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The Usage of The Vegetated Green Systems and Their Impact on The Thermal Efficiency of Residential Buildings

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Abstract: The aim of this research is to explore the effect of Vertical Greening Systems (VGS) on improving indoor environment quality and rationalizing energy consumption in residential buildings and consequently suggest a valid design guideline aiding the designer towards successful Eco-building realization. Vertical Green Walls(VGS) are considered one of the ideal solutions for treating existing buildings to increase thermal insulation and control the amount of heat gain through the outer envelope of the building, improve the thermal comfort, and reduce energy consumption. Moreover, such treat benefits in other ways such as absorption of carbon dioxide, release of oxygen and impact positively on humidification as well as improving building elevations external look. To measure the positive effect of VGS green walls, a computer simulation of applying green walls to an existing building was done, different types of VGS were compared with their different components and their effect on building indoor temperature, the ability and resistance to heat transfer, and the amount of carbon emission released to the atmosphere. A comparison was conducted to explain the difference between the original building status and the one after adding the VGS green walls. Finally, the research reviewed the results of simulation and effect ratios for several types of VGS walls, compared with the original wall, as well as with the addition of internal insulation. That final comparison associated with measuring weights was used to form design guidelines to help designers in choosing the proper type of VGS for each treated building in hand.

Keywords: building performance, energy saving, retrofitting building envelope, sustainable solutions, living walls.

1. Introduction

There is no doubt that the world is facing serious environmental problems regarding growing consumption of energy that leads to pollution of environment with harmful carbon emissions and thus to global warming.

Based on the foregoing, there are many serious attempts to reduce this disaster globally, but for Egypt, so far, there are no mandatory building requirements regarding the efficiency of thermal insulation for the building envelope, which plays a key role in saving the energy required for thermal comfort. This certainly has repercussions on human health and the surrounding environment, as the requirements of the modern lifestyle led to excessive consumption of energy and thus pollution of the environment, and it also led to the gradual separation of man from nature.

In other words, residential buildings in our modern lifestyle are suffering from “Sick Building Syndrome”. Sick Building Syndrome (SBS) describes a situation in which the occupants of a building experience acute health, or comfort, related effects that seem to be linked directly to the time spent in the building. [1]

Therefore, converting residential buildings from sick buildings to healthy ones can be achieved by making building envelopes more efficient, sustainable, and smart.

Many Eco-additives applications to building envelopes are being applied to retrofitted building envelopes to create healthier buildings. These applications increase comfort, reduce energy consumption, and accordingly create more enjoyable cities.

Many researchers [2], [3], [4], [5] have shown the importance of retrofitting existing buildings to reduce the negative impact on the environment and people. This retrofit can be relied upon as an effective technology that improves thermal comfort and reduces energy consumption in residential buildings. That opens the path to the potential of passive retrofitting techniques that leads to achieve the minimum energy goal in Egypt and other countries as well.

Previously mentioned research’s results presented a set of best strategies in retrofitting techniques, including the retrofit of the outer building envelope.

[5] reported that the treatment of the outer envelope of the building (walls) and the upgrade to LED light fixtures would reduce energy consumption in residential buildings annually by up to 42.5 %. That prompts decision-makers and building policies to move forward towards adopting different and more efficient strategies for retrofitting to solve all energy problems.

[2] presented strategies for retrofitting building envelopes through glazing upgrading that decrease cooling load and total energy consumption by up to 16.5%. Thus, replacement of the regularly used glazing by a thicker and darker one. [4] reviewed some of the essential measures used in the retrofitting procedure of the building envelope including external walls (insulation), windows (glazing

type), air tightness (infiltration), and solar shading could diminish the energy consumption by a middling of 33%. Whereas [3] conducted an economic assessment based on the most common economic tools presented values of internal rate of return, profitability index, and discounted payback period. The results of their simulation showed that how difficult retrofitting could be, in certain cases, to realize a cost-effective retrofit intervention and how economic indexes could bring users to reject a prior certain energy management measure during decision-making procedure.

Most of previously stated applications depend on applying common techniques such as using building materials, insulation, wall thickness, and shading techniques. Whereas other researchers adopted the idea of introducing nature back into the built environment to make a strong establishment of integration between nature and modern cities by retrofitting their sick building envelope using Vertical Greening Systems (VGS).

