the indirect VGS could be categorized into Green Facades (GF) and living walls (LW). [5]

Green Façade System:

The Green façade system is a vertical greening system (VGS) that uses climbing or hanging plants that are rooted in the ground directly or planters on the roof. These plants grow downward or upward by twisting around the supportive vegetation structure, which keeps this vegetation away from the wall. [5]. Some researchers considered the climbers that grew directly to the wall as a green façade. [11] According to that, we can say that GF could be divided into two main categories: direct and indirect. In the direct GF, the plants are grown directly on the wall, and the plants are rooted directly in the ground so that it depends on the climbing plants that grow along the wall, while in the indirect GF, the plants are growing in a supporting vegetation structure which is being like a double wall with an air gap between the building's wall and the vegetation structure. GF requires less maintenance and protection as it generally uses a few species of climbers, which are described with lower vegetation density, and lower diversity and needs simple vegetation supporting structures. [15] According to that, GF is considered a cheap indirect vegetation system. [6]

Living Wall System:

The Living wall is considered the most advanced type of VGS designed to integrate the tall building with vegetation [11]. It uses a wide species of vegetation which make it able to cover large vertical surfaces. Also, the LW can be installed on all building types, including skyscrapers. [5]

The LW has been divided into two main types: mat type (known as a continuous living wall) and modular type. [17] In the continuous living wall (mat type), the plants are grown in hydroponically blankets that are attached to the vegetation structure [5]. In a modular living wall, the plants are grown in modules that carry the plant's growing medium, such as soil. It is installed on a vegetation structure that could be fixed to the wall or be free-standing so that plants could be pre-vegetated and installed directly to the vegetation structure or planted on the site after wall insulation. [18, 19]

Compared to the other types of VGS, the LW is expensive and need high maintenance requirements, but according to its life cycle analysis conducted by [20], the modular living wall is more durable and sustainable than the other indirect VGS types as it uses a low impact material such as; un-plasticized polyvinyl chloride (UPVC) - hardwood and high-density polyethylene (HDPE), but in other hands, the mat living wall has a serious environmental burden whereas, despite its high environmental impact (high water and energy consumption), it used non-recycling material such as PVC, but this environmental burden could be reduced in case of using environmental material and make the system integrates with the building's envelope. [15]

After revising all the VGS classifications, the primary differentiation between Living Walls (LW) and Green Facades (GF) could be summarized as the following.

Living Walls (LW): a system composed of modules, planted blankets, or re-vegetated panels fixed vertically to building facades or the free stand structure system. The panels could be made of many materials such as metal, concrete, plastic, expanded polystyrene, synthetic fabric, and clay, which makes this system supports a great diversity and density of

plants according that the LW requires intensive maintenance. The LW is divided into three types: landscape walls, vegetated mat walls, and modular living walls.
Green Facades (GF): a system that uses climbing vegetation on a structured system that could be supported by building facades directly or with an air gap. The plants could be planted on ground level or in pots fixed in a structured system in different heights.
According to the primary research scope, the research will focus on the Green Façade Systems and their efficiency on the building energy consumption

3.2.3. The requirements of Green Façade Systems (GFS)

According to the above literature review, the GFS became a method of increasing the urban vegetation for the urban areas which do not have enough green spaces. As it is vital in urban design, the VGS installation techniques and requirements must be understood.
GFS is related to a group of elements that play a role in the system's ability to adapt to different buildings to improve the buildings' thermal performance (Tamási et al., 2015). Moreover, to identify the characteristics of the different green facade systems; it is necessary to define the main elements of this technique such as supporting system, growing media, vegetation, drainage, and irrigation. Based on the features of these elements. [11]

GFS Supporting Structure System:

The green façade: Direct Type depends on the climbing plants growing along the wall. This type could be installed in low-rise buildings (maximum 3 to 4 floors) as it faces a falling danger as the plants are not supported on the wall. [21]
The green façade: Indirect Type is considered a double façade with space (air gap) between the façade and vegetation. The plants are fixed in a supporting structure system (modular or continuous), which helps to avoid vegetation falls and keeps the building safe from the plant's roots and humidity. The indirect GFS is often applied on modular supports in which plants grow individually in modular units, makings it easy to apply in straight and curving facades. also, it allows using different types of plants with different heights, which gives a new 3D shape to GFS (Figure 5). [21]
The structural system of GFS could be either metal, wood, or plastic containers connected to the facade by Horizontal, vertical, or pivot arbores. It could be 2D, such as cables, wires, and networks, or 3D, such as Rigid Frames and Modular Trellis.
Modular Trellis panels system: It consists of lightweight standard rigid, 3D panels manufactured of welded galvanized steel wire & vertical support extension of plants. This system is designed to hold GFS with leaving span between structure and wall or as a freestanding green wall (Figure 6). [15]
Cable and wiring networks system**:** It supports fast-growing plants with denser foliage and Wires to support slow-growing plants. Plants can be at the bottom or the top of the façade, is called the “Hanging System” (Figure 7). [24]

