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Thermal Performance of Vegetated Facades – What India Can Learn

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Abstract: *The use of vegetation to mitigate the urban heat island effect has recently gained attention among researchers. The greening of vegetation is often seen as a tool to enhance the thermal performance of the building envelope, and improve the energy efficiency of buildings. This paper is based on literature review of works by various authors, which quantify the effect of vegetated facades in different climatic contexts. The paper is intended to draw inferences from the existing literature that can be used to conduct similar studies in the Indian context. The theoretical model based study for Mumbai is taken up to build a case to adopt green facades in buildings to improve their performance. The limitations and future scope in present work is also pointed out in order to be able to widen the existing body of work.*

Keywords: *Vegetated Facades; Thermal Performance; Green Walls; Energy Efficiency*

1. Introduction

Vegetated facades cover a broader area that deals with the greening of vertical surfaces in the buildings. They are known by different names: *Green facades, Living walls, Vertical gardens*, etc. that are differentiated mainly on the basis of the growth media (planted on horizontal surfaces or planted directly on walls) or the structural support of the vegetation (supported by walls directly or an external support systems). The researches show that there is a significant reduction in the surface and air temperature around the green facades, particularly in hot climates. The reduced indoor temperatures help in reducing the cooling loads and energy consumptions of conditioned buildings specifically. India, however has seen very limited acceptance to the concept of vegetated facades; green walls are used either as 'feature' walls in inhabited spaces of buildings or they are used in small scale projects for aesthetic purposes.

The literature reviewed for this paper suggest that the reduction in temperatures and air velocities near vegetated surfaces is a function of a number of factors – solar radiation, orientation, species of vegetation and density of vegetation among several others [1]. The prediction of the thermal behaviour of green facades therefore become rather challenging, as the contributing factors listed above further complicate the task. Since each climatic zone has a unique characteristics of vegetation and the micro-climate of different areas further affect these characteristics, therefore, the thermal performance of vegetated facades cannot be generalized for all the climate types, and each case has to be looked differently. Indian cities have witnessed the construction of buildings that are not relevant to the climate type, and hence end up consuming a lot more energy than required. India is the fourth largest energy consumer in the world [2], out of which 35% energy is consumed by buildings alone [3], with its variety of climate types and zonal characteristics, therefore, makes a very interesting case to study the impact of greening the vertical surfaces on the energy consumptions and the occupants' comfort. As per the Koppen climate classification, India has six different climatic zones [4], and therefore the effect of performance of vegetated facades on the indoor environment would exhibit a large variation. The recent researches on urban climate (UHI) has brought the positive impact of vegetated roofs and walls in focus, and the need of studying their impact on the urban environment has thus become more crucial.