[6], [7], [8] and others have shown, through experimental studies (prototype model), the efficiency of planted walls in improving thermal comfort rates, reducing energy consumption, and its positive impact on the surrounding environment, people wellbeing, and increase productivity.

1.1 Research significance:

The research highlights the contribution of Vertical Greening Systems (VGS) by retrofitting existing buildings and transforming them into green ones. Additionally, reducing energy consumption and enhancing thermal comfort. The research focuses on the importance of using and applying Living Walls (LW) in the development and design of buildings as Vertical Greening Systems (VGS) plays an important role in sustainability and could be an effective element in Egypt's vision of 2030 and green economic growth.

1.2 The Aim of the Work:

This paper will study the possibility and variation of applying Vertical Greening Systems (VGS) to protect building envelopes for existing residential buildings.

Accordingly, Vertical Greening Systems (VGS) have been suggested as one of the most natural, efficient, sustainable retrofitting solutions in this research which play an important role in converting buildings from sick to green ones.

As well as, correcting the relationship between man and nature by using Living Walls (LW) that has many benefits such as reducing energy consumption, increasing oxygen percentage, purifying air, having a useful impact on human health, and creating more enjoyable cities, and comfortable buildings.

1.3 Research Methodology:

The research adopted comparative analytical study of existing residential unit models to determine the typical model that will be used in this study. An experimental study was conducted through thermal computational simulation by using the Design Builder.

The paper methodology passed through three main stages as following:

- *First stage:* analyzing a typical base case with a bare wall that was located at new Heliopolis city (second settlement, Cairo) which consists of a total number of 128 flats. with a total area of 751.43m2. Each flat consists of 2 bedrooms, a living room, a kitchen, and a bathroom. It has been built 10 years ago. The selected building depends on natural ventilation only.
- *Second stage:* applying the Living Walls (LW) on the south and west façades.
  The results from the first and second stages are going to be analyzed and compared to determine the most effective Living Walls (LW).
- *Third stage*: the maximum and minimum Living Wall (LW) thermal performance will be analyzed and compared to Expanded Polystyrene (EPS) as a reference measure (regularly most used thermal insulation material).

Finally, the mentioned comparison is considered as a design guideline tool for designers to easily compare and choose a better solution for sustainable retrofitting for existing buildings.

2. RESEARCH DESCRIPTION:

[7], [9], [10], stated that the Vertical Greening Systems (VGS) is divided into two main categories which are: Living Wall (LW) and Green Façade.

- Living Wall (LW): a modern type of Vertical Greening System (VGS) is known also as green walls or walls based on the greening method or vegetated matt. It was developed by Patrick Blanc. Which classified into Vegetated matt, Hanging pockets and Linear (Planter boxes) [7].

- **G**reen **F**acade (GF): a simple type of **V**ertical **G**reening **S**ystems (VGS) in which the cascading green plant (climbing plants) are attached to the wall direct or indirect and they are a ground-based greening method. [8].

Out of those retrofitting technique for the existing building envelope, a base of guideline for using VGS as retrofitting building envelope.

2.1 The Base Case Analysis:

Table (1) and Table (2) summarize the base case envelope thermo-physical properties for walls and windows, whereas the space is not isolated. The thermal properties of the base case envelope have been calculated according to the Egyptian Code.

Figure (1) shows the Hanging Pockets that are used as a type of Living Wall (LW) that was remarked by their frame that holds the panels and protects the wall. The panel's fabric should be root-proof, permeable, flexible, drainage, and hold growing media. The Hanging Pocket consisted of several pockets that are fixed to a frame structure and waterproofing membrane. The pockets were designed to hold soil inside it (organic or inorganic).

Table (1): Base Case Components Thermo-Physical Properties – Egyptian code (Specifications of thermal insulation works items)

	Material	Thickness (cm)	Conductivity (W/m-k)	Specific heat capacity (J/kg-k)	Density (Kg/m3)
Walls	Mortar	0.02	0.800	0.896	2800
	Bricks	0.25	1.2500	880	1000
	Mortar	0.02	0.800	0.896	2800

- R-value=0.415m2k/w, U-value=2.407w/m2k

Table (2): Base Case Windows Thermo-Physical- Egyptian code

	Material	Thickness(m)	SHGC[(1)]	Direct transmission	Light transmission	U-value (w/m^2-k)	WWR[(2)]
Windows	Single Clr glass	0.006	0.819	0.775	0.881	5.778	30%

Design-Builder program is essentially employed for geometrical model input data.

