Experimental and simulation study on thermal effects and energy efficiency of a green wall in the humid condition of Rasht

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The green wall systems have numerous benefits for buildings and urban spaces. In this study, the experimental analysis was conducted on an office building with a green wall in winter and summer times to assess the thermal effect compared to the bare wall through temperature and humidity data logger devices. The existing office building, which had a suitable condition, was used for evaluation. The purpose of this study was to investigate the thermal effect on the green wall. Moreover, the annual simulation was carried out to assessing energy efficiency on the green and bare walls using DesignBuilder V. 4.5 with actual office building specifications in Rasht. The results showed that heat transmit on the green and bare walls measured at about 259.2 w/m2 and 241.92 w/m2, respectively, and in the summertime, about 66.5 w/m2 and 48.4 w/m2, respectively. Based on the simulation results, the green wall could reduce the heat transfer between the interior and exterior walls by about 7% and for winter and about 27% for summertime. Further, it monitored that the green wall had about 42% have been more effective in reducing heat loss in the summertime. Eventually, the simulation indicated that the green wall has a uniform amount of consumption, which is estimated at a bare wall, and the green wall was 343 and 67 kWh per annum, respectively and could have a better effective performance by about 80% on the energy efficiency in the humid climate.

keywords: *An experimental study, building simulation, green wall thermal performance, energy efficiency, humid climate.*

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NOMENCLATURE

Acronyms

ΔT(DT) Temperature difference
A The wall area in square meter
C Celsius
cm Centimeter
E East
h Hour
H Height
Hum. Humidity
K Kelvins
m Meter
m/s Meter per second
N North
PDS Passive Design Strategies
Q Heat energy
RH Relative humidity
T and Temp. Temperature
U (U-factor) Thermal conductivity (or U-Value)
VHI Urban Heat Island
VGS Vegetation Greenery System
W Width
W/m^2 Watt per square meter
D Depth
HVAC Heating, Ventilation and Air Conditioning
W/m-K Watts per meter-Kelvin
J/kg-K Joule per kilogram-kelvin
kg/m^3 Kilogram per Cubic Metre

1. INTRODUCTION

Optimizing energy consumption is one of the essential parameters in sustainable architecture and green building design. Nowadays, several studies have presented design strategies in this area. These suggestions that if the construction industry responds adequately to this parameter by scientific and practical methods. Energy saving is one of the essential ways to optimize energy performance [1–5]. In this regard, various passive design strategies (PDS) have been proposed to reduce energy loss through the roof, walls, ceiling, and infiltration [6–8]. The use of green walls and green roofs have several benefits, including reduction of heat transfer [9–11], reduction of annual energy demand [12], lower demand for mechanical heating and cooling appliances [13], leading to fewer greenhouse gas emission [14], cooling urban environments [15–17], failure to create a climate change phenomenon [18], improve thermal comfort [19, 20] and sound insulation [21]. The green wall has also been known as a passive system [22]. Green walls can divide into two main categories, including green facades and living walls. Plant selection for green walls influenced by the mode or method of climbing plant attachment. Green walls' surface or structure can be divided into two groups: Self-clinging and Twining and tendrils [23, 24].

Self-clinging climbers create green facades that can provide adequate and long-term cover but may not suit buildings where the surface fabric is in poor repair. Many self-clinging climbers will mark a wall surface through their attachment. However, this is rarely seen because of the foliage cover. Excessively vigorous species such as Common Ivy (Hedera helix) should avoid, and regular pruning will always be necessary to maintain proper plant growth, form, and size [25]. One of the measures to reduce heat loss is the use of polystyrene insulation between the wall layers. The use of this type of thermal insulator also has some environmental consequences, as it is not recyclable.

The present experimental study performed to investigate the thermal performance of the green wall versus the bare wall concerning the reduction of heat loss to be used as an alternative to non-recyclable insulators. The question is green walls can be utilized in a humid climate with a PDS? Hence, a field-measured study was conducted to characterize the green wall's thermal effect on exiting office buildings with the actual specification in an office building in winter and summer. This study carried out in Rasht city, Iran, in 2018. The energy efficiency and electricity demand of cooling and heating systems through numerical simulation with Design Builder Software during a year were assessed.

