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# A Study On The Efficacy Of Green Walls In Indian Perspective

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## ABSTRACT

Societies require a comprehensive lifestyle change. House design, development and operation have significant environmental and ecological impacts. Many structures are built globally, with plenty to come. The goal is to build them with limited use of non-renewable materials, low emissions and low energy usage. Buildings use many natural resources and face many challenges. Today, in the 21st century, citizens increasingly began to understand the need for green architecture as emerging technology and innovations evolved as green buildings, such as green walls, deemed a viable solution to the issue of urban heat islands and energy-saving ideas. This research would illustrate living walls' purpose, advantages, and solutions as part of the sustainable urban environment strategy. Green vertical surfaces give the urban environment major natural, social economic advantages. Studies will also show that this modern technology is a critical part of the continuum of climate change innovation and energy crisis. Living walls use vertical surfaces for buildings. In arid settings, water evaporates less on a vertical wall than in horizontal gardens. Heat isolation, acoustic isolation, enhanced air quality, energy efficiency, contribution to betterment of human psychological aspects add it's the benefits. Although certain issues like frequent and constant maintenance requirement, affordability, insufficient awareness and consciousness etc. affect its development and popularity. Finally, the study summarizes with recommendations to use the living wall technique that suits the arid atmosphere as part of a sustainable urban setting plan.

## 1. Introduction

People migrate towards the urban areas following the rising development and urbanization, expanding the cities each day. The vegetated surfaces being replaced by paved, waterproof surfs through the years, more solar radiations

are held, preserved and re-radiated compared as compared to the vegetated ground. The temperature in the urban areas can be over 6 degrees as compared to countryside [1]. Many environmental impacts are caused by various structures, their construction and their maintenance. Improved accessibility, health care and security for the people living in the houses are the important construction goals. New green design ideas and innovations have gradually started to come up as the 21st century demands the need for ecofriendly architecture. Landscaping is viewed as the sole factor that can help shift green to green walls to bring about aesthetics which is obligatory at certain age [2]. The changeover to green walls or the vertical gardens is facilitated as the areas available for green spaces horizontally is limited and this could aid in climate change adaptation and carbon capture. Vertical gardens are also known as green walls or bio walls that can be completely or partially surrounded by trees or soil [3]. There are proofs that vegetation outside the walls of structures helps in better insulation from the weather conditions during the summer and the winter seasons, providing better aesthetics, better habitats created outdoor and indoor, providing habitats for insects and birds and also aids in diminishing greenhouse gases like carbon dioxide and nitrogen dioxide.

**Commented [SPD[1]:** Review Comment 6: References are cited at appropriate places.

A Green Wall impacts a building's heat and losses, humidity, air quality and energy conservation [4]. Green walls do have positive effects on a buildings heat loss, its temperature, better air quality and energy management. Four fundamental process makes the green spaces passive energy conservatism; which are provision of vegetative shadows, vegetative shield from weather conditions, the soil's evaporative cooling, and also the advantage of wind barriers [5]. Various criteria that involving the quantity, mass, thickness of the plant foil etc., determines their efficacy. As approach to vertical areas are a requirement, it is particularly effective in town and urban regions. In dry regions where flowing water is less probable to evaporate on vertical surfaces than in horizontal landscaping they can be implemented [6,7]. The goal here is to discuss and examine the causes, specifics and challenges affecting the implementation of green walls in Indian context.

The main objectives of the research are:

- Recognize variables and problems impacting the development of vertical gardens by performing comparative studies and exploring different structures currently under Indian conditions.
- Recommend methods to substitute such techniques that may be extended to construction and execution stages and draw up design recommendations for the successful application of green walls, taking into account multiple related considerations.

**Research statement:** By incorporating landscape into building designs, urban microclimate can be reduced, and hence the urban heat island effect can be decreased. The possibility of integrating vertical gardens in the Indian context is one principal research matter. The possibility of integrating vertical gardens

in the Indian context is one principal research matter. The objective is to examine aspects that impact the implementation of green walls in Indian conditions and develop the findings. Also, better techniques and practices, economic management and encouraging the prospective for better feasible green walls in India can be identified.

## 2. Background Study

*History of Green Walls:* The idea of green wall started in 600 BC in Hanging gardens of Babylon. employing pergolas, trellises self-climbing vegetation supported implementing garden The green walls were established in the 1990s using cables and module trellis panels [8]. The use of first actual use of trellis panel systems was in the University City Walk, California in the year 1993.In 1994, a bio-filtration system was designed for an Indoor living wall. The famous Botanist Patrick Blanc, holds the name for the world's famous vertical gardens referred to as vegetable walls by himself which are so diverse and area mainly executed in Singapore and São Paulo. Paris' Pershing Hall acquired a renowned address with his spectacular interior garden. By the year 2005. Around thirty modular systems for green walls were at hand [9].

*Aesthetic values:* A city's aesthetic appeal is enhanced with vertical gardens. In the highly -built city area, green spaces provide visual barriers or partitions. It provides a perception of connection towards nature and act as seasonal indicators [10].

