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An Analysis on Efficient Vertical Greening for Exterior Application in Hot and Humid Climate

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ABSTRACT: The vertical greening technique offers a wide range of benefits. However, due to inadequate study and technical knowledge in this area, the efficiency of vertical greenery in providing a thermally comfortable indoor environment is not well known which acts as a main obstacle to its widespread adoption. This article reviews some of the successful vertical greening projects and field experiments performed to evaluate the thermal performance of vertical greening in tropical climates, particularly in hot and humid regions to conclude with an efficient vertical greening system for exterior wall application to provide a comfortable indoor environment in hot and humid climate.

KEYWORDS: Thermal comfort, field experiment, vertical greening, thermal performance, hot and humid

1. INTRODUCTION:

Construction materials used on the facade impact the microclimate around the building leading to a rise in indoor and outdoor air temperature causing discomfort to living as a result there is an increase in the energy utilized for air conditioning[Abdallah ElHady. (2019)].By shading walls and windows from direct sunlight, VGS reduces the pressure imposed on the air conditioning system. The amount of electricity used to cool a room reduces by around 6% for every degree the temperature is raised. By raising the temperature of the air conditioner from 20 to 24 degrees Celsius, users can effectively save about 24% of the energy used,

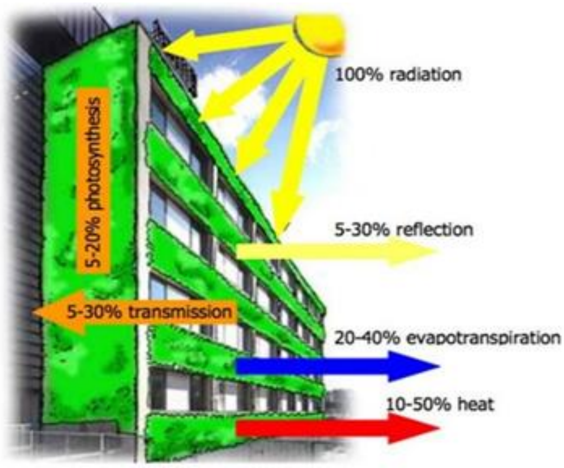

Fig 1: Solar Radiation Transmission of Green facade

according to the Bureau of Energy Efficiency [https://www.mca.gov.in]. Incorporating green infrastructure through a vertical greening system (VGS) is an alternative to reduce the heat storage and transmission through building skin as it keeps away the heat by the process called evapotranspiration. (Fig-1)[1.] There are only a few studies conducted on the thermal performance of VGS in façades, particularlyin hot and humid climates. However, thehot and humid regions are the ideal places for the growth of many different plant species to live because of the climatic characteristics, which include year-round sun and large densities of rainfall, especially during the rainy seasons[AIP Conference Proceedings 1887,]. To gain a better understanding of the efficient VGS typology and its thermal performance for exterior application in a hot and humid climate, this paper reviews some of the projects which have successfully integrated outdoor VGSand previous research to widen the knowledge of the thermal performance of VGS.

2. CLASSIFICATION OF VGS

Depending on the plant's species, planting media, and support structure VGS is classified into two types, [Antony Wood, et al. (2014)]

Parameter	Green wall	Living wall
Growing medium	It is placed at the base of the wall	It is placed along the face of the wall
Structure	Direct green and Indirect green with lightweight structure of the ground (trellis, Cable, mesh)	Felt system, vegetated mat, modular system
Cost	Less expensive than a living wall	More expensive than a green wall
Maintenance	Lesser maintenance in pruning and inspection	Higher maintenance includes inspection of the integrity of façade and structure, irrigation, pruning, and replacement of dead plants
Irrigation	Natural, manual, or automatic irrigation	Automatic irrigation system
Thermal performance	Lesser than a living wall	Higher than the green wall
Thermal Efficiency	Is influenced only by the shape and density of leaves	Is influenced by the growing medium and its water retention capacity, plants used
Lifespan	Up to 100 years or more depends on the effective plant selection	10-15 years, requires regular replacement of dead plants
Best climate	All climates	Temperate and hot climates

3. CASE STUDY REVIEW

To obtain qualitativeoutput on the efficient VGS for the external wall in a hot and humid climate,9 projects inBangkok, Singapore, and Chennai was reviewed out of which 4 are site observation. Based on it the following analysis is made

	Project	Image	Type And System	Orientation	Plant species
1	**The Met, Bangkok**		The indirect, mesh system	Podium car park: S, E, W Façade E, W	tristellateia australasiae, Jasminum laurifolium Thunbergia Grandiflora

