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Percentage Coverage of Tropical Climbing Plants of Green Facade

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Abstract. Green façade (GF) is one of vertical greenery systems used as passive solutions applied on building façade in improving indoor thermal environment and energy efficiency. However, optimum improvement of thermal environment from GF is dependent on the overall foliage coverage established on the system itself. Higher percentage coverage of the foliage is expected to regulate and lessen the heat transfer toward inside environment. Therefore, this study is to investigate the potential of selected tropical climbing plants in establishing foliage coverage on the GF. Three selected tropical species of climbers used on green façade; i.e. *Anemopaegma chamberlaynii* (AC), *Antigonon leptopus* (AL), and *Quisqualis indica* (QI). A small-scale experiment with small scale size of freestanding walls (1.5 m (height) × 1.0 m (width) × 0.15 m (thick)) attached with GFs (modular trellis) and planter boxes at ground were built for this study. Despite small size leaf, AC performed consistently and has the highest percentage coverage throughout the measurement period with average of 86.5 %. The dominant trait of AC which is vigorous and fast growth rate contributed to the dense and almost fully covered the trellis structure of green façade. Higher percentage coverage also estimated to generate an instantaneous effect on thermal environment modification.

1. Introduction
Wall and roof are an outer façade for the building to define the indoor spaces while providing security, privacy and protection. Also, the function included to offer optimum thermal environment for the end-users. However, this function sometime failed to be delivered by the building façade. Therefore, passive solution such as green façade (GF) is introduced and attached on building façade as shading device. GF is one of the vertical greenery systems (VGS) used widely to improve thermal conditions especially for indoor environment [1,2].

Performance of GF in improving indoor thermal environment has been widely studied by researchers. Coma et al. [2] studied an external surface temperature reduction of a one-room building or test cell wall with GF at the south orientation during summer in Lleida, Spain. Maximum reduction obtained was 14 K. The study also investigated on the differences of internal surface and indoor air temperatures of the test cell. The maximum results were 2 K and 1 K, respectively. Using the same research tool, Price [3] conducted an experiment using one-room building to explore the potentials of IGF on cooling effect performance in Clarksville, USA. He attached IGF at the south and west facing aspects of the test cell.

One test cell was treated as control room. The temperatures of western and southern aspect walls with GF were decreased at a maximum of 11.3 K and 6.4 K, respectively. The indoor air temperature of the test cell with GF near to the west wall was 1.8 K, meanwhile the south wall recorded 1.0 K. At the west orientation of the indoor environment, the difference of heat transferred was 10.7 W/m^2 and at the south, the difference was 3.6 W/m^2.

Another full-scale setup experiment by Koyama et al. [1] was conducted to investigate shading and transpiration cooling effect on three identical test cells, with one was left as a control unit. Two of the test cells produced lower indoor air temperature, with maximum peaks at 3.3 and 4.4 K compared to the control unit. The maximum difference for external surface temperature was 9.5 K. The experiment was then continued with climbing plants on GF at one of two test cells were severed, and another one was left intact to calculate the transpiration cooling effect. The cooling effect performance of severed plants was decreased. The indoor air and internal surface temperatures of the wall with an intact plant of GF were 0.4 K and 1.2 K lower than a severed plant test cell.

Sunakorn and Yimprayoon [4] piloted a full-scale building on empirical investigation of GF in Thailand. The experiment was run on the existing identical rooms. The study was designed to explore the use of GF with the influences of natural ventilation. The results revealed that the differences in room air temperature of IGF attached in front of openable windows were lower than control room. Without natural ventilation, the IGF room temperature was 0.5 K lower than the non-covered room. With natural ventilation allowed to go through the room, the indoor temperature was 0.9 K lower.

From the all above mentioned studies, the foliage coverage established on the GF is an important factor in determining the successfulness of this system. Koyama et al. [5] found strong positive relationship between cooling effect performance of GF and coverage percentage (*r*: 0.815). Higher percentage of foliage coverage contributed to higher wall surface temperature reduction. Therefore, this study is to investigate the potential of selected tropical climbing plants in establishing foliage coverage on the GF. This is an initiative to establish fundamental information of tropical climbing plants coverage performance used on GF.

2. Material and Methodology

2.1. Plant Selection

Plant selection for this experiment was based on several criteria suited for this experiment. Several criteria have been considered for this experiment in order to expect the best performance of coverage and density of foliage on the GF. The criteria include the growth rate, coverage, weather tolerance, maintenance, climbing pattern, leaf size, and availability in the nursery. Most importantly, the plant must be a native climbing plant of tropical biomes. An indigenous plant owns by surrounding climatic condition promotes better growth development and coverage performance. Native plants of tropical regions are mostly evergreen all through the year. Located near to the equator, vegetation receives abundant solar radiation throughout the year. Thus, the results of measurement were assumed can be predicted for an annual performance.