2. MATERIAL AND METHODS

A. Outline of the case study and climatic features

The study area (Rasht city in the northern part of Iran) is located between the latitude of 37.25° N and longitude of 49.60° E with a height of 7 m below the sea level. This city generally has humid weather, mostly in summer rather than winter, and because of the high humidity, the city often experiences very low diurnal temperature fluctuations. In Rasht, the months with the highest and lowest average temperatures are July and January, with average temperatures of 36 °C and 3 °C, respectively [26]. The existing buildings were used as samples for evaluation. For this reason, the conditions of each sample were measured according to the matrix table because each sample had limitations. To carry out the experiments, initially, five buildings were identified in Rasht. The selected sample buildings were evaluated in a matrix table based on their conditions, including six factors: accessibility, mechanical system control, proof of materials, the similarity of the walls' profile, the suitability of the building usage, and the possibility to re-access the test. All the sample buildings had a Green wall (Table 1).

Table 1. Evaluation of the results obtained from the matrix table

No.	Accessibility	Mechanical system control	Proof of materials	Similarity of profile of the walls	Suitability of the building usage	Possibility to re-access the test	Evergreen
1			✓				
2			✓	✓			
3	✓	✓	✓	✓	✓	✓	✓
4	✓	✓	✓			✓	
5	✓		✓	✓		✓	✓

Table 1, Case No. 3 obtained the highest score among other samples, and selected as a pilot sample. The selected case has an exterior wall with a thickness of 20 cm, consisting of Gypsum with a thickness of 1 cm, cement mortar 1 cm, bricks 15 cm, cement mortar 3 cm, and thickness Green wall of 20 cm, from interior to exterior.

B. Experimental set-up

During summertime, the field measurement was carried out to predict green walls' influence on heat transfer and thermal performance in a humid climate on a 5-story office building. The inner data is monitoring using temperature and humidity data logger device model Mic 98583 with specification accuracy: Temp. ± 0.6 °C, 40.0 °C ~85.0 °C; RH ± 3%, 0.1999.9% RH during one day simultaneously in two zones, one with vegetation plant (green wall) and the other without covering (bare wall). It was defined for the device to record indoor temperature and humidity every 5 minutes. In addition to building thermal wall properties, the research team also measured local weather conditions using an Onset HOBO U30 USB Weather Station Data Logger installed on the building's roof. The green wall is on the second floor, and the bare wall is located on the fourth floor, directly about that. This measurement was conducted in a room with the same user. The wall area with a green and bare wall was about 12 m (4W $\times$ 3H). Specifications relating to spatial information and building samples are shown in Fig. 1. The green wall was planted with an evergreen plant, a species of Ivy so-called "Papital". The sample office building is located in Saadi Street, Moallem Blvd., Village Four-way, in Rasht.

3. RESULTS AND DISCUSSION

A. Field measurements

The Green wall is located in the eastern direction of the building. This experiment conducted in two seasons of winter (2/2/2018) and summer (15/6/2018). Table 3 shows the temperature and

Fig. 1. Measured Green wall in the east direction.

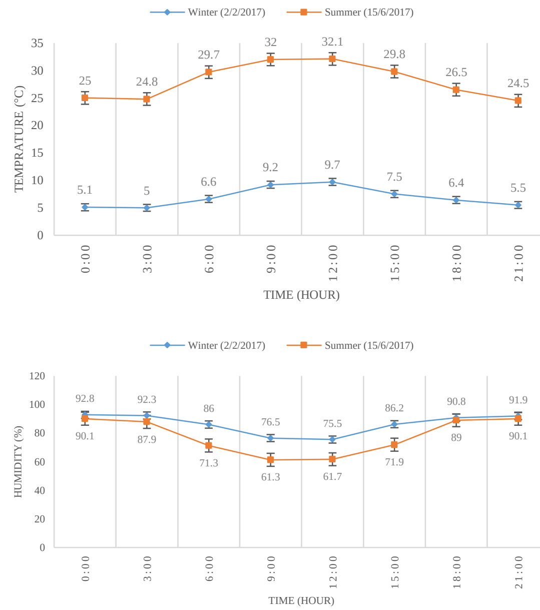

Fig. 2. Field measurements of outdoor temperatures (Left) and RH (Right) in summer and winter.

humidity data from the data logger for the winter and summer seasons. Since the device was placed inside the home, airspeed was considered negligible (0 m/s). During the measurement, the windows and doors kept closed, all mechanical devices shut down, and there was no internal heat gain. The weather conditions during the experiment summarized in Table 2.

