

Evaluating the Thermal Performance and Environmentally Responsive Energy Efficiency of Green Facades: A Simulation Study

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Abstract

The incorporation of plants on building facades is getting popular in the construction sector, as they improve energy efficiency and urban sustainability. Buildings, particularly in warm or hot climates, can take advantage of this method to provide natural insulation, shade the walls provided and have energy efficiency. Many researchers are in the process of the green wall systems, and its advantage over temperature. It has been also assessed in terms of indoor comfort and energy savings in various zone climate categories. A numerical model conducted by the simulation software IES VE has been implemented for evaluating the thermal behaviour of both green facades and traditional brick walls. In order to evaluate the thermal performance of both green facades and conventional brick walls, a simulation model was created using the IES VE program. Particularly in lightweight buildings in warm regions with ample solar radiation, the results demonstrate significant reductions in heat transfer, carbon emissions, and energy usage. The study shows that vegetated walls may improve indoor thermal comfort and reduce energy consumption. This helps in the way of sustainable urban planning and design process. The efficiency of green facades in different climate zones, their long-term durability, and their potential interactions with other sustainable technologies need to be addressed in future.

Keywords- Green Facades, Thermal Performance, Energy Efficiency, Vegetation Insulation, Carbon Emission Reduction, Urban Sustainability.

1. INTRODUCTION

Architecture and urban planning are increasingly incorporating plants into building facades. It serves as a bridge over aesthetic and energy efficiency in contemporary cities. Green facades can be more than just beautification; they serve as natural insulation and temperature regulators in urban areas. This aligns with efforts by municipalities around the world to produce less polluting urban environments. While green roofs have become commonplace in many countries, vertical greening—attaching plants to building facades—has faced technical and economic barriers.

Vertical greenery offers a unique opportunity to utilize underused building surfaces in densely populated areas, particularly where space for green infrastructure is limited. Every natural skin gives buildings the ability to grow living things, providing layers of insulation and shadows, increasing their thermal comfort, and reducing heating-cooling costs. Yet, despite their promise, rigorous research on the environmental and public benefits of living walls remains scarce. This is essential for the future development and widespread utilization of vertical greening, as well as for guiding its effective use in both new constructions and retrofitting projects. Research from the mid-1980s by Hoyano (like his 1988 study on ivy-covered buildings in Tokyo) confirms that vegetated facades can help lower external surface temperatures and reduce indoor cooling demands. These findings, along with advancements in simulation models, offer valuable insights into the thermal response of green walls in different climates and building types. Simulation tools allow for scalable exploration of environmental benefits, such as reduced heat gain, energy consumption, and heat loss. Despite technical challenges, the environmental advantages of vertical greening remain evident, particularly as urban centers become more crowded and construction shifts toward energy efficiency. More research is needed to establish the thermal and environmental benefits of green walls, refine standardized implementation processes, and promote their wider application in architectural design.

This paper examines the findings of a simulation study to investigate the long-term impact of vegetated walls on improving building thermal performance, indoor comfort, and overall energy efficiency.

2. Background

Numerous studies on green facades highlight significant thermal and environmental benefits related to vertical greening. Vegetation can reduce external wall temperatures by 18% and increase indoor air temperatures by up to 6°C, contributing to thermal comfort in hot climates, as demonstrated by Hoyano (1988). This aligns with McPherson, Herrington, and Heisler's (1998) research, which showed that greenery enhances energy savings in temperate regions, reducing residential cooling energy consumption. The thermal performance of green walls is also significantly influenced by their orientation and coverage, particularly on south-facing surfaces (Kontoleon and Evmorfopoulou, 2010), emphasizing the importance of wall orientation for energy efficiency. Chen and Wong (2009) investigated green surfaces' cooling effects on external walls in connection to urban heat islands. This expands the application of green walls to promote urban sustainability.

Evmorfopoulou and Kontoleon (2009) confirmed that green walls slow heat transfer indoors, improving thermal comfort. Perini et al. (2011) found that vertical greenery enhances ventilation and reduces heat absorption, contributing to energy savings. Koyama and colleagues (2015) further demonstrated the cooling effects of climbing plants, primarily through transpiration. These findings are particularly relevant for temperate climates with increasing cooling needs. Rosenlund and Kruuse's (2010) analysis of urban vegetation in Sweden showed its positive impact on energy savings and microclimate improvement, offering valuable insights into how green facades can be adapted to various climates.