GFS Growing Media: In the direct green facades, there is no need for growing media as its roots are growing direct to the ground, but in the modular green facades, the plants need a growing media which is made of light weighted materials and There are four types of vegetation. This modular is supported individually on the building’s façade. Each modular should be suitable and adapted with the chosen plant species, appropriate to the environmental conditions. [26]

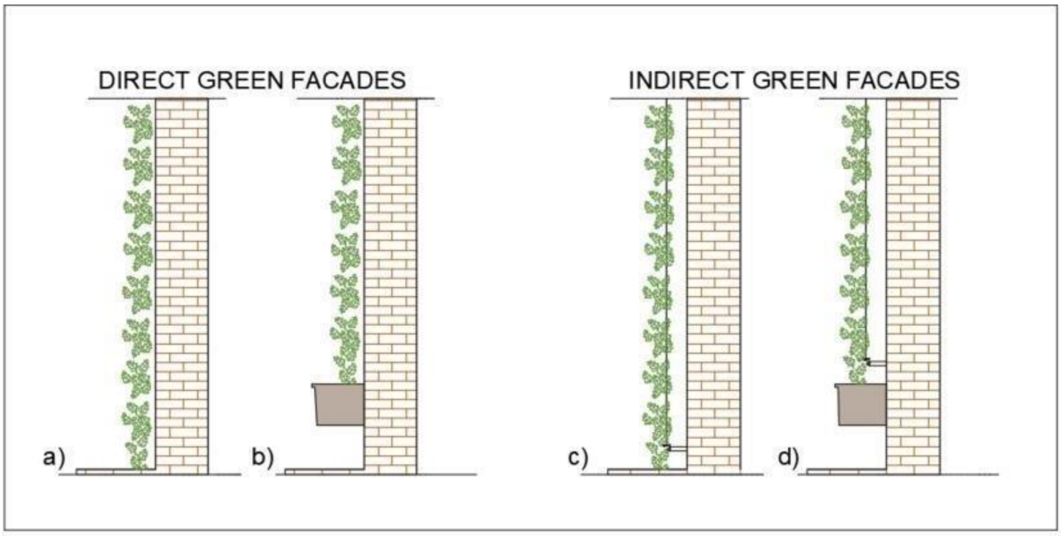

Figure 5: The direct and indirect green facades installation [22]

Figure 6: Modular Trellis panels fixation (left) - Curved & regular freestanding trellis (right) [23]

Figure 7: Grid and Wire – Rope system, MFO Park, Switzerland [25]

1- GFS Vegetation:

Many factors affect choosing the vegetation types, such as the facade characteristics, the building structure system, the surrounding environmental conditions, the climate conditions, and duration. Many plant species can be used for facades vegetation, but the most common are climbing plants, which are considered a cheap greening solution. [22]. The GFS vegetation could be divided into two types depending on the type of leaves: evergreen plants and deciduous plants. The evergreen plants need to maintain their leaves throughout the year, and the deciduous plants lose their leaves during the autumn season. [27]

There are four types of vegetation that could be used in GFS: [24]

- Bonders: self-bonders using clinging roots such as Ivy (Hedera helix),
- Twiners: twining their stem around support such as wisteria
- Shoots: such as Parthenocissus, grapevine, and clematis
- Support climbers: such as climbing rose and Winter jasmine

The Climbing plants are considered self-supporting vegetation as they can bind themselves to the wall automatically (root climbers and adhesive-suckers). However, sometimes they may need a supporting structure system such as a trellis to extend across the entire wall (twining vines, leaf-stem climbers, leaf climbers, and scrambling plants). Climbing plants could be extended in different distances depending on their species; some of them could achieve an extension of 5-6 m, others 10m, and others about 25m; it takes three to five years to achieve the facade fully covered. The facade covering speed varies depending on temperature, climatic conditions, rainfall variation throughout the year, and leaf density. [6] Furthermore, to achieve the sustainability objectives, the local low irrigation and maintenance need plants adapted to climatic conditions should be used. In the GFS, they are suitable solutions for cities with low agricultural land, giving more functional possibilities for the greening system. The GFS plants are periodically exposed to insects. Therefore, protecting it and the surrounding environment from insects is essential. Finally, if the chosen plants are healthy, they could be survived for a while, but they cannot remain protected forever. So, the chosen plants should be monitored regularly, and the pesticides should be used when necessary, considering the use of natural pesticides instead of chemical ones. [28]