Table 2. Experimental monitoring of a bare wall and Green wall

Period (H)	Winter (2/2/2018)				Summer (15/6/2018)			
	Bare wall		Green wall		Bare wall		Green wall	
	Tem.	RH	Tem.	RH	Tem.	RH	Tem.	RH
0:00	18.9	46.5	16.9	38.8	31	67.2	29.2	58.2
0:00	18.4	46	16.9	38.2	31.3	65.5	29.5	58.6
6:00	18.4	46.4	16.8	37.9	31.1	68.1	30	55.8
9:00	17.6	48.1	17.5	36.8	31	62.2	30.7	59.6
12:00	16.1	51	17.9	36.3	30.5	65.2	30.7	60.4
15:00	17.6	51.4	17.8	37.5	30.2	61.8	30.5	59
18:00	16.9	40.6	17.5	38.3	29.6	56.7	30.3	60.5
21:00	16.9	39	17.4	38	30.6	59.3	30	60
Mean	17.6	46.1	17.3	37.7	31	63.2	30.1	59

*Tem.: temperature; RH: relative humidity

Table 2 shows the green wall's experimental monitoring compared to that of the bare wall in summer and wintertime. Measured thermal parameters include outdoor air temperatures of the green and bare wall in summer and winter time and relative humidity (RH) of outdoor of the green and bare wall in summer and wintertime (Fig. 2).

Fig. 2 shows the comparison chart for the outdoor temperatures of summer and winter times and humidity in the green and bare walls in winter, and also shows the comparative diagram for the outdoor humidity of summer and winter times. The following provides the field measurements of green and bare wall indoor temperatures in winter and summer (Fig. 3).

According to Fig. 3, indoor temperature was higher in the

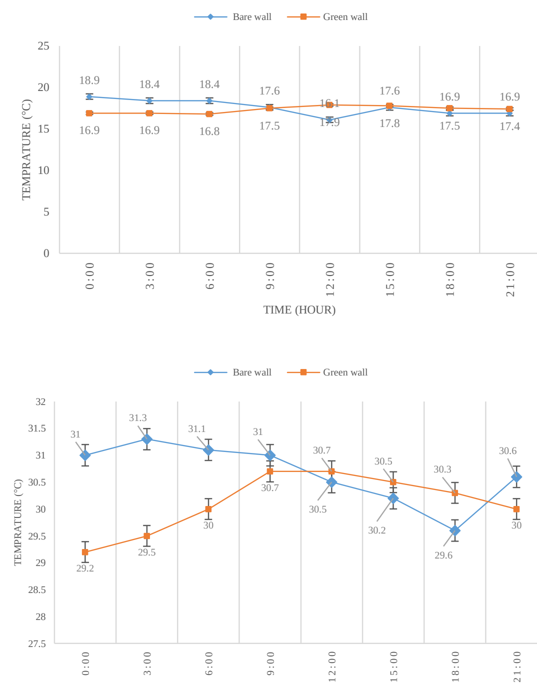

Fig. 3. Comparison of bare and green wall indoor temperatures in winter (Left) and summer (Right).

Green wall zone than in the area with the bare wall. The indoor temperature was lower in the morning in the spot with the Green wall at 06:00 than in the zone with the empty wall. However, this was vice versa at mid-day. Furthermore, RH also monitored in the green and bare walls (Fig. 4).

In this way, the amount of heat loss in the bare and the green wall assessed. The heat transfer can calculate using Eq. (1) through the wall from the hotter surface to the cooler surface.

