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Green wall: A recuperative strategy for urban life style

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Abstract
In recent eras, there has been an escalating number of perilous climate change expostulations. Urbanization is one of the most serious menaces in the 21st century, resulting in many environmental threats *viz.*, concrete jungles and population increase. Consequently, the green areas in urban areas have been vanishing and leads to various health issues for urban dwellers. Several research works had been carried out to alleviate the above issues. One of the solutions for this is bringing the concept of vertical gardening as green roofs, green facades, and living walls which are tenable building design elements and are much established practice all over the world. They are defined as gardens that cover façade walls using various plant species by systems and are also termed as contemporary forms of gardening. They can be erected in any appropriate place of the home *viz.*, balconies, porches, decks, etc. They not only accelerate urban green areas but also render multitudinous applications such as air quality improvement, energy productivity, elegant home decor, reduction of urban heat island effect, sound and heat isolation, stashing the derelict walls and positive contribution to human psychology. It also provides a great opportunity for the plant lovers who are residing in apartments to indulge in gardening.

Keywords: Green wall, types, growing medium, irrigation, plants

Introduction
The ancient concept of green walls was built in Babylon about 2500 years ago. King Nebuchadnezzar II built the Hanging Gardens of Babylon (In ancient Babylon,): a wonder of the primeval world and predecessor of the contemporary green wall. Patrick Blanc a French botanist is the modern innovator of green walls in the recent past, considered as the Father of vertical gardens and famous for his world class 'Mur vegetal' green walls. Hence, the concept of vertical garden is not new, as it arose in people's mind in the early 20th century. Now-a-days, people are getting familiar with this concept worldwide since it provides many benefits to the environment as well as human beings. Yeh (2009) [60] suggested green walls can be used to green the houses where space is very less. Vertical greenery implies to choose sustainable technologies and suitable species (Ottele *et al.*, 2010) [38]. They are artificial vertical landscaping which carry the plants that either partially or fully cover a building façade or other vertical structures. They possess various benefits, kinds and methods. They can be used to cover the exterior wall of the building, fences, balconies, courts, or other vertical structures as a green envelope, and also indoors as an interior wall or as a space divider or a panel to provide privacy. They are the effective tool to alter the outlook of the city into a living landscape. They are the comforting road map for urban sustainable development with diverse benefits to the urban quality of life and the general prosperity. They seem to be a particularly felicitous strategy for the hot and dry climate. Green wall is an ideal option for those staying in the city areas, where land is limited (Binabid, 2010) [4]. Green walls are made of planted blankets, vertical modules, or pre-vegetated panels that are vertically fixed to a frame or structural wall. The plants are supported by panels or geotextile felts, which are generally made out of concrete, metal, clay, synthetic fabric, expanded polystyrene, or plastic (Perez *et al.*, 2011; Martensson *et al.*, 2014) [40, 31].

Divisions of vertical gardens/green walls
Vertical Gardens are of two types *viz.*, green façades and living walls. Green facades are the one which is made up of climbing plants and are allowed to grow directly on a wall or, more recently, especially designed supporting structures. The shoot system of the plant grows up the side of the building while being rooted in the ground.

While the living walls are the modular panels and are often made of geo textiles, stainless-steel containers, irrigation systems, a growing medium and vegetation. The vegetation is always attached on outside walls in green façade; Although living walls can also be green walls for both outdoor and indoor usage.

1. **Container system:** It is commonly called as the trellis system or green façades. It refers to climbers and vines that grow from the ground or from big containers at various spots around the building supported either by the supporting trellis/mesh or wall itself. The most common type is the wall-climbing type. Although it is a time-consuming process, the above plants can cover the walls of a building inherently. Sometimes, they are allowed to grow upwards by mounting systems or trellis.
2. **Modular panel system:** It is generally referred to as a living wall. It comprises pre planted boards, vertical units that grasp growing media to support plants that are secured vertically to a structural wall or mount.
3. **Module type system:** This model is the modern concept related to the aforementioned two kinds. It necessitates more intricate design and planning deliberations before a vertical structure is arranged.