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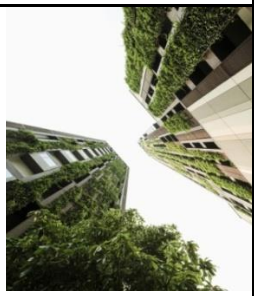
					ThunbergiaLaurifolia[Antony Wood, et al. (2014)]
2	**Ideo morph 38,Bangkok**		The indirect, mesh system	N,S,E,W	Thunbergia Grandiflora[Antony Wood, et al. (2014)]
3	**Newton suite, Singapore**		The indirect, mesh system	SE	Thunbergia Grandiflora[Antony Wood, et al. (2014)]
4	**School of arts, Singapore**		The indirect, mesh system	N,S,E,W	Thunbergia Grandiflora[Antony Wood, et al. (2014)]
5	**Helios residences, Singapore**		Indirect, Cable system	N,S,E,W	Thunbergia Grandiflora[Antony Wood, et al. (2014)]
6	**Agarwals group of eye hospital, Alwarpet, Chennai**		Living, Modular system	East, south	Syngonium, Fern plants, Song on India, Money plants, Pandanus plants, philodendron, purple heart (site observation)
7	**Global design studio of Shilpa architect,Chennai**		Indirect, Cable system	south	Thunbergia Grandiflora (site observation)

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8	**IFS officers mess campus in Velachery, Chennai**		Living, Modular system		philodendron, Jade, purple heart Tradescansia, peperomia, rhoeo , Dracena, chlorophytom, pilliea, fern, opeopogon (site observation)
9	**KSM Architecture studio,Chennai**		The indirect, mesh system	west	Passiflora incarnate (site obsevation)

Based on the detailed study on the existing case examples on VGS through literature review and site observation, it is identified that the use of indirect greening with modular mesh system andThunbergia Grandiflora is commonly used for its ease of installation and maintenance for exterior wall application in a hot and humid climate. Not many projects with the living wall are integrated into the facadesdue to their high maintenance. The living wall was mostly installed as standalone structures in interior and exterior garden spaces or perimeter walls in some of the case studies observed in Chennai by site visit (Agarwal's eye hospital, IFS officers mess, under flyovers, the airport in Chennai)

4. RESEARCH REVIEW
The following field experiments are analyzed to widen the knowledge of the efficiency of vertical greening in reducing indoor air temperature in a hot and humid climate

EXPERIMENT 4.1:
Author: Sunakorn & Yimprayoon (2011) Location: Bangkok, Thailand
Aim: To study the impact of climbing plants on indoor thermal performance with and without ventilation
Research brief: To perform this research, three climbing plants blue trumpet vine, ivy gourd, and Mexican creeper were selected and made to grow on the 1m high vertical steel frame. As blue trumpet vine grew quickly in 3 months and covered 90 % of the surface with sufficient leave density having 3 to 4 layers, this plant was taken for the study purpose. The frame of blue trumpet vine was placed at a distance of 0.70 m away from open windows facing west which was used as a test room and an adjacent room without a green wall was taken for comparison. Two experiments were carried out with and without ventilation from 1th - 4th march 2008 and 26th - 29th February 2008 respectively
Plant used: Blue trumpet vine (Thunbergia grandiflora) - Ivy gourd (Coccinia grandis) - Mexican creeper (Antigonon leptopus) Fig 2

(a) Blue trumpet vine ; (b) Ivy gourd ; (c) Mexican creeper

Fig 2: Plant used

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Fig 3: Vertical greening type

Vertical greening type: indirect greening with planter box
Analysis: green facades did not significantly reduce the temperature at night as it might hinder heat dissipation and the fact that external humidity is higher. However, ventilation might be able to overcome this issue. When wind speed is greater than 0.5 m/s, leaves do not hinder it; unexpectedly, they even enhanced wind speed.
Result: T. Grandiflora selected in this study due to the growth performance showed maximum outdoor to an indoor air temperature reduction of 9.93 C with natural ventilation and 6.32 without natural ventilation [PasineeSunakorna, ChanikarnYimprayoon.(2011)]

EXPERIMENT 4.2:
Author: Tabassom Safikhani et al,location: Malaysia
Aim: To study the thermal performance of vertical greenery systems with and without ventilation
Research brief: The experiment was conducted with three identical small-scale models made of plywood measuring 60cmx60cmx160cm and 1.2 cm thick with a green wall and living wall on the west side of two boxes and a bare model for comparison. The VGS was placed at a distance of 15cm away from the test boxes. The text boxes have an upper opening measuring and a lower opening measuring 40x20cm and 40x10cm. The impactof VGS with and without ventilation was studied.The experiment was conducted on three cloudless and sunny days from April 14^{th} -17^{th}, 2013.

