The Green Facades Systems (GFS) Consideration to Insure the Maximum Environmental Benefits

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IJASR 2021
VOLUME 4
ISSUE 3 MAY – JUNE **ISSN: 2581-7876**

Abstract: Residential buildings in Egypt consume about 40% of total energy consumption according to the 2018-2019 energy consumption report the residential buildings. Most of this energy consumes in H-VAC to achieve the thermal comfort. So that, the architects start to use the Green façade systems (GFS) to minimizing the heat gain which came from the building envelope to optimize the energy efficiency and also to reduce climatic stress (radiation, heat gain, temperature …etc.), air pollution, CO2 emissions, sound reflections & external noise with taking into consideration the operational costs to gain a market edge.

Design Builder has been used to simulate the GFS installation (directly or with 60cm air gap) effectiveness on a residential Twin House with 12cm wall thickness in New Cairo, Egypt in the directions (south – east - west) to inherit the effect of external wall thickness as a component of the building envelope on the efficiency of energy consumption. The change in thickness of the wall from 12 cm to 25 cm in the south direction reduced the energy consumption by 13.13% and in the case of the use of double wall thickness of 12 cm with 10 cm air cavity 17.2%, while in the east direction the reduction in energy consumption at 25 cm was 14.33%. While in the case of using a double wall thickness of 12 cm with 10 cm air cavity 18.65%, and finally in the case of west direction, the reduction in energy consumption at the thickness of 25 cm 15.26%, while in the case of a double wall thickness of 12 cm with a cavity of 10 cm 22.79%.

Keywords: green façade system, energy consumption efficiency; retrofitting.

1. Introduction

In the new urban development which facing a lot of challenges such as; energy, increasing in population and built up area ratio, the Vertical Greening System (VGS) could be used as a one of Green areas restorative tool playing and also as an environmental building retrofitting tool according to its ability to maximize the thermal comfort and energy saving ratio, work as a thermal insulation for buildings envelope, reduce the heat gain/loss in the indoor spaces, minimizing CO2 emissions, reduce noise … etc. [1]

Although, the VGS has a huge environmental benefits, most of residents/users reject the idea of transferring the horizontal gardens into a vertical gardens also, some of them afraid from its effect on the building structure and others afraid from its installation and maintenance cost which shows that the social aspects considers as one of the important aspects to achieve the successful VGS Installation as an environmental and economic aspects. [2]

1.1. Problem Defintion

The residential building consumes about 40% of total energy consumption in Egypt as the building material which use in the outer skin doesn't suitable with the climate and it absorb heat gains during day and reflected it during night which led to using H-VAC systems to achieve the thermal comfort which led to more energy consumption. [3]

1.2. Paper Methodology:

In this paper GFS effect will be investigated through literature review to introduce the GFS types, structure systems, irrigation, waterproofing, insect's resistance and maintenance tasks to define design guidelines to be able to reach an

Installation Process Chart. Then a practical study was carried out by simulating a Twin House in New Cairo to inherit the effect of external wall thickness as a component of building envelope in the directions (south – east - west) on the efficiency of energy consumption. Finally the research concludes with some recommendations on how to reduce energy consumption and improve thermal performance in residential buildings by building envelope treatment.

2. Green Facade as a Type of Green Walls

Green Walls or Vertical Greening Systems (VGS) are the expression that refers to any surfaces that vegetated