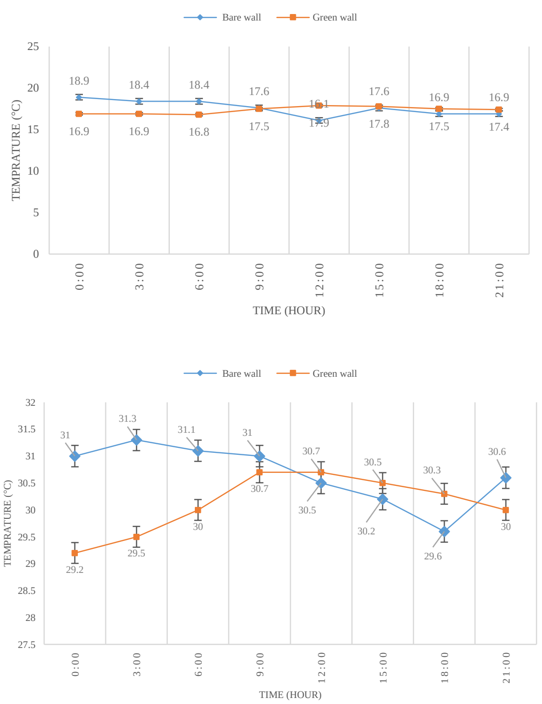

Fig. 4. Comparison of bare and green wall indoor humidity in winter (Right) and summer (Left).

The U-factor is 2.13 for the Green wall and 1.92 for the bare wall.

$$Q = U * A * \Delta T \quad \textbf{(1)}$$

In heat transfer science, the rate of heat transfer determined by the convection method. The thermal and heat loss of area (A) is defined by the building materials' U-value and the difference in exterior and interior temperature (the difference in temperature of two zones, but not two air temperatures, which might not be quite the same).

Table 3. Experimental monitoring of a bare wall and Green wall

Season	Wall type	Wall area (m^2)	U-value (W/m^2)	Δt (K)
Winter	Bare wall	12	2.13	17.6-6.8=10.8
	Green wall	12	1.05	17.6-3.8=10.5
Summer	Bare wall	12	2.13	30.28-6=2.6
	Green wall	12	1.05	30.28-1=2.1

According to Table 3, can be observed that the heat transfer value of bare and green wall was about 2.13 and 1.05 respectively. Moreover, heat transfer rate in winter time is about 276 w/m2 in the bare wall and about 132 w/m2 in the green wall whilst in summer time, it is about Table 3 shows that the heat transfer value of bare and green wall was about 2.13 and 1.05, respectively. Moreover, the heat transfer rate in the wintertime is about 276 w/m2 in the bare wall and about 132 w/m2 in the Green wall, while in summer, it is approximately 66.45 w/m2 in the bare wall and about 26.45 w/m2 in the Green wall. Based on the findings, the Green wall has a suitable thermal performance than the bare wall.

B. Simulation set-up of green wall

The simulation carried out during a year in the form of sub-hourly. The energy efficiency evaluated in a room where all HVAC systems and office equipment were on. Geometry for the building modeled with 4W × 3H × 4D proportion. DesignBuilder Ver. 4.5 were utilized to measure the green wall energy efficiency. This software uses to calculate energy efficiency in buildings. Similarly, two studies investigated the thermal performance and energy saving of the green wall through Design Builder software [27, 28]. To obtain actual specifications during simulation, an office building selected in the humid climate of Rasht, Iran, in which the building was implemented by the green and bare walls. Generically, the green wall has 6 layers that the materials' specifications are provided in Fig. 5.

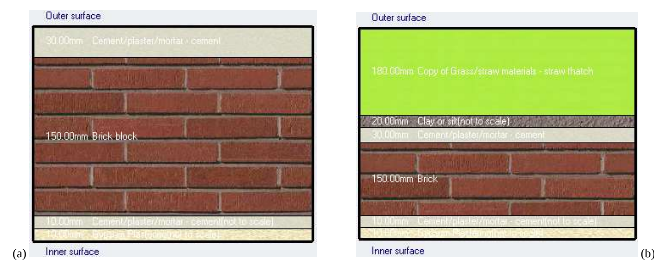

Fig. 5. Bare wall (a) and Green wall (b) layers (Plotted with Design Builder).

According to Fig. 5, it can be mention that the bare wall has four layers, including cement mortar with 30 mm, Brick 150 mm, cement mortar 10 mm, and Plaster 10mm from outside to inside. In the following, the green wall has six layers respectively, from the surface to the inside, including the vegetation plant (grass/straw materials - straw thatch) with 18mm, clay or silt 20mm, cement mortal 30 mm, brick 150 mm, cement 10 mm and plaster 10 mm. Furthermore, the Leaf Area Index (LAI) and the other specifications of green wall parameters used in the building models based on the CIBSE Guide A [29] (Table 4).