Requirements of vertical gardens/green walls

Green wall systems typically consist of a waterproofing layer, structural support, container, growing medium, irrigation system, and vegetation layer (Loh, 2008 [30]; Perini *et al.*, 2011b; Pérez *et al.*, 2011) [42].

Waterproofing layer

The waterproofing layer is commonly sprawled on the construction wall and is used to form an impermeable film. Since it is normally linked to the physical support, the dampness is incapable to go behind the impermeable film and affect the concrete façade (Weinmaster, 2009) [57]. As seepage in an operational green facade system, it involves the system to be detached entirely, an impermeable film would confirm that the complete irrigation arrangement functions normally without drip. The conventional impermeable film used for this purpose are low-density polyethylene (LDPE), Polyethylene (PE) and fleece (Ottelé *et al.*, 2011).

Structural support

It is nothing but the mount of the living wall or modular panel system. The elements used for this differ generally from exterior to interior surroundings. This support bears the loads from all the other layers. It should be strong enough to cope with shower, breeze, or snowflake loads if it is mounted outdoors. The trellis system or Green façades generally prefers network structures, reinforced structures, or modular trellises to care the climbing plants (Pérez *et al.*, 2011). Although this structure is simply deprived of too many mechanisms, it does not need to support extra load in addition to plants. The felt layer structure and modular structure are alike in structural support as both felt layers and modular panels are inclined simply to the structural frame. Structural support used for modular or felt layer systems are aluminium, galvanized steel, stainless steel, or some other non-rusting metal (Weinmaster, 2009) [57]. Among the different support materials, wood is more ecologically friendly than steel and plastic and moreover, it could be better for both interior and exterior environments, being a reasonable price (Ottelé *et al.*, 2011). The materials generally used for structural supports are wood, aluminium, plastic, stainless steel and galvanized steel.

Container

The role of a container in the living wall/ modular panel system is to grow the foliage plants or flowering plants and to hold the growing medium for its growth as well. Although, in the trellis/ green facade system, the plants grown in the ground or pots are allowed to climb over the trellis. The containers could be placed at different elevations of the façade or on the ground nearby it (Loh, 2008) [30]. But the flower pots of various sizes and kinds are generally secured on a vertical support or the wall structure in the modular panel systems.

The modular panels are of two kinds. The primary type is the true box system which comprises a hollow square caddy made of metal, plastic or some other materials. The number of plants to be planted in this caddy depends on the size of the plant species and type of caddy used, but the number generally ranges from six to fifteen. Weinmaster (2009) [57] opined that the size of the caddy differs extensively depending on the producer, but commonly the thickness must be one square foot and a few inches. Another type is plastic or metal trays, which comprehend several slanted cells. It helps the plants to keep in place and facilitate irrigation. These systems are generally positioned side by side and pyramided to add height (Weinmaster, 2009) [57].

In the felt layer system, the felt pocket is generally fastened to an impermeable pyramid and then linked to the back of the structure (Loh, 2008) [30]. Sometimes, it is putrefaction proofed and its high capillary action permits for regular water supply (Blanc and Lalot, 2008) [5]. Patrick Blanc, the father of vertical gardens developed an inimitable vertical wall which comprises synthetic fabric materials used in two layers with felt compartments. The fabric walls are supported by a frame and backed by an impermeable film (Green roofs and healthy cities, 2008).

Generally, the materials used for containers in green walls are plastics, fibres, felt bags, aluminium, steel and wood. They may create positive or negative influences on the environmental load. It plays different operations which may be functional and aesthetic in accordance with the strength, price, profile thicknesses and heaviness (Ottelé *et al.*, 2011).

Growing medium

It is the material in which the plant's grow and associated to the thermal performance and water retention of flora (Teemusk and Mander, 2007) [52]. It also delivers water and nutrients for the biological functions of plants (Franco *et al.*, 2012) [22]. The plant roots will infuse and fortify inside the medium to resist wind power and other irregular weather environments. In vertical garden systems, the growing medium should be highly porous minerals and a low organic matter content (Clark *et al.*, 2008) [12]. It performs the same role of common media. Soil is always used as natural growing medium for plant growth, but it adds heavy load to the supporting structures. Hence, the new medium is highly needed especially for green walls to fulfil the need of the plants (Bianchini and Hewage, 2012) [3].