*Improve Thermal Efficiency of built form:* By cooling down the urban areas, plant gets the advantage of direct sunlight and evapotranspiration. The vegetation used in the green walls provides shade to the building depending upon the plant's density and helps in reducing the overall temperature in and around the building and can reduce the surface temperature by 15.2-degree Celsius [11].

*IAQ improvement:* Plants are commonly the efficient absorbents of undesired gases and contaminants seen mostly in urban regions. They help in filtering out the contaminants in the air through their leaves by photosynthesis and hence enhance the air quality [12, 13]. The airborne contaminants are caught by the leaves and branches' (volatile organic compounds are absorbed by plants and the media through the process of bio filtration. For their implementation, interior or exterior walls can be used as a platform for planting varieties of vegetative species. One way to execute the green wall is prefabricated modular panel and in situ applied panels being the other one [14]. The other way of determining the categorization of the vertical gardens are the type of materials, components used and techniques followed. They are of mainly 3 types which are:

*Direct green façade:* Self-climber plants are planted at the bottom of the building wall which rises onto the designed structure.

*Double skin vertical /indirect green façade:* A platform using a further layer which can be panels like trellises or pots as a frame are placed for the plants to grow.

Green walls/living walls: Pre-vegetated or modular panels comprises the living green wall system. In order to accommodate an excellent variety of plant species (eg.: a lush mixture of ferns, soil covers, perennials and edible plants), the vertical modules are set up on a frame or a structural wall.

Modular panels that contains soil or other growing media like form, felt, mineral wool that uses hydroponics system etc. are chosen for their execution. Pre vegetated panels or matt walls can be used for the construction. As compared to other systems, this type of vertical garden system demands more maintenance and care [15,16].

**Environmental effects of green walls:**

Plants can cool down, attract light, and evaporate transpiration. Green walls include house-shade trees. It's simple, depending on green walls plant abundance. Not only can shaded building suffer relatively low temperatures. Changing temperatures can impact building and urban climate [17]. In both gaseous and particular contaminants, plants have historically been regarded as efficient scavengers. Collecting airborne toxins and gaseous compounds in their leaves and stems can improve air quality [23].

Small gaps or lack of land are no longer an issue when utilizing green walls, since it covers the façade of the building, rising high density and skyscrapers in the metropolis. Municipal storm water is typically collected from impermeable areas and diverted to local reservoirs through irrigation pipe systems [18]. Flooding can occur when drainage cannot absorb groundwater. Typically, degraded aquatic habitat coincides with storm water runoff.

Finally, trees can be used as sound barrier to minimize receiver noise. Green wall plants can absorb sound waves, reducing ambient noise.

**Economic effects of green walls:**

Many economic benefits align with green walls' sustainability advantages. The capacity of vegetation to hold flood water and roof water would further decrease the scale of the runoff scheme for roof water. Plants around buildings can improve sustainability by absorbing sunlight [32].

Using green walls would minimize climatic tension on building façades and improve construction function and functional life, not to mention decreased painting materials costs.

Another major economic advantage of urban greenery is energy conservation. Studies have been performed where the energy needed to ventilate a building can be significantly decreased. Landscaping is also used to enhance urban

beauty. Vegetation may be a source of contrast and relief [40]. Plants also offer Mother Nature a feeling of closeness in the city's hard concrete jungle.

**Social effects of green walls:**

Plants can perform different functions. According to Givoni (1991), plants offer spaces for recreation, sports and leisure, make mutual friends, isolation and escape from urban life, visual enjoyment, remote viewing, etc. Visual and physical experiences can lead to health benefits directly. Plants can produce or store restorative effects that lead to reduced stress, increase the recovery time of the patients and improve disease resistance. [31].

## 3. Methodology

For the literature review, research paper focused on the key aspects and developments needed for a successful outcome are selected. It compares and studies secondary case studies. They are selected on the basis of the notable or groundbreaking methods used that have enabled them to successfully adopt, and also on the basis of regions with similar climatic conditions. Based on the key variables and aspects that rely on the green walls, which are taken from the study of journals and case studies, the information collected is compared. They are studied and from this data collected, inference is made. In figure-1, a brief approach is outlined below.

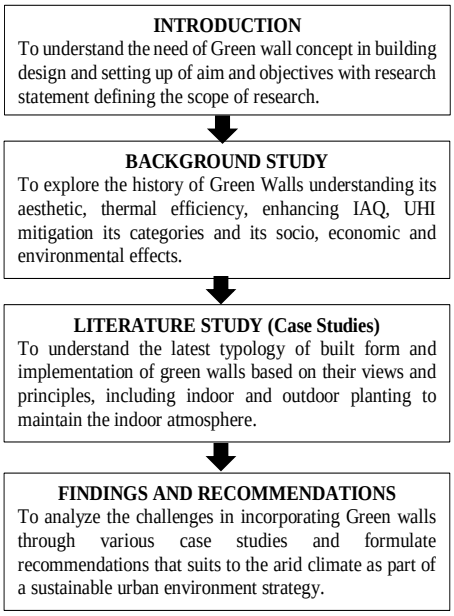


**Figure 1: Methodology for Research**

## CASE STUDIES

In recent days, a new approach has been common in incorporating plants into buildings and the main focus is on the biologically vivid building incorporation of nature into the layer of spaces [32]. The principle further considers local lighting and ventilation environment in order to cooler and preserving the internal atmosphere by using vegetation, thus limiting the use of mechanical HVAC system and reducing the energy consumption. This theory further leads to reducing external heat losses [18,25]. The following cases are known for studying the newest types of practices, including planting indoors and outside, depending on their experiences and values.