The weather data used as an EnergyPlus Weather data (EPW) format file derived from the Meteonorm software package and inputted into the DesignBuilder as a location file. Type of heating and cooling system package. The working hours were from 8 am to 4 pm. On this basis, the heating and cooling systems switched on (turn on) since the employees' arrival, and they turned off at the time of their departure. The number of working days is 6 days a week. Three men are working with three laptops, three printers, one office printer, and one scanning device in each room. The type of office activity is light office work, standing, and walking. Fig. 6 shows the activities' characteristics, and Fig. 7 shows the details of the HVAC system.

After input data, simulations performed simultaneously in two rooms. Energy efficiency assessment evaluated for one year. The purpose of this part of the paper (simulation) is to compare the energy efficiency of the green wall in reducing fuel and electricity due to heating and cooling of the building concerning the bare wall. In the following, the results of the simulation of energy consumption presented in Table 5.

Table 5 shows energy consumption fluctuations in different months of the year related to the green and bare wall, which includes electricity consumption of rooms, general lighting, and heating and cooling systems. Based on the simulation results, it observed that the different activities mentioned above in a

Table 4. Green wall model materials data on software

Thermal Bulk Properties of	
Conductivity ($W/m-K$)	0.4
Specific Heat ($J/kg-K$)	11
Density (kg/m^3)	641
Height of plants (m)	0.6
Green wall thermal parameters	
LAI	2.7
Leaf reflectivity	0.22
Leaf emissivity	0.95
Minimum stomatal resistance	180
Max volumetric moisture content at saturation	0.5
Min residual volumetric moisture content	0.01
Initial volumetric moisture content	0.15
Surface properties	
Thermal absorptance (emissivity)	0.78
Solar absorptance	0.6
Visible absorptance	0.6

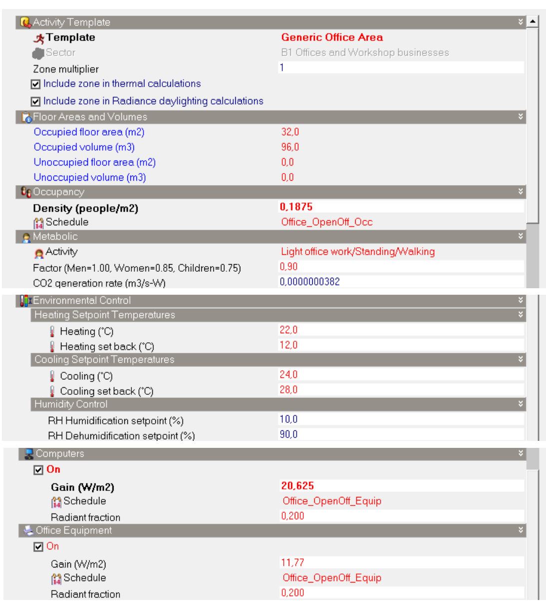

Fig. 6. Specification of activities during energy efficiency simulation.

room with a green wall are less than the bare wall. These values provided in Fig. 8 separately.

According to Fig. 8, a room's energy efficiency with a green wall related to the bare wall is visible, in which the minimum and maximum of values include 36 to 42 kWh, respectively. Jan, May, July, October consumed at peak times. Other months were less consume because of energy consumption related to office

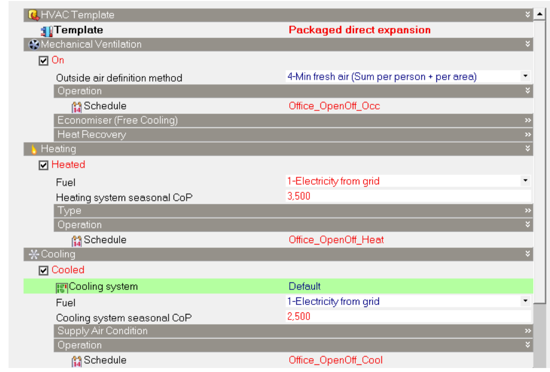

Fig. 7. HVAC system details.