Perlite is considered as a light weight, expanded, white, alumino-silicate mineral of volcanic source and is proved to be a good alternative for soil to grow *Ficus* cuttings (Calin and Bala, 2013) [8]. Moreover, coco peat or coir pith has been documented as an acceptable peat substitute with no environmental disadvantages to its usage. It possesses high water content, low shrinkage, good physical properties, high total pore space, slow biodegradation and low bulk density. Increased amount of coco peat in the medium exhibited reduced particle density, bulk density and improved the water holding capacity, porosity and CEC (Sudhagar and Sekar, 2009). In modern ages, the invention of hydroponic systems can be used to raise plants without soil, in which irrigation systems are used by adding nutrients to water (Weinmaster, 2009) [57]. In this method, plants defecate microbes developed in the rhizosphere and simulated by carbon, into the root zone. The prerequisites for the hydroponic system are air-filled porosity and water- holding capacity. Generally, porous materials are used to grow stone, expanded clay and activated carbon for cultivating indoor air quality. Biochar, a high carbon containing material (more than 50%) resulted by heating biomass in absence of oxygen. It leads to several interactions mainly with soil microorganisms, soil matrix and plant roots (Lehmann and Joseph, 2009). It also behaves as a soil conditioner by enhancing the physical and biological properties of soils such as soil nutrients retention, water holding capacity and also influences plant growth (Sohi *et al.*, 2010) [48]. It helped in declining the greenhouse gas emanations from soil, such as nitrous oxide (N_2O) or methane (CH_4), as well as enhancing the nutrient retention (Lehmann *et al.*, 2011) [29].

Irrigation system: It plays a significant role in the display of vertical gardens. It feeds the water and nutrients through specific mechanical or natural irrigation systems. Time control systems are highly important to confirm a safe and regular water supply (Loh, 2008) [30]. In earlier days, it had been irrigated manually. But in modern times, the drip system has replaced the old mechanism. An experiment was conducted by Cheng *et al.* (2010) [10] with a timer-controlled irrigation system to evaluate the thermal performance of living walls. To provide the best cooling effects, the moisture level could be sustained between 20-45% throughout the experiment by giving irrigation at fixed time intervals. Gravity plays a significant role in distribution of water in the vertical walls. To ensure the plants in the living walls has received sufficient moisture, it is necessary to place a moisture sensor in the growing media. Now-a-days, different types of irrigation systems are available in the market.

The best among them are the computerized vertical drip irrigation systems, individual water drip irrigation systems, and water retaining irrigation systems. Moreover, to get the benefits of the rain water, a rain water harvesting system should be installed and the same water will be recirculated to meet the future needs. But an average of 2.5 litres twice a day is highly required to irrigate the plants of 1 m^2 area (Wong *et al.*, 2009) [58]. This vertical wall encompasses little media and thereby the water holding capacity is also limited, growing drought resistant plants will be the good voice for long survival. Moisture content in the media between the top and bottom of a modular green wall panel has been recorded with 15-45% (v/v) (Cheng *et al.*, 2010) [10]. Irrigation frequency should be three or five times a day, depending on the season and the vertical garden's exposure (Blanc and Lalot, 2008) [5]. A highly dilute nutritive solution 0.2 to 0.3 g-1 is given with the help of a fertigation unit to maintain a mineral balance throughout the system.

Vegetation layer

The most significant part in the living walls which finds it as an eco-friendly product is the vegetation layer. Otherwise, it can be mentioned as the appealing part of the living wall. To maintain the vegetation layer, it is important to understand the prerequisites *viz.*, light, microclimate (Bianchini and Hewage, 2012) [3]. Moreover, the selection of plants for the vertical wall is highly important. It doesn't need much care and attention. It requires care only 3 to 4 times a year to take away dust, wilting foliage, and dead plants (Nedlaw living Walls, 2008) [35]. Usually, evergreen plants are highly preferred (Perini *et al.*, 2011b) [42].