Taking into deliberation the harsh conditions of the experimental site and the duration of the study, the preferred climbing plant should have the characteristic of vigorous and fast of growth rate of plant, spreading coverage pattern that can cover GF within the time frame given, full sun plant and tolerate to the extreme weather conditions, low maintenance, twining and clinging climbing pattern, large leaf size, and high supply at the nursery. The summary of the selection criteria is given in Table 1. In addition, popular climbing plants used on GF at Malaysia's building were also considered to help the architect or landscape architect to have essential information on the plants that are applied for their building and for the future.

Reviewed through literature, observed through current situation of GF in Malaysia's construction industry, and contacted with local landscape architects and gardeners, this study had identified three species potentially to be investigated. The potential species are *Anemopaegmea chamberlaynii* (AC),

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Antigonon leptopus (AL), and *Quisqualis indica* (QI) (Figure 1). The criteria of selected plants are tabulated in Table 2.

Table 1. Summary of selection criteria for climbing plants to be used for this experiment

Criteria	Selection Criteria	Remarks
Growth rate	Vigorous and fast	Limitation of research time for plant to grow
Coverage	Spreading	Able to maximise coverage on supporting structure within time frame given
Weather tolerance	Full sun	Full sun to act as shading device and able to withstand extreme weather conditions
Maintenance	Low	Low on fertilizing, pesticides monitoring and watering
Climbing pattern	Twinning and clinging	System selected with trellis support structure, not suitable for adhesive type climbers
Leaf size	Large	Larger leaf provides larger shading coverage
Availability in nursery	High supply of preferable climber	Limited supply in the market
Popularity	Most used in the construction industry	For better understanding on plant performance that been used in the industry

(a) (b) (c)

Figure 1. Specimen of selected tropical climbers (a) *Anemopaegma chamberlaynii*, (b) *Antigonon leptopus*, and (c) *Quisqualis indica*.

Table 2. Summary of potential criteria of selected climbing plants

Criteria	*Anemopaegma chamberlaynii*	*Antigonon leptopus*	*Quisqualis indica*
Growth rate	Vigorous	Vigorous	Fast
Coverage	Spreading	Spreading	Cascading down
Weather tolerance	Full sun and hardy	Full sun and semi hardy	Full sun and hardy
Leaf size	Small – 5cm	Medium -13cm	Medium-15cm
Climbing pattern	Twinning with hooked tendrils	Tendrils	Stem twinning
Maintenance	Low	Low	Medium

2.2. *Small-scale Experiment*

The small-scale experiment also used by Jim and He [6], Koyama et al. [5], Laopanitchakul et al. [7], and Wong et al. [8]. Three mock-ups of GF with free standing walls were built for this experiment. The size of freestanding walls were 1.5 m (height) × 1.0 m (width) × 0.15 m (thick) and trellises were 1.5 m (height) × 1.0 m (width) with white planter boxes at the bottom. Figure 2 shows detailed measurement of GF mock-up. Each planter box was planted with three numbers of climbers from each species. The heights of each of the climbers were almost similar before they were transferred into respective planter boxes. Climbers were left for a month for the establishment of foliage before any measurements were taken. Modules were arranged at west facing orientation. The experiment was conducted for duration of 30 days period on 10 September - 9 October 2012 at Faculty of Design and Architecture, Universiti Putra Malaysia (2.99°N, 101.71°E).

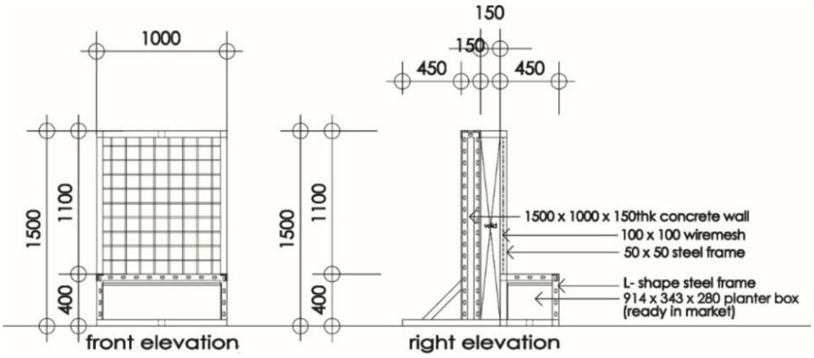

Figure 2. Details measurement of small-scale of IGF

2.3. *Percentage Coverage*

Average of coverage performance of the climbing plants was determined by the percentage coverage on selected three days (first, middle and final days of the experiment. The percentage coverage was the percentage area of the behind wall covered by the plants to the area of the wall. The percentage of the coverage was calculated through binary images. The binary images were obtained from converted digital images taken by digital camera (Nikon D3100). The images were converted to binary image and the calculation of shaded area was adopted from pixel segmentation feature in Adobe Photoshop CS4. An example of the image conversion is shown in Figure 3.