1- GFS Drainage and Irrigation:

To ensure the success of GFS and achieve the goal of sustainability, grey or recycled water have to be used as much as possible in irrigation. The type and quantity of irrigation are estimated by the type of plants, density of vegetation, and ambient climate. The plants with high density need a high rate of water, at least in the hot temperature months. The chosen water drainage system must be effective and safe for the building's structure so that the Facade and groundwater of GFS must be filtered to ensure the integrity of the building's structure and there is no adverse effect on the building by the increase in irrigation water. [10]. The chosen drainage system should be suitable for both the supporting structure system and the types of climbing plants selected for GFS. The drainage holes must be located on the side of the container, and they should be higher than the level to which the container is filled to be easy to maintain the top of the growing substrate without freezing water. The drip trays could be put under the container to collect the water that flows from the growing container’s base. [29]

The direct irrigation system reaches the water directly from its primary source. This water flows directly to the sewage with gravity downwards and is not recycled. A timing controller controls the time of turning on and shutting down the irrigation system. The irrigation systems could be divided into several parts on the GFS to be suitable for different plants and their different irrigation needs. [30]. Finally, the third type of irrigation is used in a small GFS, a manual irrigation system that depends on a portable tank carried on wheels. The plants are irrigated manually by the person who takes care of the GFS. [30]

3.2.4. GFS Maintenance

To ensure the success of GFS installation and achieve the best energy saving and thermal reduction, periodic maintenance should be done to all components of GFS. The Australian Growing Green Guide divided GFS maintenance into five main categories.

1. The Establishment Maintenance: The maintenance that happened in the first two years of the GFS application
2. Routine Maintenance: It ensures healthy plant growth, including irrigation system and plantation maintenance such as weed and pruning control. The maintenance for regular works
3. Cyclic Maintenance: It ensures that the facade is maintained according to the required functionality, appearance, and safety standard. The maintenance is responsible for building structure and the GFS components such as hanging system, plantation, soil, irrigation... Etc.
4. The Reactive and Preventative Maintenance: The maintenance that responsible for the sudden damaged and changing the fails parts in the GFS which called Reactive and Preventative Maintenance
5. Renovation Maintenance: is maintenance that is responsible for changing the design intent according to changes in the ownership or the building usage

3.2.5. The performance of Green Façade Systems – environmental and social benefits

Although the environmental and social VGS benefits are expected to be huge, the knowledge about these benefits is only concentrated in a few areas. The research on VGS thermal benefits is abundant and focused more on the building level instead of focusing on the urban city level by minimizing the UHI.

The following table is considered as a summarizing of the benefits of VGS as the following table (Table 2)

Table 2: The Green Façade Systems' Benefits [31]

Environmental Benefits	
Energy Consumption	- Saving ratio in warm–dry climates 9:30% - Reduce consumption up to 20%.
Thermal performance	- The evaporation of GFS plants cools the facade by -7°C to -15°C as it works as a sunscreen - Reduce the UHI effect. - reduced indoor temperatures 10 ◦C
Reduction of air pollution	- Reduce CO2 emissions, NO2 concentration and clean air in city scale - Reduce PM10 (microscopic Particulate Matter) by 15:23% and PM2.5 peak by 45: 71%
Reduction of noise	- Reduce noise & vibration up to 40dB - Absorb up to 18dB of the street noise. - Reduce noise 5:10 dB & traffic noise 1dB
Water management	- Irrigate by recycled grey & black water or collected rainwater
Social Benefits	**Visual Benefits**
- Enhance the urban environment aesthetic value and adds value to building identity. - Improve human health and decrease stress and	- Achieved the three categories of beauty (enjoyable, admirable, and ecological beauty). - Could be used as a public art.

which led to crime and violent behaviour reduction.	
Educational Benefits	**Economic Benefits**
- Could be used in biology or art classes in schools or in Sustainability 3D teaching textbooks - Raising the importance of ecology awareness.	- Increase the real estate up 20% - Increase residential and commercial by 7:15% - Payback reached after 16 years.

4. Case Study: Residential Unit at 6th of October, Giza, Egypt

4.1. Location and Climate

The selected case study is in Mountain View, 6th of October City, Giza, Egypt. It is considered one of the hottest and driest districts in Giza, especially in summer, as it is located in a hot-dry climate zone which is considered a BWh according to the Köppen-Geiger climate classification. (Table 3).