2. Thermal Impact of Vegetated Facades

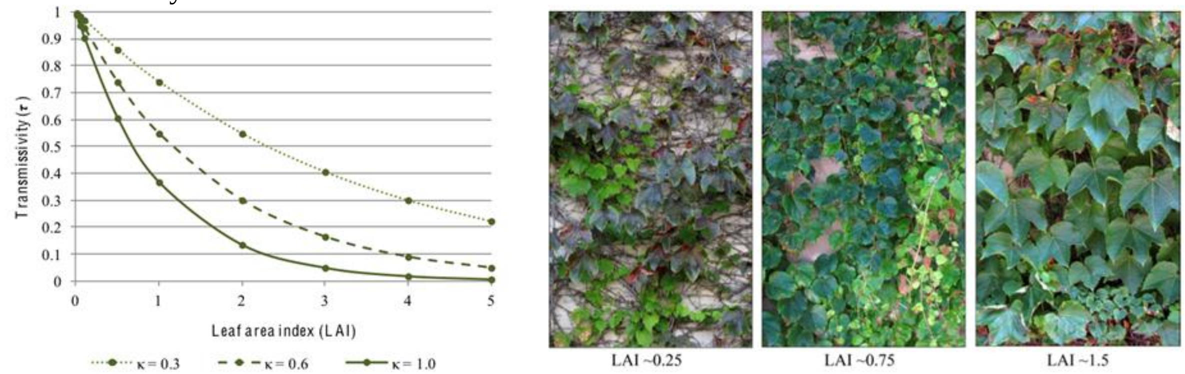
Vegetated facades act as thermal buffer and shading tool, which in turn affect the thermal performance of the building envelope. The main characteristics of the vegetated façade is its insulation properties that blocks the passage of heat through the surfaces and bring down the temperatures. The reflective and absorptive properties of the vegetation are the major contributing factors; the plants use the sunlight for evapotranspiration, and with an increased rate, it brings down the temperatures significantly. Moreover, studies also suggest through experiments and simulations conducted for buildings in temperate and Mediterranean regions that the air trapped within the vegetation (stagnant air) serves as an additional insulation layer. The stagnant air layer combined with the insulating properties of vegetated walls help in retarding the heat transfer rate between the internal and external surfaces. The insulating properties of vegetated surfaces can be increased by covering a larger portion of vertical surface with vegetation, which helps in preventing summer heat to enter inside the building and by preventing heat loss from inside during the cold winters [5]. Another study suggest that the reduction in surface temperatures is more in double skin facades as compared to direct green walls. This may be due to the air gap, which acts as an additional insulation [6].

2.1. Effect of Aspect

Data from different sources suggest that the thermal performance of vegetated facades is a function of the wall aspect (orientation). The work by Susorova, based on experimental studies relate the thermal impact of vegetated facades with the building aspect (orientation), and suggests that the reduction in air and surface temperatures is a function of the amount of solar radiation any surface receives, depending upon the orientation of these surfaces. In case of conditioned buildings in cold climate of Chicago, the most significant results in surface temperature reduction were observed on the East and West facades. This is attributed to the higher intensity of solar radiation, and lower angle of sun in early morning and late evening hours. The average reduction of 10% in heat flux was measured in the studies. However, the south wall showed a negative impact, indicating the increase in heat flux [7]. Another research carried out in humid continental climate of Beijing suggests that vegetating the West façade with thick ivy results in an approximate reduction of 28% in the peak cooling load of the building [8]. The studies reflect that the surface that receives the maximum solar radiation behave more efficiently and the temperature reduction in these cases are more significant.

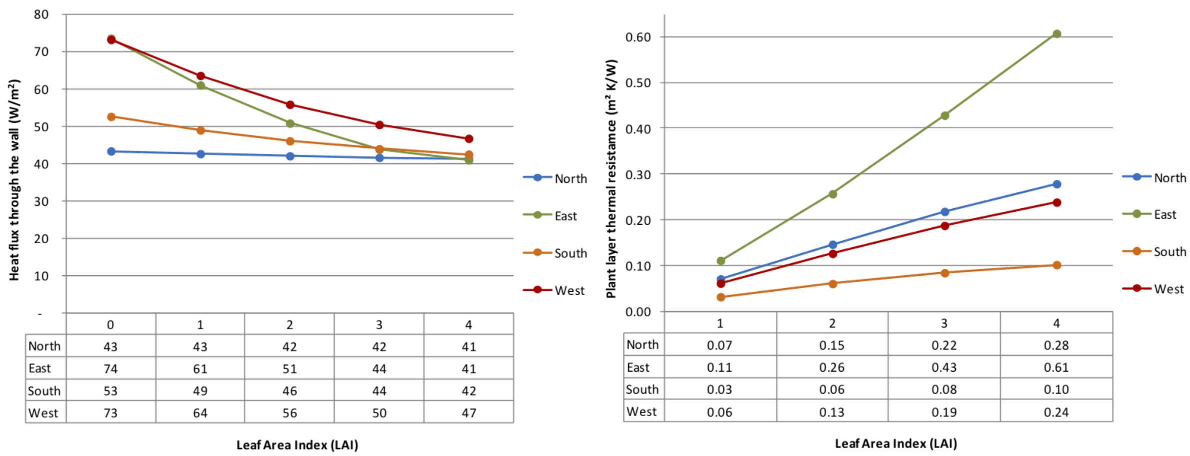
2.2. Effect of Vegetation Characteristics

