Understanding the impact of Green Walls on the Indoor Environment of Buildings in different climatic zones of India.

Akash N Achar
Manipal School of Architecture and Planning,
Manipal Academy of Higher Education
Manipal, India
akashachar5@gmail.com

Pradeep Kini
Centre for Sustainable Built Enviroment
Manipal School of Architecture and Planning,
Manipal Academy of Higher Education
Manipal, India
pradeep.kini@manipal.edu

Pranav Kishore
Centre for Sustainable Built Enviroment
Manipal School of Architecture and Planning,
Manipal Academy of Higher Education
Manipal, India
pranav.kishore@manipal.edu

Kiran Kamath
Department of Civil Engineering
Manipal Institute of Technology
Manipal, India
kiran.kamath@manipal.edu

Abstract

The world's population is on a rise, and this has resulted in a huge loss of natural green spaces as the demand for housing increases. As the land is limited in an urban area, green spaces are being cleared out to set up high-rise buildings as they can accommodate more people. The absence of green spaces in an urban area has resulted in increased pollution levels, temperature etc. To cope up with these problems faced by the urban population, green facades are an excellent solution. These methods can be applied to high-rise or mid-rise buildings which contribute a lot towards the increase in temperature around an urban area. Green walls are also a great to reduce the internal temperatures within buildings. This paper aims to discuss and assess the benefits of inculcating green facades in high rise buildings in an Indian-Urban scenario.
Design builder is the simulation software used to simulate buildings in 5 urban locations in India, and the advantages and disadvantages of introducing green walls is assessed.

Keywords: Green walls, High-rise buildings, temperature, India

1.INTRODUCTION

With the ever-growing population of the planet, the demand for housing has rapidly increased, which has resulted in a large chunk of the population hunting for job opportunities and hence moving into cities and urban areas. As the demand for housing rises, much greenery eventually gets removed, and the cities tend to expand horizontally. As per the UN report, Today, 55% of the world's population lives in urban areas, which is foreseen to increase to 68% by 2050. Predictions show that urbanization, the progressive shift in the residence of the human population from rural to urban areas, coupled with the global growth of the world's population, might add another 2.5 billion people to urban areas by 2050, with near to 90% of this increment taking place in cities in Asia and Africa. To accommodate such a drastic change in the population with limited land availability, the most acceptable option is to go vertical in the form of Skyscrapers and Multifunctional High rises. While these buildings are being designed, the designers and construction companies need to keep sustainability in mind. Increasing temperatures in urban areas due to the Urban heat island effect is also a growing problem. Urban building elements are another reason that urban areas trap heat. Many modern building materials are impervious and rugged surfaces. This means that water cannot flow through surfaces like a brick or a patch of cement like it would through a plant. Without a cycle of running and evaporating water, these surfaces have nothing to cool them down. Planting gardens on urban roofs can also help to cool down the city too. A study conducted in California estimated that changes like these would be enough to avoid close to $100 million per year in energy costs. Green Walls were especially important in the Arts & Crafts and Modern style movements in Europe, which led to an increase in its significance as an aesthetic element and a sustainable one. At the beginning of the 20th century, some movements like the 'Jugendstil Movement' used various climbing plants on building façades to merge buildings with their gardens. In England, Garden Cities are exceptional examples of Green Walls. William Robinson and Gertrude Jekyll designed outdoor vegetated rock walls used for screens and boundaries in gardens. Green Walls and climbing

IEECP '21, July 29-30, 2021, Silicon Valley, San Francisco, CA – USA

DAI : https://sci-index.com/DAI/2021.99101/IEECP/14899587

plants' usage on the façade declined after the 1930′s due to development of new building techniques and people's fear about compromises of wall life and durability. Stanley Hart White (University of Illinois Urbana-Champaign) developed the modern Green Wall with integrated hydroponics in 1931-1938. White owns the first known patent for a green wall or vertical garden, conceptualizing this new type of garden to solve the problem of modern garden design. Studies done imply that vegetated facades can decrease the effect of urban heat island around 2 degrees Celsius, improving air quality, thermal comfort, and human health, with savings in electricity consumption of up to 5% to 10%.