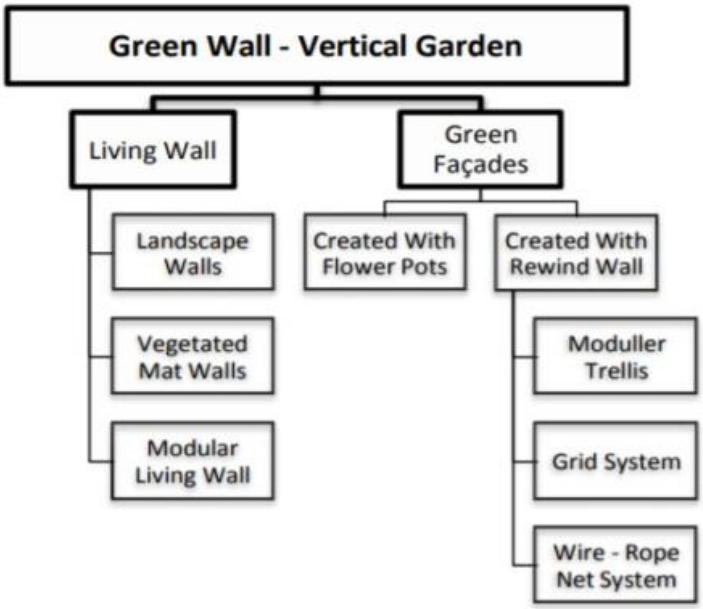

Figure 1: Green Wall Types [4]

vertically, which divided into two categories Green Facades and Living Walls. [4] (Figure 2) This system has been used due to the environmental problems resulting from the lack of green surfaces, and it has an effective role in reducing the amount of greenhouse gases and purifying the air from pollutants. [3]

2.1. Green Façade System (GFS):

GFS is a system that covers the vertical surfaces by climbing and herbaceous plants and these plants could be installed directly on facade or installed in a separated structure system with air gap. GFS takes from three to five years to give full coverage. [5] It divided into two categories;

Plants with roots grow directly in the soil:

In this species, the roots of plants are directly connected to the soil in the ground. These plants grow naturally, either directly on the facade or the system attached to the facade, as shown in (Figure 2). [4]
This system takes a long time (years) to be given full coverage of the façade, depending on the size of the wall and the quantity and type of cultivated plants. Also, there is no irrigation system for this type where plants naturally absorb water either from rain water or from water present in the soil.

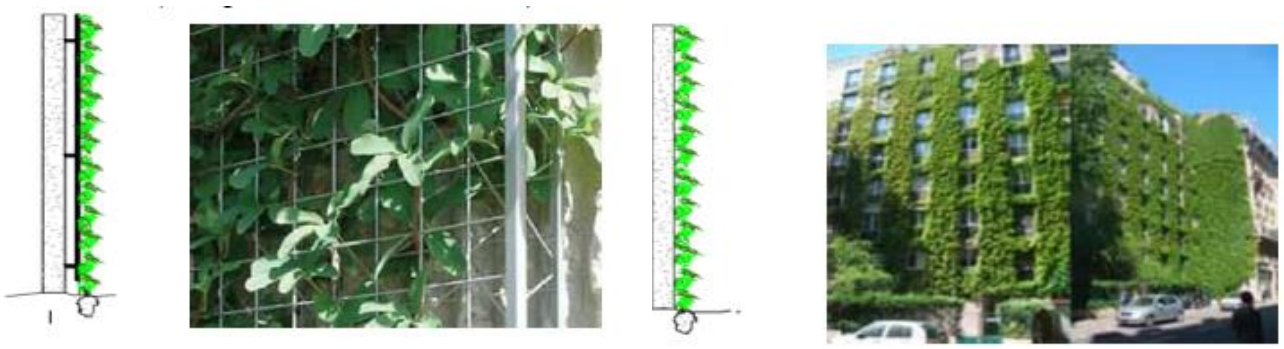

Figure 2: Plants with roots grow directly in the soil [4]

Plants with roots grow in substrates:

In this species, plants grow in ad hoc units with soil in them. These plants can be either at the bottom of the façade, or at the top and it is called the hanging system. [5] This type requires a continuous irrigation system due to the lack of direct contact with the soil on the ground, and it needs a long time to give full coverage of the facade, as shown in (Figure 3). [6]
The duration of full coverage depends on the nature of the facade surface, the amount of vegetation used, and the distance between them. This type gives the possibility to plant a part of each floor with the possibility of leaving spaces between them.