3. Problem Statement

Sustainable design techniques are increasingly being explored due to the rising urban demand for energy-efficient structures. Vertical greening systems, which utilize plants as natural insulation, hold promise for improving thermal efficiency and reducing energy consumption. However, despite the growing popularity of green facades, there is a significant lack of research that comprehensively examines their long-term effects on building performance, particularly across varied climates. Most studies focus on specific scenarios or localities, leading to an incomplete understanding of the broader applications of vegetated walls. Furthermore, the ability of vertical greening to consistently reduce energy consumption and carbon emissions across different building types and orientations remains unknown.

4. Aim

The aim of this study is to evaluate the thermal performance, energy savings, and carbon emission reduction potential of vegetated walls compared to traditional building walls, using simulation models in varied climatic conditions.

5. Objectives

The primary objectives of this study are:

- (i) To analyze and compare the thermal performance of green facades with traditional walls in different climates.
- (ii) To assess the energy-saving potential of vertical greening systems in reducing heating and cooling demands.
- (iii) To evaluate the impact of vegetated walls on carbon emissions in diverse building orientations and types.

6. LITERATURE REVIEW

Evmorfopoulou and Kontoleon (2009) confirmed that green walls slow heat transfer indoors, improving thermal comfort. Perini et al. (2011) found that vertical greenery enhances ventilation and reduces heat absorption, contributing to energy savings. Koyama and colleagues (2015) further demonstrated the cooling effects of climbing plants, primarily through transpiration. These findings are particularly relevant for temperate climates with increasing cooling needs. Rosenlund and Kruuse's (2010) analysis of urban vegetation in Sweden showed its positive impact on energy savings and microclimate improvement, offering valuable insights into how green facades can be adapted to various climates.

7. METHODOLOGY

7.1. Simulation Program:

For this study, the Integrated Environmental Solution for Virtual Environment (IES VE) software was selected to model and simulate the thermal performance of vegetated walls. IES VE was chosen for its ability to assign specific thermal properties to various building materials, allowing precise calculations of energy efficiency, heat transfer, and overall thermal behavior. This software is ideal for evaluating the influence of greenery on building systems, providing an accurate simulation of how plant-covered facades impact energy usage and indoor climate control in buildings.

7.2 Vegetated Model:

A detailed thermal model of a building featuring the climbing plant *Mucuna pruriens* was created. This plant was chosen due to its physical similarity to ivy, which has been extensively studied for its insulating properties. The model incorporated several critical components of the plant, including foliage, woody stems, air gaps, and water vapor, each contributing to its thermal performance. The simulation considered the thermal properties of the plant, such as:

Specific heat: 2.18 J/kgK (Adeyanju, 2022) and Thermal conductivity: 0.65 W/mK (Adeyanju, 2022)
 The density of the leaf layer was calculated as 690,000 g/m³, based on an estimated leaf area of 0.005 m² per leaf, with 200 leaves per square meter. These properties were used to simulate the thermal behavior of the vegetation.

Table 1. Thermal Properties of the components in the vegetative model in the simulation.

Layer Name	Width (mm)	Density (kg/m ³)	Specific Heat (J/kgK)	Conductivity (W/mK)
Water vapor	2.0	0.6	1966	5.56
Leaves	0.3 (R)	690	2.18	0.65
Air gap	T	1.3	1004	5.56

R refers to the ratio of leaf coverage, and T represents the thickness of plant coverage, divided by two (Hoyano, 1998).

7.3. Simulation of a Room (Base Case):

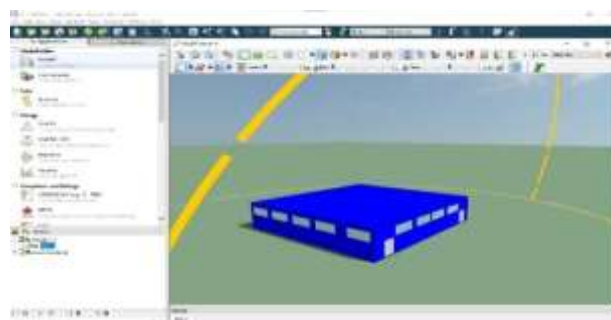


Figure 1.(a) Base case considered.

The simulation was conducted on a single space with dimensions of 20m x 20m and a height of 4m, to assess the feasibility of the study. The space is located in Saidapet, Chennai (latitude 13.0213° N, longitude 80.2231° E), a region characterized by warm and humid weather conditions. Specific climate data for Chennai, in .epw format, was uploaded into the IES VE software to ensure the accuracy of the simulation and its relevance to the local environment.

