IOP Conference Series: Earth and Environmental Science

Natural Brise Soleil: The Effects of Vegetation Shading on Thermal Environment of Residential Buildings in Hot and Humid Tropics

To cite this article: T S Mari *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **268** 012013

Natural Brise Soleil: The Effects of Vegetation Shading on Thermal Environment of Residential Buildings in Hot and Humid Tropics

T S Mari[1], S Kuppusamy[2], S Gunasagaran[3], S Srirangam[4] and F L Ang[5]

[1, 3, 4 & 5] Faculty of Innovation and Technology, Taylor's University, Subang Jaya, Selangor, Malaysia.
[2] School of Built Environment, University of Reading Malaysia, Iskandar Puteri, Johor, Malaysia.
E-mail: TamilSalvi.Mari@taylors.edu.my

Abstract. In hot and humid tropics, excess solar gain in buildings results in high cooling load. Shading is a common strategy used to protect the building's skin from excessive solar exposure. Vegetation shading is often used minimize the incident solar radiation and cool the building and affect the building's energy performance. Thus, the study present findings on effects of vegetation shading on indoor and outdoor thermal environment in the hot and humid tropics of Malaysia. The aim of the study was to assess the effects of vegetation shading on the thermal environment of urban housing. An experimental study was conducted to determine the effects of vegetation on two residential buildings of 2 1/2-storey of typical materials and construction. Findings from the study evidence that vegetation has significant effects in modifying the microclimate by shading and evapotranspiration process. The results show that the outdoor temperature of CS1 (with vegetation) is significantly lower (3.3ºC) in comparison with CS2 (non-vegetated) as the effects of vegetation shading. There is also a significant reduction of 3.4ºC in the indoor temperature compared to the outdoor at CS1. The results show that vegetation shading is an excellent passive cooling strategy for buildings, potentially improving thermal environment and conserving energy.

1.0 Introduction

Rapid development of urban housing in the cities areas is the major source of urban heat island [1]. Similarly, the increase in urban housing demand in Malaysia has increased the energy demand, be it pre-construction or operational energy is a significant factor in increasing the impacts of global warming [2]. Buildings consume significant amount of energy for cooling and ventilation to create the required thermal environment [3]. As a result, most of the environmental efforts in architecture is aimed at reducing operational energy associated with the cooling particularly in the tropics. In the tropics improving thermal discomfort by reducing the indoor air temperature through architectural design is a common energy conserving approach [4], and [22]. Residential buildings are particularly sensitive to the effect of shading since they are skin load dominated structures. Therefore, shading is a common strategy used to shelter the building's skin from solar exposure, reducing the amount of heat transmission and cool the indoors assist in energy conservation [5]. Solar shading is an essential requirement to be integrated into design particularly in the tropics [8], [7], and [6]. Natural or vegetation shading is often used minimize solar exposure, cool the building and improve the building's energy performance.

Vegetation is very effective in shading and reducing heat gain [5] and a promising solution for making buildings more energy efficient [1]. Therefore, the goal to minimize heat gain in buildings using vegetation shading should be the priority in architectural practice. Most of the studies on indoor thermal environment and energy efficiency focusses on manipulation of basic building design, ignoring the fact that use of vegetation can significantly modify thermal environment thus reduce the amount of energy consumed during operational phase of a building. However, there are considerable amount of studies that have revealed the significant effect of vegetation on outdoor temperature [10], and [12] - [17], whilst fewer studies have been conducted to understand the effects of vegetation on indoor and outdoor thermal environment mainly in different climatic zones [5], [11] and [22]. Nevertheless, relatively limited studies have investigated the effects of vegetation shading on indoor and outdoor temperature and RH through modification of immediate microclimate of urban residential buildings in Malaysia [17]. Therefore, the study aims to assess the effects of vegetation shading on indoor and outdoor thermal environment of two (2) residential buildings of 2 1/2-storey of typical materials and construction. The objectives of the study are to:-

- measure the indoor and outdoor air temperature and RH for both case study houses (with and without vegetation shading)
- determine the temperature and RH difference between the outdoor and indoor for both case study houses (with and without vegetation shading)
- evaluate the significance of vegetation shading in modifying the indoor and outdoor thermal environment by comparing the temperature and RH difference between both case study houses

The study also aims to raise the awareness of the designers on the effects of using vegetation as shading and its potential as passive strategy in energy conservation of residential buildings. The findings from the study offers insight into use of vegetation to modify the urban housing microclimate locally.