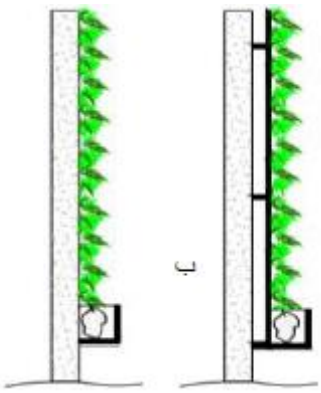

Figure 3: Plants with roots grow in substrates [7]

2.2. Green Façade Structure Systems:

The Green Facade's structure system could be from metal or wood or plastic containers which 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. [8]

1- Modular Trellis panels system: which consists of lightweight rigid and 3D panels which manufactured of welded galvanized steel wire & supports vertical extension of plants [9] This system is designed when we need to make an air gap between structure and wall or and as a freestanding green walls [9] (Figure 4)

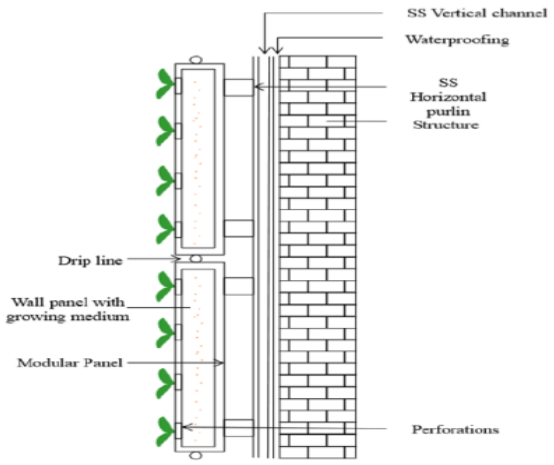

Figure 4: Trellis panels system [7]

2- Cable and wiring networks system: cables are using case of supporting the fast growth plants with denser foliage and Wires in case of supporting slow growth plants. Plants can be at the bottom or at the top of façade which called "Hanging System". [10] (Figure 4) This type requires a continuous irrigation system due to the lack of direct contact with the soil and land also; it takes a long time to give full coverage of the interface. This time depends on; façade surfaces, the amount of plants and the space between façade and plants. Finally this type gives the possibility to vegetate parts in each floor with leaving spaces betwthem. [5]

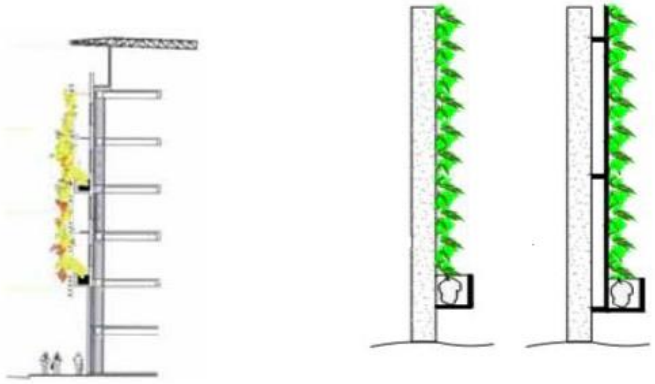

Figure 5: Plants with roots grow in substrates [7]

2.3. Green Facade Systems Irrigation:

Planter boxes that used for climbing plants should have an appropriate drainage system according to plant species. Container systems (manufactured units) should have a free draining growing substrate to avoid water logging in the periods of wet weather also, it should have holes in the side of the containers to drain the excess water on a container and re-use it for irrigation again. [11] Using climbing vegetation means that Irrigation system will be required to insure the maintenance of high-density foliage cover

2.3.1. Irrigation systems Types

1. Automatic irrigation system: It is a system that is used without human intervention and that is linked to time sensors to operate it at the specified times. [12]
2. Self-irrigation system: It is an irrigation system that relies on water that is stored in containers and is generated by building's recycled water. [8]
3. Simple irrigation system: It is consisting of plastic water tank connected to a pipe to drip the water in specified places with an automatic system includes time sensors to adjust the irrigation times. [8]
4. Drip irrigation system: It is an irrigation system that transported the filtered water or fertilizer is transported through droppers to the soil or plants roots permanently which maximizes the water use efficiency. [12]

2.4. Benifits of Green Facades

GFS has a lot of benefits not only environmentally but also socially, educationally, economically and visually