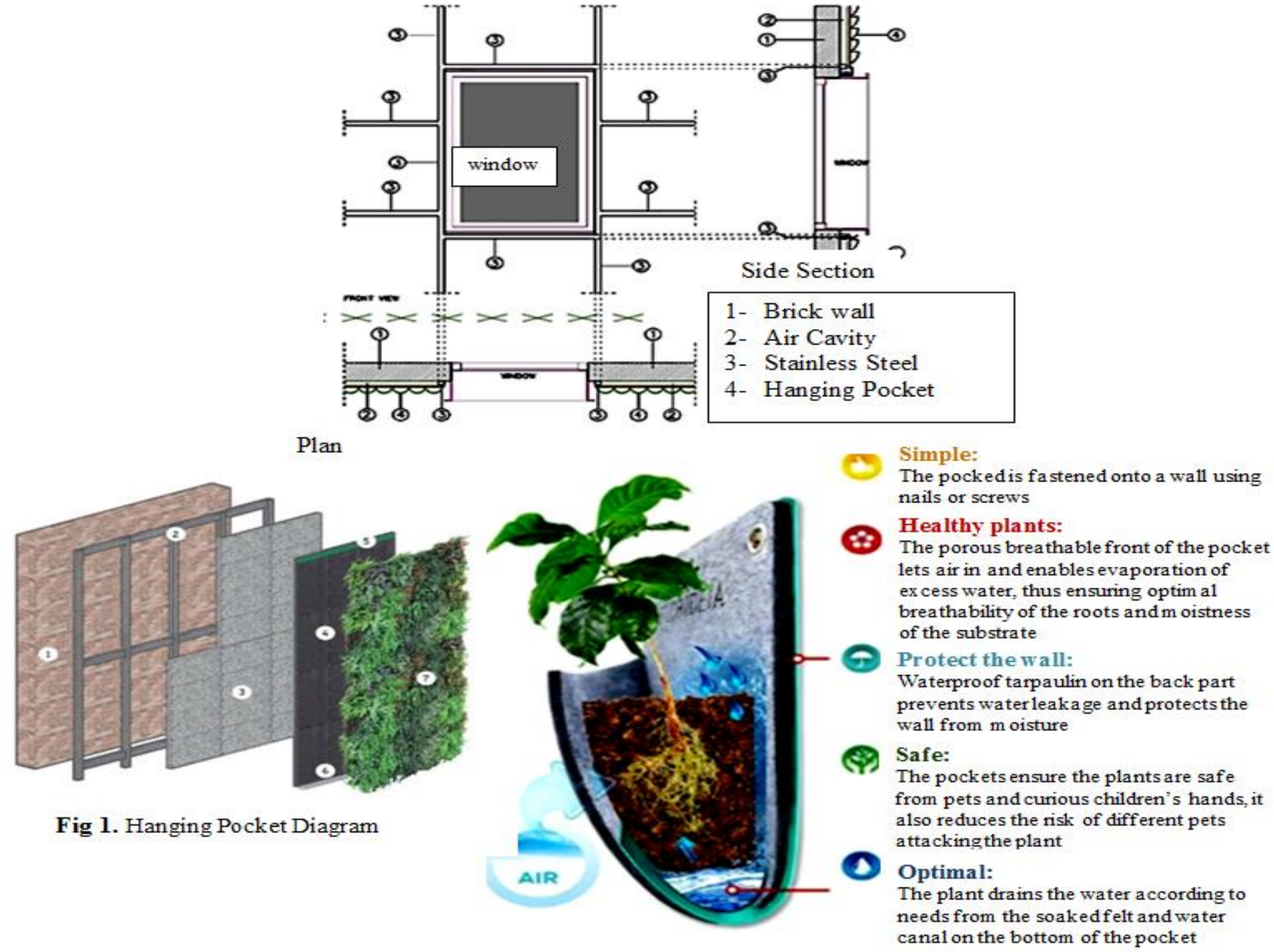


Fig 1. Hanging Pocket Diagram

[1]- SHGC: **S**olar **H**eat **G**ain **C**oefficient for a window that means a standard used to estimate solar radiation that passes through glass, in other words, it measures how well a window blocks heat from the sun where low SHGC reduces heat significantly and means lower cooling bills (Egypt Code, **N**ational **F**enestration **R**egistration **C**ouncil (NFRC)).