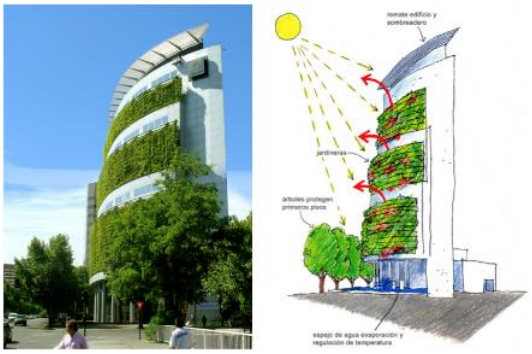

**Figure 2:Chilean Consortia Building, Chile**

### Case Study of Outdoor Planting: Chilean Consortia Building, Santiago, Chile.

National insurance at Las Condes, Santiago, Chile, was Designed by Henry Browne and Borja Huidobro (Figure 2). There are many eco- friendly characteristics of the house, rendering it clean. One feature is the indoor and outdoor thermo panels that trap solar heat. Front wall is another great attribute it has, that transforms into a vertical vegetable garden of 3000 square meters where plants turn into distinct look through the years, based on the season. Double facade architecture preserves the western orientation of the building, which allows vegetation to develop independently of construction.

### Case Study of Indoor Planting: The Genzyme Center, United States.

The Genzyme Center (Figure-3) is an example of a company doing the right things, chosen as the 2004 AIA Top Ten Green Initiative. The architecture goal was to create a building from the inside, from the human working environment to the final functional structure. Eighteen gardens contribute to ecological ideology. The house acts as a living organism and can provide access to the environment through a visual outside connection, look out on the green and bring green from the gardens into the house, and incorporating the interior pant needed great efforts and this was the right thing to do for a green building.

**Figure 3:The Genzyme Center, US**

**Case Study of Outdoor Planting: Tokyo Nara Tower, Tokyo.**

This 126-story skyscraper (Figure-4) is constructed in the cool season, deciduous woodland landscape environment. It's an ecologically aware super house. The tower is expanding sky model park. Verdant foliage by summer shade covers the house. Photosynthesis creates balanced microclimate façade. Floor fringing and atrial holes further reduce the effects of strong winds on urban climate [32].

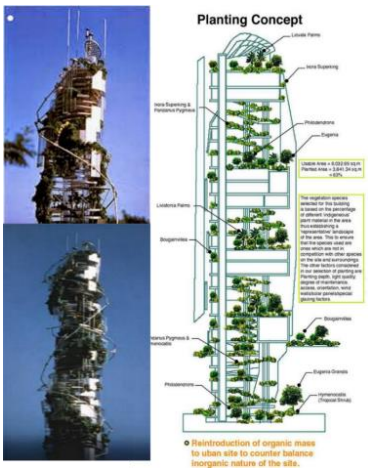


**Figure 4: Tokyo Nara Tower**

The ratio of the planting mass to the built environment is favorably comparable, meaning the bio system components are combined and function symbiotically as an artificial ecosystem of structural, mechanical and electrical systems. Literature study of aspects such as construction, maintenance methods, design strategy and irrigation method for understanding the feasibility of Green walls is listed below:

Literature study of aspects such as construction, maintenance methods, design strategy and irrigation method for understanding the feasibility of Green walls is listed below:

1. *Grey water treatment for vertical gardens in Indian context. By Nawatech.*

*Construction*: Locally available materials were utilized for the pilot system and hence affordability issue was ruled out.

Minimized horizontal part of the planter boxes causes obstruction while irrigation. The walls of the buildings will be affected in case of leakages from these components.

Lightweight and long-lasting components or materials should be used.

*Design techniques:* The affordability is determined by the material availability, space and the utilization of local materials. For watering of plants, simple approach by using trays, nursery etc can be made use of.

*Irrigation*: Making use of recycled water from kitchens. tilting plant containers at an angle of 30 degrees.

Holes required at the base of the planter boxes for aeration and drainage of soil.

*2. Advantages and risks of vertical gardens By Erdie Ekren*

*Construction*; Water proof insulation material is made use of, so as to shield the wall. Soil mixed with peat is applied that will aid in minimizing the overall weight of the structure to an extent.

*Maintenance*: The green wall type, climatic conditions, vegetative variety etc. used would decide the intervals of maintenance required. During the execution stages, components like carrier profiles, irrigation apparatus etc. adds to the high expenses.

*Irrigation***:** For the modular, foam based or felt layer system, drip irrigation system is devised.