1.1 Natural brise soleil: Vegetation

Vegetation alters microclimate of a site primarily by reducing the temperature of their general vicinity by evapotranspiration, the process by which plants release water vapor [9], and [10]. Vegetation can lower the immediate air temperatures as much as 5 ℃ [5]. Thus, vegetation can be used as shading to assist in reducing surface and air temperatures through evapotranspiration. According to [11] vegetation planted strategically around buildings, can alleviate outdoor and indoor air temperature. Irina [12] conducted a series of experiments on bare and vegetation covered building walls during summer conditions in Chicago, reported that vegetation layer decreases the outdoor air temperature close to the façade between 0.8-2.1^{o}C lower compared to the bare facade. A study [13] investigated the role of vegetation shading in cooling the hot outdoor urban spaces in the tropics, reported a significant cooling of 2-5^{o}C compared to hard surfaced areas. Vegetation shading can subsequently decrease air temperatures by 1–5 ℃ [14]. Wong and Yu [15] reported a maximum of 4.01^{o}C difference between well-planted areas within the city are in Singapore, indicating strong relationship between the reduction of temperature and presence of large area of greenery. A field measurement and computer simulation [16] using different density of tree canopies of predicted an average air temperature decrease of 2.7^{o}C. Using trees shading as a passive strategy have shown significant decrease in cooling loads [22]. An investigation on trees shading using different types of foliage in the tropics reported the lowest outdoor and indoor air temperatures of 31.8 ℃ and 28.9 ℃ respectively, with a difference ranging between 3 to 6 ℃ at the hottest time of the day, through shading and creating a cooler microclimate around the buildings by evapotranspiration process[17]

The above literatures clearly describe the significance of vegetation shading in reducing urban heat and highlight the importance of considering the influence of vegetation on thermal environment and the advocacy for it use in urban areas, thus the study investigates effects of vegetation shading on indoor and outdoor thermal environment of local residential buildings of typical materials and construction

2.0 Methodology

Methods employed in the study were completed in two parts, first part was selection of site and case study houses to ensure similarity in architecture, construction, front faced orientation and yet is dissimilar in microclimate setting, where one house is has lots of mature vegetation and the other had none. The second part, was measurement of specific climatic parameters using data loggers, which was used to explain the effects of vegetation shading on microclimate and thermal performance of the case study houses.

2.1. Study site and climate

The experiment was conducted in Puchong, (3 °1' N Latitude and 101 ° 37' E Longitude). Puchong is a rapidly developing urban area in Malaysia. The site experiences tropical climate, hot humid with significant rainfall of 2360mm annually and the annual average temperature of 32^{o}C- 27.6^{o}C, while the mean annual RH of around 77%. Generally, the wind is light, with the mean monthly wind speed of less than 1m/s over the year in Subang Jaya, Malaysia (meters per second).

2.2 Selected case study houses.

The selected case study houses are of 2-1/2-story linked terraced intermediate units of typical urban prototypes. The purpose of the houses selection was to identify buildings with similar construction within the same location and both the selected houses faced the North direction (see figure 1 below). However, the selected houses are adequately dissimilar with the presence of vegetation around it. The open space in the front yard of the one of the houses is fully planted with mature vegetation that ranges from 3-15meters height. Shading devices for instance the roof overhangs shelters the front porch, windows, and doors from the hot sun during peak time of the day.