Table 3: Case Study Climate Data

Location	**Northern / Giza, Egypt**
Geographic Position [31]	Latitude: 29°56'10.19" N Longitude: 30°54'29.99" E
Climate Condition [33]	Hot Dry
Average Annual Max. Temperature [33]	34.2°C
Average Annual Min. Temperature [33]	11.8°C
Average Max. Temperature During the Hottest Month (July) [33]	37°C
Average Min. Temperature During the Coldest Month (January) [33]	9°C
Average Annual Humidity [33]	53%
Average Annual Precipitation [33]	2.5 mm
Average Annual Rainy days [33]	1.7 Days
Predominant Average Hourly Wind Direction [34]	North
Max. Average Daily Sunshine Hours [34]	14 hr
Min. Average Daily Sunshine Hours [34]	10.25 hr
Average Highest UV Index (July) [35]	12
Average Lowest UV Index (December) [35]	5

4.2. Case Study Proposal

4.2.1. Building Information

The selected case study is a 180 m^2 Twin House in Mountain View, 6th of October City, Giza, Egypt (Figure 8), with 7.0m height.

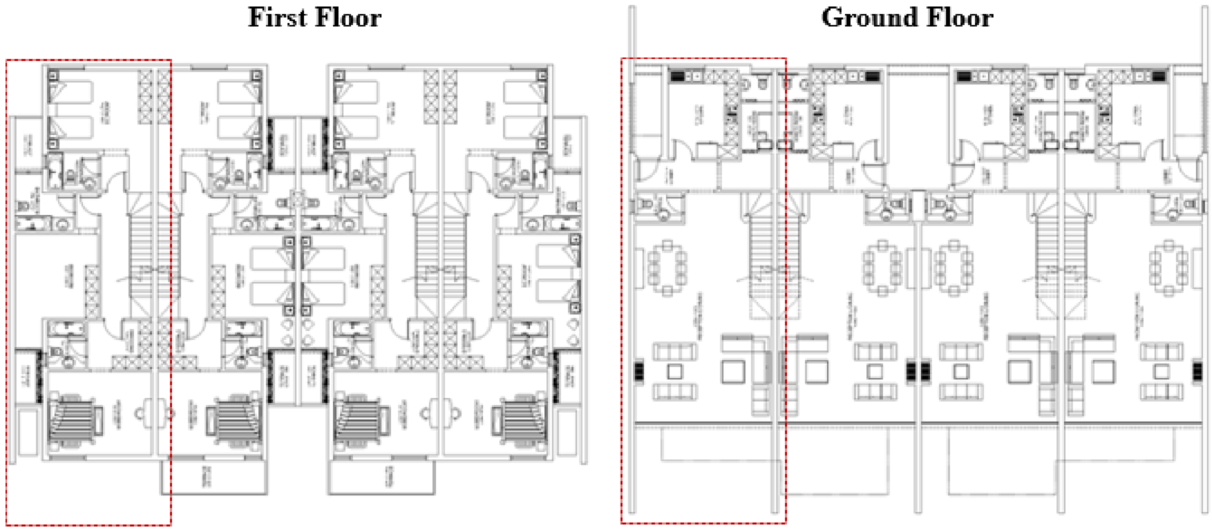

Figure 8: The ground and first plan for the chosen case study

The following table (Table 4) shows the properties of building envelope material.

Table 4: The Building envelope Thermal Data [36]

Data	Description and Thickness	Density (kg/m^3)	Specific Heat (J/kg°K)	Conductivity (Watt/m°K)
Wall Openings Data	WWR 20% 6 mm clear transparent glass	14.96	720	1.00
Wall Layers	0.002m Painting 0.025m Cement Mortar 0.12m Concrete Bricks 0.025m Cement Mortar 0.002m Painting	600 1570 2150 [34] 1570 600	1000 896 880 [35] 896 1000	0.016 1.00 1.63 [36] 1.00 0.016

4.2.2. VGS Plants

At first, a Hedera helix (Common Ivy) thermal model was created within the simulation program, and the result of a field study conducted by Nojima et al. (1993) was used to validate this model. In this study, the Hedra helix Ivy will be used too. The thermal properties of IVY leaves will be as shown in (Table 5) taking into consideration that the estimated leaf area of English Ivy (LAI): is 0.005m2/leaf (200leaves/m2), the weight of the leaf is 0.8g, and its thickness is 0.3mm. [36]