(a) (b)

Figure 3. Image conversion of *Quisqualis indica* from (a) digital image to (b) binary image

3. Results and Discussion

Percentage coverage for three species is demonstrated in Figure 4 and tabulated in Table 3. The average performance of AC, AL and QI is 86.5 %, 79.6 %, and 69.4 %, respectively. In the overall performance, despite of small leaf size, AC performed significantly remarkable. Throughout the experiment, the development in the percentages coverage of AC are almost stagnant, however, the percentage coverage is significant, with percentage ranges of 85.9 to 86.9 %. Vigorous growth rate of AC established dense foliage coverage is expected to provide instantaneous thermal environment improvement. The performances of AL and QI declined towards the end of the experiment. Both of the species performed exceptionally at the beginning of the experiment, however, the decrement of percentage is suspected to relate with the leaf lifespan and the pattern of foliage coverage.

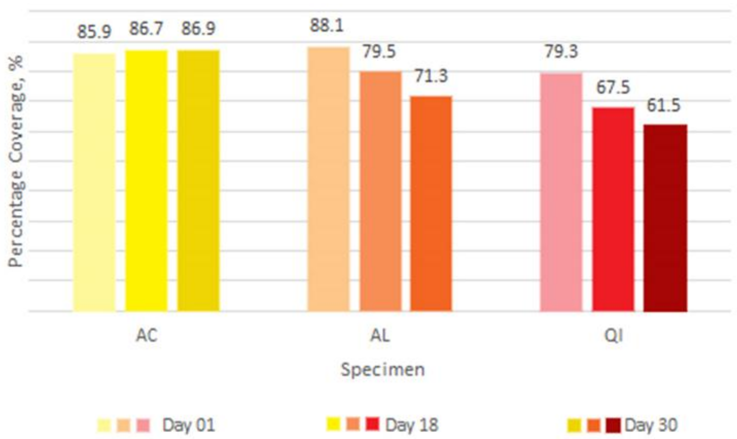

Figure 4. Percentage coverage of *Anemopaegma chamberlaynii* (AC), *Antigonon leptopus* (AL) and *Quisqualis indica* (QI) for day 1, 18 and 30 of the duration of conducted experiment (10 September – 09 October 2012).

Table 3. Percentage coverage of *Anemopaegma chamberlaynii* (AC), *Antigonon leptopus* (AL) and *Quisqualis indica* (QI) for day 1, 18 and 30 and the average of the duration of small-scale experiment (30 days; 10 September – 09 October 2012). Area of coverage is calculated in m^2 over area of trellis of IGF (1.5 m^2).

Species	Day 01		Day 18		Day 30		Average	
	%	m^2	%	m^2	%	m^2	%	m^2
Anemopaegma chamberlaynii (AC)	85.9	1.29	86.7	1.30	86.9	1.30	86.5	1.30
Antigonon leptopus (AL)	88.1	1.32	79.5	1.19	71.3	1.07	79.6	1.19
Quisqualis indica (QI)	79.3	1.19	67.5	1.01	61.5	0.92	69.4	1.04

The performance of QI is considered as the least percentage performed from all the specimens. The lessened performance towards the last day of the experiment is because of the pattern of foliage coverage. The foliage pattern of QI is cascading down. The stem climbs twinning vertically over the supporting structure with less number of leaf coverage before reaches the highest point of the structure. Only at the top position of the trellis, foliage starts to form the cascading down pattern. This pattern only establishes maximum coverage when reaching the top point of supporting structure such as trellis and take longer times to establish the optimum coverage. Thus, it is explained the reason for the weak performance of QI even though on the small coverage area. Nevertheless, the percentage coverage of QI is still acceptable for the given timeframe of the experiment.

Meanwhile, the diminution performance of AL is caused of short leaf lifespan. From the observation, the leaf tended to grow vigorously, then the leaf started to experience fast rate by wilting, drying and dying. The abundance of solar radiation in the tropics increases the rate of photosynthesis assimilation of the leaf. Therefore, the longevity of the leaf is shorter which suspected due to the high rate of photosynthesis assimilation especially for the tropical plants [9].

The selection of the plant to be applied on GF is a very important decision to be taken. Larger size of leaf can contribute to higher percentage coverage. Nevertheless, the performance of AC is remarkable with an average of 86.5 % of 30 days experiment, despite small leaf size (~5 cm). The high growth rate of AC increases vigorously the leaf layer to form the dense foliage by overlapping each other in 3- and 4-leaf layers. Therefore, the coverage pattern and growth rate of the climbing plant trait are criteria to be prioritised. However, further study on more species and on relationship between plant traits and cooling effect performance of tropical climbers need to be undertaken.

4. Conclusion

Performance of selected tropical climbing plants in providing higher percentage of foliage coverage on GF is significantly remarkable. Percentage coverages for all species are above 50 % throughout the experiment timeframe. AC is performed significantly compared to other climbers. Coverage pattern and growth rate are two important traits to be prioritised in the plant selection. More species of tropical climbers should be conducted in further study, including relationship between plant morphology and cooling effect performance.

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