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# Plant Diversity and Plant Performance of Indoor and Outdoor Vertical Greening Systems in Hong Kong

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**Abstract**
This study aimed to examine the plant diversity and plant performance of vertical greening system (VGS) and how the hardware setup (including growing substrates) potentially affect plant performance. A total of 125 VGS (including 85 outdoor and 40 indoor VGS) were surveyed in Hong Kong. We recorded the type of VGS, species composition, frequency and plant coverage; substrate medium type, and plant performance. The findings revealed that indoor soilless VGS performed comparably well as on conventional soil, and outdoor soilless VGS performed significantly better than on soil. Regardless of substrate type, plants on indoor VGS performed better than outdoor VGS.

Keywords: Vertical greening system; Floristic composition; Growing medium; Plant performance


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## 1.0 Introduction

Humans have had a long history of improving their well-being in the built environment by ameliorating the adverse effect of the built structure by introducing plants and related natural elements. Allowing plants to grow on façades is being practiced for over several thousands of years (Madre et al., 2015). As technology rapidly advanced in the last century, many inventions and VGS products had been introduced to urbanized environment to alleviate urban heat island effect and climate change (Sheweka and Mohamed, 2012), and to increase aesthetic and property values. There is an increasing number of vertical greening systems (VGS) under the trend of developing green buildings in Hong Kong and many other regions of the world. Many studies had shown that vertical greening system brings various benefits on environmental, ecological, economic, social, and aesthetic aspects. VGS could reduce the surface temperature sufficiently under hot weather (Bass and Baskaran, 2003) and have an obvious temperature reduction through evapotranspiration (Hui, 2017).

Local and international research studies proved that plant species with certain attributes will increase the cooling capability in the built environment, thermal performance and analysis on material Life Cycle Analysis (Ottelé et al., 2011; Pan et al., 2020; Pan and Chu, 2016; Mingpao, 2012), however, only one to a few plant species were accounted in their studies. Drainage Services Department (2019) of the Hong Kong Government tried to select climber species based on published literature and identify suitable climber plant species on wall surfaces (green façade). There are virtually no reviews and studies investigating plant species diversity and plant performance of existing VGS, while they are crucial information if ecological benefits (such as carbon dioxide sequestration potential) and thermal performance are evaluated. Plant performance had never been the focus of study in previous researches, and how the hardware setup of VGS and the growing substrates affect their performance had never been elucidated. In Hong Kong, there have been over 3 and 1 VGS failure cases (Sing Tao Daily, 2011; Oriental Daily, 2019; HoMemory, 2020) in public and private premises respectively reported in newspapers over the last decade, not to mention there were much more unreported among privately-owned

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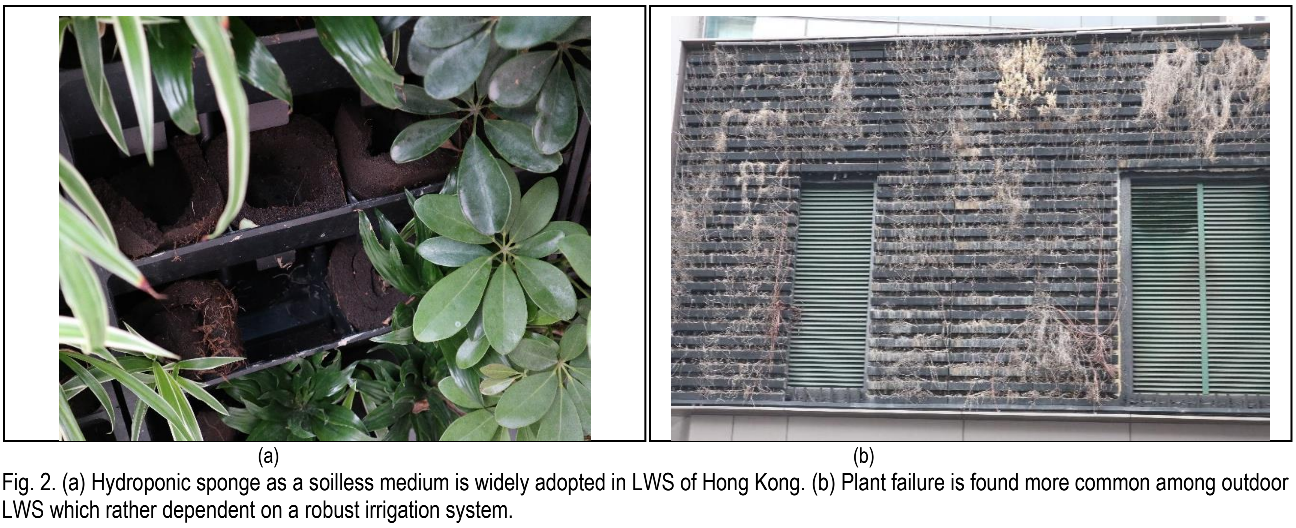
VGS. The majority of VGS is located at outdoor sites, while indoor VGS are still less common in Hong Kong, as they require intensive maintenance and high energy input by providing lighting and irrigation system. There is no failure case of indoor VGS reported in mass media so far. This study garners comprehensive site information from existing outdoor and indoor VGS and explores the possible factors affecting the plant performance for achieving long term sustainability.