Fig 4: Green Wall **Fig 5:** Living Wall

Plant selection: Thunbergia grandiflora
Vertical greening type:Indirect green façade and Modular living wall
Analysis: humidity in the air gap in the green façade was more than the living wall as the leaves were in direct contact with the air gap. The humidity inside the test box with the living wall was greater than the green facade. This makes it clear that a living wall increases indoor humidity more than a green façade.
Result: the living wall and green façade decreased interior temperatures without ventilation by 4.0 °C and 3.0 °C and with ventilation by 3.5 °C and 2.5 °C. [Safikhani, et al (2015)]

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EXPERIMENT 4.3:

Author: Akinwolemiwa OH, et Al, Location: Lagos, Africa

Aim: to build affordable community-driven living wall (VGS) prototypes in a low-income neighborhood to improve the indoor temperature.

Research brief: Research was carried out by community participation. The two different prototypes of living walls made of bamboo and HDPE, High-Density Polyethylene were installed at Lagos Street (HDPE), and Suru Street (Bamboo) (fig 7). The living was installed on the west side room and an adjacent room without a vertical green wall was taken for comparison. The experiment was carried out from May – September 2014. (Fig 6)

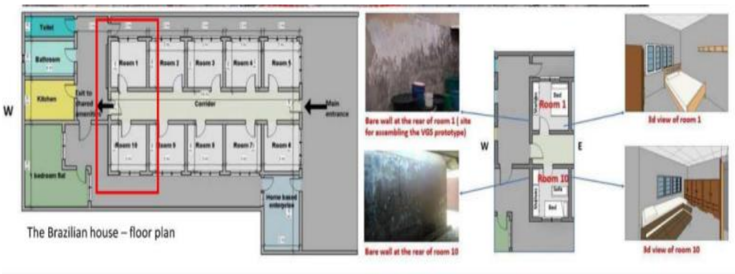

Fig 6: floor Plan

Fig 7: Living wall

Plant selection:l antana Camara(snake repellent) ,laporte Aestuans(aesthetic) telfairia Occidentalis(edible) Corchurus Olitorius (edible plant), Aloe Vera(medicinal)

Vertical greening type: Living wall

Analysis: Thermal reduction by HDPE prototype was considered successful VGS due to the effective plant growth than the bamboo prototypes.

Result: Air temperatures were reduced by an average of 2.3 °c by HDPE and the indoor thermal comfort zone ranged between 90%–100% of the time [Akinwolemiwa, O.H., et al. (2018)]

EXPERIMENT 4.4:

Author: Hazril Sherney Basher, Sabarinah Sh Ahmad: Location – Malaysia

Aim: To investigate the difference in optimum temperature reduction by using Psophocarpus Tetrogonobulus (winged bean plant) placed at two different levels in vertical greening. (fig 9)

Research brief: The test cell was made out of the brick wall and metal deck roofing measuring 4.8 m (l) x 4.2 m (w) x 3.3 m (h). The plywood rack structure that holds the VGS measures 900 mm (w) x 2100 mm. The thermal evaluation monitoring was performed on the wall surface facing the west.The reading was taken between 9 a.m. and 5 p.m,for one week period in the dry season of March 13th to 19th, 2015)(fig 8)

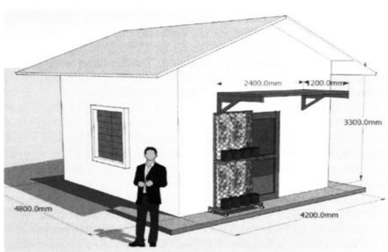

Fig 8: Indirect green wall with winged bean plant

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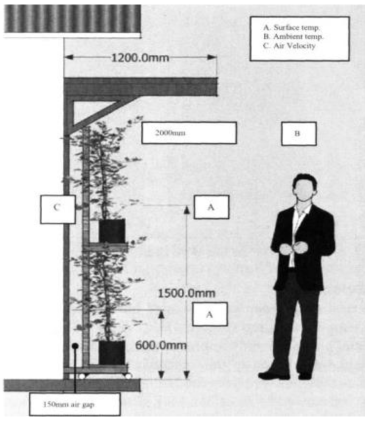

Fig 9: Indirect greening with planter box

Plant selection: Psophocarpus Tetrogonobulus (winged bean plant)
Vertical greening type: Indirect greening with planter box
Analysis: The foliage cover at the lower interval was denser and performed more efficiently than at the upper interval.
Result: the average surface temperature drop at lower and upper levels was recorded as 2.4°C and 1.1 °C respectively with the maximum surface temperature drop of about 6.4°C at the lower level.
EXPERIMENT 4.5:
Author: Qiuyu Chen, Liu Xioahu,Location:Wuhan, China
Aim: To analyzethe indoor thermal reduction using living wall,
To examine the impact of ventilation,
To analyze efficient wall-vegetation distances (w-v-d) on the LWS's thermal performance.
Research brief: In the months of July through September 2012, three series of comparison studies were conducted. The bare wall system and the living wall system thermal comparison, The impact of ventilation: comparison between different wall-vegetation distances is made. A movable steel structure is positioned facing the west.(Fig 10, 11)