Plant selection for green walls

The success of the green wall depends on the plant selection (Francis, 2012) [21]. Although the infrastructure design is supreme, plants are identified as the key factor to be taken care. The Following are the measures to be considered for plant selection.

Based on orientation of wall

According to Dunnett and Kingsbury (2004) [18], the location and direction of the wall should be considered while selecting the plants. Orientation/ direction give the idea of how much heat and solar radiation will be engrossed into the wall. During the morning hours, east facing walls experience greatest temperature fluctuations. At the same time, west facing walls do have the greatest heat absorption during the afternoon hours. While, north facing walls remain comparatively cool throughout the day, while south facing walls continuously absorb heat all day which persist at higher temperatures for an extended period of time. Hence, erecting living wall based on the orientation of the wall will provide the greatest cooling effect rather than how the wall was built. According to Eumorfopoulou and Kontoleon (2012) [20], areas facing the southern orientation will usually receive the extended period of high temperatures.

Based on amount of sunlight received

The plant selection must be made based on the amount of sunlight each section of the green wall takes (Blanc and Lalot, 2008) [5]. Generally, the exterior wall receives more sun than areas on the ground because there are no shrubs or trees beside to give evaporative cooling or shade. Hence, the sun loving plants occupies at the top of the wall which would resist extreme temperature and strong wind, while the bottom of the wall will be planted with shade and moisture loving plants.

In the experiment by Mendes *et al.* (2001) [33], it has been stated that plants grown under high light conditions evolve thicker leaves while under low light conditions exhibit a higher leaf area per unit of dry mass in vertical walls.

Based on morphological and physiological attributes of the plant: Dunnett and Kingsbury (2004) [18] has suggested that the plants selected for vertical walls have evergreen growth habit, less height, fibrous root system, adaptations to water loss *viz.*, small succulent leaves, dense twiggy growth, vegetation with a thick cuticle, pale yellow-green color with rolled leaf margins, respectively. These characters keep the plant to sustain for an extended period of time even under vagaries in climatic conditions. The plants with shallow and dense rooting system will hold the media and stops the media scouring for erosion by heavy rainfall or strong winds (Dunnett and Kingsbury, 2008) [19].

According to the study carried out in Singapore over a six-month period by Chiang and Tan (2009) [11], he suggested that the plants suitable for vertical walls should utilize crassulacean acid metabolism (CAM) and have thick, dense cover of vegetation to resist high temperatures and intense sunlight, low soil moisture as well.

Hopkins and Goodwin (2011) [25] opined that the plants found naturally on cliff tops or cliff faces are likely to succeed on the vertical walls which have sturdy stem to root connection, resistance to wind velocities, sustain high temperatures and good growth habit.

The plants with clumping growth habit rather than upright type are found to be the best option and growing of different categories of plants instead of same type can help to withstand high risk of failure through problems in cultivation or pathogen attack. Moreover, avoid the vigorous growing type which will smother neighbouring plants and overload the support structure (Dunnett and Kingsbury, 2008) [19]. The stress tolerant species are identified as the best option in new green walls which diminishes the energy inputs of cultivation aspects (Devecchi *et al.*, 2012) [16]. Growing dwarf varieties reduce the pruning operations at frequent intervals (Larcher *et al.*, 2013) [27].

Usage of modules pre-cultivated in nurseries can be a good potential resolution for green walls and also reported that full productivity of vertical vegetation can only be achieved by a high leaf area index per unit of the module. The plant species grown in green walls under tropical conditions experience high temperature. Hence, measuring the integrity of membranes of plants is helpful to identify the plants which tolerate abiotic stresses. So, the plants with biotic and abiotic stress tolerant plants are highly suitable for vertical walls Chiang and Tan (2009) [11].

Plant species suitable for green walls

Dumitras *et al.* (2010) reported that vertical walls embrace a large diversity of plants, which comprises ground covers, ferns, shrubs, climbing plants, perennial flowers and edible herbs. Blanc and Lalot (2008) [5] suggested that the plants suitable for exterior vertical walls are boundless; they differ with growing environmental conditions, the rate of growth and structural characteristics of each type.