*3. Aeroponic Plant Growth Apparatus Method :By Paul r ,Ammann jr*

*Construction*: The atmospheric air is initiated into the roots of plants and the inert air is drained from a chamber within the apparatus. The energy for this devising is given by the spray nozzles and an air inducing manifold.

*Irrigation*: Nutrient solutions are sprinkled during irrigation process. In the best possible process of this method the excess or wasted nutrients and chemicals can be recovered and recycled through filtration process and used again.

4. *Vertical gardening: an innovative element of green building technology: By Piyush Sharma*

*Construction*: Board made with PVC material is bolted at joining. Perforations for air passage is given to avoid dampness.

*Maintenance*: Automatic systems provide the required light, water, and nutrients. Therefore, minimizing the maintenance effort. They are mostly perpetual vegetation and are given their natural growing environment.

*Design*: The cost relies on the availability of the materials, type of space and preference of local materials or products.

*Irrigation*: Recycled water including grey water utilized for plant irrigation. Stainless steel metal frames used.

5. *Cost benefit analysis for living walls and green facades: By K.K. Sahu and M.M. Sahu.*

*Construction*: Study on direct green facades, indirect green walls and bio walls/living walls.

*Maintenance*: Factors like type of vertical garden implemented, climate, plant species selection and their growing medium are factors on which the maintenance depends.

*Design*: Energy efficiency in the whole building provides economic benefits.

6. *Vertical garden for present age environmental protection:*

*Construction*: Reinforced steel, wood, bamboo, plastic etc. are used to make trellises for indirect green facades and needs materials that are less heavy that includes the vegetation as well. Handmade frames made of recycled plastic and wood etc. are also available.

*Maintenance*: Maintenance factors vary according to the systems selected. Here, in hydroponic irrigation method, the requirement varies as water availability in the reservoir has to be frequently inspected as it can be depleted due to evaporation.

*Design*: Knowledge on green walls are needed as it demands constant care and good labor.

*Irrigation*: Soil selection has to be considered vital as some plants require soil that retains water whereas others require dry soils. Sprinkler system can be considered for covering large areas while irrigation but due to evaporation water can be lost.

7. *The vertical farm: a review of developments and implications for the vertical city: By Kheir al Kodmani.*

*Construction*: Issues with soil can be solved by adopting the hydroponics for growing plants where the whole system depends completely on water even for the nutrients. Automating this reduces the effort for its care and also it is a cleaner system in comparison. Nutrient provision completely relies on chemicals. Aeroponics can be considered in regions with water availability issues where in no growing medium is needed.

*Design*: Engineers have innovated LED lights that has an efficiency of 68% which could be implemented for interior vertical gardens.

*Irrigation*: Nutrient film technique (NFT) where in nutrients area carried to the plants through tubes using air pumps and water pumps is incorporated in hydroponics method. The local techniques and strategies can be adopted and developed in order to overcome its shortcomings and hence require a quantitative study.

8. *Growing green guide: Cost consideration:*

*Construction*: By including an amount in budget by roughly calculating considering the unpredicted scenarios or issues which in here is 5% of the total can give a fixation in the total budget required. The review of literature papers is summarized below in Table-1.

| RESEARCH PAPER | KEY FINDINGS |
|---|---|
| Advantages and risks of vertical gardens By Erdie Ekren | Waterproof, insulating materials and soil mixed with peat etc. are accessible for the technical support of green walls, |
| Aeroponic Plant Growth Apparatus Method By Paul R ,Ammann | Aeroponic systems can be used in areas with less water availability. |
| Vertical gardening: an innovative element of green building technology By Piyush Sharma | The maintenance effort is reduced by automated devices. Cost depends on the accessibility to materials. |
| Cost benefit analysis for living walls and green facades. By K.K. Sahu and M.M. Sahu. | The cost is affected by vertical garden type plant species, type of space. Economic benefits are provided by energy savings |
| Vertical garden for present age environmental protection. | Needs lightweight items, including plants. |
| The vertical farm: a review of developments and implications for the vertical city By Kheir al Kodmani. | The use of hydroponic irrigation system decreases the amount of water needed. |
| Growing green guide: Cost consideration | Including 5% more total budget would aid in handling unpredicted situations of maintenance |
| Green guide**:** | For a successful result various routine maintenance should be conducted at correct intervals of time. |

**Table- 1: Key findings through Literature Review**

**Commented [SPD[2]:** Review Comment-4: Review paper findings in Tabular Form

The variety of plants selected for propagation, the type of green wall, etc. decides the frequency of maintenance. Utilizing locally available materials, irrigation methods, using new technologies can contribute to overall cost reduction (figure-5). The execution expense and the maintenance labor effort and cost can be paid back by the energy consumption cut down in the whole buildings.