The cooling capacity of a green wall is also dependent on the plant species, along with the type of growth media. The cooling potential of a vegetated wall is not a function of plant species alone, but for each species, it will also vary with the type of system employed [6]. Leaf Area Index (LAI) is defined as the area of the leaf surface per unit ground surface area. For vegetated facades, LAI gives the amount of surface area covered by the vegetation, which in turn, will determine the thermal capacity of the green facades. Various studies have suggested that the thermal properties of the vegetation itself viz. growing media, plant species, planting depth, height, density of vegetation and leaf area index (LAI) influence the performance of green facades in altering the energy consumptions. The study also suggested that the cooling capacity vary as per the plants selection, and moreover different species cool down the surfaces with different mechanisms, which is again a function of leaf area, LAI, moisture content and evapotranspiration capacity [9]. The study done by Stav and Lawson reflect that an average savings of 25% cooling energy can be achieved using the green facades. LAI determines the amount of surface covered by vegetation; the higher the LAI, the more will be the savings. However, an interesting outcome of the study was that $LAI<2$ resulted in increased energy consumption rather than savings [10]. A study done at Illinois Institute of Technology, Chicago suggested that with an increase in LAI, there is a significant reduction in the transmissivity (Fig. 1) and heat flux (Fig. 2), while the thermal resistance (Fig. 2) increases linearly.



$$\tau = \exp(-\kappa \cdot LAI)$$

Fig. 1: Variation of transmissivity with LAI (Source: http://built-envi.com/wp-content/uploads/2013/06/vegwall_lai.png)



	0	1	2	3	4
North	43	43	42	42	41
East	74	61	51	44	41
South	53	49	46	44	42
West	73	64	56	50	47

	1	2	3	4
North	0.07	0.15	0.22	0.28
East	0.11	0.26	0.43	0.61
South	0.03	0.06	0.08	0.10
West	0.06	0.13	0.19	0.24

Fig. 2: Relationship between heat flux and effective R-value of the plant layer for various LAI values and wall orientations. (Source: http://built-envi.com/wp-content/uploads/2013/06/vegwall_lai_impact.png)

2.3. Thermal Behaviour of Vegetated Facades

A study conducted in Mediterranean climate, showed temperature reduction of up to 10.8 ˚C, attributed to vegetated walls [11]. Another study by Alexandri and Jones reported air temperature reduction of 4.5 ˚C in Mediterranean climates. The same study showed temperature reductions of up to 2.6 ˚C for temperate regions. The simulation based studies suggest that cities in humid climates benefit the most from vegetated surfaces, and temperature reductions can be as high as 12 ˚C (Riyadh) and can result in energy savings of up to 100% in certain cases. Moreover it was reported that the impact of vegetated surfaces is even more pronounced when the surfaces receive higher solar radiation. This is attributed to the fact that the impact of green facades is more dependent on the characteristics of the vegetation itself, rather than the physical parameters [1]. Another research suggested that vegetated facades have the potential to cool down the external wall surface temperature by up to 21 ˚C and internal wall temperature by up to 8 ˚C, in warm humid climates.

The studies mainly rely on the surface temperatures of external and internal walls, in comparison with non-vegetated wall surfaces to quantify the cooling capacity of green facades. All the studies conducted to study the impact of vegetated facades, necessarily study this reduction in temperatures, which is often seen as the determinant of the thermal performance of these green surfaces.

