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THERMAL PERFORMANCE EVALUATION OF GREEN LIVING WALLS IN COMPOSITE CLIMATE

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Abstract

Purpose of the study: Due to high solar radiation and extreme heat gain in composite climates, the envelope or the façade of the building becomes an essential part to modulate the heat transfer and temperature in the indoor environment. A passive sustainable approach to tackle heat gain is by adopting green living facades as the exterior skin. The objective of this research is to identify the potential of green living walls in modulating temperature and relative humidity in the composite climate of India.

Methodology: This research is based on data collection in the form of a Case Study. The paper evaluates the difference of variation in temperature and relative humidity of two façade samples of the same building, one with a "green living facade" and one without it.

Main Findings: The research aimed to justify that a green living facade may act as a passive strategy for composite climates. The result demonstrated that there is a significant temperature reduction between the ambient air temperature and indoor room temperature. The result also showed a notable change between ambient air temperature and the gap between the green living façade and the surface of the wall.

Implications: Significant drop in indoor ambient temperature in composite climate may save energy for cooling or heating demands.

Application of this study: This is a pilot study in order to carry out the main study for a similar application in order to categorize this as a passive sustainable façade strategy.

Novelty/Originality of this study: The study is one of its kind attempt to investigate the impact of vertical green walls on thermal comfort in the composite climate of India.

Keywords: *Composite Climate, Green Living Walls, Green Facades, Thermal Comfort, Passive Strategy*.

INTRODUCTION

Over the last decade, green living walls have taken an important existence to tackle the challenges of climate change and have become a passive sustainable strategy for the environment of urban indoor areas. This paper discusses the impact of green living walls on thermal comfort in the composite climate of India. Until now the concept of green living walls was limited to aesthetic and ecological values; however, the motivation for adopting green living walls in the building comes from the benefits it brings along in altering the indoor environment quality.

Though green living walls have gained popularity in recent times, however, their use had begun in the ancient era, mankind in many ways has tried to beautify the aesthetics of buildings skin and other structural elements with vertical greenery. As seen in the Hanging Gardens of Babylon (Wong et al., 2010) a structure replicating a ziggurat, the vertical greenery was arranged in a manner to showcase its beauty in stepped terraces. Being one of the original Seven Wonders of the World they showcased an astounding effort of construction with an outspread of vines, shrubs, and trees arranged in an ascending ordering replicating a mountain contained with greens. In recent times the methods and use of green living facades have been upgraded with the intervention of novel techniques and technologies. One of the recent examples is a vertical forest by Stefano Boeri which is a paradigm shift to a novel design of architectural biodiversity with a concept of building back the relationship of humans with nature.

The physiological process that occurs in plants, utilizes a part of solar radiation for photosynthesis, while the remaining is used in evapotranspiration. Both these processes prove to be excellent solutions to improve air quality, by absorption of carbon dioxide for photosynthesis and heat absorption during evapotranspiration. The vegetation effectively blocks solar radiation without increasing its temperature. Depending on these phenomena, it may be concluded that green living walls can reduce the heat and temperature and improve the air quality in a building.

This paper aims to evaluate the effect of vegetation on the temperature and humidity of a part of a facade covered with cascading green creeper. Observation of temperature difference, by comparing area with a green living wall on a part of the facade and an area without it, can obtain the effectiveness of green living façade and the level of comfort (Syed et al, 2014) in the adjoining area. The monitoring is carried out by measuring and recording temperature in both facades of the same building and orientation (one with the green living facade and one not using the green living facade) at the same location during both day and night.

LITERATURE REVIEW

A. Thermal Comfort

An acceptable environmental condition is achieved by incorporating a comfort standard that accommodates the building occupant's satisfaction level. According to the ASHRAE Standard 55 thermal comfort is "that state of mind which expresses satisfaction with the thermal environment." This implies that thermal comfort is achieved when an individual feels that the environment is too hot or too cold. The important essence to attain an indoor environmental situation is by creating a condition for the occupants of the building in accordance with the thermal state of the interior environment.

