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The Suitable Density of Vertical Greenery Systems on Office Buildings for Energy Saving

Aya Hassoun*, **Chirine Traboulsi**, **Mostafa Rabea**, **Mary Felix**
Faculty of Architecture, Design and Built Environment, Beirut Arab University, Lebanon
E-mail: amh301@student.bau.edu.lb

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Abstract: One of the more optimistic strategies to generate energy savings in buildings and help mitigate the effect of the urban heat island is to "green" the building envelopes. In general, a vertical greenery system (VGS) has excellent possibilities for cutting building energy use, particularly during cooling periods. One of the most important factors is the shadow effect factor, which is greatly affected by the plants. Simulating the facade foliar density using Revit energy analysis is one technique to describe the potential shadow effect of flora. This paper will analyse and investigate to answer the following question: Does the variation in density of the VGS affect the energy savings of the building? The VGS has several factors that affect the energy savings of the building, such as the types that thrive in each region, the facade's direction, the thickness of the foliage, the presence of air layers in the context of green walls, and the make-up and thickness of the substrate layer. This paper will focus on one factor: the density of the green vertical system. The goal of this study is to develop a standard and simple method for calculating the leaf area index (LAI) and connecting it to the energy savings offered by VGS studies on the office building. Additionally, research was done on the energy savings made at the "Karim Centre", an office building located in Tripoli, Lebanon. Moreover, the facade direction has many impacts on the indoor thermal system that affect energy savings using the VGS, including green walls and double-skin green facades. There is, however, a dearth of information on operating during the heating season as well as throughout the entire year. This paper will discuss the four evaluation variations of the density of VGS on the facade of the office building, resulting in the suitable density of VGS4, which saves 15.7% less energy with 50% green density on the facade.

***Keywords*:** LAI, VGS, energy analysis, green facades, energy savings

1. Introduction

The rise in environmental awareness in the latest generations has encouraged the use of sustainability standards in the design of buildings and urban infrastructure. The provision of effective public transportation and the reduction of waste and pollution are only a few of the many interconnected factors that must be taken into account for sustainable development. One of the most impacted factors is green space, which includes the greening of buildings. Closing the water and material cycles and lowering energy use are top priorities in this sustainable construction method. Today, the economy's major energy consumer is the building industry, where more than one-third of all energy and 50% of

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the countries on earth use electricity. By 2050, the world's population is projected to expand by 2.5 billion people, which will put further strain on the planet's energy infrastructure as economic growth and living standards rise. Energy demand in the building industry is also projected to climb dramatically by 50%. In most parts of the world, the main energy end-use in the building industry is typically represented by heating and cooling loads. To dramatically lower the energy required to cool and heat buildings, it is possible to improve the building envelope, which includes the wall that separates the interior and exterior temperatures. As a result, it is highly required to increase building envelope energy efficiency because the building envelope's construction and design have an impact on 20 to 60% of all the energy used in buildings.

Urban green infrastructure, which includes all vertical greenery systems (VGSs) and green roofs, is one of the most promising new solutions to enhance the thermal efficiency of building envelopes. These cutting-edge, eco-friendly envelope technologies offer numerous ecosystem services at the urban level, including the decrease of urban heat islands in addition to improving the building's thermal performance. This study focuses primarily on the thermal efficiency of building-based VGS. In this regard, it is necessary to consider the various methods for vertically "greening" a building because distinct distinctions have already been made, both in terms of design and thermal performance. The first major distinction is between green facades and green walls (living walls), whereas the latter calls for more intensive upkeep than green facades (extensive). It is possible to distinguish between the green facades and the green wall. The green wall, wherein climber species are generally adopted. The green facades are to use plants as scaffolding, with a gap between the facade and the green plants, resulting in the creation of a true double skin. This modern take on classic green facades, based on simple forms, is feasible because it is essentially wide, requires little effort, and just visually engages with the built environment. A double-skin green facade has been investigated in the current research as a passive technique for energy savings in buildings. This ecosystem activity, which refers to how these VGS help buildings save energy, is typically made possible by the shadows that the plants cast. A modest but considerable effect could be made by the wind barrier effect, Insulation, deep percolation from surfaces and plants (the ability of the construction system's many phases, including the substrates, felts, air, and plants), and other factors (attributed to the prevalence of vegetation and safety nets, the wind's effect on the walls and floors is altered).

As per the prior research on the possibility of double-skin facades to be a passive tool for energy savings in buildings, the duration of the analysis (heating, cooling, or both), the species used, the facade direction, the foliage thickness (or the cover percentage), and the air gap thickness between the building facade wall and the plant layer are the most fascinating things to consider in their analysis concerning its function in energy preservation.