2 - WWR: **W**indow to **W**all **R**atio that means the ratio of the window areas to the gross exterior wall area (Building Energy Efficiency Standards,2013)

2.2 simulation conditions

In the simulation the research considered some factors of the input data to be constants and others be variables in order to facilitate the simulation process and data.

2.2.1 Constant factors:

- Orientation: Figure (2) showed the selected space's facades were oriented to South and West as both orientations exposed to maximum amount of solar radiation.

Fig (2). Base Case 3D Model, Plans – Showing Hanging

- Soil Type: Table (3) shows the thermo-physical properties of Soil [11] and [12] used AgriTerram soil (substrate used for growing plants) which is a mixture of (peat, lapillus, and pumice, expanded perlite, bark)[3], coconut fibers, special clays, soil improvers, and organic fertilizers that have a saturation volumetric moisture content is 0.05 and residual volumetric moisture content is 0.02.
- Air Cavity: [13], [6] and [14] discussed the air cavity Width, naming it an Isolating Layer whose thickness varies from 30mm to 60mm. In our simulating model, the air cavity Width is 5cm. (Table-3)Frame: made of stainless steel. (Table-3)
- Pocket: as shown in Table (3) the thermo-physical properties of Geotextile[4]has been used in many projects. It was manufactured from 100% polyester needles (non-woven) which have high-temperature and corrosive resistance, durable, based on raw materials fibers, and can filter the air. The natural fibers used in geotextile are (jute, coir, flax, hemp, sisal, and kenaf) [1]. [15] mentioned that **L**iving **W**alls (LW) are made of Geotextile pockets and/or panels, sometimes pre-vegetated, and resting on vertical supports or wall structures. Geotextile panels and pockets provide support to vegetation formed by, among others, lining plants, ferns, small shrubs, and other climbing plants. Out of the mentioned above, the research relied on Geotextile material in the **L**iving **W**alls (LW).

2.2.2 The Variable Factors:

- Plant: As stated by [17], [18], [15] and [19] the type of plant affected the efficiency of the Living Wall(LW), and determining suitable plants for specific purposes influences the performance of vertical greenery systems and increases system efficiency. Selecting the native species of plant is a must to achieve an efficient living wall. Plant choice is constrained by various factors. Table (4) shows the plant's properties affecting the plant selection. Different types of plants have the chance to grow together in Living Wall (LW). So, the plants were classified into three main families. (Shrubs, Perennial Flowers, and Grass)
- Insulating Materials: Table (5) shows the thermo-physical properties of the most used insulating materials for Living Walls (LW) and the thermo-physical properties of the reference insulating material, Expand Polystyrene (EPS). As [6] and all the previous research mentioned that PVC is a more common insulating material than the other two types. Expanded Polystyrene (EPS) is a Thermal Insulation board used for exterior and interior insulation and finishes. Expanded Polystyrene (EPS) is a closed-cell lightweight cellular plastic material produced from polystyrene.

3 -Natural leaf fibers each have a different cellulose content between 31% to 78% and each has different densities varied between 1.2g/cm3 and 1.5g/cm3. They could be extracted by three different methods including hand harvest, retting, scraping

4_ Are those fabrics used in geotechnical application as they are permeable fabrics, able to separate, filter, reinforce, protect and drain.It is made of polyester in three forms woven (resembling mail bag) , non-woven (resembling felt) or heat bonded(resembling ironed felt).For planted walls , it is good drainage , healthy for roots. (Geotouch,2017)

3. Simulation Results and Discussions

Simulation results were compared based on annual energy consumption. Table (7) showed the simulation results and comparison between Hanging Pocket types and base case.

Minor difference between the Hanging pocket wall types was detected. While the major difference was between Hanging pocket types and the base case.

Figure (3) showed a summation of the measuring weight of Hanging Pockets according to differences in other variables such as weight, cost, carbon capture, carbon emissions, maintenance, and shading coefficient. a scale is assigned for such comparison based on measuring weight (3 – better, 2 – average, 1 – poor). Those weights are illustrated in the main comparison in Table (7) as well.