Table 5. A summary of fuel breakdown and energy consumtion

Month	Room Electricity	Lighting	Heating (Electricity)	Cooling (Electricity)
Bare wall				
Jan	1,220,726	6,439,798	4,142,816	0
Feb	1,066,606	5,599,824	300,847	0
Mar	1,127,764	5,879,815	7,870,209	7,520,661
Apr	1,169,352	6,159,806	268,528	356,754
May	1,220,726	6,439,798	0	8,341,709
Jun	1,076,391	5,599,824	0	1,244,945
Jul	1,220,726	6,439,798	0	1,569,292
Aug	1,174,245	6,159,806	0	1,516,614
Sep	1,122,872	5,879,815	0	1,139,314
Oct	1,220,726	6,439,798	0,231122	5,295,286
Nov	1,122,872	5,879,815	486,136	1,340,248
Dec	1,174,245	6,159,806	3,290,855	0,092925
Green wall				
Jan	4,185,477	22,08	3,036,357	589,537
Feb	3,657,049	19,2	2,478,113	0
Mar	3,866,742	20,16	1,605,369	0
Apr	4,009,334	21,12	9,856,387	0
May	4,185,477	22,08	1,836,529	2,119,553
Jun	3,690,599	19,2	0,150234	9,671,187
Jul	4,185,477	22,08	0,006148	1,654,766
Aug	4,026,109	21,12	0	1,755,183
Sep	3,849,967	20,16	0,18418	8,756,532
Oct	4,185,477	22,08	4,492,216	0,198894
Nov	3,849,967	20,16	8,772,176	0
Dec	4,026,109	21,12	2,499,648	0

work equipment such as laptops, printers, photocopiers, and scanners. The bare wall's minimum and maximum electricity consumption are 110 to 121 kWh, which is related to January, May, July, and October, respectively. The bare wall's peak time of energy consumption also has 63 kWh, and a minimum is about 57 kWh. Further, the amount of energy used for General lighting in the green wall is 19 and 22 kWh.

The green and bare wall energy consumption for heating and cooling systems show some impressive results. Based on the findings, the demand for heating systems for the green wall is much lower than the bare wall at the beginning and end of the year. The minimum and maximum amount of electricity

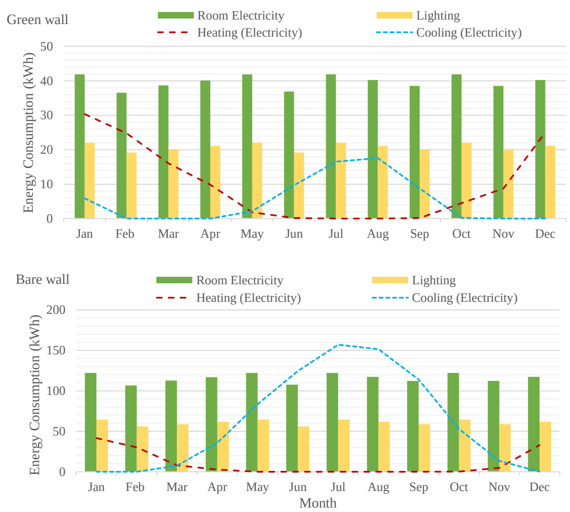

Fig. 8. Results of fuel breakdown and energy consumtion of building.

used are 30 and 24 kWh at the beginning and end of the year. However, the maximum and minimum of electricity used for the bare wall are 43 and 37 kWh. In addition, the energy demand for a green wall at the cooling system at the beginning and end of a year is uniformly, and the peak time is related to Aug (warm season) 16 kWh. Nevertheless, this amount is highest in the bare wall. In this way, the cooling system's energy demand is maximum in June, July, August, and these fluctuations seen from the beginning of April until to end of October. The total amount of energy consumed in a year presented in Fig. 9.

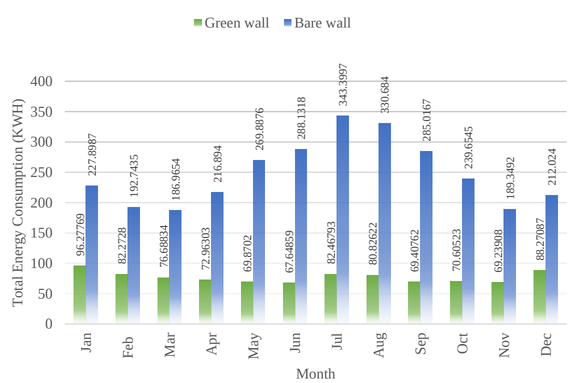

Fig. 9. Results of total fuel consumption.