Larcher *et al.* (2013) [27] has studied the appropriateness of *Myrtus communis* L. for green walls in a Mediterranean environment. They have used the modular living wall system REVIWALL® (Reviplant Nursery, Revigliasco, Turin, Italy). The plant was exposed to four orientations (North, South, East and West) and modular panels of 40x50 cm and pots of 13 cm diameter were used with 18 plants. They were pruned at the end of the primary vegetative phase. Irrigation was given through the automatic fertigation programme and was set according to the ecological conditions. The results showed that the plants covered 100% of the board surfaces irrespective of its orientation and hence, it was suggested that this species is found to be best in the vertical walls.

The plants *viz.*, *Ficus sp.*, *Pandanus*, *Rhoeo discolor*, *Philodendrons*, *Schefflera*, *Pilea*, *Nephrolepis sp.*, *Syngonium podophyllum*, *Chamaedorea*, *Ophiophogons*, *Spathiphyllums*, *Sanseveria sp.* and *Peperomia* are highly suitable for green walls under tropical conditions (Blanc and Lalot, 2008) [5].

The merits of using these green walls embrace lighter substrates, lesser plant infections and disease incidences, lesser irrigation through recirculation of water drained and faster plant growth (Sales, 2008; Sales, 2009). The list of plant species given below are found extremely suitable for the different types of vertical gardening.

Table 1: The table between defined botanical Common name and Family

Botanical name	Common name	Family
Green Facade		
Hedera helix	Common ivy, English ivy, European ivy	Araliaceae
Parthenocissus spp	Virginia creeper	Vitaceae
Hydrangea petiolaris	Climbing hydrangea	Hydrangeaceae
Polygonum bauldschianicum	Tickseed	Asteraceae
Lonicera spp.	Honeysuckle	Caprifoliaceae
Clematis spp.	western blue virgins bower	Ranunculaceae
Aristolochia spp.	Dutchman's pipe, Common pipevine	Aristolochiaceae
Jasminum officinale	Jasmine	Oleaceae
Passiflora caerulea	Blue crown passion flower	Passifloraceae
Living Wall		
Dracaena	Red edge dracaena, Madagascar dragon tree dracaena, dragon blood tree, Tree dracaena.	Asparagaceae
Phalaenopsis spp	Moth orchids	Orchidaceae
Asparagus sprengeri	Asparagus fern	Asparagaceae
Kalanchoe	Flaming katy, Christmas kalanchoe, florist kalanchoe, Madagascar widow's-thrill.	Crassulaceae
Cordyline spp.	Ti plant, palm lily, cabbage palm.	Asparagaceae
Chlorophytum spp.	Spider plant	Asparagaceae
Haworthia spp	Cushion Aloe	Piperaceae
Tradescantia sp	Wandering Jew, Spiderwort.	Commelinaceae
Fittonia spp	Red fittonia plant	Acanthaceae
Nephrolepsis	Fishbone fern, Tuberous sword fern, Tuber ladder fern, Erect sword fern, Narrow sword fern and Ladder fern, Herringbone fern.	Nephrolepidaceae
Clematis	Java Clematis, Gourian Clematis	Ranunculaceae
Gardenia spp.	Gardenia Tree	Rubiaceae
Asplenium nidus	Bird's-nest fern	Aspleniaceae
Maranta spp.	The prayer plant, arrowroot	Marantaceae