Table (3): Hanging Pocket Element's Thermo-Physical Properties

	Material	Thickness (cm)	Conductivity (W/m-k)	Specific heat capacity (J/kg-k)	Density (Kg/m3)
Soil	AgriTerram	8	0.20	1348	400
Air gape	Air	5	0.025	1006	1.23
Frame	Stainless steel	5	26.1	460	7800
pocket	Geotextile	0.015	0.2700	1200	0.75

Table (4): Plant Thermal Properties

	Shrubs	Perennial Flowers	Grass
Height (cm)	60	18	40
LAI(m^2/m^2)(5)	2.70	3.04	5
Leaf reflectivity	0.220	0.40	0.3
Leaf emissivity	0.950	0.950	0.950
Min. stomatal resistance(s/m)(6)	180	80	120

Table (5): Insulating Materials Thermo-physical properties.

	Material	Thickness (m)	Conductivity (W/m-k)	Specific heat capacity (J/kg-k)	Density (Kg/m3)
Insulating materials	Anti-rooting	0.002	0.23	900	110
	PVC	0.018	0.2	880	1330
	Bitumen	0.004	0.5	1000	1700
	Expanded Polystyrene (EPS)	0.05	0.040	1400	15

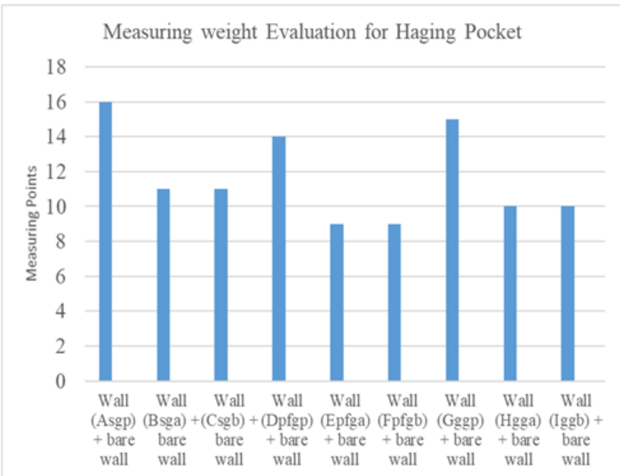


Fig 3. Evaluation of Hanging Pockets type

5 - LAI (m2/m2): Leaf Area Index which means A dimensional quantity that characterizes plant canopies, as the one-sided green leaf area per unit ground surface area LAI = m2/m2.in other words, it is the projected area of leaves over a unit of land. It is measured by using special equipment. It is a dimensional number between 0.001 and 5 (Design-Builder help, v7).

6 - Min. Stomatal Resistance (s/m): Represents the resistance of the plants to moisture transport. It has a unit of (s/m). Plants with low stomatal values will result in higher evapotranspiration rates than plants with higher resistance. The values range from 50 to 300 (Design-Builder help, v7)

Table (7): Hanging Pocket Simulation Result

Construction	plant type	shrubs			Perennial Flowers			Grass			Notes
	insulation material	PVC	Anti-rooting	bitumen	PVC	Anti-rooting	bitumen	PVC	Anti-rooting	bitumen	
	wall code	Wall (A_{sgp}) + bare wall	Wall (B_{sga}) + bare wall	Wall (C_{sgb}) + bare wall	Wall (D_{pfgp}) + bare wall	Wall (E_{pfga}) + bare wall	Wall (F_{pfgb}) + bare wall	Wall (Gggp) + bare wall	Wall (H_{gga}) + bare wall	Wall (I_{ggb}) + bare wall	
U-value (w/m2.k) (bare wall 2.407 w/m2.k)		0.35	0.36	0.36	0.35	0.34	0.36	0.33	0.36	0.36	**minor difference** between wall types while major difference to bare wall
Building Envelpoe	Indoor Temperature (c) (bare wall 25 c)	27.5	28	28	27.3	27.3	27.3	27	27.2	27.2	
	Thermal Discomfort(h/year) (bare wall 4056 h/y)	3434	3465	3431	3432	3445	3431	3429	3444	3445	
	Humidity (%) (bare wall 69.13%)	56.54%	57.86%	56.49%	57.13%	57.24%	57.05%	56.46%	57.62%	57.64%	
	Electricity Consumption(Kwh) (bare wall 463 kwh)	354	362	361	354	345	361	338	362	361	
	Carbon emissions (Kg/y) (bare wall 281Kg/y)	215	220	219	215	209	219	205	220	219	
Carbon Capture (Carbon Rate)		3	3	3	2	2	2	1	1	1	depend on the woody stem percentage
Weight (kg/m2) (Weight Rate)		28 (3)	32 (2)	36 (1)	28 (3)	32 (2)	36 (1)	28 (3)	32 (2)	36 (1)	planted and totally saturated
Total Initial cost (L.E./m2) (Initial cost Rate)		2200 (3)	2600 (1)	2400 (2)	2200 (3)	2600 (1)	2400 (2)	2200 (3)	2600 (1)	2400 (2)	varies according to markets without irregation system
Maintenance	plant (lifespan) (Plant Rate)	10 : 20 years (3)	10 : 20 years (3)	10 : 20 years (3)	3 : 8 years (1)	3 : 8 years (1)	3 : 8 years (1)	2 : 10 years (2)	2 : 10 years (2)	2 : 10 years (2)	depend on life span and cost (varies in market)
	insulation material (Insulation Rate)	3	1	1	3	1	1	3	1	1	
shading coefficient (depend on LAI) (LAI Rate)		1	1	1	2	2	2	3	3	3	depend on the LAI and leaf density
Total Evaluation Points		16	11	11	14	9	9	15	10	10	