All topics that are studied in research have literature related to them that talks about the same selected topics or has some common ideas with the desirable thesis. This topic, "the suitable density of VGSs on office buildings", has different literature connected to it that is divided into five categories or classifications. The selected topic could be divided into energy savings. Thus, some of the literature is related to VGSs and talks about them, their needs, their organisation, and their types, while other literature is related to the distance between the VGSs and buildings, with their different options and different importance, and how it affects the density of the green area in the VGSs.

1.1 *Energy saving*

Energy policy is now a national concern, and there is a worldwide problem with energy scarcity [1]. A sustainable technique to reduce energy consumption inside buildings has been established as a result of the shortage of energy and the rise in its price [2]. Impressive economic growth until the 1990s has caused energy usage to rise quickly [3]. As a result, energy use in residential buildings has increased to be a substantial growth factor. Consequently, it is crucial to control the behaviour of energy-saving [4].

1.2 *VGS*

The term "green walls" refers to any method for using a variety of plants to green a vertical surface, such as a wall, a blind wall, a partition wall, etc. This includes all techniques for growing plants on, up, or inside a building's wall [5]. The VGS has many different types of structural systems and fixation, such as living wall systems and green facades. These two types also include additional types and techniques of fixation, which are explained in detail in Figure 1. In addition to these, the building's exterior elements are the most crucial factor to take into account while designing a

VGS [6]. To produce a design that is appropriate for the climate in a VGS, it is essential to understand the criteria of the facade and design accordingly [7].

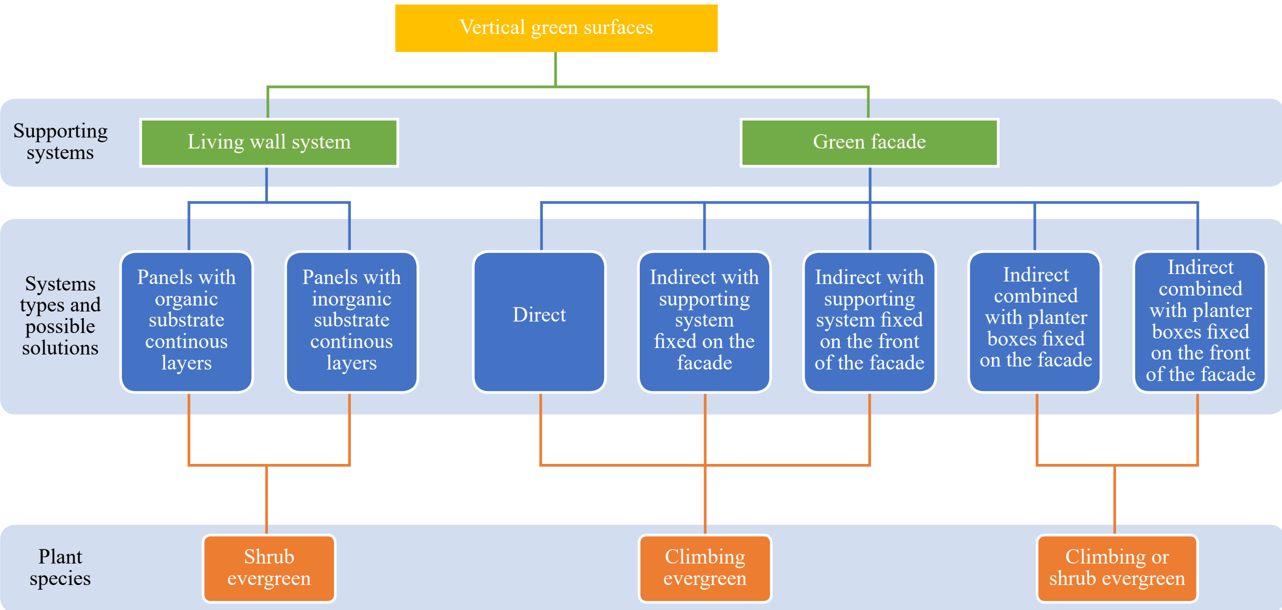


Figure 1. Process tree for green facades and living wall systems [6]

1.3 *Distance between the VGS and building*

The VGS has a variety of types; three main types are the directly greening facades, the indirectly greening facades, and the living wall. The directly greening facades located in Delft, the Netherlands (referred to as VGS1 in Table 1) include a special type of plant called *Hedera helix* that grows in a vertical direction by climbing. The plants referred to in this study cover the facade with a thickness of 20 cm and are older than 25 years; the material of the wall used is masonry. This case is located in Rotterdam, the Netherlands. The second system is the indirectly greening facade (referred to as VGS2 in Table 1) that has the same plant type, *H. helix*. These plants are well developed, have a thickness of 10 cm that covers the facade, are 2 to 3 years old, are supported on steel frames, and have an air gap of 20 cm between the plants and the masonry wall. This case is located in a crowded urban area.