| Type of vertical garden | Plant species | Structural components | Irrigation system |
|---|---|---|---|
| Direct and indirect green facades. | Bougainvillea glabra (requires framework for support.) Trellises used her for holding the plant.<br>Price: Rs. 12/piece.<br>Devil's ivy -Minimal care<br>Cost: Rs -249/pot<br>Trachelospermum jasminoides-adapts in sun and<br>Needs irrigation with well-planned drainage system<br>Rs.210. | Trellis – Stretchable mechanism Dimension are of 1800mm x600mm<br><br>Cost: Rs.3240 for a single piece | Drip irrigation system rate – Rs.999 Rs.1582 |
| Green walls | Plant species: Iresine<br>Should be planted on exterior facades<br>Lighting specification: Sunlight required throughout.<br>Irrigation –Not frequently needed<br>Temperature – Thrives between 10 to 45 °C.<br>Rate: Rs.199 per pot.<br>Plant species: Wedelia trilobata<br>Should be grown outdoors.<br>Lighting specification –Sun needed full time or partially<br>Watering – reduced frequency<br>Temperature – Needed between 20 to 45°C | Cost efficiency: Can be attained by simple methods of execution and providing easy maintenance by the right irrigation system.<br><br>Rate:<br>Rs.777 per panel.<br>Dimension -(500 mmx500mm)<br>Box with 6 units.<br><br>Basic frame work needed making it<br>Planning planting patterns drainage system for each is effortless. | |
| Living walls | Jasminum grandiflorum, a local plant species in South Asian countries.<br>Should be propagated on the exteriors.<br>Light – Can adapt to full or partial exposure to sunlight. Watering – demanded in minimal frequency<br>Price: Rs.349/piece<br>Tradescantia zebrine<br>Has to be grown outdoors Lighting specifications – Can adjust in complete or limited sunlight exposure.<br>Watering –required within long intervals only. | Design: Flexible as it is horizontally and vertically stretchable. Mounted in units but without compromising the aesthetic appeal.<br>Construction: Simple execution<br>Maintenance: Does not require much effort if based on automation.<br><br>Cost: Rs 9149 per sq. Feet | Drainage tubes incorporated with drainage system. Enhanced drip irrigation apparatus that goes from top of the panel to base are mounted to living wall units.<br>Price: 21000rs per month |

**Figure 2:COMPARATIVE COST ANALYSIS OF DIFFERENT VERTICAL GARDENS**

RESEARCH GAP: To mitigate the high cost and maintenance effort and maximize reliability, local materials should be chosen. Innovations should be taken to such strategies, although preferable to other approaches, it can have its own disadvantages, such as the cost or other functionality.

## 4. Comparative Study Analysis Of Various Aspects Through Case Studies

Secondary case studies relating to regions with similar climatic conditions and having notable technics and methods carried out for an effective green wall implementation has been chosen.

Tables 6 below summarizes the various aspects for comparative study of case study green walls with respect to its design, construction system, irrigation, system, plant variety, growing medium, maintenance and cost efficiency with the inferences is mentioned.

**Commented [SPD[3]:** Review Comment-5: Single table for comparative analysis of all the factors associated with the case studies