1.1 Green walls

Green walls are vertical surfaces /structures that have different types of plants or other greenery growing on or attached to them. The greenery is planted in a growth medium such as soil, stone, or water. A green wall will also usually have a built-in water supply system so as to irrigate the plants. According to the CTBUH guide, the main elements of green walls are:
i) Plants
ii) Planting media
iii) Structures that support and attach plants to the façade
iv) The irrigation system

Green walls can be broadly divided in two categories:
i) Façade Supported Green Walls
ii) Façade Integrated Green Walls
Façade supported green walls include 2D and 3D systems in the form of vertical cables, rods, trellis, nets etc whereas the Façade integrated green walls include climbing plants and Living walls. These Living walls usually have the irrigation system integrated. within the green wall panels.

1.2 Background Study

In the Thermal Performance Simulation of Hydroponic Green Wall conducted in Shahrekord City, Iran which enjoys cold climate, where a green wall was modelled at a distance of 20cm from the exterior walls of a school building using Energy Plus Software. Results showed that during the warmer seasons, the indoor temperatures reduced by a maximum of 1.13°C and a minimum of 0.7°C. During the colder seasons, the temperatures increased by an average of 1.46°C. [1]
In the study mentioned in the book "Green Walls in High-Rise Buildings: An output of the CTBUH Sustainability Working Group" wherein several case studies of high rise buildings with green walls is included, Consorcia Santiago Building in Chile, with a Mediterranean climate, experienced a reduction in energy consumption in floors of the building having external green walls of up to 35% and operation costs of up to 25% as compared to the floors without the green walls. [2]
In Athens City, which falls under the Mediterranean climate zone, while testing the thermal performance of a green wall using the design builder software, it was observed that the application of a green wall on the East side brings a reduction of the building heating need to about 10%. Average decrease in the internal surface temperatures of the eastern walls of two rooms was 1.08 and 1.48 Celsius, respectively [3].
In Cairo, Egypt the simulation of a green wall was conducted using the Design Builder Software on three typical Residential buildings. It was observed that in Arid Climates such as the one Cairo Experiences, the results show that an extensive soil thickness of 15cm performs better in the arid climates. Annual electricity consumption reduced by 17% to 25% per annum when a vegetated layer was added, in addition to enhancing the indoor air temperature by 5°C [4].
In a simulation study conducted using the TRNSYS software in two cities La Rochelle with an oceanic climate and Athens with a Mediterranean climate it was found that the green walls decrease the surface heat transfer from indoor to outdoor and the façade surface temperature. As a result, the green walls will contribute, also, to the urban microclimate mitigation. The difference in the operative temperature was more prominent in Athens where average reduction of 1.5 °C between the reference building and the vegetated building [5].
In a field experiment conducted by the Department of Architecture, NUM, Malaysia in a tropical climate on two identical thermal labs, one with a green wall and one without, the results indicated that indoor air temperature of thermal lab with the green façade is always lower than indoor air temperature of reference thermal lab at all times. Maximum reduction of indoor air temperature is 1.7°C. Daily average of indoor air temperature with Green Facades is 1.0°C lower compared to indoor air temperature of reference thermal lab, with 29.8°C and 30.8°C, respectively [6]. In another live study and monitoring of summertime indoor temperatures of a 5 storeyed building in Shanghai, where green wall was integrated within a double skin glass façade, the results showed that the indoor thermal improvement by the Vertical Greening System, evaluated by operative temperature, is 1.1 °C averagely and 2.7 °C maximally on the South-facing office, and 0.6 °C averagely and 1.9 °C maximally on the North-facing office. [7]
To assess the benefits of a green wall in an urban microclimate, Envimet Software was used to model a locality in Hong-Kong. The urban temperature was recorded. It was found that when 30% of each building's façade was incorporated with greenery, the urban temperature dropped by 1°C. This proved that the green walls are not only beneficial for better indoor temperatures but also helps in reducing the temperatures in an urban level. [8]

2. METHODOLOGY

The research will be conducted with the help of DesignBuilder Software. Design Builder is an Energy Plus based software tool which is used for energy, carbon, lighting and comfort measurement and control. Design Builder is developed to help in easing up the building simulation process.

Step 1: Selection of Urban Areas

The first step involved the selection of 5 urban areas in India. Since India is a large country with varying climate zones throughout the region, ECBC has divided the country broadly into 5 climatic zones i.e., Hot & Humid, Hot & Dry, Moderate, Composite, and Cold. An urban area from each of these climatic zones has been selected to run the simulation.