The last system is the living wall (referred to as VGS4 in Table 1), which has plant species that do not climb, are in a healthy condition, cover a thickness of 10 cm, and are less than 12 months old. This system's supporting material is soil-filled planter boxes with an air gap of 4 cm between them and the facade. This case is located in a rural area [8].

Table 1. Summary of ambient temperatures [9]

VGS	Temperature (°C)					
	0.15 m away		0.30 m away		0.60 m away	
	Lowest	Highest	Lowest	Highest	Lowest	Highest
Control wall	26.34	34.85	25.17	33.59	25.17	33.59
1	24.79	31.93	26.34	34.01	25.17	32.34
2	25.56	32.76	25.56	32.76	25.56	32.76
4	25.17	31.52	25.17	31.93	25.95	32.76

VGS1 has the highest temperature among other systems with an air gap of 30 cm due to the high thickness of the plants, which helps to decrease the heat. VGS2 shows a similar ambience. It's no longer influencing the ambient temperature. On the other side, VGS4 has the lowest temperature along with other systems, indicating that it still has an impact on the ambient temperature with an air gap of 60 cm. The three VGSs (VGS1, VGS2 and VGS4) showed a similar ambient temperature [9].

1.4 *Leaf area index (LAI)*

Due to its significant impact on the shadow effect, LAI is a crucial metric for determining the foliar density and, in turn, the thermal behaviour of VGS, particularly for green facades. The indirect approach is the easiest and fastest way to quantify LAI to describe the foliar density of VGS. Comparable shadow factor values can be obtained from the double-skin facade. In addition, several tests were done under different conditions and variations (as shown in Figure 2), proving that double-skin green facades have many pros as a passive system when compared to a traditional façade, offering optimum energy savings of up to 34% for cooling durations with an LAI of 3.5 to 4 throughout the summer (Table 2), in the Mediterranean continental climate [10].

Figure 2. Direct LAI measurement process during the summer of 2013 [10]

Table 2. Three levels of LAI measurements according to the direct method on the east orientation of the double-skin [10]

Level	Number of leaves	Leaf average surface (cm^2)	Measured leaf area (cm^2)	LAI
Upper level	1,387	15.08	20,914.64	2.1
Middle level	1,224	26.29	32,185.04	3.2
Lower level	992	39.60	39,283.75	3.9

1.5 *Energy savings through VGSs*

In addition to being visually pleasing, vertical green walls have other advantages, such as lowering energy costs for air conditioning and lowering carbon dioxide emissions. The vertical green wall system has a yearly reduction capacity of 2,650 x 106 kWh of electric power and 2,200 x 106 kg of carbon dioxide emissions [11].

The right building materials must be chosen to minimise energy consumption, particularly for heating, ventilation, and air conditioning (HVAC) systems, and to provide users with year-round thermal comfort through space cooling and heating [12].

VGSs have become more prevalent in building designs over the past ten years, contributing to several urban ecosystem services. One of them is the ability to offer buildings energy savings, which has a major impact [13].

According to simulations, VGS's passive energy advantages are likely to be favourable during the summer while potentially harmful all through the winter. However, VGS can still offer the building net passive energy gains in mildly temperate areas [14].

2. Methodology

The study design is based on simulated studies, and the methodology is a quantitative research strategy. To comprehend this exclusive energy saving of VGS, the investigation borrows ways from the ethnographic type, jointly with simulated indoor heating changes depending on LAI, like a study for energy saving.

2.1 *Simulation*

Simulations must use models; the model represents the fundamentally different traits of the selected software programme, while the simulation shows the development of the model. The simulation is routinely done digitally.

2.2 *Energy analysis with Revit*

To confirm that we are continually striving for the most energy-efficient building feasible, energy analysis must be performed on the building design at all stages, from the earliest conceptual phase to the detailed design phase.

The flow of energy into, out of, and through the rooms and volumes in a building model can be examined with the aid of energy modelling. This knowledge can aid architects and designers in making more sensible choices that will enhance performance and lessen the environmental impact of buildings.

Based on the building's geometry, climate, type, envelope characteristics, and active systems, the overall building energy simulation calculates predicted energy use (fuel and electricity) for HVAC and lighting. It considers the building's interdependencies as an overall system.

The energy analysis in Autodesk Revit is used to carry out full building energy simulations for Revit models. The design process of Revit is coupled with the analysis prowess of Autodesk Green Building Studio via this add-in. Green Building Studio is the main whole-building energy simulation engine from Autodesk. The DOE-2 simulation engine is used by this adaptable cloud-based solution. It enables you to run simulations of a building's performance early in the design phase to maximise energy efficiency and move towards carbon neutrality. Your capacity to design high-performance buildings at a fraction of the time and expense of traditional approaches is increased with the aid of Green Building Studio.

