607: Study on outdoor thermal comfort in hot and humid context

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Abstract

In tropical context, the conditions of thermal comfort in outdoor environments extremely affect the people's satisfaction towards usage of open areas. Hence, creating acceptable thermally comfortable outdoor areas could be considered as one of the significant strategies for enhancing the quality of urban life and achieving a sustainable city in tropics. Therefore, this paper elucidates the thermal conditions of outdoor spaces in Malaysia to identify influential environmental parameters affecting thermal comfort of humans. Evaluating thermal comfort conditions highlights the noteworthy effect of T_{mrt} (mean radiant temperature) on the variation of the thermal index, *PET* (Physiologically Equivalent Temperature) in hot and humid conditions. Furthermore, it is demonstrated that plants and vegetation surfaces, shade structures, characteristics of areas and design of built environment are substantially influential in contributing towards thermally comfortable outdoor environments. The findings illustrate that high shading level leads to a reduction in the PET values of an area (with a maximum value of about 18°C) by protection from direct solar radiation.

Key words: Outdoor Thermal Comfort, Tropical Context, Physiologically Equivalent Temperature

1. Introduction

Nowadays, outdoor spaces are considered as the integral constituent of urban development in order to provide the opportunities for recreational activities. Thereby, thermal comfort of outdoor spaces is one of the substantial issues which must be highly considered within the design process [1]. Likewise, it is demonstrated that microclimatic characteristics of outdoor spaces significantly affect the usage of such spaces. Correspondingly, researchers argue that the unconscious responses of user to the microclimatic conditions of outdoor environments affect the usage of these open spaces [1,2]. Nevertheless, despite the crucial role of thermal conditions of outdoors spaces, it is argued that there are very limited studies on the thermal comfort conditions of outdoors spaces comparing to indoors. This inadequacy is due to the wide range of factors affecting outdoor environments. [3].

On the other hand creating thermally comfortable outdoor environments considerably affects the comfort perception of users within indoors spaces. Accordingly, the uncomfortable conditions in outdoor environments lead to growing need for comfortable indoor ambiance [4]. Correspondingly, it is vital to focus on the thermal conditions of spaces in order to create comfortable microclimatic for outdoor environments as an integral approach towards future urban design implementations. Thus, the objective of this study is to evaluate thermal comfort conditions of outdoor spaces in tropical climate of Malaysia.

2. Materials and Methods

Basically, climatic characteristics and weather data provide a perspective of area and define the specific attributes of climatic conditions. In addition, thermal comfort studies have expressed that four main meteorological parameters, namely, air temperature, air humidity, radiation fluxes and wind speed can characterize the thermal environment and influence thermal comfort sensation of people [5]. In view of that, Malaysia, as a tropical country near the equator, encounters abundant sunshine and therefore solar radiation while the average sunshine is about six hours per day. According to Malaysian Meteorological Department [6], one of the considerable features of the climate of Malaysia is the uniform temperature. Malaysia is subjected to constantly high air temperature, humidity and heavy rainfall throughout the year. In addition, light seasonal wind causes to uncomfortable thermal environments, which would be worsen without the cloudy sky conditions during the day [6].

Due to this specific climatic conditions and weather issues, there is a need to investigate thermal conditions of outdoor environments in order to create more comfortable spaces for public use. Hence, this paper is a part of a field study conducted in the campus of UPM (*University Putra Malaysia*) focusing on the measurement of microclimatic parameters in order to evaluate thermal comfort conditions of shaded outdoor environments in hot and humid context of Malaysia. Meanwhile, during this study, the thermal comfort conditions of selected areas would be calculated using Physiologically Equivalent Temperature (PET) as an appropriate thermal index to investigate the thermal components of outdoor environments [7,8,9]. PET values which are presented in degrees Celsius were calculated using Rayman model [10].

3. Results and Discussions

The field measurements of Study Area A and B were performed on 7 and 8 April 2010, respectively, while the microclimatic data were recorded from 9 am to 5 pm. The Study Area A positioned at the central segment of UPM campus while Space I (A) is provided with a translucent, green color, polycarbonate roofing on the top and surrounded by single story buildings and Space II (A) has a pergola covered by plants and vegetation near a multi-story building. The Study Area B has a central courtyard surrounded by buildings. While, the Space I (B) was extremely near a multi-story building and Space II (B) was located at the central section of the courtyard. Since the field measurements were conducted within two study areas during the two days, the thermal conditions of each area were examined separately. Hence, the components of thermal conditions in Space I and Space II of Study Area A and B are represented in the following sections.

3.1 Study Area A, Space I and Space II

In terms of measurement results for Study Area A, most of the time, the value of air temperature (Ta) in Space I was higher than the Ta values of Space II. The lower value of Ta in Space II was due to the presence of vegetation leading to reduce air temperature through transpiration and evaporation process [11]. The findings indicate that approximately, the air temperature varied between 29 °C to 38 °C in Space I, while 28 °C to 36 °C temperature was recorded in the Space II. Furthermore, it is found that through the measurement time, higher air temperature normally occurred between 11 am to 4 pm which was during the afternoon hours (Average Ta difference between Space I and II from 11 am to 4 pm: 2.5 °C). As expected, the values of relative humidity (RH) in Space II which has a pergola shaped filling plants were recorded slightly higher than the measured RH values in Space I. It was observed that high amounts of humidity happened in the beginning and the end of the measurement periods which was from 9 am to 11 am and 4 pm to 5 pm respectively where it was recorded around 60 %- 80 %. Correspondingly, the values of vapor pressure in Space I were mostly higher than Space II while the most significant differences were recorded during the noon hours (11 am-3 pm). Meanwhile, the variations of wind speed values within Study Area A were between 0.1 m/s to 1.5 m/s in the measurement period. It is observed that the values of wind speed were almost higher in Space II during the data collection periods although, decreasing values and overlapping two curves occurred infrequently.