## 2.0 Outdoor and Indoor VGS

This study follows an integrated definition and classifications of VGS by several researchers including Krusche and others (1982), Dunnet and Kingsbury (2004), Köhler (2008) as described by (Ottelé, 2011). VGS could be classified as green façades (GF) and living wall systems (LWS). Green façades are planted with climbing plant species either growing directly on a wall or indirectly on reinforcing structures, such as meshes, cable rope, grids, or trellis (Fig 1a), fixed on the wall. These climber plants usually establish inside a planter or at grade blended into the landscape. Living wall systems (LWS) are composed of pre-vegetated panels, modular units, or fabric systems (like non-woven fabric) affixed to a frame or wall, it comes together with the required hydroponic system to support plant growth (Fig 1b). While the materials as growing substrate or planting medium could vary due to recent technological breakthrough, conventional soil mix which similar to normal potting mix is becoming less popular than soilless mixes (e.g. perlite, compost, pumice, expanded clay aggregates, coconut pith, hydroponic sponge (Fig 2a), silica gel). According to personal communication with VGS contractors in Hong Kong, older (built before 2010) LWS in Hong Kong are mostly using conventional soil mix, while increasing prevalence of soilless substrate is observed over the last decade. This change is contributed by hot and humid weather favours the excessive weathering of soil mineral and leaching of nutrients exacerbated by high water demand to sustain the plants under long harsh summers. To make things worse, almost all leaf litters fall directly off the LWS, rather than decomposed inside the pots of the modules, hence, this cuts off the nutrient cycle and replenishment of organic matter.

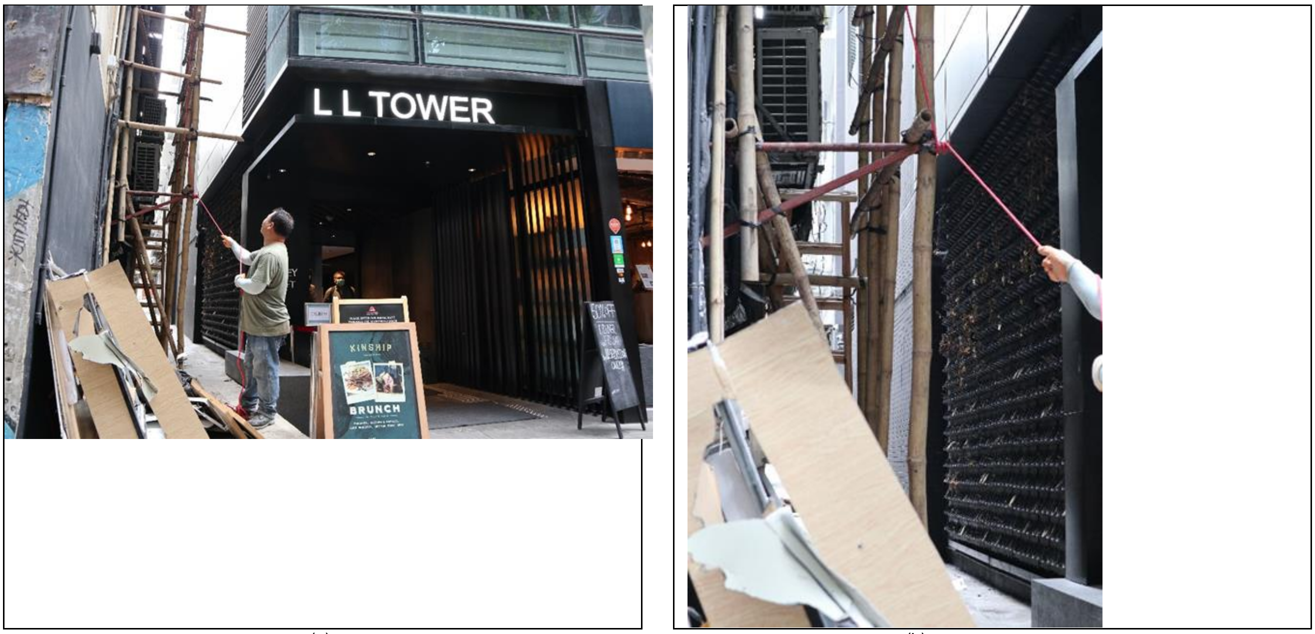
(a) (b)