Step 2: Modelling of Reference Building

A 9 storeyed building (g+8) was modelled on the Design Builder Software. The reference building has an exterior dimension of 90m x 39m (aspect ratio of 1:2.3 [9]) The reference building was divided into various zones with Core and Perimeter Zones. A Perimeter width of 4.5m was considered. The details of the building envelope have been shown in table 1.

Table 1. Reference Building Model Envelope Details

City	Wall U-value	Roof U-Value	Window U-Value
Mumbai	1.26 - Fly Ash Brick Wall (200 mm) with plaster	1.18	2.05
Ahmadabad	1.46 - Brick Wall (200 mm) with plaster	0.64	2.05
Delhi	1.46 - Brick Wall (200 mm) with plaster	0.64	2.05
Bangalore	1.46 - Brick Wall (200 mm) with plaster	0.64	2.05
Srinagar	2.15	1.65	1.1

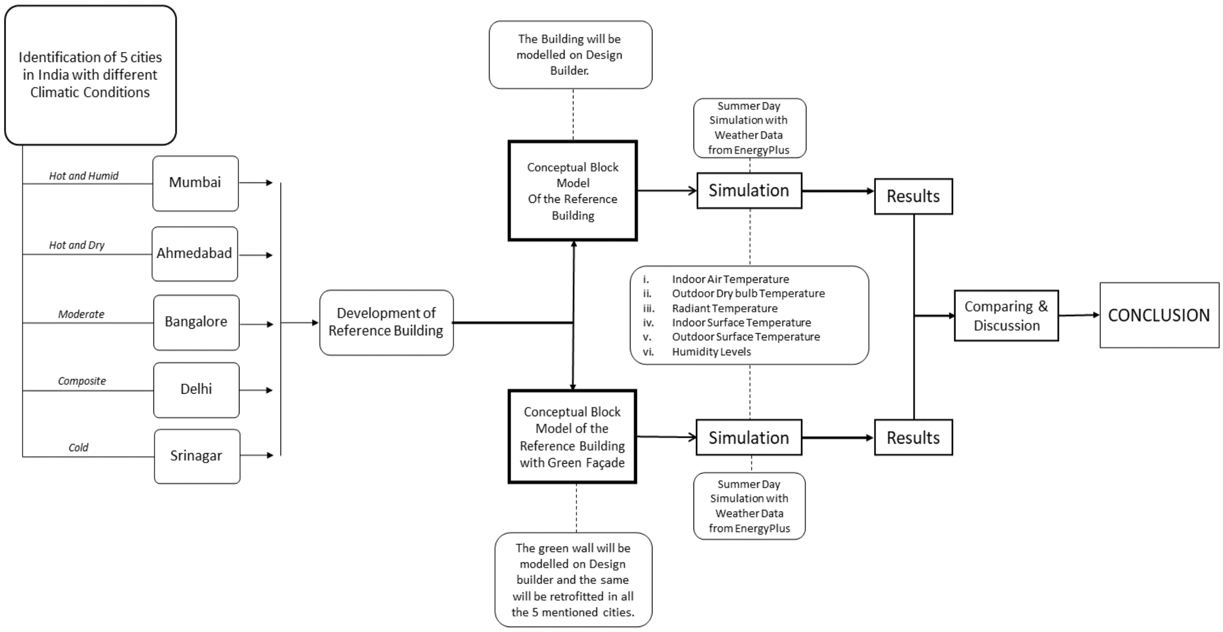

Figure 2: Methodology Flowchart

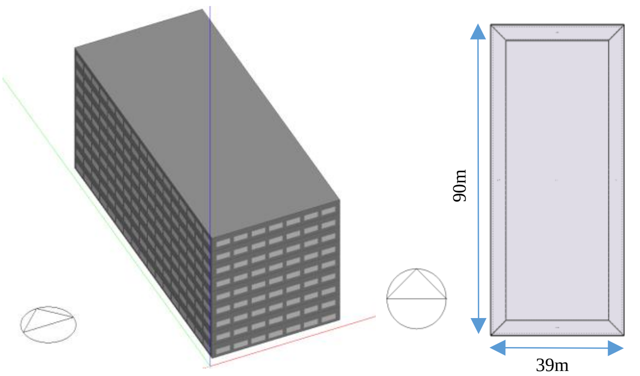

Figure 1: Reference Building Model Isometric View and thermal Zone Divisions on the floors.