2.4.1. Environmental Benefits (Table 1)

GFS can be reduced the indoor temperatures reduced by 10 ◦C which led to reduce energy consumption for up to 20%. Thermal performance depends on many factors such as; climate, building envelope material and the density of plant coverage. [13]

It also work as an insulation layer that can protect the facade from a lot of physical environmental influences such as; reduce climatic stress (radiation, heat gain …etc.) , maximize the building life time if it maintained periodically and reduce the facades final finishing (painting, cladding .. etc.) cost that will lead also to reduce the building negative impact on natural environment. [5]

A lot of studies concluded that GFS maximize energy savings in warm–dry climates by 9:30% and improves the buildings energy balance through transpiration & reflectance.[12]

GFS can also reduce sound reflection from roads & street canyons [14]. It also provides a building's noise buffer as it reduces noise & vibration (up to 40dB) [13]

Finally GFS maximize the LEED credits in the following points; Innovation In Design (ID) , the Sustainable Sites (SS), Materials and Resources (MR) and Water Efficiency (WE). [15]

Table 1: The environmental benefits of GFS

	Roots grow in Substrates			Cable and Wire System	Double Skin Facade
	(Pocket)	(Modular)	(Trellis panels)		
Thermal performance [17, 18]	The evaporation of GFS plants cools the facade (by -7°C to -15°C) and also work as a sun-screen and increase humidity				
Reduction of air pollution [19]	Use to clean air in city scale specially in the lack of green space areas Reduced the concentration of NO2, PM10 (microscopic Particulate Matter) by 15:23% and PM2.5 peak by 45.3: 71.4% Reduces CO2 emissions.				
Reduction of noise [19]	Reduce noise from 2 to 5 dB Absorbs up to 18dB of the street noise.				Reduce noise (low to middle frequency) from 5 to 10dB Maximize sound insulation by 1dB for traffic noise & 3dB for a pink noise
Hydrology and water management [19]					Irrigate by recycled grey & black water or collected rainwater

2.4.2. Social Benifits

GFS enhances the urban environment aesthetic value, improves human health and adds value to building identity. [17] Also, it leads to decrease stress and maximize the resistance to illness which led to crime and violent behavior reduction. [20]

2.4.3. Visual Benefits

Green facade systwms can achieved the 3 categories of beauty (enjoyable, admirable and ecological beauty), also could be used as a public art. [18]

2.4.4. Educational Benefits

GFS has a great impact in ecological education. It could be used in biology or art classes in schools or in Sustainability 3D teaching textbooks [19], also it has a great value in raising the importance of ecology awareness. [21]

2.4.5. Economic Benefits

GFS could increase the real estate up 20% and Increase residential and commercial by 7:15% [20] and its payback reached after 16 years. [21]

2.5. GFS Maintenance

All GFS need a regular maintenance because they are a live system. Maintenance considered as the main factor that control the choice of plant type and construction system. [16]

2.6. Maintenance Tasks

According to Australian Growing Green Guide maintenance tasks divided into 5 categories [13];

First: Establishment Maintenance

It happened in the first two years of GFS Installation to ensure the healthy plant growth. It includes; irrigation system and plantation maintenance (weed and pruning control).

Second: Routine Maintenance

It includes the regular works to ensure that vegetated facade is maintained according to its required standard of functionality, appearance and safety.

Third: Cyclic Maintenance

It's responsible for building structure and the GFS components to insure its safety and effectiveness.

Fourth: Preventative Maintenance

It's responsible for the sudden damaged and changing the fails parts in the GFS.

Fifth: Renovation Maintenance

It's responsible for any changing the in design intent according to changes the ownerships or the building usage.

