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Procedia Engineering 21 (2011) 34 – 41
Procedia Engineering
www.elsevier.com/locate/procedia

2011 International Conference on Green Buildings and Sustainable Cities

Thermal performance of biofacade with natural ventilation in the tropical climate

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Abstract

Facade and roof greenings enhance thermal comfort in building environment both indoor and outdoor by reducing heat transfer to and from building envelope. They shade buildings from solar radiation, absorb solar radiation for photosynthesis and evapo-transpiration, reduce solar reflection and re-radiation to atmosphere. Green façade and roof has been included as one of major green building evaluation criteria for many sustainable cities in the world nowadays. This research aims to study the use of climbing plants as vertical shading devices, "biofacade", for naturally ventilated building with windows facing west. Blue trumpet vine *(Thunbergia grandiflora*) was selected due to its fast growth and consistently full leave coverage. Two experiments were carried out to compare air temperature of a room with biofacade and a room without. Natural ventilation were added to both rooms and the thermal performances were compared. It has been found that biofacade performance increased when room air velocity was high from the case with natural ventilation. The room air temperature was reduced from outside ambient air temperature to the maximum of 9.93 °C, with an average of 3.63 °C during day time (9:00 a.m. - 8:30 p.m.). When air velocity was low, the temperature difference had maximum of 6.72 °C, average of 0.91 °C lower than normal room. At night (9:00 p.m. - 8:30 a.m.), however, biofacade had slightly higher air temperature than normal room and outside ambient air in both cases. Unexpectedly, leaves of the selected climbers did not obstruct wind when cross ventilation was provided and air velocity inside room with biofacade was higher than room without biofacade especially in the daytime. Besides, in tropical climate, air behind leaves always maintain lower temperature than ambient air temperature, which is different from research in temperate climate where air behind leaves can sometime obtain higher temperature. From the 2 experiments, the room temperature with biofacade reduced significantly but still could not reach comfort zone (22-28 °C) during the day time. However, the application can be recommended to use for pre-cooling the fresh air-intake of air conditioning systems, so it can help reduce cooling load efficiently.

Selection and/or peer-review under responsibility of APAAS

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1877-7058
doi:10.1016/j.proeng.2011.11.1984

Keywords : façade greening; biofacade; climbing plants; shading device; heat gain;thermal performance; energy efficient.

1. Introduction

Increasing green area to urban environment has been policy for sustainable cities, in order to reduce heat island effect and mitigate Carbon dioxide [1]. Unfortunately, high density city cannot allow enough open space for more green area. Greening the building by applying green roof or green facade are now becoming popular solutions [2]. There are guidelines to increase green area by occupying minimum space and can be counted as major credits for green building evaluation criteria, since it can improve thermal comfort and improve air quality. The application problems always come with cost of construction and maintenance.

It is widely known that façade greening can enhance thermal comfort for indoor environment as well as outdoor by shading buildings from solar radiation, reflecting and transmitting only a small amount of solar radiation into buildings. Unlike building materials, leaves absorb major part of solar radiation for photosynthesis and evapo-transpiration [3]. Thus, it can effectively reduce heat gain through building. The more leave coverage, the better thermal performance and energy efficient.

The early research about greening the building for passive cooling has been established for more than 20 years [3, 4]. The experiment was carried out on walls or pergolas covered with vines [5] as well as green roofs [1, 2]. The result proved the effectiveness of this passive cooling technique, though it was discovered that leaves can block ventilation and sometimes obtain higher temperature than ambient air in temperate climate [4]. In U.S.A., Canada, Germany and Japan, it has become building ordinance and incentive has been initiated strongly from government.

Since the decade of Environmental Crisis (2000-2010), research on plants' thermal performance were re-investigated on new techniques as well as innovation on green roofs and walls. Ip et al. [6] investigated a dynamic shading coefficient of deciduous climbing plants on glazed facade and found a method to calculate shading coefficient through image processing. Stec et al. [7] investigated the use of plants instead of blind in double skin facade and found a better performance in heat gain reduction. Wong et. al. [8] investigated thermal performance of extensive roof garden in Singapore and found significant effect in reducing heat gain through roofs .Recently, Wong et al. [9] also evaluated 8 types of vertical greenery thermal effect on surfaces and ambient temperature.