Fig. 1. (a) Green façades (GF) with climber plants growing indirectly against a wall with a stainless steel frame and cable ropes. (b) A typical Living Wall System (LWS) in Hong Kong -- about 4-7 plant species were applied to compose patterns with contrasting colors and texture, to make the VG more aesthetic and vivid.



(a) (b)

Fig. 2. (a) Hydroponic sponge as a soilless medium is widely adopted in LWS of Hong Kong. (b) Plant failure is found more common among outdoor LWS which rather dependent on a robust irrigation system.




(a) (b)

Fig. 3. (a) An outdoor VGS was built on a façade facing a narrow alley between two tall buildings. (b) A close up view showing dead wilted plants remains on this VGS.

## 3.0 Materials and Methods

Hong Kong has a mean annual temperature of 23.3ºC (1988-2010) and a mean annual rainfall of 2398mm (1981-2010), with around 80% of the rain falls between May and September, which is a typical subtropical monsoon climate. In winter, it is dry with breeze and sunshine, the temperature rarely falls below under 10 ºC (Hong Kong Observatory, 2020).

Site surveys were conducted by two trained undergraduate students from November 2019 to March 2020 in publicly accessible indoor and outdoor VGS sites in Hong Kong. The sampling size is hoped to be maximized as far as possible to include all VGS in Hong Kong, thus no sampling strategy is followed. A total of 125 VGS were surveyed in Hong Kong, including 85 outdoor VGS and 40 indoor VGS. The number of surveyed VGS is limited by available manpower and the information gap. Global Positioning System (GPS), TruPulse 200L Laser Rangefinder, binocular, trundle wheel, steel measuring tapes, and some calculation apps such as SunCalc.net, SketchAndCalc, compass, etc. were used to ensure the accuracy of the survey. Laser Rangefinder, a professional measurement to measure inclination, slope distance, azimuth, and calculate the horizontal and vertical distance to take the most accurate measurement possible in the field. For the app "SunCalc.net", it was used to check the available sunlight of the VGS with GPS location. The mobile device application "SketchAndCalc" was used to calculate the coverage area of each plant species on each VGS.

A site visit survey sheet was designed for the inspection, record some basic information and objective data of the site including the name of the site, date of survey, location, direction, GPS location, available sunlight direction (90 for East, 180 for South and so on), size, installed location (on wall or pillar), type of vertical greenery system, substrate, irrigation method, and available water. A table was created to record the health or visual performance of each plant species on the VGS to examine whether the plants have any problem with wilting, pest, disease (signs of virus infestation/mottling), and signs of improper pruning. Plant health in form of health scores ranged from 0 to 4 on the above four aspects were rated by trained students to ensure the consistency of rating. Plants were scored with 4 if they were excellent; 3 as good; 2 as fair; 1 serious or poor; 0 if plants were dead. Weeds and each species would be calculated the coverage. Planting pattern on the VGS with different species was sketched and labelled to give a general idea on which species were commonly or widely applied. The surrounding environment with any external factors such as buildings or construction that might cast shade or affect the VGS was remarked.

## 4.0 Results and Analysis

It is found that all 40 indoor VGS adopted LWS, and 31 (78%) of them use the hydroponic sponge as the soilless plant growth medium, 9 (22%) of them used conventional soil substrates. Within 85 outdoor VGS, 65 (76%) of them adopted LWS, 20 (24%) of them are green façades (with climber plants), and 16 (19%) of them used soilless medium, 69 (81%) of them are using conventional soil.