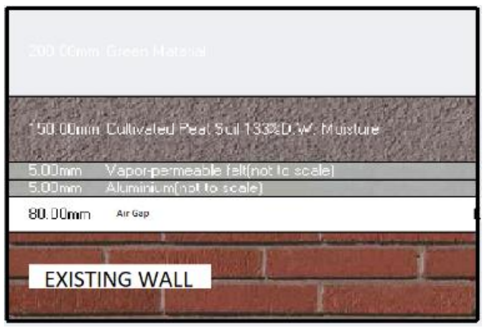

Figure 3: Green Wall Cross Section

Step 3 : Retrofitting of Green wall

A façade integrated green wall was modelled on the Design Builder Software. This Green wall was then retrofitted into the existing walls of the Reference Building Model. An Air Gap of 8cm was considered between the existing wall and the green walls aluminum back panel for the provision of irrigation lines for the green wall. Peat soil has been chosen as the growing medium for the plants as peat soil is an organic matter that can be found throughout the country irrespective of the climatic region. The details of the Green Wall have been given in Table 2. A cross section of the green wall has been shown in figure 4.

Table 2: Details of Green Wall Given to Design Builder

Plant Height	0.2m
Leaf Area Index	3
Air Gap between Exterior wall and Green wall	0.08m thickness
Growing Medium: Peat soil with 133% Moisture	0.15m thickness
Vapour Permeable Felt	0.005m
Aluminium Backing	0.005

Step 4: Running of Simulation

The 8th Floor of the reference Building model was simulated for the summer day of May 19th to check the Indoor Air Temperatures, Radiant Temperatures, Inside Surface Temperature, Exterior Surface Temperature, Humidity Levels, and the Outside Dry Bulb Temperature in all the four perimeter zones of the floor. Once the Simulation was completed for the Reference building in a Climate Zone, the modelled green wall was retrofitted into the Exterior walls and the simulation was run again. The results where then Compared. The same Procedure was followed for all the 5 Cities.

3. RESULTS

Case 1: Hot and Humid

In Mumbai, the Outside Dry Bulb Temperature was 30.75°C. The average reduction in Air Temperature and the Radiant Temperature on the 8th floor was 1.13°C and 1.47°C, respectively.
The floors interior surface temperatures reduced by 1.65°C and the exterior surface temperatures reduced by 2.48°C. Figure 4 Graphically compares the temperature levels before and after retrofitting a green wall. It is observed that the highest temperature reduction is seen on the building’s exterior Surface.

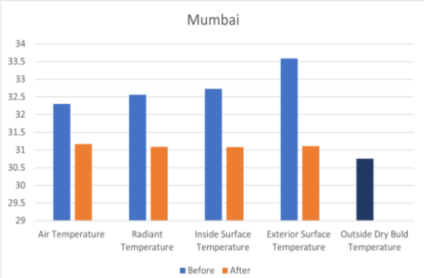

Figure 4: Graph of Average Temperature Levels before and After Retrofitting a green wall in Mumbai.

The maximum air and radiant temperature decrease is seen on the Northern perimeter zone, with a temperature dip of 1.1°C and 1.27°C respectively, and the least decrease in the air and radiant temperature is seen on the Western Perimeter with a dip of 0.76°C and 0.86°C, respectively. The inside surface temperatures experience a maximum dip of 1.33 on the northern zone and the least dip is observed on the Eastern Façade with a temperature decrease of 0.71°C. The exterior surface temperature reduction is the max on the southern wall with a decrease of 1.37°C and the least is observed on the Western side with a reduction of 0.31°C. The difference in the temperatures on the various perimeter zones before and after introducing a green wall is graphically represented in figure 5.

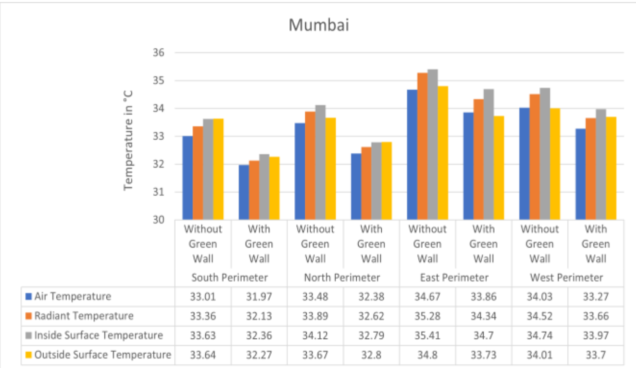

Figure 5: Perimeter Zone wise recorded temperatures before and after retrofitting a green wall in Mumbai.