Cotoneaster	Rock spray cotoneaster, Chinese rock spray	Rosaceae
Euonymus fortune	Wintercreeper	Celastraceae
Hedera	Common ivy, English ivy, European ivy	Araliaceae
Hydrangea	Bigleaf hydrangea, French hydrangea, Lace cap	Hydrangeaceae
Lonicera	Common honeysuckle, Woodbine	Caprifoliaceae
Parthenocissus	Virginia creeper	Vitaceae
Polygonum	Knotweed, Knotgrass	Polygonaceae
Pyracantha	Narrow leaf fire thorn, Slender fire thorn, Woolly fire thorn.	Rosaceae
Selaginella	Starry spike moss, Lesser clubmoss, Resurrection plant	Selaginellaceae
Wisteria	Chinese wisteria, Wisteria, water Wisteria	Fabaceae
Rose	Rose	Rosaceae
Petunia	Deep purple petunia	Solanaceae
Nasturtiums	Nasturtium, Garden nasturtium	Tropaeolaceae
Daisies	Lawn daisy, English daisy	Asteraceae
Bromeliads	Silver Vase Bromeliad, Urn Plant	Bromeliaceae
Exterior Wall		
For full sunlight		
Lavendula	English lavender, French lavender, Lavender	Lamiaceae
Thymus	Common thyme, German thyme, Garden thyme	Lamiaceae
Rosmarinus	Rosemary	Lamiaceae
Salvia	Sage, Common sage, Garden sage, Golden sage	Lamiaceae
For shady locations		
Begonia	Wax begonia, Begonia	Begoniaceae
Arum	Bengal Arum,	Araceae
Davallia	Rabbit's Foot Fern, Paku Tertutup	Davalliaceae
Asplenium	Bird's-nest fern	Aspleniaceae
Fuchsia	Hummingbird fuchsia, Hardy fuchsia, Lady's eardrops	Onagraceae
Interior Wall		
Philodendron	Lacy tree philodendron, Selloum, Horsehead philodendron	Araceae
Epipremnum	Golden pothos, Ceylon creeper, Hunter's robe, Ivy arum, House plant, Money plant, Silver vine, Solomon Islands ivy, Marble queen, Taro vine	Araceae
Aeschynanthus	Lipstick plant	Gesneriaceae
Columnea	Flying goldfish plant	Gesneriaceae
Saintpaulia	African violet	Gesneriaceae
Begonia	Wax begonia, Begonia	Begoniaceae
Nephrolepis	Fishbone fern, Tuberous sword fern, Tuber ladder fern, Erect sword fern, Narrow sword fern, Ladder fern, Herringbone fern	Nephrolepidaceae
Pteris	Chinese brake, Chinese ladder brake, Ladder brake	Pteridaceae
Many species of *Peperomia*	Radiator plant	Piperaceae

Advantages of vertical garden

Recent research work highlights the importance of vertical walls as the boon for urban lifestyle in the following ways (McCarty *et al.*, 2001 [32]; Getter and Rowe, 2006 [23]; Yang *et al.*, 2008 [59]; Molineux *et al.*, 2009 [34]; Santamouris *et al.*, 2007 [47]; Czemiel Berndtsson, 2010 [14]; Cheng *et al.*, 2010 [10] and Martensson *et al.*, 2014) [31]. They are

- Air quality improvement
- Thermal regulation and insulation properties
- Urban Heat Island Effect
- Sound absorption
- Aesthetic and psychological benefits
- Ecological preservation and beautification

Air quality improvement

Pollution is pervading the entire globe due to changes in lifestyle, food habits etc. Among these, release of pollutants into the air becomes the major factor for creating health hazards in the life of all living beings in the entire globe. Hence, air pollution is one of the major reasons for human health risks. Joshi and Chauhan (2008) [26] have suggested that the modernization of today's world due to automation, urbanization, and transportation leads to improved pollutant levels in the air due to the increase in the release of toxic gases like Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and Suspended Particulate Matter (SPM) as anthropogenic pollutants. Indoor air pollutants are categorized into three types. They are volatile organic compounds (VOCs), inorganic gaseous compounds (ICs) and particulate matter (Soreanu *et al.*, 2013) [49]. Green walls would seclude the pollutants *viz.*, CO_2, VOCs (Volatile Organic Compounds) under indoor conditions to purify the indoor air (Darlington *et al.*, 2001) [15]. Several species of plants were identified to sequester the air pollutants including high concentrations of benzene in a significant amount. Although, the soil microbes were performing in an appropriate way for its removal (Orwell *et al.*, 2004) [37]. The findings of Young and Johnson (2005) [61] showed that the vegetation in green walls/ vertical gardens diminishes the air contaminants in a substantial amount by its own activities, especially photosynthesis. To meet the requirement of oxygen for a single person for the entire day, the vegetation of 155m^2 was desired. This vegetation can attenuate the noxious pollutants such as Sulphur dioxide, Nitrogen dioxide, ozone, Carbon monoxide, dust and ash by cleansing the air in a satisfactory manner. It has been assessed that a grassed roof top of 1m^2 depreciates 0.2 kg of airborne particulate matter from the air every year. As a result of installing green walls, the surrounding area was witnessed with negligible deleterious gases (Loh, 2008) [30]. This green wall renders various benefits in the indoor atmosphere to enhance the aesthetic surroundings and also to filter the injurious gases (Cunliffe *et al.*, 2012) [13]. It was resulted by the removal of dust and pollen from air (deposition on leaves), filtering the contaminants, noxious gases *viz.*, nitrous oxides, sulphur oxides, VOCs, carbon monoxide and sequestration of carbon. The following are the list of plants which eliminate the respective pollutants.