From Table (7) and Figure (3), it was found that wall (A_{sgp})[7] has the best measuring weight and lower thermal performance while wall (G_{ggp})[8] has the best thermal performance and 2nd class measuring weight, but wall(B_{sga})[9] has bad thermal performance and 3rd class measuring weight.

Naming code was used for different wall types to differentiate between different wall compositions whereas example

7-wall(A_{sgp}) refers to Wall (A) + Shrubs + Geotextile + PVC

8 - wall(G_{ggp}) refers to Wall (G) + Grass + Geotextile + PVC

9 - wall (B_{sga}) refers to Wall (B) + Shrubs + Geotextile +Anti-rooting

So, the wall (G_{ggp}) and wall (B_{sga}) were selected because of their maximum and minimum thermal performance to be compared with another thermal insulating material which was Expanded Polystyrene (EPS).

3.1 Comparing the Hanging Pocket with Expanded Polystyrene (EPS):

Simulation results were compared based on annual energy consumption. It was recognized that there was a difference between the selected hanging pocket and the Expanded Polystyrene (EPS) as demonstrated at the following Figures (4 ,5-a ,5-b,6-a ,6-b,7):

3.1.1 U-value (w/m^2-k)[(10)] Comparison:

There is an inverse relation between wall thickness and the U-value. Also, the air cavity has an important role in heat loss or gain to have a better wall thermal performance, the insulation should have a U-value near to zero.

In other words, the lower U-value leads to the better wall performance. So, from this fact, it was recognized that base case U-value readings were = 2.40w/m2-k, as the wall (G_{ggp}) = 0.34w/m2-k and wall (B_{sga}) = 0.36w/m2-k while for the Expanded Polystyrene (EPS) =0.603w/m2-k. that means that lower U-value leads to better wall performance which will require less power for heating and cooling and less energy consumption.

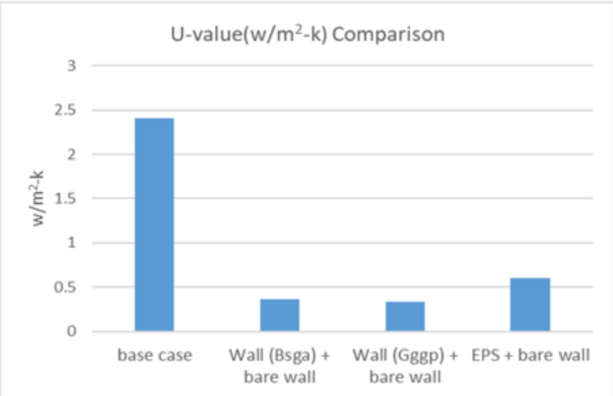


Fig 4. U-value (w/m2-k) Comparison

Accordingly, it was concluded for Expanded Polystyrene (EPS) that high U-value must directly affected the other thermal measurements by raising them.