The Hedra Helix Ivy will be fixed on one Façade with twelve different alternative directions starting from north and rounding with a sequence of 30°. The Ivy will be installed on a free-standing stainless steel wire grid with a 0.6m air gap between the structural system and the building. The plants will cover all the Façade except the openings, as shown in (Figures 9 and 10), and the Properties of the Building after VGS installation will be as shown in the following table (Table 5)

4.2.2.1. Validation of vegetation model

A test cabin was used in the field experiment led by Nojima et al. (1993) to validate the vegetation model. It was recreated within the software; these test cabins were built in

Tsukuba, located 50 km north of Tokyo, in the summer of 1995. The cabin was oriented to the south and constructed with 0.47 cm properties asbestos Cement Board and covered by climbers with a thickness of 0.50 cm. The internal wools and roofs are insulated by glass wool to reduce the glass wool. The model is divided into three parts; the first includes no vegetated room, the second is a vegetated room, and the third is a non-examined space. [36, 37]. The researcher used energy plus to simulate the effect of the vegetated façade on internal heat reduction and compared it with the field measurements to validate the results; he compared the results from the annual weather data of Tokyo, which was imported from Energy Plus, and two hot days in the field and he found that the results not identical, but it is near to the results that outputted from the program, and he found that the results not identical, but there are near to each other, and he mentioned that it was happened due to the lack of weather information, but he found that in the vegetation wall case both simulation results and field measurements results in the internal temperature was cooler than the external by 6.1°C (experiment) and 5.3°C (simulation), while the non-vegetation on was warmer than the outside by 5.9°C (experiment) and 5.5°C (simulation) [37,38]

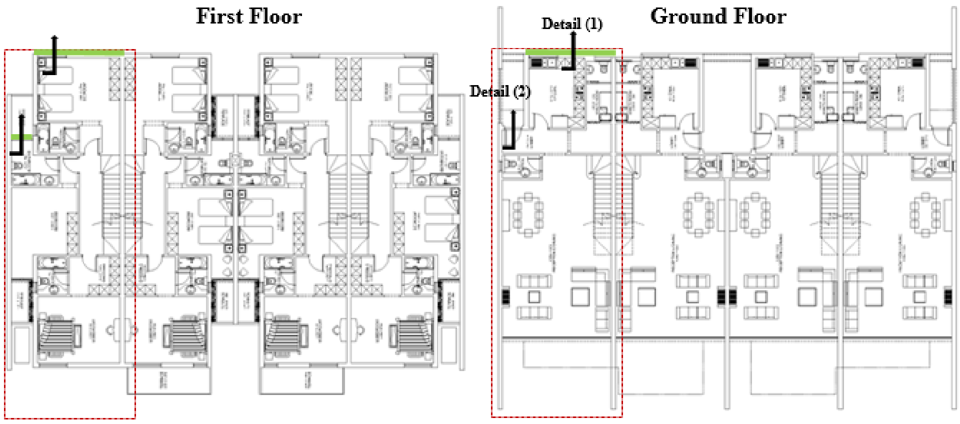

Figure 9: The VGS installation on ground and first plan for the chosen case study

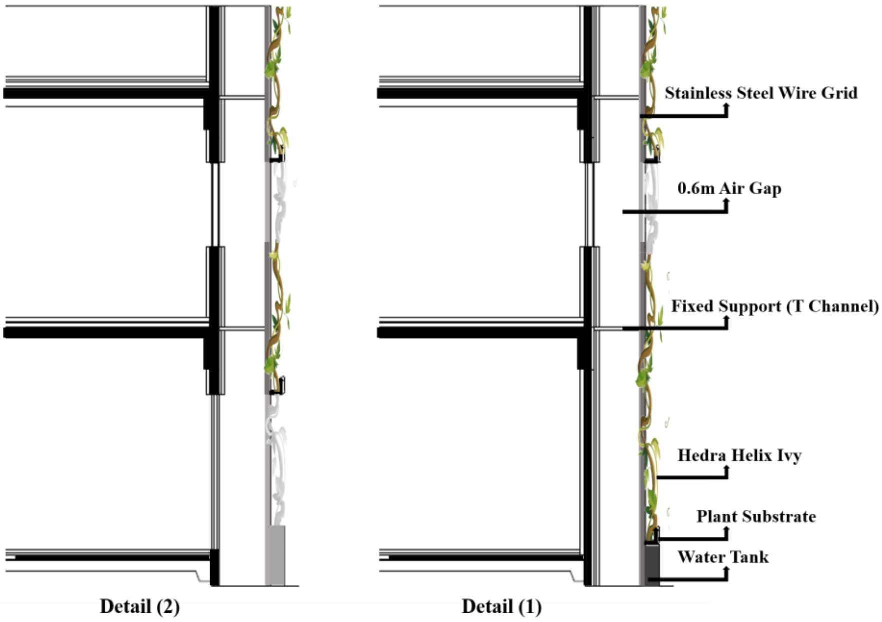

Figure 10: The detailed sections for VGS installation on the case study (Researcher)