1. Thermal Comfort Factors

Since thermal comfort varies from individual to individual, it is difficult to set a common definition for all. However, according to ASHRAE Standard 55, thermal comfort is based on six primary factors that may lead to comfortable surroundings. These are further divided into personal factors and environmental factors (Othman & Sahidin, 2016, Susorova et al, 2013). For this study measurements of temperature and humidity are considered.

Personal Factors

1. Metabolic rate

2. Clothing insulation

Environmental Factors

3. Air temperature

4. Radiant temperature

5. Air speed

6. Humidity

2. Composite Climate

As per Indian National Building Code 2016 Vol. 2, New Delhi falls under a composite climate. In a composite climate, the conditions of weather fall outside of normal conditions for a minimum duration of half a year. Such a climate displays combined attributes hot and dry, warm and humid as well as cold climates. These attributes vary from season to season.

3. Characteristics of Building in Composite Climate

According to Energy Conservation Building Code User Guide 2007, the buildings in the composite climate zone should aim to reduce the amount of heat gain in summer and reduce the amount of heat loss in winter. The characteristic of a building should depend on various factors:

a) Orientation and shape of the building

The maximum heat gain in this region is via the east and west façade. To reduce gain, the surface area of the building should be decreased by the orientation and shape of the building. External landscape can behave as wind barriers to filter heat before entering the building envelope (Kumar et al., 2011).

b) Thermal resistance & thermal capacity

Insulation of roofs and walls can increase thermal resistance. Thicker walls increase the thermal capacity by increasing the time lag for heat transfer (Kumar et al., 2011).

c) Shading and reduced solar heat gain

Buildings in the composite climate should adopt glazing with a lower SHGC component. The windows should be provided with shading. Walls and glass surfaces are to be protected with overhangs, fins, and trees/plantations. Minimum glazing should be provided in the east and west façade (Kumar et al., 2011).

B) Green Living Walls

"Green Walls", "green system", "green living walls", and "vertical green systems" are few nomenclatures adopted by previous studies for identification and classification of these systems (Manso & Castro-Gomes, 2015)(Safikhani et al., 2014)(Bustami et al., 2018)(Medl et al., 2017). Green living walls can be of two types; exterior walls which are planted against the building's external façade and interior walls constructed individually in small replicable units within the interiors of the building. They are further classified as green facades and living walls (Manso & Castro-Gomes, 2015) (Köhler, 2008).

4. 1. Green facades

A green façade is a type where the plants climb or suspend along with the vertical building envelope. Traditionally, plants were grown against the wall in an upward direction, or they grew downwards over the vertical surface from the point of suspension (Manso & Castro-Gomes, 2015). Green facades are categorized into two as direct facades and indirect facades (see Figure 1).

a) Direct Green Facades

In direct facades, the plants attach themselves directly to the vertical building envelope. Whereas in an indirect façade a vertical support system assists the growth of plants. An example of a direct green façade is the traditional green facade, in which the ground rooted climbers grow clinging to the wall. Green facades can either be rooted directly to the ground or they can be planted in boxes, and guided to grow along with the support structure.

b) Indirect Green Facades

The indirect green facades consist of continuous and modular systems. Continuous guides assist the development of plants along the vertical surface, which is depended on a single support structure. A modular system as the name suggests has multiple trellises acting as an individual module to support the growth of green facades (Jim, 2015).

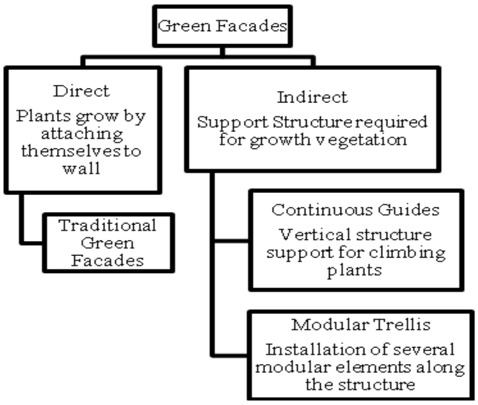

Figure 1: Classification of green facades

B. 2. Living Walls

In high-rise structures, the growth of direct green facades is restricted to a certain height. Living walls have turned out as a solution to integrate plantations in high buildings. With the ability to cover a large surface area and with a uniform growth pattern, the living walls can reach higher areas and can adapt to any building form or shape. Furthermore, they can accommodate a wider variety of plant species.