3.1.2 Building Envelope:

3.1.2.1 Indoor temperature (^{0}C) and Thermal discomfort (h/y)[(11)]:

Figure (5-a) showed the different readings between Base Case Indoor Temperature reading was = 350C, as the wall (G_{ggp}) = 270C and wall (B_{sga}) = 280C while for the Expanded Polystyrene(EPS) = 290C. That means, Expanded polystyrene(EPS) has high indoor temperature than that of Hanging Pocket walls.

Figure (5-b) showed the different readings between Base Case Thermal Discomfort = 4056 (h/year), as the wall (G_{ggp}) =3429(h/year) and wall (B_{sga}) = 3465(h/year) while for the (EPS) expanded polystyrene =3581(h/year).

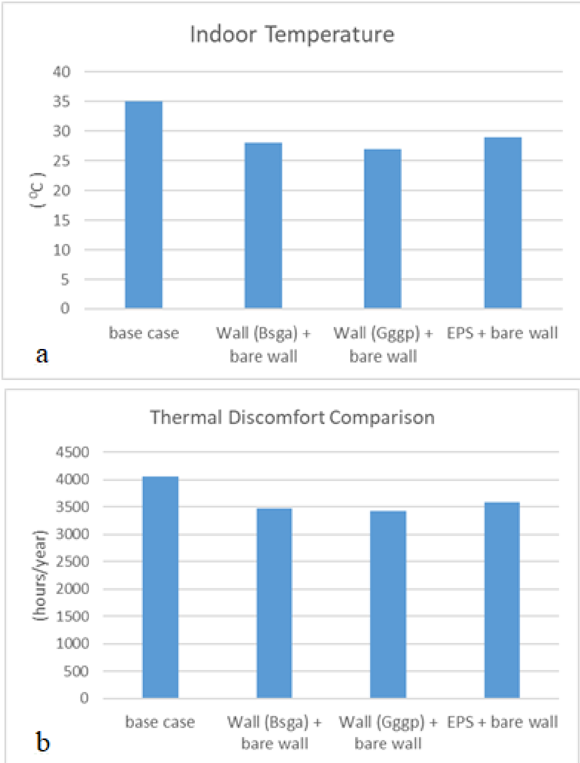


Fig 5. (a) Indoor Temperature (^{O}C), (b)Thermal Discomfort(h/y) Comparison

3.1.2.2 Humidity (%) and Electricity consumption (kwh/y)[(12)]:

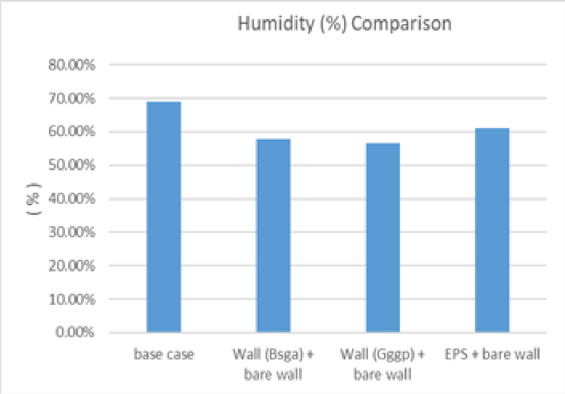
10 -U-value: is a measure of heat loss in a building element such as a wall, floor or roof. It can also be referred to as an 'overall heat transfer coefficient' and measures how well parts of a building transfer heat. The units of measurement are W/m²K (watt per meter square. kelvin). This means that the higher the U value the worse the thermal performance of the building envelope. A low U value usually indicates high levels of insulation. They are useful as it is a way of predicting the composite behavior of an entire building element rather than relying on the properties of individual materials [20]

11 -thermal discomfort: is exposure to either excess cold or excess heat, that is the exposure for a period of time to temperatures below 180C or above 24^0C [21]. is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation (ANSI/ASHRAE Standard 55). The unit (h/y) (hours per year)

12 -Electricity Consumption: whereas electricity consumption represents the amount of electrical energy that has been consumed over a specific time, in units of Wh (or kWh)(watt hour or kilo watt hour), electricity demand represents that rate at which electrical energy is consumed for a needed output rating, in units of W (or kW)(watt or kilo watt [22].in this paper the unit (kwh/y) (kilo watt hour per year) because it measured annually.