Energy analysis in Autodesk Revit is also used for modelling the conceptual shapes and simulating the analysis of energy made by them. To learn how much energy is used by buildings, the simulation results are analysed. After that, the designs are refined to raise their sustainability scores.

It may inspect and validate the energy model used for analysis in Revit by displaying the energy model generated from the Revit building model. The energy model can also be exported to outside programmes for additional analysis in several standard file types, including green building XML (gbXML), DOE-2, and energy plus.

3. Applied study

Karim Centre is an office building located in Tripoli, North Lebanon (Figure 3). This place contains a combination of modern and heritage buildings, especially the Al-Hallab Palace. This centre includes many important offices and banks, such as credit banks, travel offices, employment offices, etc. The altitude and longitude are 34.4378365 and 35.833854, respectively, as shown in Figure 3. It is located on Riad Al Soloh Street, with a curtain-walled south facade.

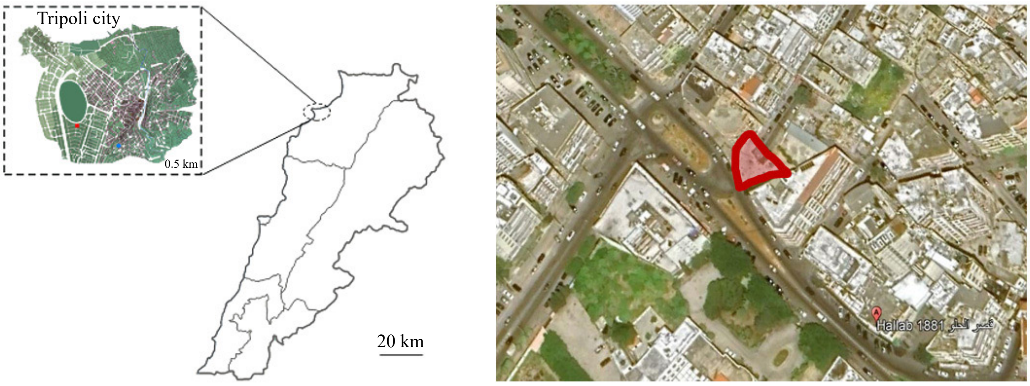


Figure 3. Karim Centre location

3.1 *Project weather station*

The project utilises the project default utility rates that use the project default weather station location established when the project was created. This project runs using uploaded utility history data (existing building projects) that use the 3TIER weather data application. This weather data analysis is needed to recognise the surrounding weather conditions in the studied area and determine if any additional analysis is required. Tables 3 and 4 show the cooling and heating degrees per day and the annual design condition, respectively. Figure 4 shows the monthly design data with the temperature variation. Figure 5 shows the dry bulb frequency and cumulative distributions. Figure 6 shows the average wind rose and speed frequency distributions. Figure 7 shows the dew point and relative humidity frequency distributions. Figure 8 shows the radiation frequency distributions.

Table 3. Heating and cooling degrees per day

Cooling degree day		Heating degree day	
Threshold (°F)	Value	Threshold (°F)	Value
65	2,216	65	889
70	1,314	60	267
75	575	55	46
80	82	50	9

Table 4. Annual design conditions

Threshold (%)	Cooling		Heating	
	Dry bulb (°F)	MCWB (°F)	Dry bulb (°F)	MCWB (°F)
0.1	88.2	73.5	43.3	40.1
0.2	87.6	74.9	43.7	40.2
0.4	87.1	75.1	46.2	44.2
0.5	86.9	75.3	47.3	42.8
1	86.0	74.9	49.8	46.7
2	85.3	74.9	51.4	48.0
2.5	84.9	75.0	52.0	48.7
5	83.8	74.5	54.0	50.8