According to the method of construction, the living walls can be categorized as continuous systems or modular systems (see figure 2). In Continuous living walls, the growth of plants over the vertical surface is based on the application of lightweight and permeable screens in which plants are inserted individually (Manso & Castro-Gomes, 2015). A continuous screen allows the integration of varied plant species in the desired pattern.

A modular living wall system consists of modules in the form of vessels, trays planter tiles, or flexible bags, contained with growing media to support plant growth. Each module is then fixed on a support structure or is directly fixed to the vertical surface of the envelope.

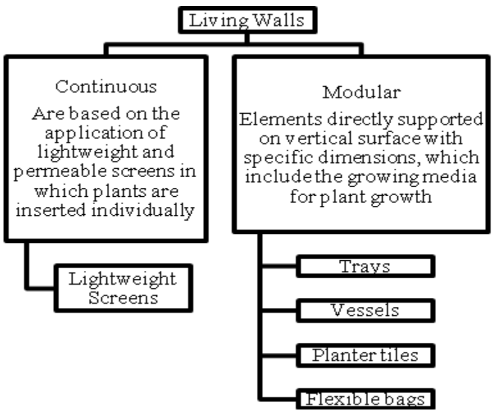

Figure 2: Classification of living walls

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C) Physiological Process in Plants

1. A part of the solar radiation incident is utilized for photosynthesis.
2. The remaining is used in the evaporation of water, in which plants undergo a mechanism of temperature regulation, known as evapotranspiration.

In the process of adopting these processes, the vegetation effectively blocks solar radiation without increasing its temperature. Since the transmittance, a leaf is 0.2 and the absorbance is 0.5, so when solar radiation incidents, due to the number of leaves in vegetation the combined effect of the plant mass that transmits and reflects is reduced because of mutual cancellation (Sheweka & Mohamed, 2012).

D) Benefits of Green Living Walls for thermal comfort

1. The use of traditional elements such as metal or PVC for shading will radiate heat back to the surroundings. Whereas vegetated facades depending on the density of foliage functions as a blocker of solar radiation
2. The temperatures of the different layers of a double-skin facade are generally lower if plants are used against slats. For the same solar radiation, an increase in the temperature is two times lower than in the case of plants to the slats.
3. Bio-shader is the application of a vertical green living wall as the outermost skin of the façade. It doubles up as both a shading device and an evaporative cooler, thereby cooling the internal space (Sheweka & Mohamed, 2012, Russell, et al.(2013)).
4. Through evapotranspiration, plants contribute to converting large amounts of solar radiation into latent heat which does not cause the temperature to rise. This may lead to a reduction in loads of an HVAC system (Built & Delft, 2017).

METHODOLOGY

The study was conducted at CSIR Science Centre, wherein the front façade covered with the green living facade is facing the south direction (see figure 3). To conduct the study quantitative method of measurement is adopted. Data loggers were used to recording the temperature and relative humidity for three consecutive days. The study was a comparative analysis, in which two identical rooms are compared where on the south-facing wall one has a green living wall (1 in figure 4) and the other one is a bare wall (2 in figure 4). The wall where the traditional green facade is grown is constructed of rubble masonry (250mm thick); the bare wall is normal brick masonry (200mm). Since the u-vale of rubble masonry of a 250mm wall is 2.5W/(m2K) (Waterfield, 2019, Perini, et. al, 2011, Malakar, et. al, 2018, Hakim, et. al, 2016) equivalent to the u-value of 200mm brick masonry(Kisan & Sangathan, 1978, Farid, et. al, 2016), and the surface area equivalent it is considered that the thermal performance of both the walls shall be equal.