In Thailand, green facades or vertical gardens are also becoming popular landscape design for home and building for the main purpose of decoration rather than energy or environmental solutions. Ministry of energy encourages energy efficient law in terms of overall thermal transfer value and roof thermal transfer value (OTTV and RTTV) which can be applied by using insulated material, tinted or reflective glass and shading device. There is insufficient information in performance of plants in such area to suggest the application, and few researchers investigated this topic. Sunakorn and Yimprayoon [10] investigated thermal performance and CO_2 uptake ability of climbing plants façade in the tropical climate. Recently, Thailand Green Building Council just launched Thai's Rating of Energy and Environmental Sustainability (TREES), adapted from U.S.A.'s LEEDS that gives credits to the use of green roof and wall in Heat Island Mitigation section.[11]

This paper reports the study of thermal performance of vertical climbing plant shading, "biofacade", that applied on west facade of a real building, comparing with an identical room without biofacade. Natural ventilation was added in this experiment. Room temperature and air velocity were recorded in each case to compare the increasing performance with different conditions of ventilation. The results show practical information which can be recommended for energy efficient designs.

2. Methodology

In Thailand, though green facade has become popular since the successful installment of Patrick Blanc's "Vertical Garden" at Siam Paragon shopping mall, the system was not affordable to middle or low-income consumers. Climbing plants on trellis, the simplest system for green facade can be applied as insulation for solid wall and also shading device for window. However, it was not widely used nor the application was not well known for its energy efficient benefit.

2.1 . Plant selection

Different climbing plants were explored through its growth and leave coverage on 1 m x 1 m vertical frames. They were Blue trumpet vine (Thunbergia grandiflora), Ivy gourd (Coccinia grandis) and Mexican creeper (Antigonon leptopus). It was found that Blue trumpet vine grew very fast and gave a consistent density and full leave coverage through minimum pruning (Figs. 1a,1b,1c).

Fig. 1. (a) Blue trumpet vine ; (b) Ivy gourd ; (c) Mexican creeper

2.2. Measurement of thermal performance of "biofacade"

2.2.1 Test Facility

Blue trumpet vine was selected to plant on the rooftop residence of the Faculty of Architecture building using 2 ready-made plant box constructed with vertical steel frames and transparent net for plants to climb. The systems were placed 0.70 m from opened windows of one room which will be used as "test room" with "biofacade". Another room next to the test room is identical, but without any shading device, was used as "normal room" for comparison. Blue Trumpet Wine filled the frame within 3 months and climb 1 m higher than window height, protecting solar radiation from the west oriented room. The coverage was almost 90% and there were maximum of 4-5 layers of leaves. (Fig. 2)

Fig. 2. Test rooms with and without Biofacade

Both rooms are 4 m x 6 m , located in the middle of 4 identical rooms facing west. The roof was metal sheet with plaster cement board ceiling. There was one door for each room that open to the back corridor. Polystyrene wall (density 24 kg/m3) of 3 m x 3 m was built inside both rooms to cut down undesirable radiation from all sidewalls and roof, with 0.60 m x 0.60 m operable void for adjustable ventilation.

Two cases of ventilation were applied:

- C1. No ventilation by closing back door, 26th - 29th February 2008. (Fig.3.)
- C2. Natural Ventilation by opening back door. 1th - 4th March 2008. (Fig.4.)