Figure (6-a) showed the different readings data between Base Case Humidity (%) = 69%, as the wall (G_{ggp}) =56% and wall (B_{sga}) = 58% while for the Expanded Polystyrene(EPS) = 61 %.

Figure (6-b) showed the difference between Base Case Electricity Consumption = 463(Kwh/y), as the wall (G_{ggp}) = 338(Kwh/y) and wall (B_{sga}) = 362(Kwh/y) while for the Expanded Polystyrene (EPS) =375(Kwh/y).



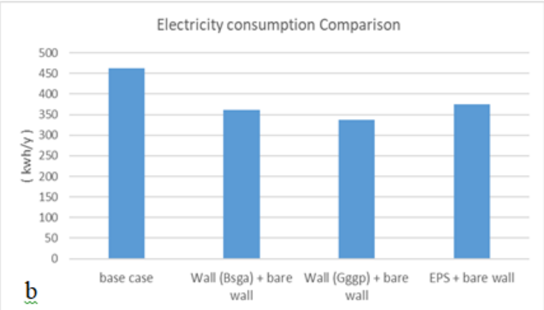


Fig 6. (a)Humidity (%), (b)Electricity Consumption (kwh/y) Comparison

3.1.2.3 Carbon emissions (kg/y):

Figure (7) showed the different readings data between Base Case Carbon Emissions = 281kg/y, as the wall (G_{ggp}) = 205kg/y and wall (B_{sga}) = 220kg/y while for the (EPS) expanded polystyrene =228kg/y.

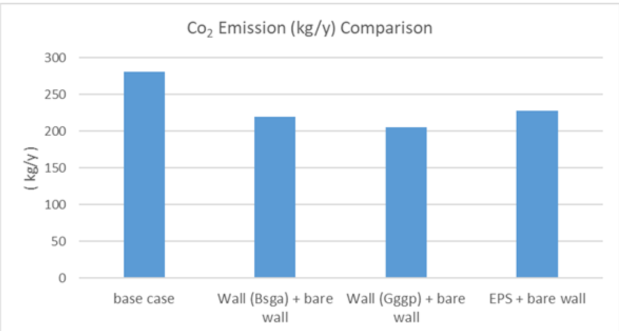


Fig 7. Carbon emissions(kg/y) Comparison

4. CONCLUSION

Nature and the environment are in danger as was publicized in most of the international conferences such as COP27. As well as there are no mandatory building requirements set regarding the efficiency of thermal insulation for the building envelope.

Therefore, residential buildings mostly considered sick buildings and suffering from "**S**ick **B**uilding **S**yndrome".

Most of previous studies theoretically indicated the acceptance of Vertical Greening Systems (VGS) for application as an effective retrofit technique that works on the thermal reliability of the outer building envelopes.

Comparing the thermal performance of the base case with the Hanging Pocket, it is seen that Hanging Pockets were more effective in improving the thermal performance of the building envelope annually in the south and west orientation and in the presence of natural ventilation only.

Hence, it has been concluded that Hanging Pockets created an insulation layer by providing natural blocks to an exterior wall and reduced heat transfer from outside to inside and vice versa annually which led to decreasing heating and cooling demand.

The study proved that the Hanging Pockets used in treating opaque parts of the building envelopes (walls) have a positive effect on the windows, as the plants have an effective role in reducing the thermal effect on the windows. In other words, the plants have decent shading effects on windows.

Therefore, the research emphasized the importance of the Hanging Pocket as an effective thermal and natural passive insulation technique for existing buildings that enhances the environment and has a positive psychological impact on humans by turning sick buildings into healthy ones plus a considerable added value to the surroundings.

Although Expanded Polystyrene (EPS) and Hanging Pockets have the same function for the building envelope, it was clear that Hanging Pockets have better thermal performance and ecological effect than Expanded Polystyrene (EPS).

It is worth pointing out that use hanging pockets for the sake of all their environmental benefits on human health, air purification, biodiversity, and economic green growth and could be applied easily as ***retrofitting*** cladding to turn the building from sick one to a green healthy building.

Finally, applying Vertical Greening Systems (VGS) as one of the mandatory solutions that must be codified in terms of building codes, laws, and licensing related to the efficiency of thermal insulation of the outer building envelope and the improvement of the urban environment. So, this will help the designers to select the suitable type of Living Wall using the comparison output to retrofit and/or re-develop their building or to be used in the early design stage.

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