The empirical measurement is carried out on both the locations, at the same time of the days to make sure the incidence of the same quantity of solar heat on both the facades for three consecutive days of mid-October 2019 from 14th October to 17th October 2019.

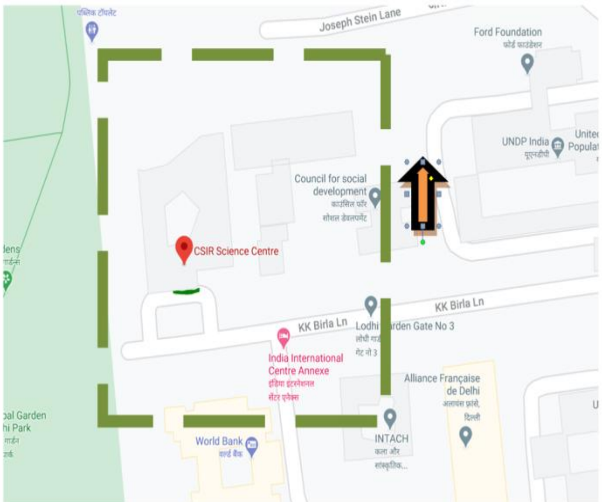

Figure 3: Location & Orientation of CSIR Science Centre

Figure 4: View of CSIR Science Centre

1. Location of instruments

Hourly measurements of temperature and relative humidity of both indoor and outdoor of the façade are recorded using five data loggers. The placements of these loggers are shown in Figure 5.

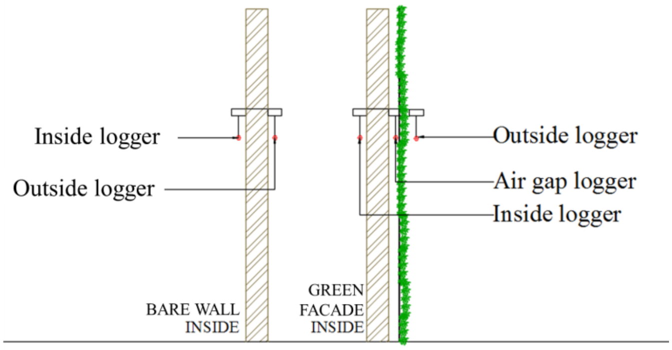

Figure 5: Location of Instruments

2. Data Recorded

The data is continuously recorded at 1 hour interval for three days from 14th October 2019 to 17th October 2019. Nine values were recorded as given below:

1. Outside temperature of green living wall - Tog
2. Airgap temperature of green living wall - Tagg
3. Airgap relative humidity of green living wall - RHagg
4. Inside temperature of green living wall - Tig
5. Inside relative humidity of green living wall - RHg
6. Outside temperature of bare wall - To
7. The inside temperature of bare wall - Ti
8. Outside relative humidity of bare wall - RHo
9. Inside relative humidity of bare wall – Rhi

Table 1 below shows recordings at 2 hours interval:

Table 1: Data recordings of temperature & relative humidity

Date	Time	Tog	Tig	Tagg	To	Ti	RHo	RHagg	RHig	RHi
14-10-19	11:00 AM	45.7°C	28.8 °C	32.1 °C	42.3 °C	28.4 °C	37.0%RH	60.9%RH	60.8%RH	63.4%RH
14-10-19	2:00 PM	45.6°C	28.7 °C	33.5 °C	41.7 °C	28.0 °C	31.3%RH	48.9%RH	59.7%RH	63.9%RH
14-10-19	5:00 PM	28.7°C	28.6 °C	29.3 °C	30.6 °C	28.5 °C	60.3%RH	67.2%RH	60.3%RH	61.9%RH
14-10-19	8:00 PM	23.6°C	28.7 °C	26.7 °C	25.9 °C	28.6 °C	77.6%RH	75.4%RH	60.5%RH	61.6%RH
14-10-19	11:00 PM	22.1°C	28.7 °C	25.6 °C	23.9 °C	28.3 °C	88.1%RH	81.3%RH	61%RH	63.2%RH
15-10-19	2:00 AM	21.3°C	28.7 °C	24.9 °C	22.9 °C	28.0 °C	91.6%RH	83.2%RH	60.8%RH	63.9%RH
15-10-19	5:00 AM	20.8°C	28.6 °C	24.3 °C	22.2 °C	27.5 °C	93.2%RH	84.0%RH	61%RH	64.7%RH
15-10-19	8:00 AM	25.3°C	28.5 °C	25.3 °C	25.5 °C	27.4 °C	86.0%RH	86.7%RH	60.5%RH	66.5%RH
15-10-19	11:00 AM	45.7°C	28.7 °C	31.8 °C	43.0 °C	27.9 °C	34.0%RH	62.3%RH	63%RH	66.0%RH
15-10-19	2:00 PM	45.3°C	28.7 °C	33.9 °C	42.6 °C	28.3 °C	28.5%RH	47.8%RH	59.5%RH	58.0%RH
15-10-19	5:00 PM	29.3°C	28.8 °C	29.6 °C	31.1 °C	28.6 °C	60.0%RH	66.6%RH	59.7%RH	61.1%RH
15-10-19	8:00 PM	24.1°C	28.8 °C	27.0 °C	25.9 °C	28.9 °C	77.0%RH	74.3%RH	60.5%RH	60.8%RH

15-10-19	11:00 PM	23.1°C	28.9 °C	26.2 °C	24.9 °C	28.8 °C	85.6%RH	80.6%RH	61%RH	62.7%RH
16-10-19	2:00 AM	22.2°C	28.9 °C	25.5 °C	23.4 °C	28.4 °C	92.3%RH	83.3%RH	61.5%RH	63.9%RH
16-10-19	5:00 AM	21.6°C	28.8 °C	25.0 °C	22.9 °C	28.0 °C	93.7%RH	84.9%RH	61.3%RH	64.7%RH
16-10-19	8:00 AM	25.5°C	28.7 °C	25.6 °C	25.7 °C	27.9 °C	87.7%RH	87.4%RH	61.8%RH	66.5%RH
16-10-19	11:00 AM	44.1°C	28.8 °C	31.7 °C	41.9 °C	28.2 °C	34.3%RH	60.5%RH	61.3%RH	64.7%RH
16-10-19	2:00 PM	42.7°C	28.8 °C	33.5 °C	41.7 °C	28.3 °C	32.1%RH	51.0%RH	60.3%RH	63.9%RH
16-10-19	5:00 PM	29.6°C	28.9 °C	29.9 °C	31.0 °C	28.8 °C	65.6%RH	70.3%RH	61.3%RH	62.4%RH
16-10-19	8:00 PM	24.7°C	28.9 °C	27.4 °C	26.6 °C	29.0 °C	78.2%RH	77.1%RH	61.8%RH	62.9%RH
16-10-19	11:00 PM	23.2°C	29.0 °C	26.4 °C	25.0 °C	28.8 °C	84.0%RH	79.9%RH	62.0%RH	63.2%RH
17-10-19	2:00 AM	22.2°C	28.9 °C	25.5 °C	23.8 °C	28.4 °C	89.1%RH	82.2%RH	61.8%RH	63.9%RH
17-10-19	5:00 AM	21.4°C	28.9 °C	24.9 °C	22.9 °C	27.9 °C	90.9%RH	82.8%RH	61.0%RH	64.2%RH
17-10-19	8:00 AM	25.3°C	23.5 °C	25.5 °C	25.7 °C	25.2 °C	84.5%RH	85.5%RH	49.9%RH	47.6%RH
17-10-19	11:00 AM	43.4°C	27.5 °C	31.3 °C	41.6 °C	26.6 °C	34.8%RH	60.8%RH	60.5%RH	63.9%RH