Fig 10:6 different plant species

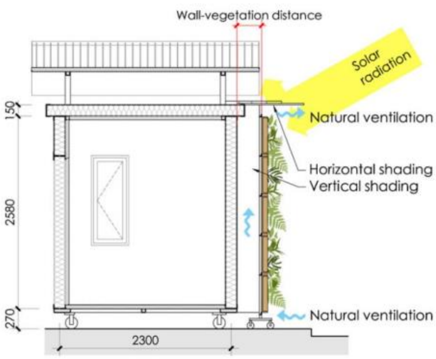

Fig 11: Living wall modular system

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Plant selection:6 different plant species
Vertical greening type:Living wall modular system
Analysis: LWS with a sealed air layer performs better in reducing indoor temperature than the naturally ventilated air layer. However, the air layer is more humid in the sealed air layer resulting in condensation on the wall. The LWS with a smaller w-v-d has a high cooling effect and humidity in the air layer, low cooling effect and humidity while increasing the wall to vegetation distance.
Result: The maximum temperature reduction at the internal and external wall surface was 7.7°C and 20.8°C.The maximum internal air temperature drop was 1.1°C. The sealed air layer has a mean relative humidity of 88.2%, which is substantially higher than the ambient air (74.7%) and the open air layer (75.6 %). [Chen, et al. (2013)]

5. ADVANTAGE OF FIELD EXPERIMENT

1. The major benefit is that the procedures are performed directly on the object; they are simple to implement, observe, and measure.
2. To conduct further studies to evaluate the thermal performance of VGS, the Field experiment is reliable; as it provides more accurate results than the simulation method due to the plant's varied responses to the climatic condition.

6. DISADVANTAGE OF FIELD EXPERIMENT

1. It requires a lot of time for constructing the test cells, waiting for the plants to grow to the desired size, and for observing and measuring.
2. Requires lots of funds for its construction
3. In addition, certain outside elements, such as fluctuating weather or improper growth of plants, might affect the outcome of the investigation.[AIP Conference Proceedings 1887,]

7. DISCUSSION&ANALYSIS

Based on the previous research as mentioned above the following factors are concluded

s.no	Parameters	Description
1	**Orientation**	West orientation is preferred in all the above experiments due to better thermal performance than other orientations in hot and humid climates.
2	**Structure**	Indirect greening is easy to install, measure, and cost-effective than living walls. The living wall requires the replacement of dead plants as the overall performance of the system will be affected
3	**Plant selection**	Research on suitable Edible plants, Flowering plants, and climbers for vertical greening in tropical climates has to be explored as the evapotranspiration rate varies with plants for different weather conditions.The use of ornamental plants to demonstrate indoor thermal reduction is more common than the edible and herbal plants

4	**Cavity**	Open air gap with ventilation is required to avoid condensation on the wall. However, to achieve the best cooling effects of the LWS; a small wall to vegetation distance is preferable as a large wall to vegetation distance will reduce the Thermal performance of vertical greening due to increased airflow that carries hot air. To avoid the structural damage due to condensation, the air layer should be open and/or reinforce the damp-proof of the building wall.
5	**Ventilation**	It is required to provide natural ventilation to control indoor humidity while using a vertical greenery system.
6	**Thermal performance**	Thermal reduction of living walls is higher than indirect greening as the soil layer comes between vegetation and wall. However, the indoor humidity level is higher while using the living wall than the green wall due to its thick structural system. The thermal performance of the green wall is directly dependent on the leaves size and density while in the living wall it is dependent on the growing medium, its water retention capacity, and plant type.

8. CONCLUSION

The need to evaluate the thermal performance of vertical greening for hot and humid climates is high due to the lack of sufficient research to demonstrate the efficiency of vertical greening. The field experiment method is the best choice for a better understanding of thethermal performance of plants,as it varies based on the weather condition for the same climatic region. A green wall with an indirect system is most commonly installed for the outer wall due to its ease of maintenance and longevity. Research has proved that thermal reduction of living with ventilation is better than green wall however the indoor humidity is increased while using a living wall than a green wall. Most of the research is performed using ornamental ThunbergiaGrandiflora and not much research on edible or herbal plants. Further research may focus on different types of climbers and plants to widen the knowledge of vertical greening.

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