Fig. 9 shows the final comparison of fuel total in a green and bare wall. The bare wall in the middle of months has more consumption (maximum) and at the beginning and end of a year has the minimum consumption. Albeit, the green wall has a uniform amount of consumption, which estimated at the bare wall, and the green wall was 343 and 67 kWh in a year, respectively. Eventually, the total annual fuel and energy consumption in the bare and green walls are about 248 and 77 kWh, respectively. Besides, Fig. 10 shows the demand for heating and cooling systems.

Fig. 10 shows the demand for heating and cooling systems over a year in green and bare walls that presented information includes the total cooling and zone heating. The results show that the amount of zone heating in the bare wall is low, which is much higher in the green wall. This means that the green wall is

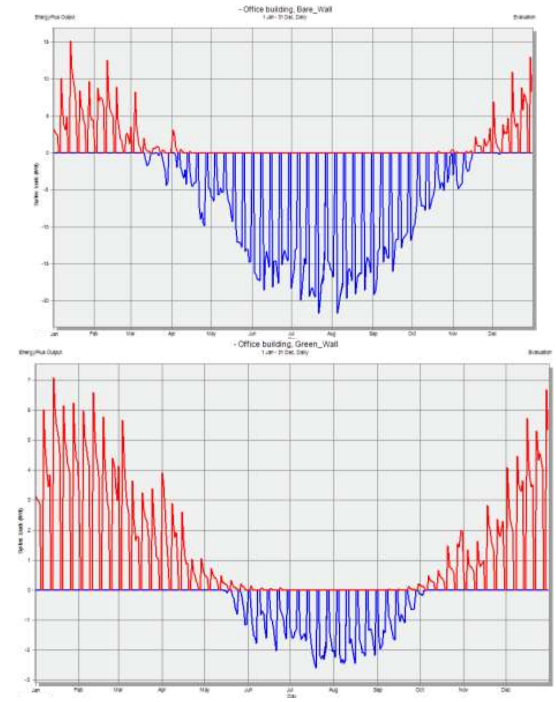

Fig. 10. Results of HVAC system loads.

a better thermal insulator and can maintain the building's heat. Furthermore, the cooling system in the middle of the year in the bare wall heavily seen. The green wall can be more useful for thermal insulators in the warm seasons than the bare wall. Based on the finding, annual total system loads of cooling and zone heating in the green and bare walls were calculated to be 137-625 and1850 420, respectively.

4. CONCLUSION

According to the present study's purpose, energy efficiency is one of the most crucial issues in construction and building science. This study carried out through experimental and numerical simulation on a green wall's thermal effect and energy efficiency in a humid climate. The experimental measurements showed that the heat loss rate was higher in the bare wall than in the green wall in both winter and summer times. The green wall in a humid climate can reduce the heat transfer compared to the bare wall. The bare and green wall findings also showed that in winter, the heat transfer was about 259.2 W/m2 for the bare wall and about 241.92 W/m2 for the Green wall. Moreover, it was 66.5 and 48.4 W/m2 for the bare and green wall in summer, respectively. It concluded that the green wall could increase the heat transfer between the interior and exterior walls by about 7% in winter and by about 27% in summer.

This means that the Green wall in the humid climate in winter can act as an insulator to heat transfer and energy saving. The research team also observed that the green wall had a better thermal performance in summer than in winter, reducing the thermal loss. A significant relationship found between humidity transfers from the outdoor environment to the indoor environment in the walls. The mean humidity difference was about 48.3 in the zone with a green wall and about 54.7 in the zone with a bare wall (in winter and summer). This means that the green wall can prevent humidity from entering the zone by about 12%. In the following, numerical simulation conducted for assessing the energy efficiency during a year in the existing office building with actual properties. The findings showed that the energy demand for heating and cooling systems in the room with a green wall has less of the room with a bare wall. The total annual fuel and energy consumption in the bare and green walls are about 248 and 77 kWh, respectively. In addition, the green wall has a uniform amount of consumption, which estimated at a bare wall, and the green wall was 343 and 67 kWh in a year, respectively, in which the green wall can affect about 80% of the energy efficiency in comparison with the bare wall.

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