DATA ANALYSIS AND FINDINGS

A. Difference in Indoor and Outdoor temperature of façade without green wall

Based on the recordings as shown in the graph Figure 6, the minimum temperature recorded in both indoor and outdoor of the façade is at 6:00 am for all three days. This comes to an average of 22.47°C & 27.59°C respectively. The average maximum temperature recorded was at 12:00 pm. The average maximum temp inside the building was 28.4°C, in comparison to the outside average temperature which was 42.6°C. Furthermore, it is observed that the inside temperature is constant with a variation of ±2°C, whereas there are major day-night fluctuations in the outdoor temperature. The temperature difference of an average of 10°C is observed between indoors and outdoors. This may be due to the thermal capacity of the masonry wall which is cooling the entire room to achieve thermal equilibrium. There may be further factors that might affect the results.

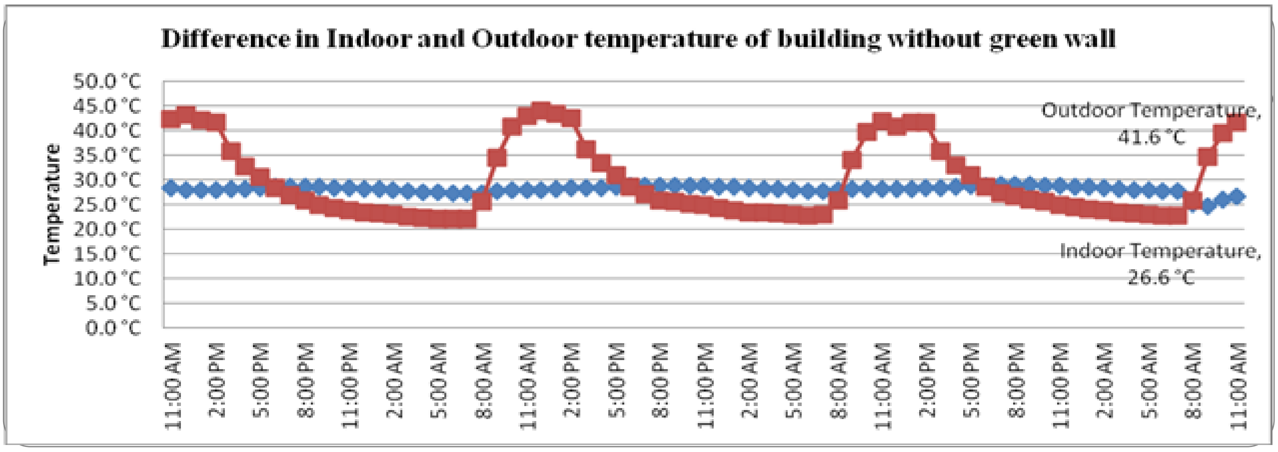

Figure 6: Difference in indoor and outdoor temperature of the wall without green living wall

B. Difference in Indoor and Outdoor temperature of façade with green wall

Figure 7 shows that the façade with the presence of a green living wall showed a significant temperature difference between the outdoor temperature, air gap, and indoor temperature. The maximum average outdoor temperature was recorded at 12:00 pm with a value of 43.4°C. The average air gap temperature recorded was 31.3°C. Approximately an average difference of 10°C is observed between outside temperature and air gap temperature. Furthermore, the average inside temperature recorded is 27.5°C. An average difference of 3.2°C is recorded between air gap and indoor

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temperature. During night time the indoor temperatures are still constant around an average of 28.6°C, even when the outdoor temperature at night drops to an average of 22.5°C with a negative average difference of 6.4°C. This might be as the resultant thermal capacity of masonry wall.