In this study, cultivars and varieties were regarded as different species, this is to attain the highest level of accuracy for plant species identification. In terms of plant diversity and coverage abundance, a total of 61 plant species are used in outdoor VGS which cover 3,480 m², and 36 species for indoor VGS which cover 618 m²; the species which have the highest frequency do not necessarily have the highest cumulative coverage, which means that some species are covering a high proportion of VGS only occur in a few numbers of sites. The common species used in both indoor and outdoor VGS is *Schefflera arboricola* which occurs in 33 and 45 sites respectively. Tables 1 and 2 showed the species found in more than 3 sites in indoor and outdoor VGS with their coverage area and occurrence frequency respectively.

Table 1. Species found in more than 3 sites out of 40 indoor VGS with their coverage area and occurrence frequency.

| Scientific name | Total coverage area ( m² ) in all sites | Frequency |
|---|---|---|
| *Schefflera arboricola* | 74.18 | 33 |
| *Dracaena marginata* | 16.35 | 29 |
| *Dracaena deremensis* 'Compacta' | 113.00 | 26 |
| *Epipremnum aureum* | 43.29 | 23 |
| *Philodendron* 'Con-Go' | 48.52 | 19 |
| *Dracaena deremensis* 'Roehrs Gold' | 22.68 | 18 |
| *Chamaedorea elegans* | 12.14 | 17 |
| *Ficus elastica* | 4.62 | 16 |
| *Podocarpus macrophyllus* | 4.52 | 11 |
| *Schefflera arboricola* 'Variegata' | 15.72 | 10 |
| *Murraya paniculata* | 1.05 | 7 |
| *Chlorophytum comosum* 'Variegatum' | 5.56 | 6 |
| *Asplenium nidus* | 11.55 | 4 |
| *Anthurium andraeanum* | 9.48 | 4 |
| *Syngonium podophyllum* 'Neon' | 5.01 | 4 |
| *Scindapsus pictus* | 4.35 | 4 |
| *Nephrolepis auriculata* | 13.57 | 3 |

Native species only contributed to an insignificant proportion in both indoor (4 out of 36, covering 28m² (4.5%)) and outdoor (6 out of 61, covering 911m² (26%)) VGS. Three species, namely *Asplenium nidus, Nephrolepis auriculata, Nepenthes mirabilis* cover 99.5% native species coverage. *Ficus pumila, Nephrolepis auriculata*, and *Asplenium nidus* are the three native species covering 93% (848m²) of outdoor VGS. It is very obvious that the exotic plant species are the absolute majority in indoor VGS, the native-exotic proportion for outdoor VGS is comparable to other public urban green space in Hong Kong (native shrub coverage: 20.9%; native herbaceous plant coverage: 39.4%) (unpublished data) in term of coverage (relative abundance), but not in terms of species number.

Table 2. Species found in more than 3 sites out of 85 outdoor VGS with their coverage area and occurrence frequency.

| Scientific name | Total coverage area ( m² ) in all sites) | Frequency |
|---|---|---|
| *Schefflera arboricola* | 654.52 | 45 |
| *Schefflera arboricola* 'Variegata' | 256.34 | 29 |
| *Nephrolepis auriculata* | 248.15 | 23 |
| *Parthenocissus tricuspidata* | 311.01 | 11 |
| *Chlorophytum comosum* 'Variegatum' | 46.65 | 11 |
| *Dracaena fragrans* 'Compacta' | 29.77 | 11 |
| *Duranta erecta* | 82.23 | 10 |
| *Loropetalum chinense* f. rubrum | 57.88 | 9 |
| *Asparagus densiflorus* 'Sprengeri' | 85.13 | 7 |
| *Chamaedorea elegans* | 30.47 | 7 |
| *Ficus pumila* | 511.97 | 6 |
| *Codiaeum variegatum 'Indian Blanket'* | 47.24 | 6 |
| *Aglaia odorata* | 13.88 | 6 |
| *Dracaena fragrans* | 80.13 | 5 |
| *Syngonium podophyllum* | 16.36 | 5 |
| *Tradescantia spathacea* | 11.55 | 5 |