Table 2: Chemical pollutant Plants effective at removing the chemical pollutants

Chemical pollutant	**Plants effective at removing the chemical pollutants**
Carbon Monoxide (CO)	-Spider plant (*Chlorophytum comosum*) -Janet Craig Dracaena (*Dracaena deremensis*) -Ficus (*Ficus sp.*)
Volatile Organic Compounds (VOCs)	-Golden Pothos (*Scindapsus aureus*) -Devil's ivy (*Epipremnum aureum*) -*Philodendron sp.*
Benzene / Toluene / Xylene	-Kimberly Queen Fern (*Nephrolepis obliterata*) -Orchid sp. (*Phalenopsis sp.*) -*Dieffenbachia sp.*
Trichloroethylene (TCE)	-Mother-in-law's tongue (*Sansevieria trifasciata* 'Laurentii') -Chrysanthemum (*Chrysanthemum morifolium*) -*Dracaena sp.*
Formaldehyde	-Peace lily (*Spathiphyllum wallisii*) -Boston fern (*Nephrolepis exaltata*) -English ivy (*Hedera helix*)

Su and Lin (2013) [50] suggested that the indoor green walls not only adorn the surroundings but also helps to relieve the pressure and tiredness of the dwellers by filtering the contaminants in the air and diminishing the temperature by its own activity (transpiration). Moreover, it releases oxygen and by taking CO_2 and CO, the micro-organism living in the substrates of the vegetation also contributes to get rid of the noxious volatile organic compounds (Burritt, 2013) [7].

Thermal regulation and insulation properties

Green walls/ vertical gardens provide the refrigeration and insulation for a building. It performs a profound role irrespective of seasons. During summer, it proliferates warmness into the building and at the same time, it could alleviate heat loss during winter, through which it maintains the proper balance of temperature in the indoor conditions throughout the year (Castleton *et al.*, 2010). The energy savings in non-insulated buildings by this green wall reached the level of 37% (Niachou *et al.*, 2001). The findings made by Perini *et al.* (2011a) [42] have suggested that an extra insulation layer was developed in the building as a result of the green walls.

The phototropism effect of plants grown in green walls was well explained by Ottelé *et al.*, 2011. He stated that the sunlight falling on the vegetation uses only 5-20% for photosynthesis and 5-30% for reflection, 20-40% for evapotranspiration, 10-50% for the conversion of heat, respectively. During summer, the reduction of temperature of 23% was reported (Bass and Baskaran, 2001) [2].

An experiment was conducted to compare the thermal performance of bare concrete sections and vegetation covered building façade by Eumorfopoulou and Kontoleon (2012) [20]. The results exhibited the surface temperature of the bare concrete was relatively higher than the surface temperatures of vegetation covered building façade with an outcome of diminished surface temperature of 10.8 °C from the vegetation covered building façade. Similarly, the surface temperature of vegetation covered buildings reduced the surface temperature of 11.6 °C when compared to standing walls as a result of study carried out by Wong *et al.*, 2010a [58].

Adding vegetation in the standing wall as a green wall contributed a cooling effect and reduced the temperature rise in summer and also reduced the cooling and heating energy consumption. This vegetation in the vertical garden gained the energy savings of 35 -90% based on the amount and position of plants in the green walls (Alexandri and Jones, 2008) [1].