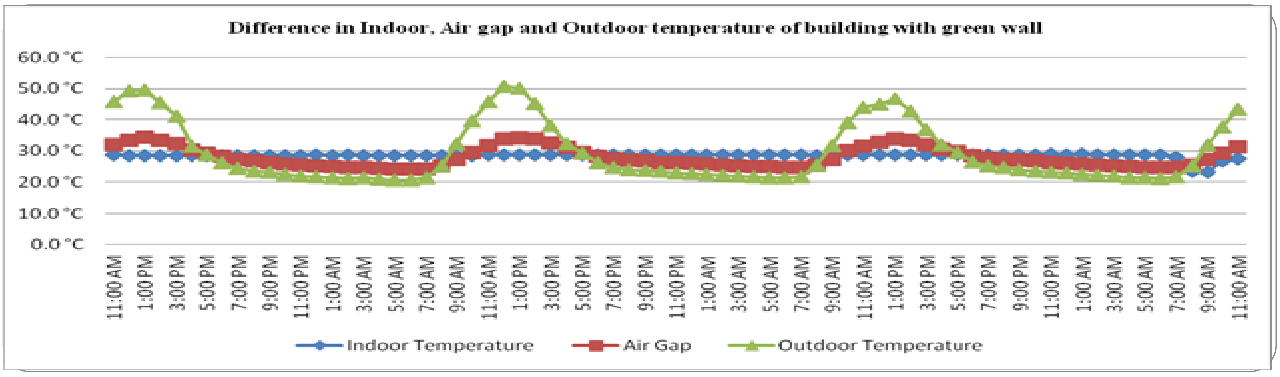

Figure 7: Difference in indoor, airgap, and outdoor temperature of the wall with green living wall

C. Difference in temperature reduction percentage in both facades

It is observed that there is a difference in percentage reduction of average 42% across the outdoor and indoor temperature of the part of facade with green wall. An average difference in percentage reduction of 25.1 % is observed without green wall. Though observations show temperature difference in both the types, however, the facade with the vertical greening is more effective as it can reduce the indoor temperature by 16.9% more during day time. (See figure 8)

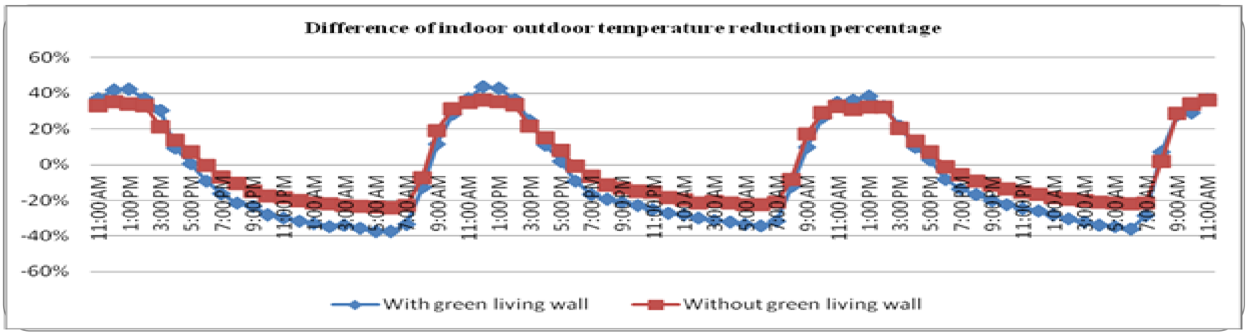

Figure 8: Difference of indoor and outdoor temperature reduction percentage

D. Comparison of humidity percentages of both facades

All the readings in figure 9 show a similar fashion across all the three days. There's a significant difference in the percentage of humidity of outside air, the air gap and inside air. Humidity levels are low across the three days during day time, whereas the readings show higher levels at night. Comparatively, the average RH at air gap is 11.9% RH more than outside air during day time and 7.6%RH less during night time. Despite a similar pattern, the percentage of humidity in inside of façade with green façade is relatively lower at an average of 60.7%RH, compared to bare wall at 63.0%RH.