Table 5: The VGS thermal data [36, 39, 40, and 41]

Data	Description and Thickness	Density (kg/m^3)	Specific Heat (J/kg°K)	Conductivity (Watt/m°K)
Wall Openings Data	WWR 20% 6 mm clear transparent glass	14.96	720	1.00
Wall Layers	0.002m Painting 0.025m Cement Mortar 0.12m Concrete Bricks 0.025m Cement Mortar 0.002m Painting 0.6m Air Gap 0.05m Stainless Steel wire Grid 0.2m Plantation	600 1570 2150 1570 600 1.3 7900 533	1000 896 880 896 1000 1004 460 2.8	0.016 1.00 1.63 1.00 0.016 5.56 17 0.36

4.2.3. Simulation Program

The Simulation Study will be done through Design-Builder Simulation Program, which is considered the first comparison simulation program that includes the same Energy-Plus program's interface. It is a three-dimensional environmental model designed for engineers, architects, and energy assessors around the world to simulate the environmental effect such as temperature reduction, energy consumption, CO2 emissions … Etc. of any project at the early design. [42] As it is used to study the buildings' thermal loads in terms of the percentage of CO2 emission, ventilation, and internal air movement. Also, it studies the raw materials that are located inside the buildings and the rates of cooling and heating reduction. Finally, it calculates the buildings' energy consumption. According to that, Design-Builder is considered an identification certificate for the building. [42, 43]

This study uses the Design-Builder to explore the energy saving potential when using indirect green facades by calculating the annual energy consumption for both cooling and heating loads.

4.3. Results

The VGS works as thermal insulation, protecting the building envelope from direct radiation, reducing the needed cooling and heating loads, and directly affecting energy consumption efficiency. And as shown in (Table 6, Figure 11) the VGS installation at the North Direction reduced the energy consumption by 19.6%, in case of installed the VGS on 30° North East direction the energy consumption has been reduced by 20.3%, in case of installed the VGS on 60° North East direction the energy consumption has been reduced by 21%, in case of installed the VGS on East direction the energy consumption has been reduced by 27.6%, in case of installed the VGS on 120° East South and 150° East South direction the energy consumption has been reduced by 27.2%, in case of installed the VGS on South direction the energy consumption has been reduced by 27%, in case of installed the VGS on 210° South West direction the energy consumption has been reduced by 28%, in case of installed the VGS on 240° South West direction the energy consumption has been reduced by 29%, in case of installed the VGS on West direction the energy consumption has been reduced by 27.7%, in case of installed the VGS on 300° West North direction the energy consumption has been reduced by 22% and finally, in case of installed the VGS on 330° West North direction the energy consumption reduced by 21%

Table 6: The case study energy consumption after and before VGS Installation in different orientation (Researcher)

	Energy Consumption Efficiency	VGS Installation With 60 cm Air gap	Initial Case
Orientation	(%)	Energy Consumption (Cooling loads + Heating Loads) (K Watt.hr)	Energy Consumption (Cooling loads + Heating Loads) (K Watt.hr)
North	19.6	2824.48	3510.67
30° N-E	20.3	2871.29	3601.48
60° N-E	21	2974.14	3775.89
East	27.6	3156.34	4369.28
120° E-S	27.2	3135.69	4305.8
150° E-S	27	3112.64	4269
South	26.5	3067.19	4194.6
210° S-W	28	3365.54	4674.15
240° S-W	29	3395.05	4781.8
West	27.7	3356.4	4501.6
300° W-N	22	3131.2	4009.2
330° W-N	21	3115.6	3952.6

As shown in (Figure 11), the most efficient VGS installation is in the 240° South West direction as it reduces the energy consumption by 29%. Also, the VGS installation not only maximizes the thermal insulation of buildings' facades and reduces the energy consumption but also maximizes the indoor air quality as it reduces CO2 emissions.

As many variables affect the VGS performance, such as; the distance between the system and the facade (air gap) and the plant's LAI, and as the LAI *"leaves total area per unit ground area and directly related to the amount of light that can be intercepted by plants"* is one of these variables as it has a massive impact on the performance so that the LAI will be changed from 2.0 to 4.0 in case of 240° SW to measure how it effects on the energy saving as shown in (Table 7). Moreover, to measure the effect of these variables, the simulation will be done in case the Plants are growing directly to the wall without any air gap in the best installation direction, which is 240° SW. The energy saving decreased by 27.2% in LAI 2.0 and 29.3% in LAI 4.0 in the direction of 240°.