| | | |
|---|---|---|
| *Codiaeum variegatum* 'Vanoosterzeei' | 10.41 | 5 |
| *Dianella ensifolia* 'Silvery Stripe' | 20.61 | 4 |
| *Dracaena marginata* Lam. | 12.12 | 4 |
| *Carmona microphylla* | 9.02 | 4 |
| *Ficus elastica* | 4.96 | 4 |
| *Asplenium nidus* | 87.90 | 3 |
| *Asparagus densiflorus* 'Myersii' | 64.09 | 3 |
| *Lonicera japonica* | 51.42 | 3 |
| *Syngonium podophyllum* 'Emerald Gem' | 46.06 | 3 |
| *Murraya paniculata* | 28.20 | 3 |
| *Combretum indicum* | 16.02 | 3 |
| *Sansevieria trifasciata* 'Golden Hahnii' | 13.68 | 3 |
| *Gardenia jasminoides* | 10.08 | 3 |
| *Aglaonema spp.* (Red) | 7.61 | 3 |
| *Epipremnum aureum* | 5.41 | 3 |
| *Codiaeum variegatum* | 5.03 | 3 |

For plant diversity, Shannon index (H') and evenness index (J') of plant species between indoor and outdoor VGS were calculated and compared (Table 3). For the sake of simplicity, the plant coverage area is used to represent the count when calculating the above. Outdoor VGS plant diversity and richness is higher than that of the indoor counterpart (H' Outdoor= 2.86; H' indoor=2.53), while the evenness for indoor, outdoor VGS is similar with relatively high evenness, that means a small number of species are representing a high proportion of plant coverage.

Table 3. Comparison of Shannon index (H') and evenness index (J') of plant species between indoor and outdoor VGS in Hong Kong

| | Indoor VGS (*n*=40) | Outdoor VGS (*n*=85) | All VGS (*n*=125) |
|---|---|---|---|
| Shannon index (H') | 2.53 | 2.86 | 3.08 |
| Evenness index (J') | 0.71 | 0.69 | 0.70 |

Table 4. Mean plant health score and variance in 266 species occurrence of Living wall system and in 29 species occurrence in Green façade for outdoor VGS

| | Outdoor VGS | |
|---|---|---|
| | Living wall system (*n*=266) | Green façade (*n*=29) |
| Plant health performance score (mean) | 2.7481 | 2.7931 |
| StdD | 0.432 | 0.313 |
| Std Error Mean | 0.026 | 0.058 |
| Levene’s test for equality of variances | F value: 0.502 Sig. 0.479 | |

Note: Mean plant health performance score ranges from 0 to 4

As all indoor VGS adopted LWS, no comparison could be done for plant health scores. The mean plant health performance score of outdoor VGS is compared between groups of LWS and GF. The mean score for GF is 2.79, slightly higher than that (2.75) of LWS, while the standard deviation for the LWS group is slightly higher than the GF group, meaning that the health performance for LWS has higher variance (Table 4). Since the probability (Sig.=0.479) for F value is larger than 0.05, the variances in the groups are equal, thus equal variance is not assumed.

The lower mean score of LWS may reveal that the hydroponic system may be affected by various factors such as (a) possibility of failure of the automatic irrigation system, (b) human judgment to provide optimal water level, (c) confined growing spaces may lead to pruning need or replacement of plants. 225 out of 266 plant occurrences in LWS are served by automatic irrigation systems, the remaining 41 require manual irrigation. Thin tubing, nozzles, emitters of the automatic irrigation systems will get blocked by water contaminants such as suspended solids, dissolved solids, bacteria population, other compounds (iron, manganese, hydrogen sulphide), water pH. If water filters and other system parts are not well maintained, plant failure will result (Fig 2b). It is worth noting that all the 4 VGS with total plant failure recorded are under the category of outdoor LWS, while there is no indoor VGS recorded with total plant failure. Indoor VGS often receive more attention by the landscape and property managers, the causes of any plant decline may be promptly investigated and addressed to avoid any eyesores.

On the contrary, plants on GF performed slightly better consistently and stably. The following might be possible explanations: (a) climber plants on GF usually have massive soil volume to take root and they are more resilient to water shortage through evaporation during hot and dry days; (b) plants on GF mainly rely on established extensive root system in planters, at grade planting stripes, suckers from plants themselves to survive, that why water shock is less common; (c) plants on GF can be benefited by availability of leaf litter to complete the nutrient cycle and also help water to infiltrate with the presence of higher organic matter and plant root mass.