| CASE STUDIES | DESIGN | CONSTRUCTION SYSTEM | IRRIGATION SYSTEM | PLANT VARIETY | GROWING MEDIUM | MAINTENANCE | COST EFFICIENCY | INFERENCE |
|---|---|---|---|---|---|---|---|---|
| Newton Suites, Singapore  Fig.1. Newton suites, Singapore | In the residential building passive climate control techniques are followed. The green wall façade is north facing. | Adjacent external staircase incorporated with the design. It is shielded with a mesh horizontally where the mesh is held up. | Timing sensors included with the irrigation system; also, for the wall on which it is mounted is guarded by a water-resistant membrane. | Plumeria, Thunbergia grandiflora, Yellow iris Boston fer are species chosen, which takes 3 months to get to its full-grown stage. | For guarding the plants and the growth medium, elastomeric components which are fluid applied are available. | Access to the green wall provided by an adjacent external staircase. | Cost savings can be attained by minimizing the cost for the labour charge required for the effort put for access. | The designers were able to evaluate the viability of the vertical garden within the time taken for the plants to mature. |
| Trio Apartments, Sydney.  Fig.2. Trio apartments, Sydney | The base of the wall incorporates the plants that require more watering and less sunlight and at the top the plants requiring complete exposure to sun are planted. | For structural bracing, steel or recycled plastic fixtures can be incorporated for supporting the vertical garden which includes fabric pocket units in which the plants are propagated. | Dripper irrigation method that utilizes water supplied by the rainwater harvesting system used providing water through tubes that irrigates 6 times a day at interval of 3m. | At the top of the garden Acacia and Poa are used which has the capacity to withstand harsh sunlight as well whereas, Goodenia and Viola part which are sensitive towards sunlight are planted at the base. | | Needs monthly survey and inspection to assess the vegetation health .2 staffs are required to go up and down the green wall for inspection | It can depend on the maintenance effort. Also, recycling plastics or other materials for forming the frame structure can reduce cost during the installation. | By choosing the local plant varieties, issues regarding the lifespan, appeal etc. are compensated. |
| PNC Bank, Pittsburgh, green wall.  Fig.3. PNC Bank, Pittsburgh green wall | Living wall is mounted on the south facade of the building. Engineered GO2 living wall implemented that can sense the moisture, salinity, temperature etc. And transmits the data accordingly to meet the necessary requirements. | The engineered GO2 panels are mounted on a wall with an area of 2380 .2q.ft.. all the materials and components used are from Pittsburgh which makes it a completely local project. | The GO2 wall helps in providing even water distribution via closed loop water supply. | 8 local species that is able to sustain in the weather conditions of that region is chosen. | Insulation materials and water conservation layer are available to guard the plant roots, equal water distribution is managed by using specially engineered soil medium. | Roof davit system (with swing stage) which are basically crane systems are implemented from approaching the plants from above helping the reduction of maintenance labor cost and assisted the client in working out the overall maintenance budget. | Specially engineered GO2 walls implemented helped in minimizing the cost by water usage efficiency with just needing only 15 minutes watering per week using an embedded irrigation system. | Provision of advanced sensory systems can help in cutting cost during the maintenance stages. |
| Ch2 council house (6-star green building rating)  Fig.4. Ch2 council house | The north facade of the building incorporates the green wall. The balconies adjacent to the green walls facilitates easy access. | Recycled plastic utilized for making planter boxes and other components on which the plants are mounted. Galvanized mesh holds a stainless-steel cable mesh which holds the apparatus for the plants to grow. Hyrdocell flakes and watering wicks that has water retention ability etc. are used for self-watering. | | Akebia quinate, Cissus Antarctica. | Hydro cell flakes and watering wicks which has the ability to retain water are used which helps in controlled water supplied. *2)Maintenance:* Staffs with good training preferred. *3)Cost efficiency:* Considering the foliage of the plants access directed from balconies from all floors for | | | Taking advantage of recycled materials for components and providing easy access for maintenance and careful selection of plants are important for its feasibility. |
| Pam Perez: Art Museum Miami (LEED silver certification)  Fig.5. Pam Perez: Art Museum, Miami | Vegetation covers the columns of the museum building therefore, making the lighting requirement of each plant the basic strategy in their execution | Small cases are provided held by steel tubes on columns with a felt layer for holding the plants. | | In warm and humid climate or tropical climate, utilizing rainwater is suggested | Soil medium for the plants contained in modules. | Local plant varieties are chosen for the garden that has the capacity to adjust to all the weather conditions of that region. | | Planting local plant species reduces the maintenance requirement hence reducing the cost. |
| Le Nouveau Apartment, Malaysia.  Fig.6. Le Nouveau Apartment, Malaysia | The exterior walls are completely surrounded by vertical garden. | It is an amalgamation of green and sustainable wall. | Drip irrigation system with the large flat roof supplying rainwater. | Local plant species that has the capacity to thrive in all weather conditions | Planter boxes containing only soil medium. | Provided through simple access | Cable materials are used as a part of the frmenwork of trellis garden which is a cheaper option than other components. | Appropriate material choice and the strategies selected for maintenance adds to cost savings. |

**Figure 3: Case study green walls with respect to its design, construction system, irrigation, system, plant variety, growing medium, maintenance and cost efficiency**

## 5. Comparative Analysis Of Native Plants And Foreign Species:

Table-2 summarizes a comparative analysis of foreign species and local species giving an understanding about cost analysis and maintenance factors of both the categories. Use of native varieties of plants can with their ability to adapt extreme weather conditions of that particular region, hence demanding less irrigation and watering can be used which can add to cost savings even though there isn't a huge variation in their market rates.

| FOREIGN SPECIES | LOCAL SPECIES |
|---|---|
| English ivy<br>Easy propagation.<br>Difficulty in adjusting to all weather conditions therefore, demanding high maintenance.<br>Irrigation required frequently.<br>Rate: Rs.399. per piece.<br><br>Geranium<br>Possess good appeal in terms of aesthetics.<br>Proper maintenance needed.<br>Frequent inspection is needed for presence of pests or weeds.<br>Cost: Rs.499 /plant<br><br>English lavender<br>These herbs should be planted in complete exposure to sun and alkaline, sandy soil for the best results.<br>Rate: Rs.125 /plant. | Bougainvillea glabra<br>Trellises can be used for supporting their growth.<br>Cost: Rs. 12/piece.<br>DEVIL'S IVY-Specifics**:** Can be used for starters as it needs only less care; These evergreen climbers can grow quickly.<br>Price: Rs. -249/pot.<br>Trachelospermum jasminoides ***(***Star Jasmine) –<br>Has woody stem and is an evergreen climber.<br>Requirement of only garden watering with proper draining and its capability to thrive under direct sun and also under shade makes it a good viable option to be considered as suitable evergreen species in the country.<br>Price: Rs.210.<br>Jasminum grandiflorum<br>Can be located outside the building. Light -Can adapt to full or partial exposure to sunlight. Watering – doesn't demand frequent watering<br>Price: Rs.349 per piece |

**Table-2: Comparative Study of Foreign and local species.**

## 6. Discussion

The extension of the plant or greenery to the façade of the building demonstrates the ability to enhance the air quality and minimize the surface temperature of the built environment. As they refresh the façade and cool down by transpiration, plants definitely help foster thermal comfort. This can be seen

from the analysis as the outdoor environment stays at the level of thermal comfort, where plants have a temperature balance. Therefore, while there is not a shading device the ability of the green walls to improve atmospheric air and temperature has been created. While photosynthesis is the fundamental mechanism for absorbing CO2, it is important to note that, based on the vertical garden alone, improved environmental efficiency would not be recommended. Nevertheless, in urban areas, the process entails restoring natural habitats and maintaining biological structures in urban environment. The main results from the studies are:

- Direct and indirect green walls, especially those implementing the correct irrigation system are more economical in terms of their ease of installation and maintenance phases.
- It is recommended to provide adequate gaps between the walls and the trellis system in the case of indirect green facades and to provide a catwalk for workers to approach.
- Given the smaller number of structural materials needed, for implementation, direct green facades can be more feasible, thereby offering cost savings. In case of waterproofing and power, the maintenance of the structural wall supporting it should be considered critical.
- Given the cost of construction and upkeep, living walls should be considered as they make a maor contribution to the building's energy savings.

## 7. Recommendations

Ground cover, glass walls, sky courts, indoor plants and rooftop landscapings combine to create 'urban'. One variant of the rooftop garden is the vertical landscaping; other example being the green wall, which embodies the multifunctional single feature concept. According to the sky courts, the breathable wall with vegetated façade aims to concentrate on improving the built forms as an ecologically diverse and heathy plant, microbial and human ecosystem that helps in the betterment of air quality in the relationship between natural processes and climate based building structure. With social, economic and environmental benefits, the whole system works. The results will be significant drop in the electricity usage and clean air for a heathy environment. Guidelines were drawn up by analyzing the comparative analysis etc. on the different technologies or approaches that were more productive or repetitive in the comparative study and showed positive results in arid conditions through case studies. Design criteria are enlisted for such conditions.

- The use of water during irrigation can be saved by implementing drip irrigation system that ha proven to be very successful.

- In the case of green walls with planter boxes for growing plants, compared to the other system, drip irrigation or hydroponic system is preferred because of its water usage efficiency.
- As living walls helps to achieve sustainability in the building by providing energy efficiency through thermal comfort in the building, thus decreasing the need for mechanical cooling, its introduction should be taken into account.
- By using grey water or water from rainwater collection systems for irrigation purposes, cost saving can be achieved.

## 8. Efficient Green Facades Variables

In the arid climates, design, construction, maintenance specifications for green facades and living walls may vary by selected design systems and built and natural environment conditions, Planner, installer, vendors and maintenance workers need close attention to green façade designs.

- Envelope for structural construction- how the dwelling or stand-alone frame is shielded. Measurement of structural loads that result from conditions such as snow, wind and plants.
- Set of wind and light exposure species, areas of hardness and history of amenities.
- Plant morphology and concrete goal associated with growth- some programs require 3-5 year to be fully developed.
- Plant management and/ long term conservation initiatives to ensure efficiency including oil and irrigation, of all living processes.
- To complete the job, consult with the suppliers who may have approved or highly trained installers.
- For optimum coverage and detachment from temporary support systems used by the nursery, adequate regional plant selection, proper plant placing.

## 9. Conclusion

For sustainable development in the present and future scenarios especially in the urban context, the role of vertical gardens is crucial and beneficial in a number of ways, even though it can pose many constraints in terms of its feasibility based on the execution maintenance expenses and its sustainability aspect. But carried out these aspects in following the right strategies and techniques such as the maintenance approach, choice of recycled materials for the structure, and preferring native plant varieties can help in making the vertical gardens viable in the warm and humid climate in the Indian context.

## References

Feng, Y.; Feng, Y.; Feng, Q.; Zhi, Z.; Jiawei, Y. Summertime Thermal and Energy Performance of a Double-Skin Green Facade: A Case Study in Shanghai. Sustain. Cities Soc. 2018, 39, 43–51.

Alexandri, E.; Jones, P. Temperature Decrease in an Urban Canyon due to GreenWalls and Green Roofs in Diverse Climates. Build. Environ. 2008, 43, 480–493.

Hui, S.C.M.; Zhao, Z. Thermal Regulation Performance of Green Living Walls in Buildings. In Proceedings of the Joint Symposium 2013: Innovation and Technology for Built Environment, Hong Kong, China, 12 November 2013.

Koyama, T.; Yoshinaga, M.; Maeda, K.-I.; Yamauchi, A. Transpiration Cooling Eect of Climber Greenwall with an Air Gap on Indoor Thermal Environment. Ecol. Eng. 2015, 83, 343–353.

Rahman, A.M.A.; Yeok, F.S.; Amir, A.F. The Building Thermal Performance and Carbon Sequestration Evaluation for Psophocarpus tetrogonobulus on BiofacadeWall in the Tropical Environment. World Acad. Sci. Eng. Technol. 2011, 5, 206–214.

Sunakorn, P.; Chanikarn Yimprayoon, C. Thermal Performance of Biofacade with Natural Ventilation in the Tropical Climate. Procedia Eng. 2011, 21, 34–41.

Koyama, T.; Yoshinaga, M.; Maeda, K.-I.; Yamauchi, A. Identification of Key Plant Traits Contributing to the Cooling Effects of Green Facades Using Freestanding Walls. Build. Environ. 2013, 66, 96–103.