Figure 1. Visual of both case study houses, CS1 (with vegetation) and CS2 (non-vegetation)

These houses were constructed according to the standard plans and approved specifications by the local authorities. Both houses had very minimal renovations. The selected houses are constructed are constructed of reinforced concrete structure with exterior masonry walls and pitched roof covered by concrete tiles. The building materials and its thermal transmittance value (U-value) of the case study houses are as described in table 1. below.

Table 1. Thermal properties of building materials of both case study houses

Element Description	U value (W/m^2 K)
External wall of 114mm brick wall with 19mm thick cement sand plaster on both sides	2.62
Solid core timber door (35mm)	2.28
Window single glazing 3mm thick	5.82
Concrete roof tiles with aluminum foil paper insulation	1.82

The front facade of the selected houses face North, where the vegetation is planted in front yard of the case study house1 (CS1) whilst case study house 2 (CS2) is bare without any vegetation.

2.3 The scheduled measurement

The study was conducted during eight (8) days in the month of April, in Puchong, Malaysia during when the mean air temperature and RH was 29°C and 77% respectively, using data obtained from Subang Jaya Meteorological Station [18]. Site microclimate air temperatures stretched between 35oC (high) to 30.3°C (low) during the study period. The days were sunny with light precipitation mainly in the evenings after 19:00hours on most of the experimental days. The experiment was conducted from 9th to 15th of April 2018, the warmest month. The measurements were taken from 07:00 to 19.00 hours every day and the average of maximum temperature and RH at that time for each experimental day was then calculated and used in the analysis. The following climatic parameters were measured at 30minutes intervals for the eight days:

- Outdoor air temperature and RH within the roofed porch area of CS1 and CS2.
- Indoor air temperatures and RH of CS1 and CS2 at the center of ground floor

2.3.1 Outdoor (microclimate) measurements. The daily outdoor temperature (℃), and RH (%), solar radiation, and cloud cover for was acquired from Subang Jaya Meteorological Station (Latitude: 03° 07'N, Longitude: 101°33'E). Average solar radiation in the study was around 6.2 hours with per day with average of 4.2kW/m-^{2}, with the average mean cloud cover of around 7oktas

2.3.2 Indoor measurement. The measured interior spaces are occupied by not more than five people. Data was measured for eight days period only in the study however, these days are sufficient representation of the measured conditions. The Lutron HT-3027SD data loggers was used to measure the indoor temperature (°C) and RH. The data loggers were placed 1.5 meters off the ground in the center of the houses in the dining and-living room away from sources of heat, cold, moisture, and dryness.

2.3.3. Immediate outdoor-porch area measurement. To measure the external temperatures within the roofed car porch areas the data loggers (Lutron HT-3027SD) were placed 1.5meters off the ground in a shaded location that is protected from sources of moisture, heat, direct sunlight, and away from the windows. For greater accuracy, the data loggers were placed 0.30 metres away from the building's exterior wall on a flat surface where air moves freely.

2.4 Vegetation used for landscape and shading in the case study houses

Few types of vegetation are used for landscape in front yard garden of CS1, they are mainly Quisqualis indica (Quisqualis), Heliconia rostrate (Hanging Lobster Claw), Tabebuia rosea, (The Malaysian Sakura), and other green plants. The mature height of these plants ranges from 3-15meres. The Quisqualis is a climbing plant, with dense foliage that provides good green coverage. Quisqualis indica has the ability to reduce temperature between 0.5-2.5°C [19]. Whilst, the Tabebuia rosea is commonly planted along roadsides or in parks because of its shading properties [20]. The CS2 had no vegetation.

3.0 Results

3.1 The air temperature

The results derived for the both CS1 and CS2 are shown in figure 2 below. A comparative analysis was done using the measured data for CS1 and CS2 houses to determine the effects of vegetation shading on indoor and outdoor air temperature and RH. Differences in modification of microclimate with vegetation was shown in thermal environment of CS1 in comparison to CS2 (see Fig. 2). The average maximum outdoor temperature for the eight experimental days for CS1and CS2 was highest on day 4 (11th April) were 31.7°C and 35.7°C with the difference of 3.3°C. The difference of 3.3°C evidently shows the effects vegetation shading in reducing the outdoor temperature.