Two scenarios were simulated for comparison:

- A standard brick wall construction.
- A vegetated wall applied as external insulation over the brick structure.

As shown in Figure 1, the base case simulation model was developed with all relevant parameters incorporated. The vegetation's thermal properties, detailed in Table 1, were applied to assess the influence of plant-covered facades on heat transfer and energy efficiency. The simulation compared the thermal

performance of the vegetated and non-vegetated walls, analysing key factors such as heat transfer, indoor temperature stabilization, and energy consumption for heating and cooling. The results, presented in graphical and tabular formats, provided a clear comparison of the two scenarios. The findings demonstrated that green facades significantly enhanced insulation and reduced energy consumption compared to traditional brick walls, offering valuable insights into their potential for sustainable building design.

8. RESULTS

Simulations were conducted to evaluate the thermal performance and energy efficiency of green facades, specifically focusing on vegetated and traditional brick walls. The findings, summarized in Table 1: Environmental Data for CO₂ Emission and Power Consumption of Various Wall Types, indicate that vegetated walls significantly reduce energy consumption and emissions compared to traditional brick walls, particularly when oriented to maximize solar shading. Vegetated walls demonstrated notable benefits in thermal performance by reducing heat absorption during warm months and maintaining more stable indoor temperatures during colder periods. In terms of CO₂ emissions, vegetated walls consistently showed lower values, with a peak of 0.5 kgCO₂/h compared to 0.7 kgCO₂/h for brick walls, highlighting their contribution to lowering carbon emissions. A similar trend was observed in electricity consumption, where vegetative walls had a maximum of 0.9606 kW, significantly lower than the 1.2725 kW for brick walls. This reduction is attributed to the insulating properties of vegetation, which decreased the demand for HVAC systems. Additionally, total energy consumption was lower for vegetative walls, with an average of 0.6549 kW compared to 0.7431 kW for brick walls. The results suggest that green facades can mitigate peak energy loads, especially during summer months when cooling demands are high, thus demonstrating the energy-saving potential of vegetated walls. Overall, the study underscores the effectiveness of green facades in reducing energy consumption, lowering carbon emissions, and enhancing indoor thermal comfort, making them a promising option for energy-efficient building designs, especially in warm climates.

Table 2 Environmental Data for CO₂ Emissions and Power Consumption of Various Wall Types

Var. Name	Filename	Type	Min. Val. (kW)	Min. Time	Max. Val. (kW)	Max. Time	Mean (kW)
Total CE	vegetative wall 1 .aps	CO ₂ emission (kgCO ₂ /h)	0.1	04:30, 07/Aug	0.5	19:30, 09/Apr	0.3
Total CE	vegetative wall .aps	CO ₂ emission (kgCO ₂ /h)	0.1	05:30, 22/Jan	0.5	20:30, 28/May	0.3
Total CE	brick wall .aps	CO ₂ emission (kgCO ₂ /h)	0.1	05:30, 27/Jan	0.7	20:30, 28/May	0.4
Total CE	brick wall 1 .aps	CO ₂ emission (kgCO ₂ /h)	0.1	04:30, 15/Dec	0.6	18:30, 09/Apr	0.3
Total Electricity	vegetative wall 1 .aps	Power (kW)	0.2247	04:30, 07/Aug	0.8743	19:30, 09/Apr	0.5254
Total Electricity	vegetative wall .aps	Power (kW)	0.2184	05:30, 22/Jan	0.9606	20:30, 28/May	0.5462

Total Electricity	brick wall .aps	Power (kW)	0.1506	05:30, 27/Jan	1.2725	20:30, 28/May	0.6344
Total Electricity	brick wall 1 .aps	Power (kW)	0.1810	04:30, 15/Dec	1.1398	18:30, 09/Apr	0.6043
Total Energy	vegetative wall 1 .aps	Power (kW)	0.3334	04:30, 07/Aug	0.9830	19:30, 09/Apr	0.6342
Total Energy	vegetative wall .aps	Power (kW)	0.3271	05:30, 22/Jan	1.0693	20:30, 28/May	0.6549
Total Energy	brick wall .aps	Power (kW)	0.2593	05:30, 27/Jan	1.3813	20:30, 28/May	0.7431
Total Energy	brick wall 1 .aps	Power (kW)	0.2897	04:30, 15/Dec	1.2485	18:30, 09/Apr	0.7130

8.1. Total Carbon Emission

The building system's carbon emissions can be calculated accurately by inputting specific dates and times, allowing for precise monitoring and assessment.