3. Vegetated Facades – Indian Context

The building industry in India has seen a rapid growth over the last few decades, however, there is still a reluctance to adopt the vertical greening measures by the Indian market, despite its enhanced environmental benefits. This may be due to the lack of verifiable data to establish the relevance of vegetated facades in the Indian context. Very limited work has been done by Indian authors, and there are very few documents that talk about the impact of vegetated facades in the Indian context. Only one of the works reviewed for this paper documented the thermal performance of green facades in Mumbai, India [12]. However, since it a simulation based theoretical study, and is not validated by real-time experiments, the exact behaviour of these vegetated facades is yet unknown.

The studies conducted for the climate of Mumbai, India shows that the application of green facades in buildings of Mumbai help in reducing the temperatures by about 2.7 – 4.4 °C. The study also suggested that if the roofs and walls are both vegetated, there can be up to 72% of cooling energy savings, while in case of the applications of green walls alone, the reduction can be up to 35%. Fig. 3 shows the air temperature decrease (%) inside the canyon for the green-all and green-walls cases, for the different canyon geometries examined for Mumbai. Fig. 4 shows a comparison of air temperature decrease (%) 1m above the roof (ΔTf[gr a]) for green-roofs and green-all cases with the air temperature decrease inside the canyon for the green-walls and green-all cases, for the H5W10 canyon, Mumbai. Fig. 5 shows the average cooling load decrease (%), with a 23 ˚C indoors temperature, for the green-walls and the green-all cases for Mumbai as examined [12].

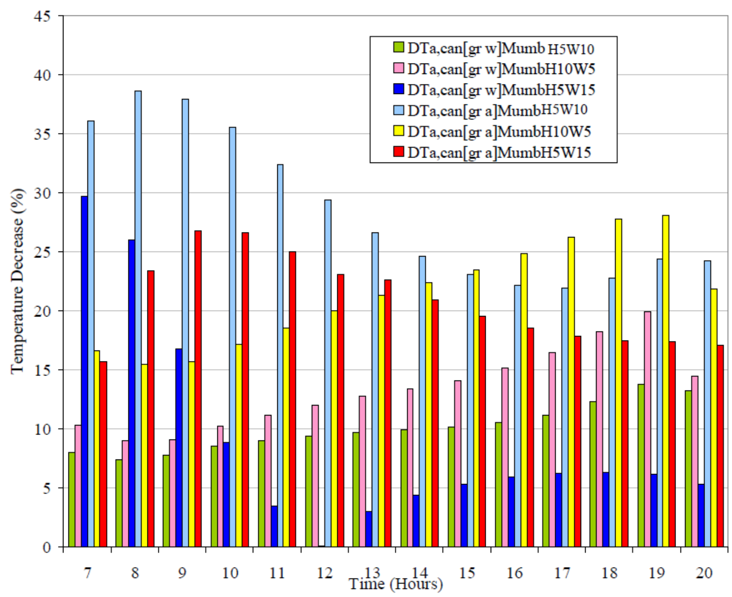


Fig. 3: Air temperature decrease (%) inside the canyon for the green-all and green-walls cases, for the different canyon geometries examined for Mumbai

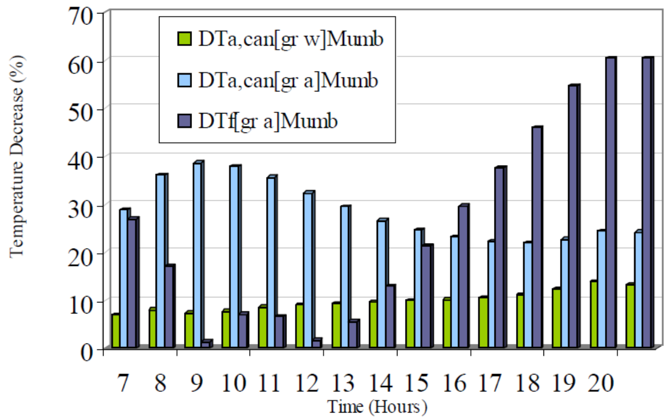


Fig. 4: Comparison of air temperature decrease (%) 1m above the roof (Tf[gr a]) for green-roofs and green-all cases with the air temperature decrease inside the canyon for the green-walls and green-all cases, for the H5W10 canyon, Mumbai