Case 2: Temperate Climate

In Bangalore, the Outside Dry Bulb Temperature on the 19th of May was 27.74°C. The average reduction in Air Temperature and the Radiant Temperature on the 8th floor was 0.89°C and 1.09°C, respectively. The floors interior surface temperatures lowered by 1.25°C and the exterior surface temperatures decreased by 2.63°C. Figure 6, Graphically compares the temperature levels before and after retrofitting a green wall.

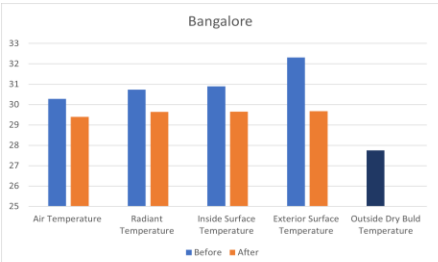

Figure 6: Graph of Average Temperature Levels before and After Retrofitting a green wall in Bangalore.

The maximum air temperature and radiant temperature decrease is seen on the Northern perimeter zone, with a temperature dip of 0.59°C and 0.72°C respectively, and the least decrease in the air and radiant temperature is seen on the Western Perimeter with a dip of 0.39°C and 0.49°C, respectively. The inside surface temperatures experience a maximum dip of 0.9°C on the Southern zone and the least reduction is observed on the Western Façade with a temperature decrease of 0.46°C. The exterior surface temperature reduction is the max on the southern wall with a decrease of 4.59°C and the least is observed on the Western side with a reduction of 0.47°C. The difference in the temperatures on the various perimeter zones with and without the green wall is graphically represented in figure 7.

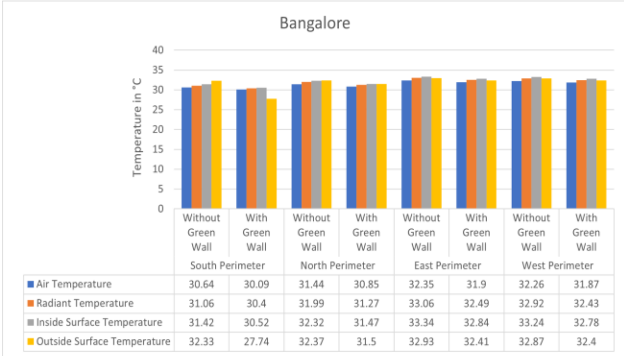

Figure 7: Perimeter Zone wise recorded temperatures before and after retrofitting a green wall in Bangalore.

Case 3:Hot and Dry

In Ahmadabad, the Outside Dry Bulb Temperature on the 19th of May was 34.27°C. The average reduction in Air Temperature and the Radiant Temperature on the 8th floor was 2.27°C and 2.77°C, respectively. The floors average interior surface temperatures lowered by 3.05°C and the exterior surface temperatures decreased by 5.32°C. Figure 8, Graphically compares the temperature levels before and after retrofitting a green wall.

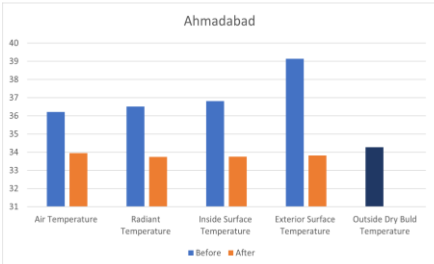

Figure 8: Graph of Average Temperature Levels before and After Retrofitting a green wall in Ahmadabad.