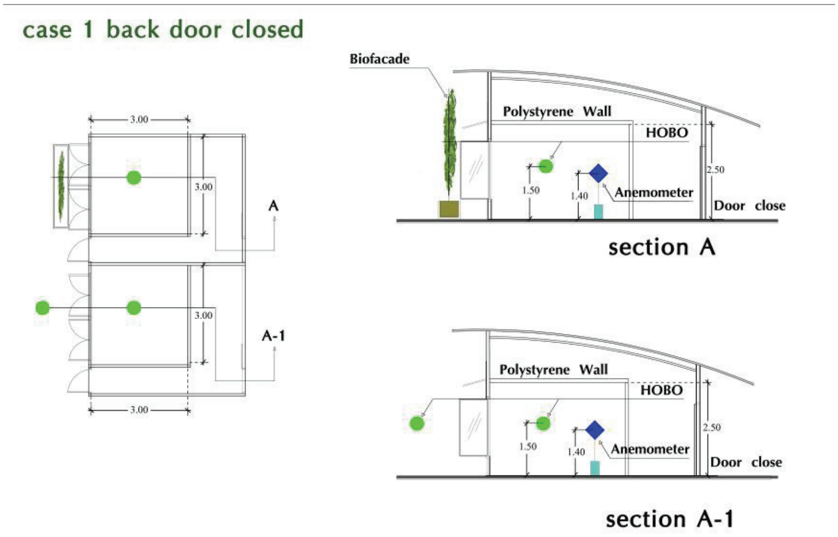


Fig. 3. Case C1 is assumed to be without ventilation by closing back door of the test rooms

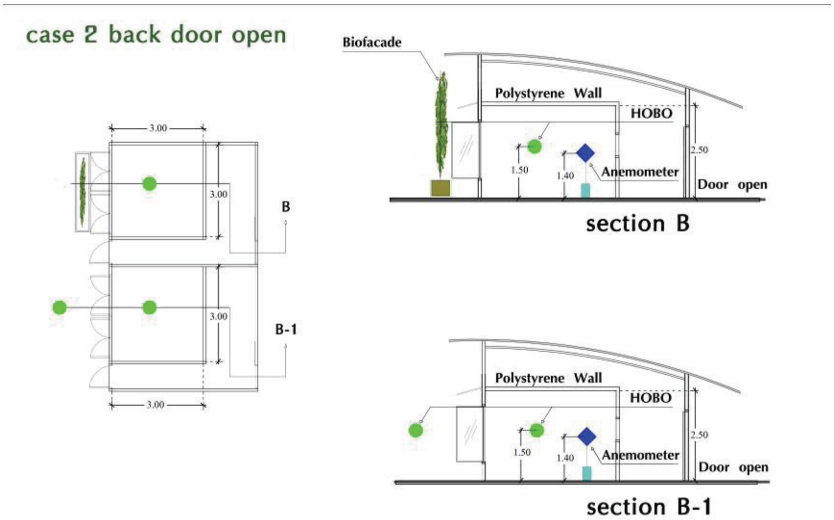


Fig. 4. Case C2 is assumed to be natural ventilation by open back door of the test rooms

2.2.2. Instrument and Parameters

Test parameters are room temperature, relative humidity and air velocity. Sensor specifications that were used with data loggers are as follows:

- Air temperature measurement (Hobo) range: -20°C to 70°C (-4°F to 158°F)
- Temperature accuracy: ±0.7°C at 21°C (±1.27°F at 70°F)
- RH Measurement (Hobo) range: 25% to 95% RH, accuracy: ±5% RH
- Contact temperature measurement range: -40°C to 100°C (-40°F to 212°F)
- Temperature accuracy: ±0.5° at 20°C (±0.9° at 68°F)
- Wind velocity measurement (Hot wire anemometer) range 0 -10 m/s, accuracy ±0.03 m/s.

Outdoor ambient temperature sensor was located in front of both rooms while indoor temperature sensors were hung inside both rooms at the same height of 1.40 m from floor. Hotwire probe for wind measurement was also located at the same height in front of 0.60 m x 0.60 m opening for adjustable ventilation

3. Test Results

Data was collected during 2 periods of 2ventilation cases. Each period lasted 4 days. Each day was divided into 2 sections: 9:00 a.m.-8:30 p.m. was considered daytime since ambient and indoor temperature started to rise and temperature of room with plant started to decrease at around 9:00 a.m. while 9:00 p.m.-8:30 a.m. was considered night time since indoor temperature started to rise higher than ambient temperature at around 9:00 p.m. Data were recorded every 30 minutes. Experiment time was at the beginning of summer, February to March 2008.