Note: MCWB = Mean coincident wet bulb

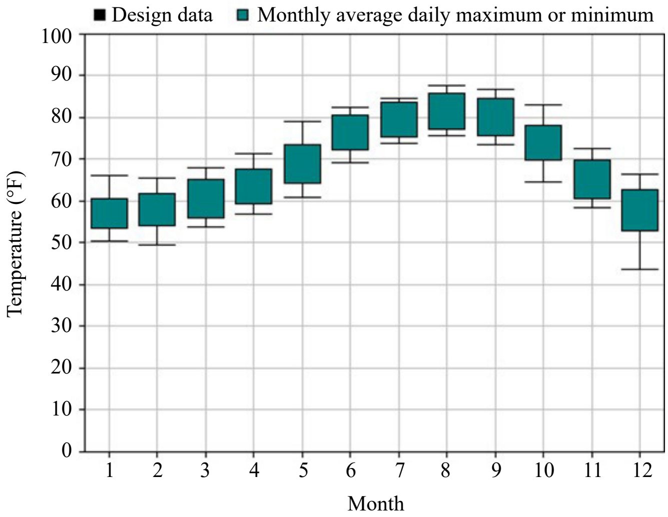


Figure 4. Monthly design data

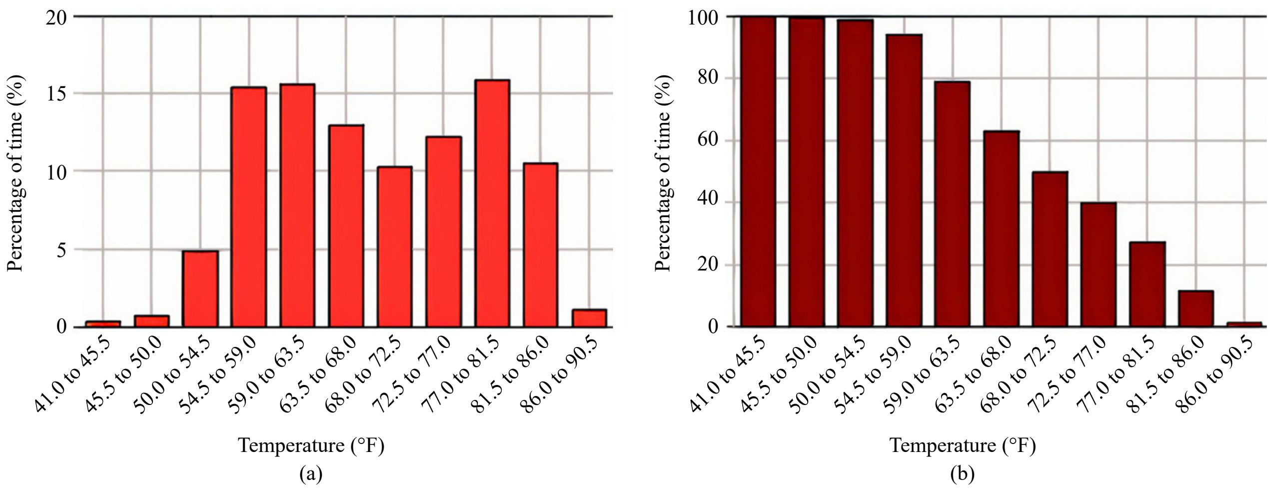


Figure 5. Annual dry bulb (a) frequency and (b) cumulative distributions

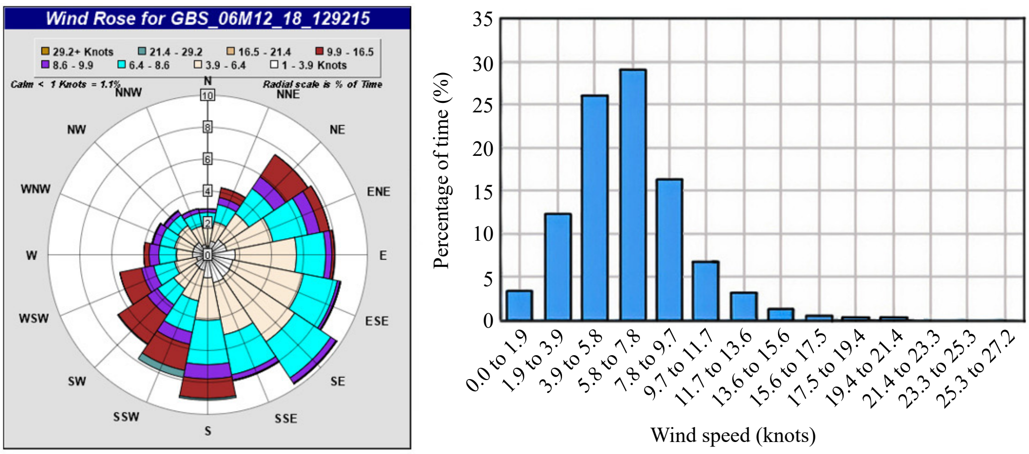