The maximum air temperature and radiant temperature decrease is seen on the Northern perimeter zone, with a temperature dip of 2.64°C and 3.19°C respectively, and the least decrease in the air and radiant temperature is seen on the Western Perimeter with a dip of 2.22°C and 2.61°C, respectively. The inside surface temperatures experience a maximum decline of 3.47°C on the Southern zone and the least reduction is observed on the Western

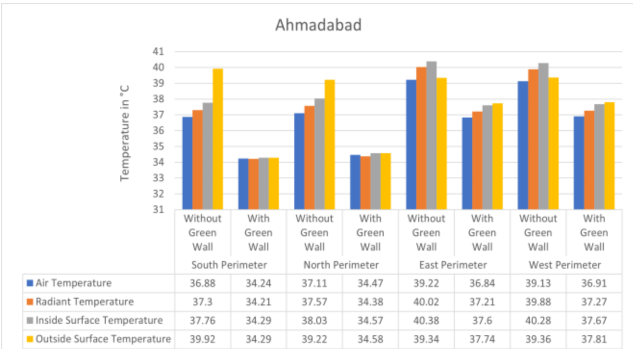

Figure 9: Perimeter Zone wise recorded temperatures before and after retrofitting a green wall in Ahmadabad.

Façade with a temperature decrease of 2.61°C. The exterior surface temperature reduction is the max on the southern wall with a decrease of 5.63°C and the least reduction is observed on the Western side with a reduction of 1.55°C. The difference in the temperatures on the various perimeter zones with and without the green wall is graphically represented in figure 9.

Case 4: Composite Climate

In Delhi, the Outside Dry Bulb Temperature on the 19th of May was 32.06°C. The average reduction in Air Temperature and the Radiant Temperature on the 8th floor was 1.9°C and 2.37°C, respectively. The floors average interior surface temperatures lowered by 2.7°C and the exterior surface temperatures decreased by 6.1°C. Figure 10, Graphically compares the temperature levels before and after retrofitting a green wall.

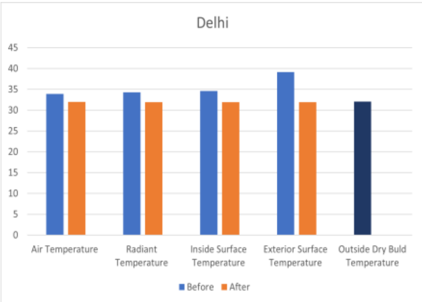

Figure 10: Graph of Average Temperature Levels before and After Retrofitting a green wall in Delhi.

The highest air temperature and radiant temperature decrease is seen on the Northern perimeter zone, with a temperature dip of 2.02°C and 2.22°C respectively, and the least decrease in the air and radiant temperature is seen on the Eastern Perimeter with a dip of 1.65°C and 1.95°C, respectively. The inside surface temperatures experience a maximum decline of 2.71°C on the Southern zone and the least reduction is observed on the Eastern Façade with a temperature decrease of 1.98°C. The exterior surface temperature reduction is the max on the southern wall with a decrease of 6.1°C and the least reduction is observed on the Eastern side with a reduction of 3.3°C. The difference in the temperatures on the various perimeter zones with and without the green wall is graphically represented in figure 11.

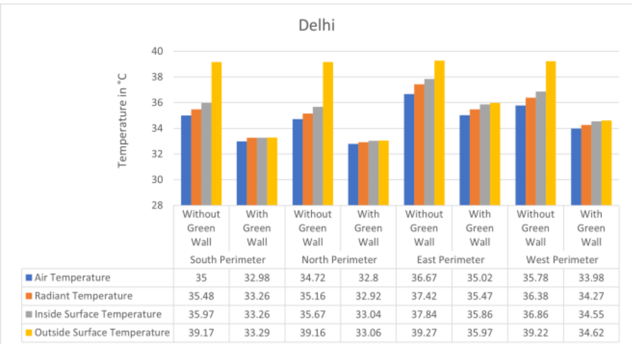

Figure 11: Perimeter Zone wise recorded temperatures before and after retrofitting a green wall in Delhi.

Case 5: Cold Climate

In Srinagar, the Outside Dry Bulb Temperature on the 19th of May was 14.24°C. The Air Temperature and the Radiant Temperature on the 8th floor increased by 1.46°C and 2.34°C, respectively. The floors average interior surface temperatures increased by 2.89°C and the exterior surface temperatures increased by 5.41°C. Figure 12, Graphically compares the temperature levels before and after retrofitting a green wall.

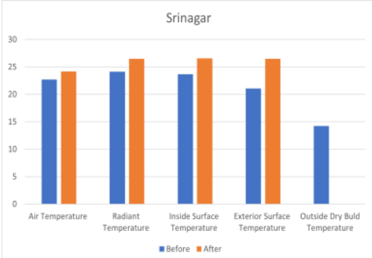

Figure 12: Graph of Average Temperature Levels before and After Retrofitting a green wall in Srinagar.