Nori, C.; Olivieri, F.; Grifoni, R.C.; Bedoya, C. Testing the Performance of a Green Wall System on an Experimental Building in the Summer. In Proceedings of the 29th Conference, Sustainable Architecture for a Renewable Future, Munich, Germany, 10–12 September 2013; pp. 215–230.

Mazzali, U.; Peron, F.; Scarpa, M. Thermo-Physical Performances of LivingWalls via Field Measurements and Numerical Analysis. WIT Trans. Built. Environ. 2012, 4, 251–259.

Perini, K.; Bazzocchi, F. Field Monitoring in Mediterranean Climate to Quantify Thermal Performances of Vertical Greening Systems. Powerskin Conf. Proc. 2017, 113–122.

Hopkins, G.; Goodwin, C. Living Architecture: Green Roofs and Walls, 1st ed.; CSIRO Publishing: Melbourne, Australia, 2011; ISBN 9780643103078.

Blanc, P. The Vertical Garden: From Nature to the City, 1st ed.; W.W. Norton Company: New York, NY, USA, 2008; ISBN1 -13 978-0393733792. ISBN2 -10 0393733793.

Uelen, C.V. Facade Greenery: Contemporary Landscaping, 1st ed.; Braun: Englewood, CO, USA, 2011; ISBN 978-3-03768-075-9.

Perini, K.; Ottelé, M. Designing Green Facades and Living Wall Systems for Sustainable Constructions. Int. J. Des. Nat. Ecodyn. 2014, 9, 31–46.

Reznik, G.; Schmidt, E. Reduction of Emissions by Vegetation—Dry Collection and Wet Resuspension of Fine Dust Particles on Ivy. GRdL 2009, 69, 434–438.

Stec,W.J.; van Paassen, A.H.C.; Maziarz, A. Modelling the Double Skin Facade with Plants. Energy Build. 2005, 37, 419–427.

Dunnet, N.; Kingsburry, N. Planting Green Roofs and Living Walls, 1st ed.; Timber Press: Portland, OR, USA, 2008; ISBN1 -13 9780881929119. ISBN2 -10 0881929115.

Loh, S.; Stav, Y. Green a City Grow aWall. In Proceedings of the Subtropical Cities 2008 Conference: From Fault-lines to Sight-lines: Subtropical Urbanism in 20-20, Brisbane, Australia, 3–6 September 2008; pp. 1–10.

Green over Gray. Available online: http://www.greenovergrey.com/ (accessed on 30 December 2018).

Wood, A.; Bahrami, P.; Safarik, D. Green Walls in High Rise Building, 1st ed.; Images Publishing: Chicago, IL, USA, 2014; ISBN 9781864705935.

Roehr, D.; Laurenz, J. Living Skins: Environmental Benefits of Green Envelopes in the City Context. WIT Trans. Ecol. Environ. 2008, 113, 149–158.

Jialin, T. Living Wall: Jungle to Concrete, 1st ed.; Design Media Publishing Limited: Hong Kong, China, 2013; ISBN 9789881545107.

Sheweka, S.; Magdy, N. The Living Walls as an Approach for a Healthy Urban Environment. Energy Procedia 2011, 6, 592–599.

Loh, S. Living Walls–A Way to Green the Built Environment. In Environment Design Guide; Australian Institute of Architects: Brisbane, Australia, 2008; pp. 1–7.

Manso,M.; Castro-Gomes, J. GreenWall Systems: A Review of their Characteristics. Renew. Sustain. Energy Rev. 2015, 41, 863–871.

M. Haggan A. Hassan (2015) Cost benefit analysis of living wall systems on school building skins in a hot climate

Manfred Kohler (2008) Green facades – A view back and some visions.

Gulzinar Basdogan (2016) Ecological -social-economic impacts of Vertical Gardens in the Sustainable city model.

Magalena Chudy (2014) Vertical Garden.

Alexandra Tamasi, Gergely Dobszay (2015) Requirements for Designing Living Wall System Studies on Hungarian Projects.

Farida Hanim Mohammed Farid,Sabarina Sh Ahmed, Abu Bakra Abd.Raub,Mariam Felani Shari(2016), Greeen Breathing Facades for Occupants Improved Quality of Life.

Kheir Al Kodmany (2018) The Vertical Farm: A Review of Developments and Implications for the Vertical City.

Ar. Ankith Kumar (2017), Vertical gardens for India social architecture acceptance and Practice

Erdi Ekren (2017), Advantages and disadvantages of vertical gardens

NaWaTech, Vertical garden for grey water treatment

Katia Perini, Paolo Rosasco (2013), Cost -benefit analysis for green facades and living wall systems.

Piyush Sharma, Vertical garden, an innovative element of green building technology.
Paul R. Amman Jr. (1996) Aeroponic plant growth apparatus method.
Growing green guide.: A guide to green roofs, walls and facades.
Urban green guidelines (2014)
Antony wood, Payam Bahrami &Daniel Safarnik, Green walls in High rise buildings