Figure 6. The average wind rose and speed frequency distributions

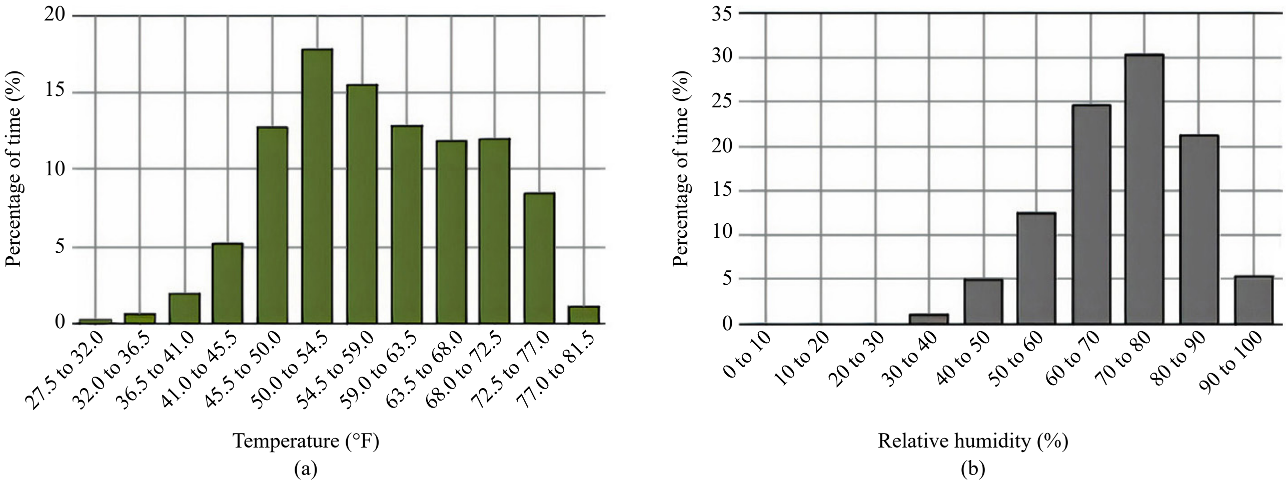


Figure 7. Annual (a) dew point and (b) relative humidity frequency distributions

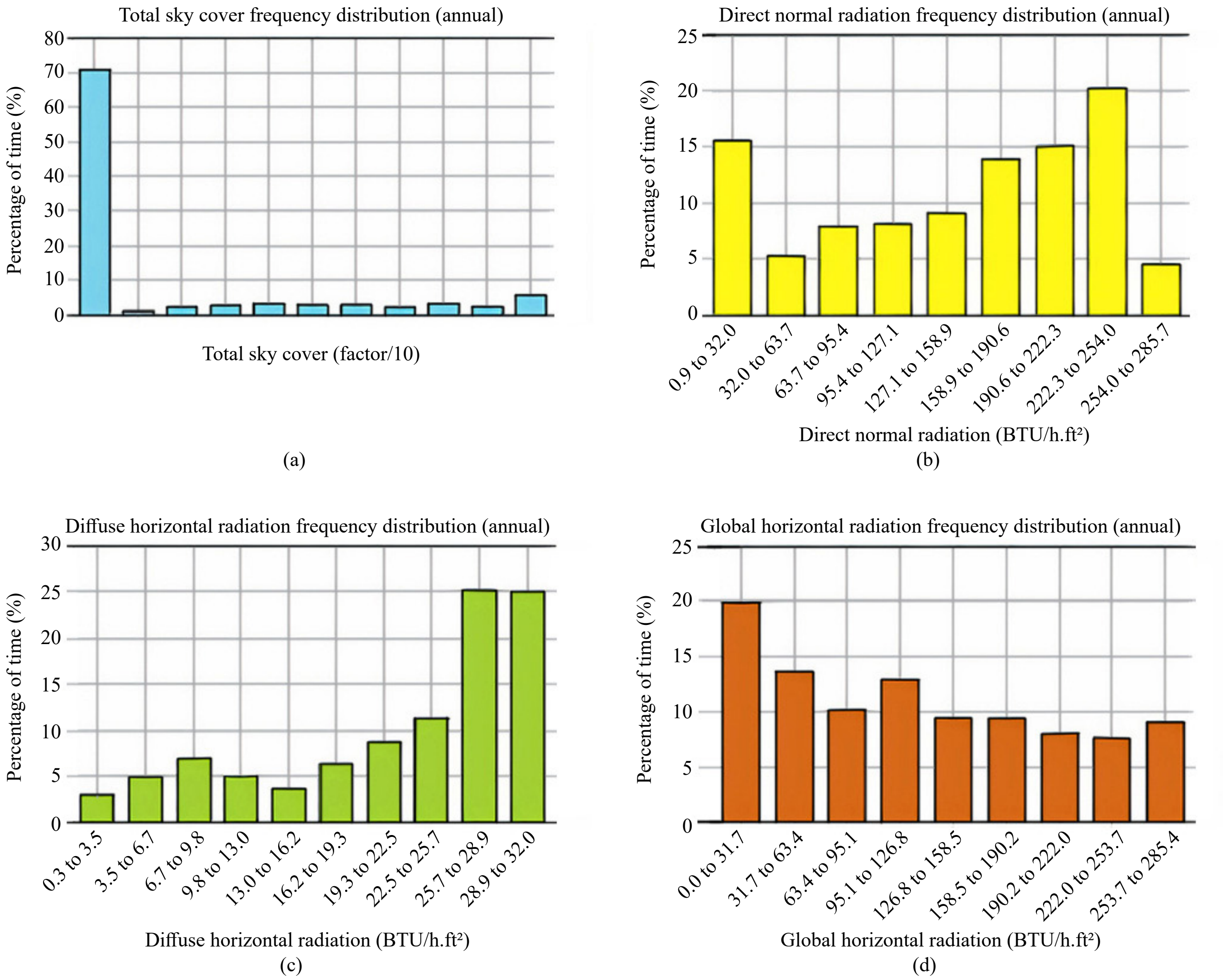
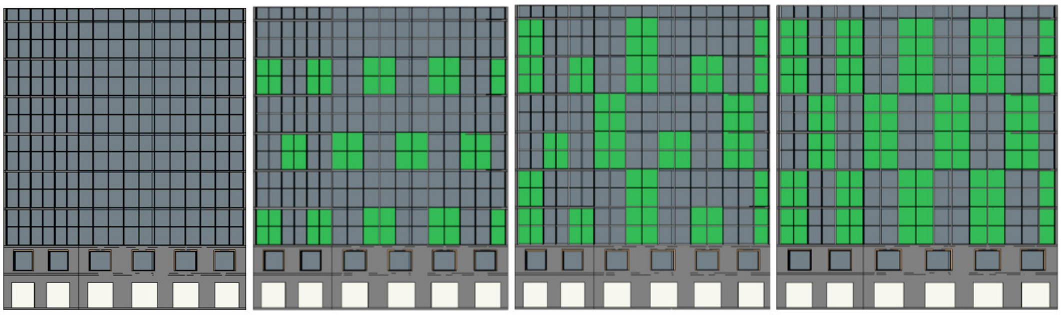