3. Green Facade Consideration

According to the benifits of GFS alot of Europe and Asian couuntries tried to put polices and technical standards to insure the GFS success and define the consideration that should be taken into consedration to achieve the best environmental effectiveness such as;

3.1. Policies

Berlin, Germany developed a BAF (Biotope Area Factor) an urban planning parameter which sets out the ratio between the area of the surfaces that effect on the ecosystem such as; vertical greening systems, green roofs... etc. and the site total area. [13]

The City of Seattle, USA established a score system to increase the amount of green spaces in new development projects and it called the "Green Factor Program" and it depended on the German BAF (Biotope Area Factor) and to get the score your building vegetated area must equivalent 30% of building in economical buildings and 50% in multi-family residential. [13]

The city of Sidney, Australia adopted the "Green roofs and walls policy", to promote the use of green roofs and walls in both residential and commercial sectors also; the vertical greening system has been recognized in rating tools Such as LEED® building certification programs. [13]

Singapore launched "Sky rise Greenery Incentive Scheme" (SGIS) in 2009 which finances the installation cost of green roofs and vertical greening system to 50% (or 500$ per square meter) on existing and new buildings.

London, UK developed a plan to maximize the vegetated area percentage by 5% in 2030 in the central of London through using green roofs and vertical greening system. [13] According to that, a technical guide has been published to investigate the benefits of living roofs and vertical greening systems and the aspects that should be considered such as; location, orientation, plant's, structural capability, etc. [24]

3.2. Technical Standards

There are four technical standerds and guidelines that give detailed information about Green walls (green Façade and Living Wall) life cycle stages:

- The Growing Green Guide (Melbourne – Australia) [13]
- The short-guide to safe practices for vertical greenery (Singapore , Republic of Singapore) [25]
- The Végétalisation des murs et des toits (Paris, France) [26]
- The UK Guide to Green Walls (United Kingdom) [24].

3.3. Concideration of Green Facades

After reviewing all the above literature review the concideration of green facades could be classified to 5 different concederations. (Table 2)

Table 2: The GFS Consideration

Architecture Considerations [27]	To determine suitable GFS, structure system and maintenance tasks, building location and its façade characteristics (with/without opening) are very important
Structure and Construction Considerations [20]	Steel frame additional weight in GFS 3D systems should be considered. The air gap distance in GFS free standing system air gap distance should be determined according to the building construction and structure state.
Environmental Considerations [14, 20]	To ensure the high effectiveness of GFS installation the vegetated area, soil availability, orientation, drainage, water supply and grey water usage availability sould be determined. Try to reduce the site water discharge by integrating the Green infrastructure techniques (vegetated swale & rain garden) with storm water management. [35]

Plants and Irrigation Considerations: [20]	Irrigation Plan should be defined according to rainfall harvesting, possibility of using grey water, drainage, water supply and the plant's needs. Gree facade plantation should be choose according to; Site Location (to define the native plants, water supply and drainage availability) Installation and srtructure system type and façade coverage area ratio Plantation seasonal cycles and leaf area index (LAI) Combination between Evergreen and deciduous Plantatiom to achieve the maximum efficiency in different seasons. Scramblers and root climbing vines should be installed on 3D freestanding system In case of GFS installed direct to the wall or with air gap is < 40 cm the twining vines is be best choice
Maintenance and Economic Considerations [13, 20]	A maintenance plan should be defined to manage a long term of required functions, lasting installation A Periodical maintenance plan should be defined in case of air- gap space is less than 15:20cm or using drip irrigation. The maintance budget should include all the GFS installation components such as; structure system, plants, soil, waterproofing, irrigation... etc.

4. Green Facades Environmental Benefits Efficiency Experimental Study:

The GFS Environmental benefits (Energy Saving, CO2 emissions, heating and cooling loads) have been explored through generating GFS models in Design Builder simulation program and a "green roof material" is used to act as a "green façade".

4.1. Experimental Study Input Data:

The simulation will be done for a residential unit (Twin House) in New cairo (Figure 6) located at the 1st floor (to avoid heat gain/loss from ground and roof) in East and West Orientation in both Red Brick Walls Thickness (12 and 25 cm).