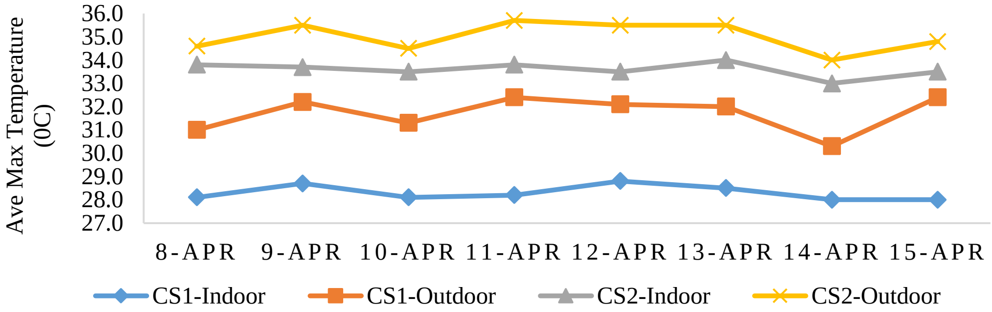

Figure 2. Comparison of average max. outdoor-indoor air temperatures of the houses (CS1 and CS2)

Additionally, the average maximum temperature of CS1 was 2.8ºC lower than temperature of Subang Jaya (average maximum of 34.5ºC), whist CS2 revealed a difference 0.5ºC higher temperature compared to temperature of Subang Jaya. Vegetation shading in CS1 lead to cool down the indoor and outdoor air, mainly during the daytime. The result conforms to the study findings in [14], which suggested that vegetation decreases air temperature by 1–5 ℃.

The average maximum indoor air temperature for the experimental days for CS1 is 28.3ºC, with the highest peak of 28.8ºC on day 5 (12th April). The indoor temperature was maintained within the range of 28.1 28.8ºC, whilst the temperature in CS2 ranged between 33ºC to 34ºC. The maximum indoor temperature of CS1 (28.3ºC) is lower compared to CS2 (33.6ºC) with a significant difference of 5.3ºC. The indoor temperature of CS1 was retained closer to the comfort zone as compared to CS2. This concurs with field study results on adaptive comfort by [21] which suggested that a comfort zone of 2–3◦C, either lower or higher from the ideal is acceptable with condition assisted by fans.

3.2 Measured relative humidity (RH)

The influence of vegetation on modifying the RH) within site microclimate is shown in figure 3. below. The vegetation around CS1 altered the outdoor RH compared to RH around CS2. The difference in outdoor RH between CS1 and CS2 ranged from 4.3-5.4% throughout the experimental days, with highest recorded on day 7 (14thApril) 76.3% and 72% for C1 and CS2 respectively, where the outdoor temperature was recoded the lowest for both case study houses. The mean RH at CS1 was 68.6%, with a difference of 5.7% compared to 62.9% at CS2. This shows although the vegetation increases the RH values around the house, the effect is seen clearly in decreasing of the temperature than actually modifying the RH.

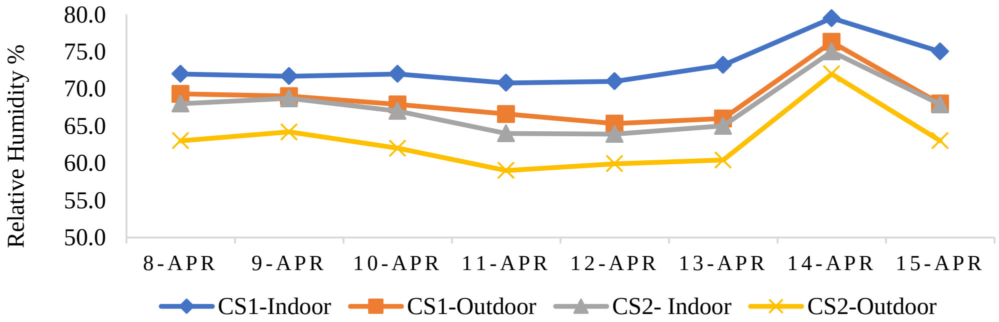

Figure 3. Comparison of average outdoor-indoor relative humidity (RH) of CS1 and CS2 houses