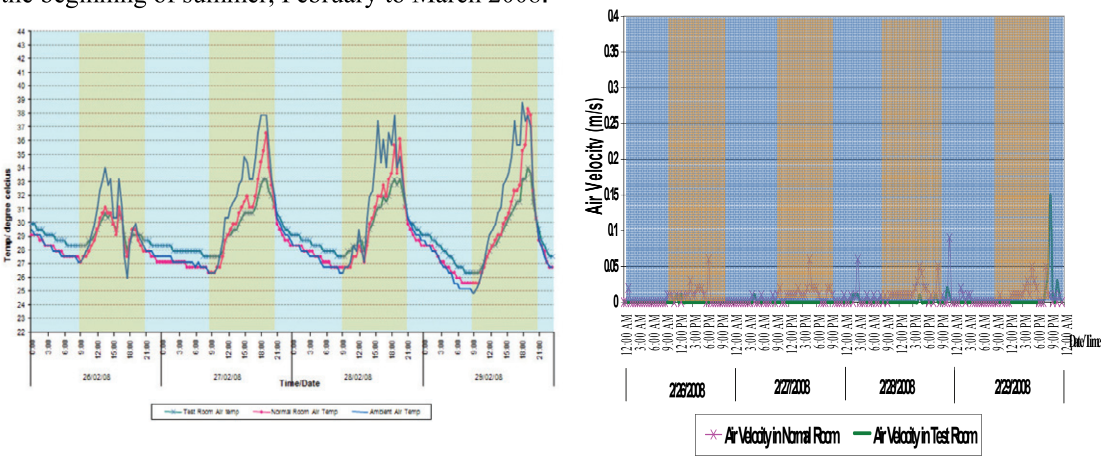


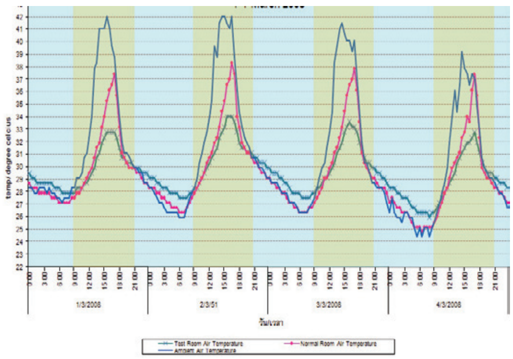
Fig. 5. (a) Temperature comparison of case C1 without ventilation; (b) Air velocity comparison of case C1 without ventilation

3.1. Outdoor ambient air temperature

Daytime average temperature (9:00 a.m. – 8:30 p.m.) in both cases has minor difference. C2 34.25 C and C1 32 C respectively. Nighttimes average temperature (9:00 p.m. - 8.30 a.m.) also has minor difference. C1 27.48 C and C2 27.44 C. (Figs.5a,6a)

3.2. Comparison of air velocity between test room and normal room in

In C1 with backdoor close, there was minor ventilation as air velocity was less than 0.05 m/s in normal room while no wind was recorded in test room.(Fig.5b) In C2 with back door open, there was natural ventilation in both rooms. Unexpectedly, test room with biofacade has higher air velocity of 0.05-0.35 m/s while normal room without biofacade has less than 0.05 m/s in the daytime.(Fig.6b)All nights there were minor air velocity in both rooms.



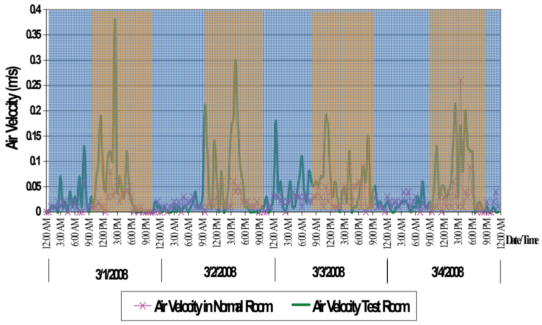


Fig. 6. (a)Temperature comparison of case C2 natural ventilation ; (b)Air velocity comparison of case C2 natural ventilation

When air velocity is higher than 0.05 m/s, leaves might become non-obstruct to air flow due to its movability enhanced by stronger wind. The small void between leaves contain higher air pressure due to lower temperature of air around leaves while there is a lower air pressure at back door. Thus, driving higher air velocity through room with biofacade.