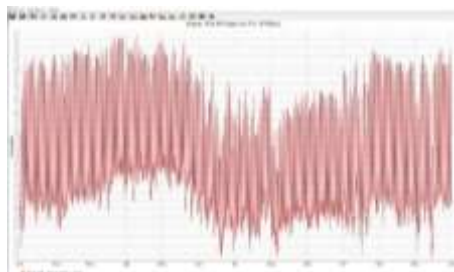


Figure 2. (a) Brick wall emission

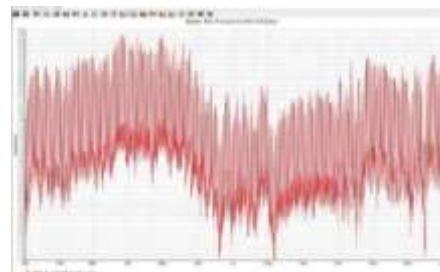


Figure 2.(b) Vegetated wall emission

8.2. Total Electricity

The total electricity consumption of the building is calculated by considering the electrical appliances present. In this scenario, the calculation includes one ton of air conditioning, a ceiling fan, a television, a personal computer with a network connection, and a fluorescent tube light. These appliances were used as the basis for determining overall energy usage. The resulting chart provides a clear representation of electricity consumption, offering insights into how different devices contribute to the building's total energy demand.

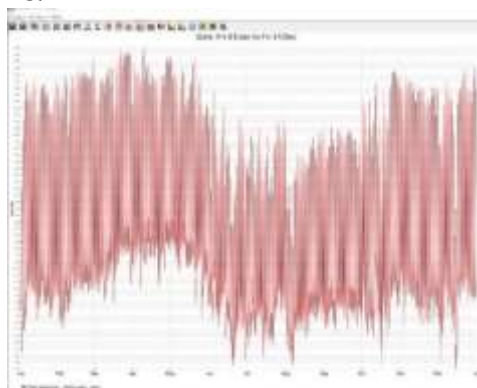


Figure 3.(a) Brick wall consumption

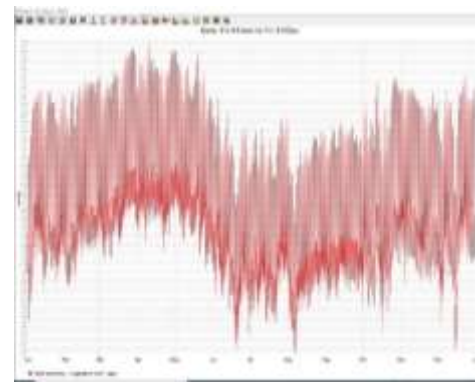


Figure 3.(b) vegetated wall saving

8.3. Total Energy

Total energy refers to the overall energy consumption of the building system, encompassing the operation of the HVAC system, ventilation, and the comfort requirements of the space. It provides a comprehensive measure of how much energy is used for maintaining optimal indoor conditions and ensuring a comfortable environment.

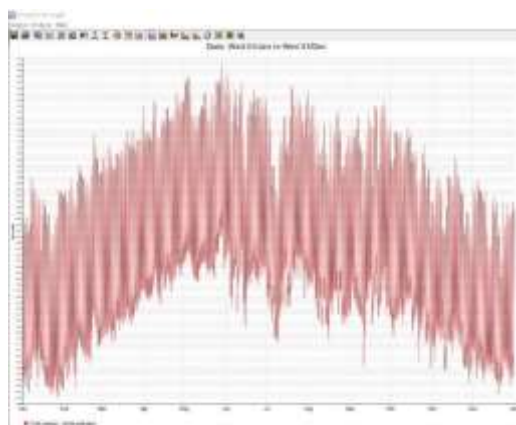


Figure 4.(a) Brick wall consumption



Figure 4.(b) vegetated wall Redemption

9. DISCUSSION

The simulation results reveal that vegetated walls contribute significantly to reducing carbon emissions, electricity consumption, and overall energy usage, compared to traditional brick walls. Figure 5 clearly illustrates the difference in carbon emissions between the two wall types. Vegetated walls consistently exhibited lower emissions across all seasons, particularly during periods of extreme weather. This reduction is attributed to the plant layer's ability to regulate indoor temperatures, thus minimizing the need for energy-intensive cooling or heating systems. Additionally, Figure 6 highlights the electricity consumption trends, with vegetated walls requiring less electricity for climate control, as shown by the lower peak demand when compared to brick walls. This demonstrates the insulation effect of vegetation, which reduces the reliance on HVAC systems. Finally, Figure 7 emphasizes the overall energy consumption for both wall types, where vegetated walls consistently consumed less energy. The cumulative effect of reduced electricity and carbon emissions indicates that vegetated walls offer a more sustainable solution for building energy efficiency. These findings underscore the potential of integrating vegetated walls into building designs to achieve significant energy savings and environmental benefits, particularly in regions with hot climates.