The measured indoor RH of both CS1 and CS2 was generally higher than their respective outdoor RH throughout the study. The indoor RH of CS1 was higher than the RH of CS2, where the RH in CS1 ranged between 70.8%-79.5%, whilst the indoor RH of CS2 ranged from 64%-75%. The indoor RH of CS1 was maintained at 73.2% whilst CS2 was at 67.4%, with the difference of 5.8%. The highest indoor RH was recorded on 14 April (day 7) for both case study houses, 79.5% and 72% for CS1 and CS2 respectively. The higher RH value was established in CS1 due to the presence of vegetation.

4.0 Discussion

4.1 Air temperature and RH

The results from the eight experimental days was used to understand the effects of microclimate modification towards outdoor and indoor air temperatures. Figure 1 and 2 above shows the relationship between air temperature and RH in case study houses, the lowest air temperature with the highest value of RH. CS1 with vegetation appears to have the decreased air temperature and increased humidity compared to CS2 throughout the eight experimental days. The lowest temperature was observed on day 7, 28°C and 30.3°C with increased RH on 79.5% and 76.3% with for indoor and outdoor respectively at CS1. Besides CS2 also recorded the lowest temperature and increased RH. However, the values for temperature was higher and the RH was lower compared to the values observed at CS1.

The average maximum outdoor temperature and RH for CS1 and CS2 was 31.7°C and 35°C, with the RH of 68.6% and 62.9% respectively. These values compared to the obtained temperature of 34.5°C for Subang Jaya, reveals a reduction of 2.8°C at CS1 and an increase of 0.5°C for CS2 (. The difference in outdoor temperature for CS1 and CS2 was 3.3°C. The results are due to the existence of vegetation in CS1 house that appears to have modified the immediate microclimate around the house, these results conforms to earlier findings by [9]. Whilst, the results for CS2 showed an increase in temperature of 0.5°C due to absence of vegetation and modification of the site with hard and dense surfaces, for instance concrete and tiles that reradiated the absorbed heat. Vegetation planted in CS1 complemented the existing shading provided by the building elements such as roof overhangs and reduce the outdoor air temperatures through the evapotranspiration process which increased the water content of the air, thus resulting in increased RH as suggested in [17], and [14].

The modification of outdoor microclimate of CS1 has further influenced the indoor thermal environment by further reducing the air temperature by 3.4°C, this result corresponds to suggestion in [16]. This outcome can be due to vegetation at CS1 not only shades the building walls but also cools the outside air by the evapotranspiration process before it enters the house, consequently increasing the RH indoor. The indoor temperature for CS2 is only 1.4°C lower than the outdoor as consequence of the hard and reflective building and ground surfaces. The RH of CS2 is 4.5% higher indoor, because of the moisture produced in household activities for instance cooking or running the shower stays locked up inside. The difference of indoor temperature and RH between CS1and CS2 was 2°C (lower) and 5.8% (higher), while the difference derived in outdoor results are 3.3°C and 5.7%. Findings from the experiment evidences that the presence of vegetation can lower indoor and outdoor temperature, while increasing the RH through the shading and evapotranspiration process.