The maximum increase in air temperature and radiant temperature is seen on the Western perimeter zone, with a temperature rise of 1.77°C and 2.97°C respectively, the other perimeter zones experience a similar result with the least increase seen in the eastern perimeter zone with 1.63°C and 2.73°C.The inside surface temperatures experience a maximum increase of 3.46°C on the Eastern zone while the other perimeter zones also had a similar result. The maximum average exterior surface temperature increase is seen on the eastern façade with an increase of 6.41°C. The least increase is seen on the south perimeter with 5.27°C. The difference in the temperatures on the various perimeter zones with and without the green wall is graphically represented in figure 13.

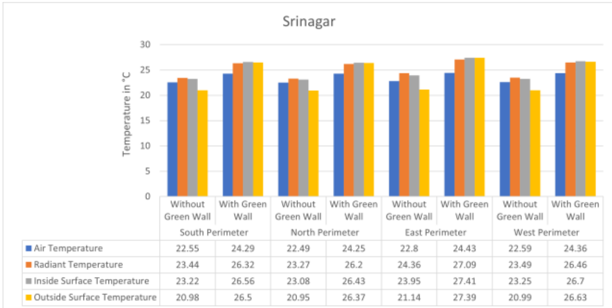

Figure 13: Perimeter Zone wise recorded temperatures before and after retrofitting a green wall in Srinagar.

Humidity

Although the green walls help in having a better ambient temperature within the building's environment and its surrounding, a major drawback of green walls are its potential to increase the humidity levels within the building and its surroundings. The Average increase in the humidity levels in the all the 5 cities is 5.26% with the maximum increase seen in Bangalore with a Temperate climate. The least increase is observed in Srinagar of cold climate with an increase of 3.27%. Figure 14 graphically represents the increase in humidity in the 5 mentioned cities.

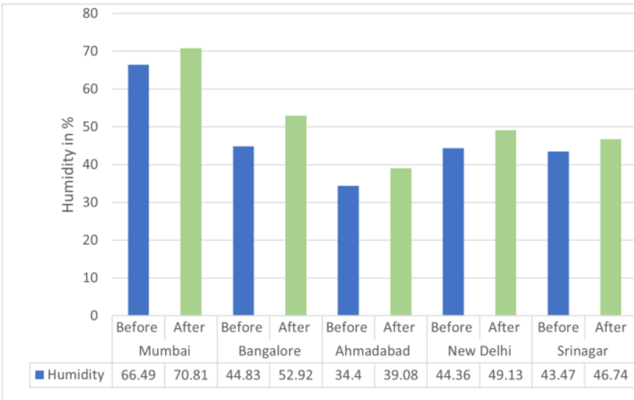

Figure 14: Graphically representation of change in the humidity levels in the 5 mentioned cities.

4. DISCUSSIONS

The simulation' results suggest that the green walls thermal impacts on the building and its surroundings are dependent on the climatic zone of the building site. In terms of temperature reduction pertaining to the interior of the building, the green wall seems to be the least effective in Bangalore with a temperate climate, where the Air temperature, Radiant Temperature and the interior surface temperature reduced by 0.89 °C, 1.09°C, 1.25°C, respectively. Whereas the results suggest that the green wall is most affective in Ahmadabad with Hot and Dry climate, where the Air temperature, Radiant Temperature, and the interior temperatures reduced by 2.27°C, 2.77°C and 3.05°C, respectively.

Though Ahmadabad and Delhi fall under two different climate zones, during the summer month of May, both the cities experience Excessive heat and very low air humidity which are the two most significant climatic indicators. The reduction in the temperatures in both of these two cities are the highest and similar.

Figure 15 shows the percentage wise change in the temperature levels in all the 5 climatic zones. It can be inferred that, a green wall is most effective in a hot and dry climate, where the average reduction in interior surface temperatures in Ahmadabad and Delhi is 3.05°C and 2.07°C. The effectiveness of green walls is reduced with the decrease in the outdoor dry bulb temperature and the increase in the humidity levels. This is evident in the case of Mumbai, when compared with the results of that of Ahmadabad and Delhi. In the case of Srinagar with a cold climate, it is observed that the results are different than the rest. Here the green wall is increasing the temperature levels within the building as well as the exterior wall temperature.