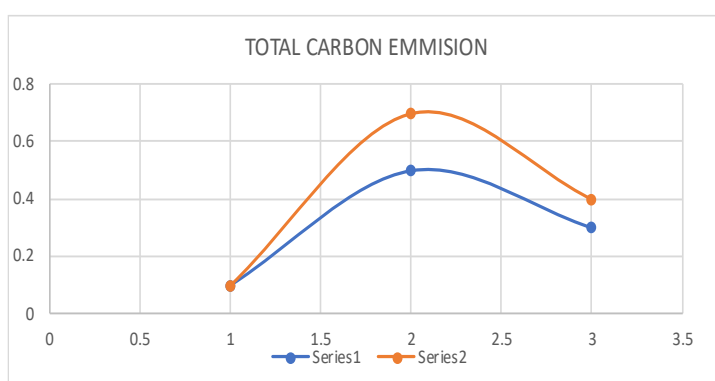


Figure 5. Carbon Emission by Brick and vegetated wall

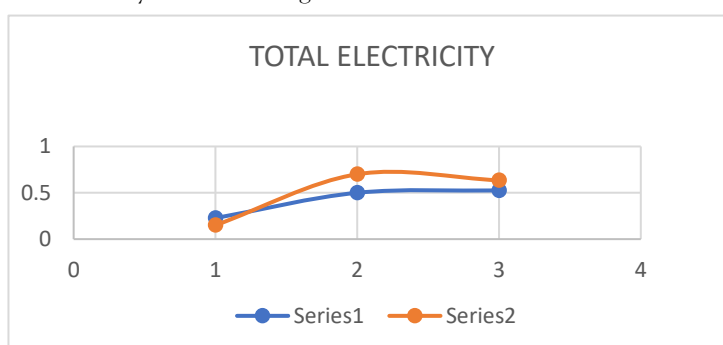


Figure 6. Electricity consumption when Brick and vegetated wall is employed.

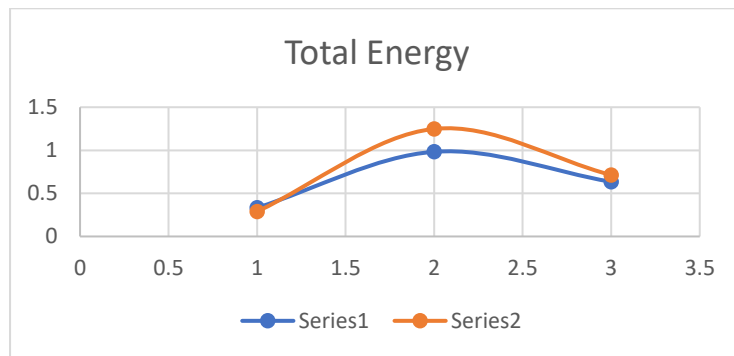


Figure 7. Total Energy consumed in Brick and vegetated wall

10. CONCLUSION

The simulation results demonstrated that vegetation on external walls significantly stabilized indoor air temperatures by reducing daytime solar heat gain and providing insulation during the night. This effect was observed in both hot and cold climates, contributing to a reduction in carbon emissions and overall energy consumption. By moderating the temperature fluctuations, vegetated walls also lessened the need for mechanical heating and cooling, resulting in lower energy demands. Furthermore, the plant layer helped reduce conductive heat transfer through the walls, minimizing heat gains and losses. This led to a decrease in energy loads required for maintaining comfortable indoor temperatures. Specifically, the presence of vegetation on a brick facade reduced the exterior surface temperature and led to notable reductions in energy consumption and carbon emissions. The study estimated that the total electricity usage dropped from an average of 0.6023 kW to 0.5254 kW, while energy consumption decreased from 0.7431Kw to 0.6549 Kw. Additionally, carbon emissions were lowered from an average of 0.4kg co2/hr to 0.3 kgco2/hr primarily influenced by the wall's orientation and the leaf area index of the plants. These findings underscore the potential of vegetated walls to improve energy efficiency and contribute to environmental sustainability, particularly in urban settings where energy demands are high.

Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication

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