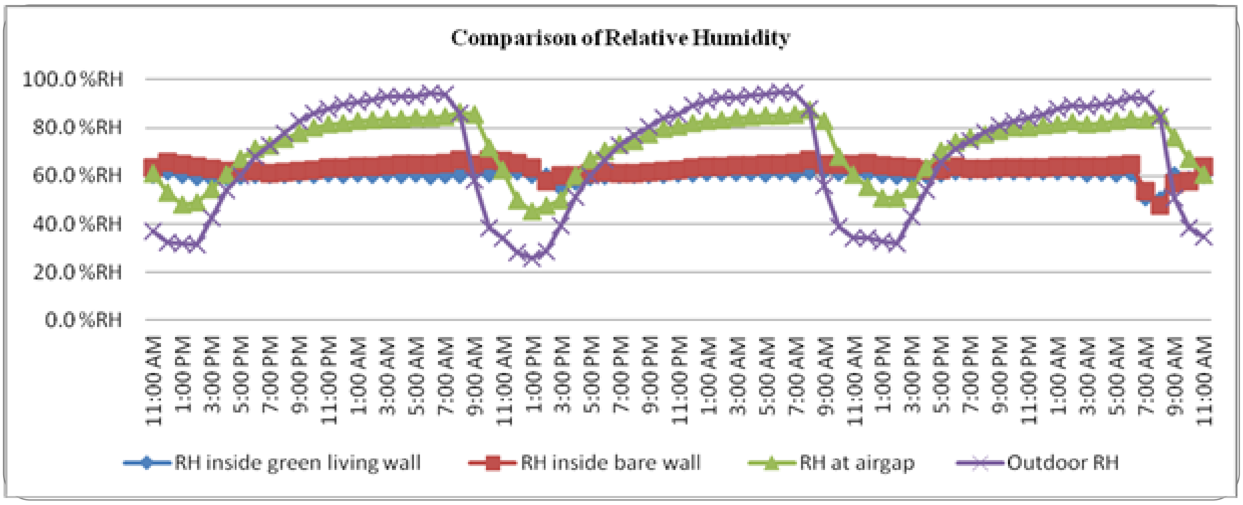

Figure 9: Comparison of relative humidity

CONCLUSION & RECOMMENDATION

This paper aims to evaluate the impact of green living walls on the temperature and humidity of a building in the composite climate of New Delhi. The performance of the façades was evaluated in terms of measured temperature and humidity difference on a part of façade with green living walls and one without it. According to the results, the green living façade depict higher capabilities of regulating temperature and relative humidity as compared to a façade without one.

On the basis of analyzed data, the implementation of a green living façade shows great potential in the reduction of temperature and humidity of a building. It can be deduced that facades with green living walls have a greater ability to modulate the temperature due to shading of the wall and acting as double skin.

It is also observed that the humidity levels are higher during the day and lower during the night in the inside of the room in comparison to the outdoor humidity levels. Since thermal comfort levels are achieved by acceptable temperature and humidity by an occupant, it can be said that the façade with a green living wall can help regulate the indoor environment.

This study shows that green facades can act as a passive sustainable approach in altering the thermal comfort levels in the urban area of composite climate. However more detailed study and a comparison between two buildings one with the green facade and the other without, throughout the year noting differences in peak seasons may help establish standards for this approach.

RECOMMENDATIONS

The study shows the potential benefits of green living walls on a part of building a façade of composite climate. However, there is still a lack of solid and significant figures available to understand all the possible benefits of the green facades as a sustainable system. Forthcoming studies may evaluate other effects such as improvement of indoor air quality along with thermal, visual, and acoustic comfort provided by green facades in the composite climate of India.

LIMITATION AND STUDY FORWARD

As the study was conducted to analyse the impact of green living walls in the composite climate, the limitation, in this case, was the material of walls in the two compared rooms. In further studies, the comparison shall be conducted for the same material with a dedicated green living wall for a better understanding of thermal properties for a longer duration of study and analysis.

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AUTHORS CONTRIBUTION

The contribution of the first, second, and third author is 60%, 20% & 20% respectively.

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