Figure 7. Annual radiation frequency distributions of (a) total sky cover, (b) direct normal, (c) diffuse horizontal, and (d) global horizontal

3.2 *Simulation*

The project has a southwest curtain wall facade. The simulation starts with the building in the same condition as shown in Figure 9(a). For the building with more additions on the facade, Evaluation 2 has 20% VGS (Figure 9(b)), Evaluation 3 has 35% VGS (Figure 9(c)), and Evaluation 4 has 50% VGS (Figure 9(d)).



(a) (b) (c) (d)

Figure 9. Evaluations (a) 1, (b) 2, (c) 3, and (d) 4

This simulation is for two scenarios: the first is with Net Zero, and the second is with Architecture 2030. Net zero (Figure 10) is a new standard for architectural buildings that combines the cost-effective energy efficiency that is measured with on-site and/or off-site renewable energy, resulting in zero-net carbon energy [15]. Architecture 2030 (Figure 11) calls for all new buildings to decrease their fossil fuel and greenhouse gas emissions consumption by 60% [16]. The main purpose of using these two scenarios is to achieve optimum energy savings, following the new architectural trend concerning sustainability.

Figure 10. Scenario sample: Net Zero

The first sample (Figure 10) shows that the cost maximum, mean, and the minimum is the same for each evaluation: Evaluation 1 is 6.92, Evaluation 2 is 7.54, Evaluation 3 is 8.02, and Evaluation 4 is 8.42, but it grows from 6.92 in Evaluation 1 to 7.54 in Evaluation 2, 8.02 in Evaluation 3, and 8.42 in Evaluation 4.

Figure 11. Scenario sample: Architecture 2030

It is evident in the second sample (Figure 11) that there is a change in the maximum, mean, and minimum cost in each evaluation. In Evaluation 1, it decreased from 10.3 in cost maximum to 8.8 in cost mean and 11.1 in cost minimum. Meanwhile, in Evaluation 2, the value drops from 11.8 in cost maximum to 11 in cost mean and 9.5 in cost minimum. Next, Evaluation 3 shows a decrement from 12.3 in cost maximum to 11.5 in cost mean and 10 in cost minimum. Lastly, Evaluation 4 shows the cost reduction from 12.8 in the cost maximum to 11.9 in the mean and 10.4 in the minimum.

The cost maximum grows from 10.3 in Evaluation 1 to 11.8 in Evaluation 2, to 12.3 in Evaluation 3, and 12.8 in Evaluation 4. Meanwhile, the cost mean grows from 8.8 in Evaluation 1 to 11 in Evaluation 2, 11.5 in Evaluation 3, and 11.9 in Evaluation 4. Then, the cost minimum grows up in Evaluation 1 from 11.1 to 9.5 in Evaluation 2, to 10 in Evaluation 3, and to 10.4 in Evaluation 4.