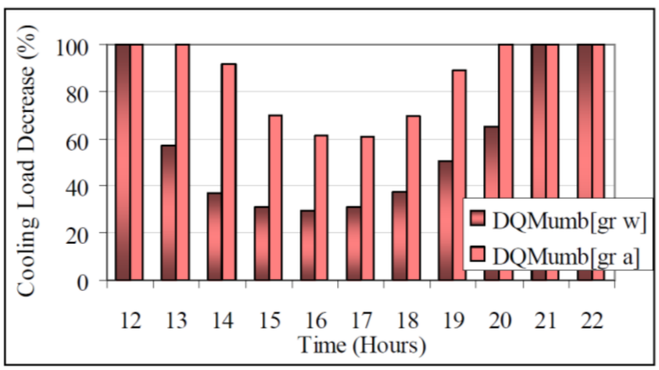


Fig. 5: Average cooling load decreases (%), with a 23 ˚C indoors temperature, for the green-walls and the green-all cases for Mumbai

If the data collected, as shown in Fig. 4 and Fig. 5, is to be quantified to measure the energy savings, it can be a useful information to progress in the field of vegetated facades. On an average, an office building in temperate region of India (Mumbai) consume 18.55 kWh/ft^2/yr. (Source: Bureau of Energy efficiency), while a residential building consumes about 15-30 kWh/ft^2/yr. Since office and residential buildings eat up the maximum energy, the impact of vegetated facades on these buildings will be an interesting case to see. As per the research, green walls can save up to 35% of energy for buildings in Mumbai. This means that the energy consumption by office and residential buildings (based on typical consumption) can be brought down to 12 kWh/ft^2/yr. and 9.75 – 19.5 kWh/ft^2/yr., respectively. That means per square feet of area, an energy reduction of about 6.55 kWh for offices, and 5.25 – 10.5 kWh for residences annually can be achieved. Table 1 summarizes this for an annual energy saving.

TABLE 1: Energy savings for a typical office and residential building (Based on data from BEE)

	Average annual energy consumption in normal case (kWh/ft^2)	**Annual energy consumption in case of green walls (kWh/ft^2)**	**Annual energy savings (kWh/ft^2)**
Office Buildings	18.55	12	6.55
Residences	15-30	9.75 – 19.5	5.25 – 10.5

http://dx.doi.org/10.17758/UR.U1215317

4. Conclusion

The literature reviewed for the purpose of this paper shows that vegetated facades significantly enhance the thermal performance of the building envelope, and can be used to reduce the energy consumption by conditioned buildings. The theoretical model used to quantify the energy savings by the employment of vegetated facades in the buildings for the region of Mumbai suggest that there can be an energy savings of up to 30% annually, which can bring down the working costs significantly. The reluctance in the Indian market to employ green facades is however primarily due to the limited body of work in the design and development field of vegetated facades, which pose a serious challenge, as there are very limited works that rely on site measurements and real-time experiments. Moreover, the existing studies based on simulations or experiments lack the ability to be replicated as they consider only selected number of parameters to study the thermal behaviour of green facades, and often overlook the ecological characteristics of vegetation itself. There is an urgent need to integrate the experimental studies with simulation based studies, to achieve more realistic results. In combination with simulating standalone vegetated facades, it is advisable to include other parameters of building such as the various thermal zones, anthropogenic heat generation, internal heat gains (function of the occupants), etc. Another important issue at present is the need to incorporate the horticulture, soil sciences, botany and geological sciences along with the building sciences to better understand the behaviour of these green facades. The existing studies have given sufficient evidences to support the hypothesis that the use of vegetated facades help in improving the building performance. The application of these facades however, should not be seen as mere a corrective measure to enhance the performance in a poor design. The more appropriate approach would be to treat vegetated facades as a design element, and must be integrated within the building planning and design.

5. Acknowledgements

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