Table 5. Mean plant health performance in indoor and outdoor VGS in terms of growing substrate types.

| | Indoor VGS (*n*=40) | | Outdoor VGS (*n*=85) | |
|---|---|---|---|---|
| | Soil (*n*=9) | Soilless (*n*=31) | Soil (*n*=69) | Soilless (*n*=16) |
| Plant health performance score (mean) | 3.3778 | 3.3758 | 2.7083 | 2.8544 |
| StdD | 0.16392 | 0.05943 | 0.48574 | 0.19027 |
| Std Error Mean | 0.05464 | 0.01067 | 0.03401 | 0.01995 |

Table 5 showed that plant performance scores for both indoor and outdoor VGS do not have significant differences between VGS using soil and soilless medium, while the standard deviations for performance score for both indoor and outdoor VGS using soil as the growing medium are higher than that of soilless medium (Indoor performance score: soil: 3.3778 (StdD: 0.16392 ), soilless: 3.3758 (StdD: 0.05943); Outdoor performance score: soil: 2.7083 (StdD: 0.48574 ), soilless: 2.8544 (StdD: 0.19027). We can conclude that the plants on the soilless medium perform stably than its counterpart in both indoor and outdoor settings, assuming that maintenance interval is not considered. Also, it is evident that plant performance for indoor VGS is generally better than outdoor VGS, this might be valid for generally higher maintenance frequency for indoor VGS. Abiotic factors in Indoor VGS are rather stable with (a) provision of regular supply of artificial lighting to compensate the deficiency of sunlight, (b) provision of an air-conditioned environment which keep a warm (around 25ºC all year round) growing condition without the abnormalities as in outdoor, (c) sources of pest and disease are fewer in indoors, and stable temperature discourages the growth of pathogenic bacteria and fungi.

## 5.0 Recommendation and Conclusion

From the above result and analysis, further recommendations could help to improve the performance of VGS:

(1) More native plants should be adopted in VGS for both LWS and GF to increase the ecological value for providing food sources for birds, reptiles and other animals, and larval and nectar plants for insects. As native plants are adapted to local climatic conditions, they will help to reduce the carbon footprint related to irrigation system set up, electricity and also water consumption.

(2) GF should be further promoted as a more sustainable VGS type due to lower resource consumption, and higher plant health scores mean that GFs are more reliable and robust to face extreme conditions. GFs are designed to stand for several decades, however, LWS tends to wear and tear over time in PVC based module parts and they will be more costly to be repaired. In most cases, plants in LWS needed to be pruned and replaced regularly about 2 to 3 times per year, while GF needs minimal trimming and need to zero maintenance need. Many PVC modular LWS have limited life span up to several decades, and it is observed in Hong Kong, the metal frame and steel beams are prone to rust, thus undermining the safety of the VGS structure.

(3) As far as indoor VGS is concerned, planting medium type is not a major issue, both soil and soilless systems contributed to good plant health performance. Soilless outdoor VGS seems to sustain to pertain better plant health, however, it seems to be a bit assertive to make such a conclusion as the sample size for soilless outdoor VGS is merely 16 sites, more sites of this kind should be surveyed and observed to make a reliable conclusion.

(4) Outdoor VGS with soil planting medium needs more attention to improve their performance, especially extreme climate events are more frequent due to climate change, and more severe air pollutants. As these systems age, they tend to more costly to maintain. Particulate matters rich in pollutants constantly arrive and evolve with this kind of Technosol (artificial growing medium) (González-Méndez and Chávez-García, 2020) together with high hydric erosion assisted by ample and constant water supply from irrigation systems. Hard crusted and heavily weathered soil is resulted, which cannot support healthy plant growth. Older outdoor VGSs with soil are generally facing the above problems. It is recommended to innovate and formulate suitable soilless planting mix components (e.g. coconut pith, compost, pumice) to resist the above treats. Soilless hydroponic sponges need fertigated water and precise adjustment of irrigation systems, they need more experienced expertise to manage.

(5) There are many parameters (breakdown health scores e.g. wilting, virus, and mottling, improper/untimely pruning) collected in this study not yet analyzed, it is hoped to contribute more knowledge to the design, setup, management of VGS.

(6) This study benchmarked the use of plant species of both LWS and GF in Hong Kong, this information will be very valuable to the analysis of ecological benefit, thermal performance, and carbon sequestration potential. Further studies deploying these data will be useful to draw some light on these unexplored areas.

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