As shown in Table 5 and Figure 12, the energy use intensity decreases from 1,052 in Evaluation 1 to 971.2 in Evaluation 2, to 916.9 in Evaluation 3, and to 872.3 in Evaluation 4. The total annual electric cost went from 38,399 to 35,620 in Evaluation 2, to 33,840 in Evaluation 3, and to 32,364 in Evaluation 4. The annual fuel cost went from 1,324 in Evaluation 1 to 1,173 in Evaluation 2, 1,044 in Evaluation 3, and 943 in Evaluation 4. The annual energy cost went from 39,723 in Evaluation 1 to 36,792 in Evaluation 2, 34,884 in Evaluation 3, and 33,307 in Evaluation 4. The total annual energy (electric) decreases from 426,658 in Evaluation 1, to 395,774 in Evaluation 2, to 376,003 in Evaluation 3, and to 359,604 in Evaluation 4. The total annual energy (fuel) decreases from 179,054 in Evaluation 1 to 158,632 in Evaluation 2, to 141,163 in Evaluation 3, and to 127,533 in Evaluation 4.

Table 5. The comparison between the four-evaluation based on their annual cost and energy.

					Total annual cost			Total annual energy	
Name	Floor area (m^2)	Energy use intensity ($MJ/m^2/$year)	Electrical cost (L.L/kWh)	Fuel cost (L.L/MJ)	Electric (L.L)	Fuel (L.L)	Energy (L.L)	Electric (kWh)	Fuel (MJ)
Evaluation 4	1,630	872.3	0.09	0.007	32,364	943	33,307	359,604	127,533
Evaluation 3	1,630	916.9	0.09	0.007	33,840	1,044	34,884	376,003	141,163
Evaluation 2	1,630	971.2	0.09	0.007	35,620	1,173	36,792	395,774	158,632
Evaluation 1	1,630	1,052.0	0.09	0.007	38,399	1,324	39,723	426,658	179,054

Note: L.L = Lebanese Lira

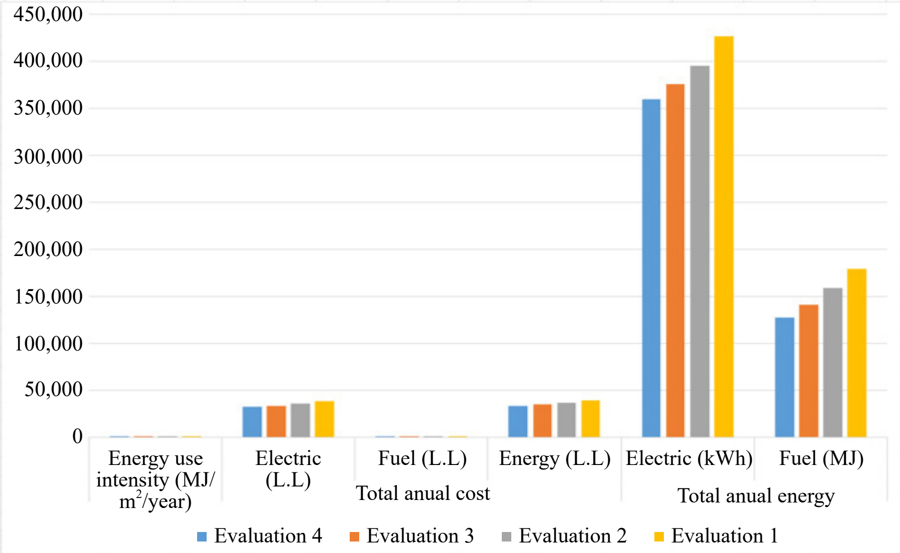


Figure 12. The comparison between the four-evaluation based on their annual cost and energy

4. Discussion

Figures 10, 11, 12, and Table 5 compare the benefits of the four VGSs in the Kamal Centre on lowering building energy costs and usage. VGS4 provides the most optimal energy savings with a reduction of 15.7% and 50% green density on the facade when compared to the control wall in terms of the maximum reduction in average energy cost and usage. This paper has more information and data about VGS. However, this paper did not discuss in depth the plant species, the type of VGS, interior lighting, or wall-to-green facade distance. It also did not specify which type of VGS would be the most cost-effective.

5. Conclusion

A key component of a society's sustainable development is energy savings. In a humid tropical city in Lebanon, this study looked at how VGS on a facade might lower the cooling requirements of buildings in urban blocks. The findings can serve as a factual foundation for encouraging extensive vertical greening, offer guidance for making the best site selection decisions, and shed insight on the underlying process of green-facade energy impacts. The main factor involved in this research is the density factor. This factor has a great effect on energy savings through VGS, but it does not cover all types of green species; it mainly focuses on their densities.

Conflict of interest

The authors declare no conflict of interest in this study.

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