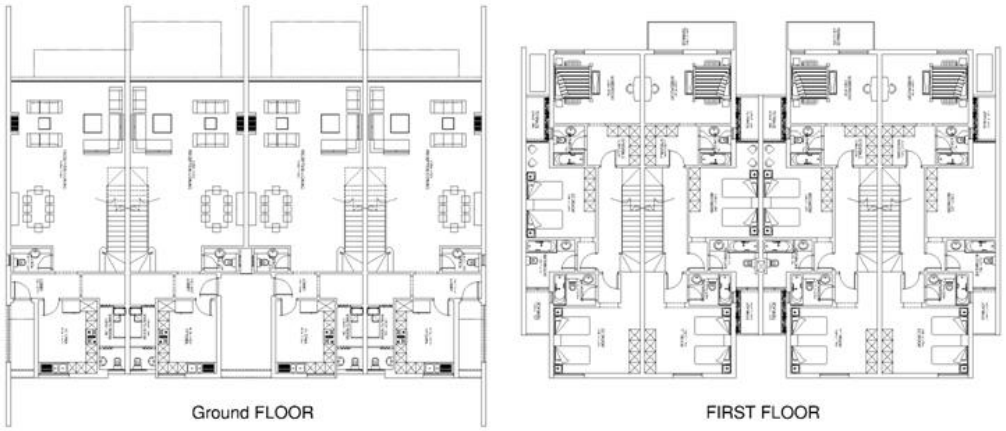

Figure 6: Town House Plan

The chosen installation system is a Grid-net system and it installed in two alternatives:

- Directly on façade surface (no air gab), hanging 12 sturdy steel planter box (100 x 500 x 15 cm) contains a pre-vegetated plants sheet with no need to irrigation system
- Free stand system (60 cm air gap), hanging 12 sturdy steel planter box (100 x 500 x 15 cm) contains a pre-vegetated plants sheet with a simple self-irrigation system.
  The chosen plant is "Hedra Helix – Ivy" with LAI: 0.005 m2/leaf [28] - 100% coverage, Opening: 40% WWR – clear single glazing 6mm, the simulation required data as shown in (Table 3 and Table 4))

Table 3: wall layers thermal property [29]

	Wall Layers			
	Sp.H J/kg.K	Den. g/m³	Cond. W/m.K	Thickness m
Plaster	1000	600	0.16	0.005
Mortar	896	1570	1.00	0.02
Red Bricks	838	1790	0.60	0.12
Mortar	896	1570	1.00	0.02
Plaster	1000	600	0.16	0.005

Table 4: Green Facade thermal property [29]

	Green Facade Layers			
	Sp.H J/kg.K	Den. g/m³	Cond. W/m.K	Thickness m
Water vapor[39]	1966	0.60	5.56	0.002
Vegetation [39]	2.8	533,28	0.36	0.20
Air gap [39]	1004	1.3	5.56	0.60
Stainless steel [40]	460	7900	17	0.05

Results and Discussion:

To investigating the Environmental benefits of GFS, simulations were carried out with all exposed walls and vegetation. The study was focused on Energy saving, CO2 emissions, heating and cooling loads of the building in East and West Orientation.

Environmental Benefits:

1- Heating and Cooling Load: The GFS has a great effect on minimizing heating and cooling loads as shown in (Table 5) according to its ability to minimize the heat gain/loss inside spaces and also work as a thermal insulation for the outer surfaces.
2- Energy Saving: The following table (Table 5) shows the effect of GFS installation in both Direct and with air gap on energy consumption

Table 5: Annual energy consumption and saving ratio for South, West and East orientation

Orientation	Wall Case	Cooling - Annual (KWh)	Heating - Annual (KWh)	Annual Energy Consumption (KWh)	Saving %
South Orientation	Initial case	2587.16	759.56	3346.72	
	GFS: Direct to the Wall	2187.15	689.97	2868.12	**14.3**
	GFS: with air gap 60 cm	2058.08	669.76	2727.84	**18.5**
East Orientation	Initial case	2749.25	835.72	3584.97	
	GFS: Direct to the Wall	2234.76	786.98	3021.74	**15.7**
	GFS: with air gap 60 cm	2160.93	736.91	2897.84	**19.2**
West Orientation	Initial case	2946.7	948.09	3894.79	
	GFS: Direct to the Wall	2484.97	784.97	3269.94	**16.1**
	GFS: with air gap 60 cm	2190.83	763.84	2954.67	**24.1**

3- CO2 Emissions: The GFS purifys the surrounding air and decrease the CO2 emission which maximize the indoor and outdoor air quality (Table 6)