5.0 Conclusion

The study generates insights by investigating the effects of using vegetation as shading on thermal environment of residential buildings in hot and humid tropics. Observations and field measurements have assisted understanding the effects of vegetation shading in modifying the immediate microclimate by lowering the outdoor and indoor temperature and RH. In hot-humid tropics, lack of vegetation around building is one of main reasons in increase of daytime temperatures. Findings from the study evidence that presence vegetation is significant in modification of the site microclimate by shading and evapotranspiration process. The results shows that the outdoor temperature of CS1 (with vegetation) is significantly lower (3.3°C) in comparison with CS2 (non-vegetated) as the effects of vegetation shading evident during the daytime. There was also a significant reduction of 3.4°C in the indoor temperature compared to the outdoor of CS1. Therefore, the study suggest that there are potential savings in energy associated building cooling when vegetation is used to shade the external surfaces of buildings. This study also suggests the need to create thermally more comfortable spaces to accommodate day living in residential buildings, as the ground level where the kitchen, dining, and living rooms are used most of the time by occupants. The study suggest the need to plant appropriate types vegetation around the urban housing areas to lower the surrounding temperature to provide shade. The cooling effects of vegetation in tropics is to be taken advange of by designers and occupants to create a more comfortable thermal environment that would substantially lower the energy loads and urban heat island issues.

References

[1] Raji B, Tenpierik M J and van den Dobbelsteen A 2015 Renewable *and Sustainable Energy Reviews* **45** 610-23
[2] Mari T S, Kuppusamy S and Gunasagaran S. 2018 *Proc. of 2nd Malaysia University, Industry Green Building Collaboration Symposium (MU-IGBC)*
[3] Yang L, Yan H and Lam J C 2014 *Applied Energy* **115** 164-73
[4] Harimi D, Ming C C and Kumaresan, S 2015 *Energy and Buildings* **88** 276-87
[5] Ahmadkhani B 2011 *IJTPE J.* 72-9
[6] Emmanuel M 2005 *An Urban Approach to Climate-Sensitive Design: Strategies for the tropics*1st ed (New York: Spon Press)
[7] Yeang K *Ecodesign* 2006 (Chichester: Wiley)
[8] Grimmond C *et al* 2010 Procedia Environmental Sciences vol. 1 ed M V K Sivakumar *et al* pp 247-74 (Amsterdam: Elsevier)
[9] Hes D, Dawkins A, Jensen C and Aye L Modelling method to assess the effect of tree shading for building simulation *Proc. of Building Simulation 2011: 12th Conf. of Int. Building Performance Simulation Association* Sydney pp 161-8
[10] Shashua-Bar L, Pearlmutter D and Erell E 2009 *Landscape and Urban Planning* **92** 179-186
[11] Morakinyo T E, Balogun A A and Adegun O B 2013 *Urban Climate* **3** 76-93
[12] Susorova I, Azimi P and Stephens B 2014 *Building and Environment* **76** 113-124
[13] Kang H K, Syed Fadzil S F and Shuib N A 2009 *Int. Sym. in Developing economies*: *Commonalities among Diversities* pp 245-50
[14] Akbari H, Pomerantz M and Taha H 2001 *Solar Energy* **70** 295-310
[15] Wong N H and Yu C 2005 *Habitat International* **29** 547-58
[16] Shahidan M, Jones P, Gwilliam J and Salleh E 2012 *Building and Environment* **58** 245-57
[17] Misni A, Baird G and Allan P 2013 *International Review for Spatial Planning and Sustainable Development* **1** 29-48
[18] *Subang Jaya Weather Data* 2018 (Petaling Jaya: Malaysian Meteorological Department)
[19] Chu L M 2014 Vertical Greening-1st Seminar on Urban Greening in Hong Kong Online: http://hkihs.org/legacy/urban_tree_seminar2014/4_Vertical_Greening-Opportunities_and_Challenges_LMChu%20.pdf
[20] NParks Flora & FaunaWeb 2018 Singapore Tropical Native Species Reforestation Information Clearinghouse (TRIC) Online: http://reforestation.elti.org/resource/374/
[21] Nicol F and Parsons K 2002 *Energy and Buildings* **34** 529-32
[22] Abdel-Aziz D M 2014 *J. Architectural Eng. Technol.* **03** 135