Figure 11: The Monthly energy consumption after and before VGS Installation in different orientation

Table 7: The case study energy consumption after and before VGS Installation in different orientation (Researcher)

		Energy Consumption Efficiency	VGS Installation With 60 cm Air gap	Initial Case
Orientation		(%)	Energy Consumption (Cooling loads + Heating Loads) (K Watt.hr)	Energy Consumption (Cooling loads + Heating Loads) (K Watt.hr)
LAI 2.0 + 60 cm air gap	240° S-W	29	3395.05	4781.8
LAI 4.0 + 60 cm air gap		32.3	3235.4	
LAI 2.0 without airgap		27.2	3482.9	
LAI 4.0 without airgap		29.3	3379.7	

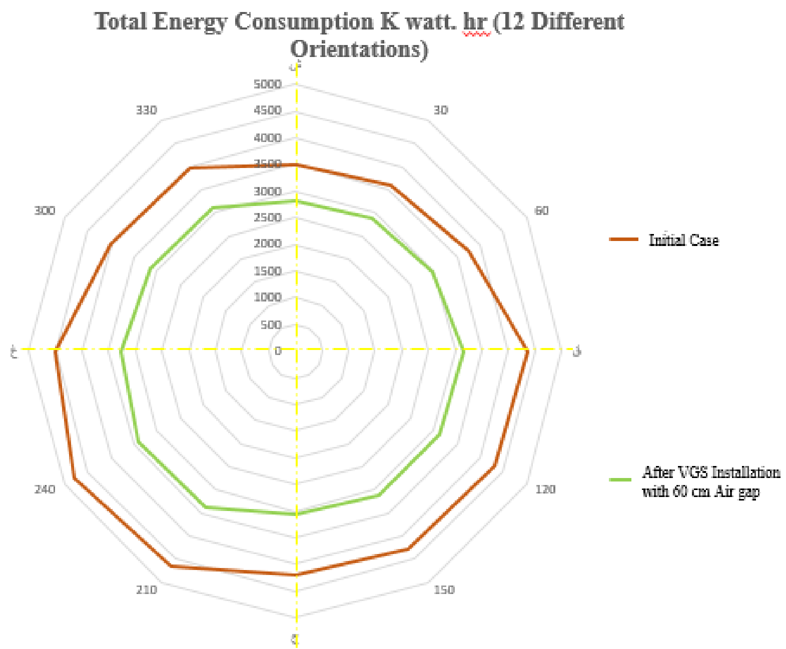

Figure 12: The effect of VGS installation in different orientation (Researcher)

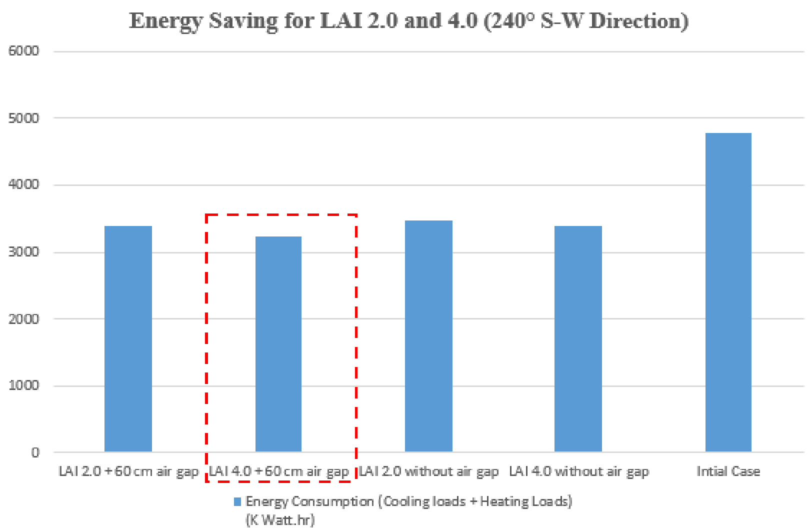

Figure 13: The effect of VGS Different LAI on Energy Consumption in 240° SW direction without air gap and with 60 cm air gap (Researcher)

1. Conclusion

As mentioned before, the construction Industry considers the largest energy-consuming sector in the global economy, with over one-third of all energy and one-half of global Electricity consumed there. Also, they are responsible for approximately one-third of global carbon emissions due to their energy consumption. The residential buildings Sector consumes over 40% of electricity. Furthermore, most of this consumption uses HVAC systems to reach thermal comfort inside the space. It uses non-environmental material, which maximizes heat gain and reflects directly in the energy consumption. Moreover, this construction material not only affects maximizing the heat gain inside spaces but also maximizes the effect of the Urban Heat Island (UHI) Effect.