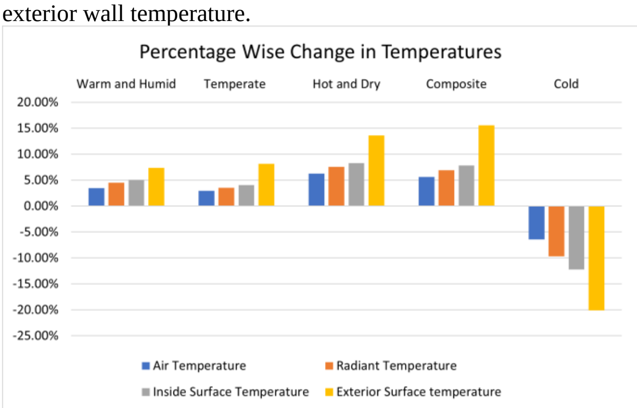

Figure 15: Changes in the temperature levels in the 5 climatic zones

The exterior walls of a high-rise building are one of the highest contributors of heat in an urban canyon. A bare plastered wall would re-radiate the suns heat into the surroundings which results in the central business districts of a city to have higher temperatures than the exterior of the city. Figure 15 suggests that the maximum change in the temperature levels is happening at the exterior surface, whereas in cities like Delhi, a reduction in the temperature by 15.58%. This would suggest that a green wall not only helps in having better interior ambient temperature levels but also contributes to having a better microclimate within a city.

The exteriors wall temperatures are reducing the most towards the southern façade. This is probably due to the direct solar heat gain on the south façade experienced by most of the buildings in the northern hemisphere. Because of the presence of a constant inbuilt irrigation system and the process of evapotranspiration undertaken by the plants, in all the climatic zones, it is observed that the humidity levels are increasing with the introduction of a green wall.

5. CONCLUSION

The results of the study have shown that the green walls help in reducing the internal temperatures in warmer regions and in a colder climate such as Srinagar a green wall helps in increasing the temperatures. This shows that they also act as insulation assisting to regulate a building's temperature, keeping it warmer in Winter and cooler in Summer. Results show that the green walls not only contribute to having better interior temperatures, but also contributes to regulating the temperatures on the building's exterior, which would lead to a better urban microclimate. Humidity is one of the key parameters in thermal comfort. When installing green walls to reduce temperature, attention must be given to ventilation and humidity control especially in cities such as Mumbai with an already prevailing humid climate.

The climate of the area is a crucial factor for the magnitude of the thermal effect of green walls in a building's microclimate. It is observed that areas with higher temperature and lower humidity (hot and dry regions), tend to benefit more from green walls.

REFERENCES

[1] S. R. A. G. Maryam Farhadian, "Thermal Performance Simulation of Hydroponic Green Wall in a Cold Climate," December 2019.

[2] Council on Tall Buildings and Urban Habitat, Council on Tall Buildings and Urban Habitat, 2014.

[3] R. F. D. M. F. d. R. Margarita-Niki Assimakopoulos, "GreenWall Design Approach Towards Energy Performance and Indoor Comfort Improvement: A Case Study in Athens," 2020.

[4] B. A. K. K. M. N. Sherine M. Wahba, "Effectiveness of Green Roofs and Green Walls on Energy Consumption and Indoor Comfort in Arid Climates," Civil Engineering Journal, October 2018.

[5] E. B. R. B. Rabah Djedjig, "INTEGRATION OF A GREEN ENVELOPE MODEL IN A TRANSIENT BUILDING SIMULATION PROGRAM AND EXPERIMENTAL COMPARISON".

[6] J. L. F. Gabriel Pérez, "Vertical Greenery Systems (VGS) for energy saving," *RenewableandSustainableEnergyReviews*, 2014.

[7] F. Y. F. Q. FengYang, "Summertime thermal and energy performance of a double-skin green facade: A case study in Shanghai," May 2018.

[8] A. L. K. K.-L. L. E. N. Tobi Eniolu Morakinyo, "Thermal benefits of vertical greening in a high-density city: Case study of," Hongkong, 2017.

[9] V. G. M. B. Jyotirmay Mathur, "Development of reference building models for India," *Journal of Building Engineering*, pp. 267-277, 2019.