3.3. Test Room and Normal Room Air temperature

During the daytime (9:00 a.m. – 8:30 p.m.), the temperature in both rooms rise and fall according to outdoor air temperature while test room (with biofacade) remain lower than normal room and outdoor air temperature in all cases. While outdoor air temperature started to rise at 9:00 a.m., the indoor air temperature of both rooms stay a little lower at the beginning and becomes more difference when outdoor air rose to the maximum at 4:00 p.m. – 7:00 p.m., then the difference started to decrease toward the nighttimes. (Figs.5a,6a)

At nighttimes, while outdoor air temperature decreased down to the minimum at 6:00 p.m. - 9:00 p.m., indoor air of test room decreased accordingly. From 9:00 p.m. test room temperature with biofacade becomes higher than normal room and outdoor air in both cases.(Figs. 5a,6a) It was noticed that leaves obstruct heat dissipation of test room, while in normal room heat dissipated easily without obstruction.

3.4. Comparison of Heat Reduction in 2 ventilation cases

During the daytime, the best thermal performance occurred in case C2 (natural ventilation and highest air velocity) where the difference of outdoor and indoor air reach maximum of 9.93   C, average of 3.63   C. The difference between test room and normal room is at maximum of 4.71   C, average of 0.89   C in the daytime.(Fig.6a)

In C1 (no ventilation and lowest air velocity) the difference of outdoor and indoor air is at maximum of 6.32   C, average of 1.65   C. The difference between test room and normal room is at maximum of 4.31   C, average of 0.33   C in the daytime.(Fig.5a)

4. Conclusion

It was proved that ventilation improved thermal performance of climbing plant shading in reducing daytime and nighttimes temperature. The higher air velocity increased the reduction of heat gain in the daytime, from C2 with natural ventilation. Leaves do not obstruct wind while air velocity is higher than 0.5 m/s, unexpectedly it even increased air velocity. The maximum difference between outdoor and indoor temperature is 9.93 C, average of 3.63 C from this case.

At nighttimes the increasing air velocity help dissipate heat from test room with biofacade and the difference came down to average of 0.71 C.

The application of biofacade thus has the best thermal performance in the daytime due to its shading, photosynthesis and evapo-transpiration. At night, on the contrary, biofacade did not help much in decreasing temperature, as it may obstruct heat dissipation. However ventilation could help solving this problem.

5. Discussion

Not all types of climbing plants will come up with the same result. Physical property of leaves will give different effects in air velocity and room temperature. Further experiment may be conducted with different kinds of climbers.

Blue trumpet vine has big round soft leaves that moves easily by wind flow. Though it covers well but the maximum layers will not be more than 4-5. The smaller and denser leaves may provide better thermal effect by increasing surface for evapo-transpiration.

This experiment was carried out in the beginning of summer. Though the thermal performance increased, indoor temperature in the daytime had not reached comfort zone (22 °C - 28 °C).The application of biofacade can better be applied to pre-cooling of the fresh air intake before air condition system. Not only energy efficient purpose, but it can also enhance air quality by absorbing CO_2 and dust particles. leaves

In tropical climate, air temperature affected by leaves are always lower than ambient air , while in temperate climate , it can be higher than ambient air and can perform like insulation in winter.

Relative humidity increase from plants occurred only in daytime while relative humidity of ambient air is the lowest. The increase of relative humidity is not significant (maximum of 6.8 %) give minor effect to thermal comfort. At night while relative humidity of outdoor air is the highest, the normal room had higher relative humidity than test room with leaves protected.

Acknowledgements

This research was funded by Kasetsart University Research and Development Institute, under the special research unit in Green Building Innovation, Faculty of Architecture, Kasetsart University. The research plan was collaborated with Dr. Kenneth Ip, School of Environment and Technology, University of Brighton.

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