The case study shows that the VGS has a significant impact on energy consumption efficiency and shows that the best energy saving was achieved by installing the VGS on 240° SW, then 210° SW, and finally in the West direction, then 120° and 150° ES. (Figure 12) in the case of using plants with LAI 2.0. Furthermore, according to the importance of plants LAI, the study measured the effect between LAI 2.0 and 4.0 in the best-resulted orientation of 240° SW, which shows that the energy saving has been increased by 32.3%, as shown in (Figure 13). Moreover, in the case of using the plants directly to the wall without air gaps, it shows that the energy saving has decreased by 27.2% in the case of LAI 2 and by 29.3% in the case of LAI 4.0, and that shows that the system which fixed as free-standing with air gap achieved higher energy saving than the one that fixed directly to the building's façade and also, the free-standing system (indirect system) is safer to the building structure than the direct system.

Finally, to ensure the best effect of VGS installation on energy consumption, the designer should install it in a proper orientation according to the building location and climate zone. Moreover, to ensure the safety of the building and long-term success, a comprehensive maintenance plan should be defined. It should include a periodic maintenance plan divided into three sections: structure system and building envelope, irrigation system and insulation, and plants and their substrates.

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انظمة التخصير الرأسي وتأثيرها على كفاءة استهلاك الطاقة في المباني السكنية دراسة عملية: توين هاوس بمدينة السادس من اكتوبر

ملخص البحث:

عانت مصر من مشاكل في مجال الطاقة، خاصة في السنوات العشر الماضية، حيث تحولت من دولة مصدرة إلى مستوردة للنفط والغاز [١]. تستهلك المباني السكنية أكثر من ٤٠٪ من الكهرباء. علاوة على ذلك، فإن معظم هذا الاستهلاك لاستخدام أنظمة التدفئة والتهوية وتكييف الهواء للوصول إلى الراحة الحرارية داخل الفراغات، حيث ان هذه المباني تستخدم مواد غير صديقة للبيئة مما أدى إلى زيادة اكتساب الحرارة من خلال الغلاف الخارجي للمباني.

تهدف الدراسة إلى قياس تأثير الغلاف الأخضر الرأسي ومتغيراته مثل: تأثير مؤسر مساحة سطح الورقة LAI والتجويف الهوائي على استهلاك الطاقة. تتضمن منهجية البحث مراجعة أدبيات وأساليب أنظمة التخضير الرأسي (VGS) وأنواعها والنباتات المستخدمة ... إلخ وتأثيرها على الغلاف الخارجي للمباني لتحقيق أقصى قدر من الكفاءة في استخدام الطاقة. تم إجراء دراسة عملية عن طريق محاكاة لمبنى توين هاوس ذو اتجاه واحد في السادس من أكتوبر، مصر، كل ٣٠ درجة بدءًا من الشمال باستخدام برنامج design-builder.

قارن البحث استهلاك الطاقة بين الوضع الحالي للمبنى مع طوب خرساني ١٢ سم وتركيب انظمة التخضير الرأسي مع وجود تجويف هوائي بعرض ٦٠ سم. حيث قامت انظمة التخضير الرأسي بتقليل استهلاك الطاقة بنسبة ١٩,٦: ٢٩٪ في اتجاهات التثبيت المختلفة ، بينما سجل اتجاه ٢٤٠ ° جنوب غرب أعلى توفير في استهلاك الطاقة في حالة LAI كان ٢,٠ ولقياس تأثير LAI بجانب اتجاه التثبيت تم عمل مقارنة بين كلا من الحالتين لمؤشر سطح الورقة LAI 2.0 و LAI 4.0 في اتجاه ٢٤٠ درجة جنوب غرب حيث زاد التوفير في استهلاك الطاقة في حالة LAI 4.0 إلى ٣٢,٣٪ مع وجود تجريف هوائي بعرض ٦٠ سم، بينما في حالة عدم وجود تجويف هوائي كان التوفير في استهلاك الطاقة ٢٩,٣٪ مما يعني أن مؤشر سطح الورقة LAI وعرض التجويف الهوائي له تأثير فعال على أداء انظمة التخضير الرأسي وليس فقط اتجاه التثبيت.