Table 6: Annual CO2 emissinos and saving ratio for South, West and East orientation

Orientation	Wall Case	CO2 Emissions (Kg)	Saving %
South Orientation	Initial case	2707	
	GFS: Direct to the Wall	2462	**9.05**
	GFS: with air gap 60 cm	2428	**10.3**
East Orientation	Initial case	2980	
	GFS: Direct to the Wall	2682	**10**
	GFS: with air gap 60 cm	2650	**11.07**
West Orientation	Initial case	3140	
	GFS: Direct to the Wall	2735	**12.89**
	GFS: with air gap 60 cm	2705	**13.85**

The above tables (Table 4 and 5) show that the GFS installation with air gap has a better effect than the one who installed direct to the wall and also shows that the best result came when the GFS installed on the west orientation. As the GFS installation with 60 cm air gap reduced energy consumbtion by 24.1% and CO2 emissions by 13.85%.

5. Conclusion

The GFS has alot of environmental benifits such as; reducing heating and cooling loads, minimizing the the energy consumption and CO2 emissions which will maximize the human thermal comfort inside the space and also maximizing the outdoor air quality through reducing the air pollutants.

According to the importance of GFS in minimizing the harmful effect of building environment on natural environment a lot of countries defined a polices to be encourge the owners and designers to increase the vegetated areas through vegetated the vertical facades and also defined a technical guides suitable with its climate to make it easy to install.

The practical study shows that the best results came when the GFS installed with 60 cm air gap. As when it installed in south direction it minimized the energy consumption by 14% and CO2 emissions by 9% when it installed directly to the wall and the energy consumption by 18.5% and CO2 by 10% when it installed with 60 cm air gap and t, in east direction the energy consumption minimized by 15.7% and CO2 minimized by 10% when it installed directly to the wall and the energy consumption by 19% and CO2 by 11% when it installed with 60 cm air gap, finally In west direction the energy consumption minimized by 16% and CO2 minimized by 13% when it installed directly to the wall and the energy consumption by 24% and CO2 by 14% when it installed with 60 cm air gap. (Figure 7 and Figure 8)

Figure 7: GFS Energy Saving Ratio (both direct and 60 cm air gap)

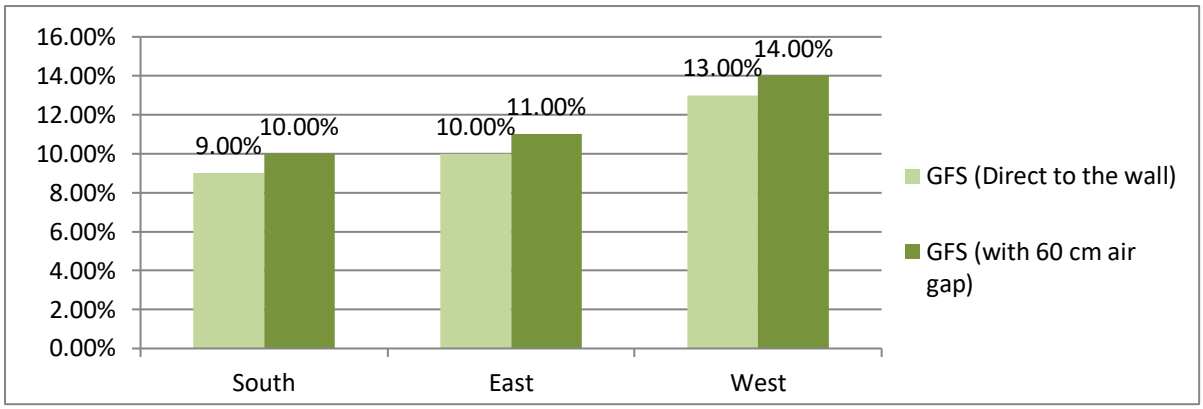

Figure 8: GFS CO2 Reduction Ratio (both direct and 60 cm air gap)

Finally to insure achieving the best outcome of GFS, a periodic maintenance of plants and its structural system is must and also the façade maintains is very important to insure the safety of the building and its structure from penetrating the roots.

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