In the outdoor environment, installation of modular vegetated panels over the concrete wall reduced the wall temperature of 16 °C in summer. Through this, interior wall temperature of more than 2 °C was sustained at night. This clearly indicated the vegetation played a significant role in reducing power consumption to create the cooling effect of a building (Cheng *et al.*, 2010) [10].

Urban heat island effect

It is nothing but the significant rise in urban temperatures due to the expansion of concrete buildings in metropolitan cities without vegetation (McCarthy *et al.*, 2001). In contrast, this problem does not occur in rural areas due to the existence of trees, shrubs, all categories of plants in profound manner which keeps the temperature under control through the activity of evapotranspiration (Sailor *et al.*, 2008). Hence, incorporation of greenery in urban set up assists to mitigate Urban Heat Island effect in an esoteric way. The temperature build-up in greed faced buildings reduced to an average of 5.5 °C rather than the bare concrete wall and it was reduced to 17.6 °C on the North West side of a building in September in Lleida, Spain (Pérez *et al.*, 2011).

A study conducted by Alexandri and Jones (2008) [1] in the hottest months in Hong Kong to understand the effect of vegetation on a bare concrete building and the results expressed that the temperature reduced to the maximum of 8.4 °C in the standing building covered with vegetation in both roof and walls.

Sound absorption

Reflection of sound from the standing wall will be in higher amount. Whereas the vegetation in the living wall absorbs the sound waves in a considerable amount. Hence the surrounding areas of living walls create ambience atmosphere for the dwellers. With the sound waves of lower frequencies, the plants delivered diffraction, while at higher frequencies, plants reflected the sound waves (Getter and Rowe, 2006) [23]. With sound at lower frequencies, plants may offer diffraction, and with sound at higher frequencies, plants may reflect the sound onto other surfaces that may then absorb the sound. Van Renterghem and Botteldooren (2011) [55] expressed that vertical gardens resulted with constant and substantial sound reduction at places where only diffracted sound waves reach. An experiment was conducted at Hort Park in Singapore with 8 different living walls to determine sound absorption coefficient. The results indicated that the vegetation on living walls created profound effect on sound engrossment rather than standing buildings. Additionally, the sound absorption coefficient increased with an increase in frequencies of sound. It was also observed that greater greenery coverage increased the sound absorption coefficient (Wong *et al.*, 2010b) [58].

Aesthetic and psychological benefits

The living walls can provide face lifting to the concrete buildings and also create calmness to the residents and it was observed that this kind of living wall in the workplace helps to enhance the productivity, efficiency of the workers and also creates the ambience condition to work. Similarly, in hospitals it helped to increase the recovery of patients quickly (Ulrich, 2002) [54].

Ecological preservation and beautification

Living walls in the outdoor environment renders various benefits as that of indoors in cleansing the air, thermal regulation, sound absorbents and aesthetic beauty. In addition to this, it also played a significant role in ecological conservation and protecting biological diversity. It thus enhanced the habitat of birds and butterflies in metropolitan cities. Its colour, sound, movement fulfils the principles of landscaping as in the garden. It provides great opportunities for the urban dwellers to create a unique design and to enjoy the benefits of flora as in rural areas. Ultimately, health and wellness of the urban residents were improved through this horticultural therapy (Rachael, 2005) [43].

Brenneisen (2003) [6] suggested that the selection of plants for this green wall invites the movement and activity of birds, insects and butterflies in a given area to render a more sustainable ecosystem in urban environments. Hence, it provides food and shelter for the wildlife even in urban society (Thompson and Sorvig, 2000) [53].

Future thrust

Research on various aspects of vertical landscaping *viz.*, insulation properties, endurance features, sustentation, plant preference for outdoor and indoor living wall and also for facades in relation to prevailing environmental conditions will be focussed for the upcoming generations of urban dwellers to lead a healthy, pollution free ambient conditions for their sustainable wellbeing. Moreover, developing cost effective green wall with suitable media, modules, panels, nutrient and irrigation requirement will be concentrated.

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