Furthermore, the value of mean radiant temperature (Tmrt) was estimated from measurement of globe temperature. The Tmrt was estimated using air temperature, globe temperature and wind speed based upon ISO standard 7726 [12]. The results show that differences between estimated values of mean radiant temperature in the two locations were very small in the beginning and the ending hours of measurement procedure. However, during the period of time between 11 am to 4 pm, there was a considerable difference between the values of Tmrt in Space I and Space II. Based on the position of sun in the sky during these hours, the selected locations especially Space I, perceived a large amount of solar radiation at the warmest period of the day. Meanwhile, Space II which was protected by plants shade showed lower amplitude, with a maximum value of about 18 °C lower (Average Tmrt difference between Space I and II from 11 am to 4 pm: 13 °C).

With regard to comparison between air temperature and mean radiant temperature, it can be observed that the difference between the values of Ta and Tmrt during the middle hours of measurement period were bigger than during the beginning and ending hours (See Fig 1). Due to the high amount of solar radiation, especially in Space I, there was a considerable difference between the values of recorded Tmrt and Ta. Meanwhile, the partly cloudy conditions significantly decreased the level of solar radiation at some indefinite time. In addition, the effect of cloudiness on the fluctuation of measured Tmrt is clearly illustrated.

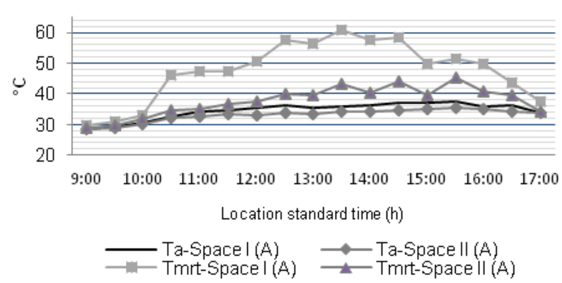


Fig 1. Variation of Ta and Tmrt Study Area A, Space I and Space II

3.2 Study Area B, Space I and Space II

During the data collection procedure, the values of air temperature gradually reached to pick during the noon hours (from 11 am to 3 pm). In contrast, the recorded values of air humidity decreased dramatically in the mentioned period. At Study Area B, the variations of air temperature, humidity and vapour pressure in Space I were recorded very close to Space II and the overlapping curves were occurred generally (i.e., Average Ta difference between Space I and II: less than 1 °C). Hence, there is no significant difference between two locations regarding the air temperature, humidity and vapour pressure values. However, before noon hours (9-12 am) the Ta values of Space II (central pergola) were recorded lower than Space I. Therefore, Space II covering by plants was slightly cooler before 12 pm in contrast to the air humidity of the mentioned location which was higher than Space II.

Furthermore, it was observed that the values of wind speed in Space II were considerably higher than Space I during the data collection process. Space II is a pergola situated at the central section of a courtyard while being in front of the openings of that area. The higher value of measured wind speed in Space II represents the crucial role of pergola location. Moreover, this fact demonstrated the effect of different height of surrounding buildings on the air flow in the central point of the courtyard [13]. Nevertheless, the measured values were matched with the light and variable wind conditions of Malaysia while, almost varied from 0.3 m/s to 0.9 m/s in Space I and recorded from 0.4 m/s to 1.6 m/s in Space II.

The mean radiant temperature in Space II was higher than Space I during the measurement procedure. Meanwhile, the variety of Tmrt in Space I occurred in a short range in comparison with Space II (Average Tmrt difference between Space I and II from 11 am to 4 pm: 8 °C) as represented in Fig 2.

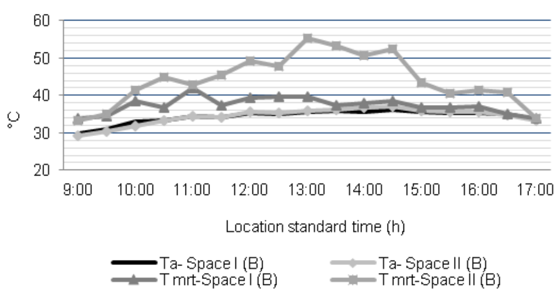


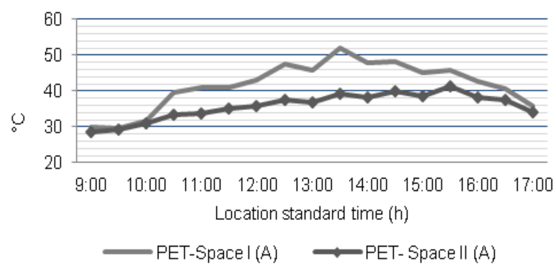
Fig 2. Variation of Ta and Tmrt Study Area B, Space I and Space II

It can be observed that there was a considerable difference between the measured mean radiant temperatures of the two locations during the noon time (with a maximum value of about 16 °C). The lower Tmrt values of Space I was due to the protection of area from direct solar radiation by solid roof of gazebo and the shade of nearby buildings. However, the wood cover of the pergola with plants could not completely protect the area from high level solar elevation especially during the noon hours.

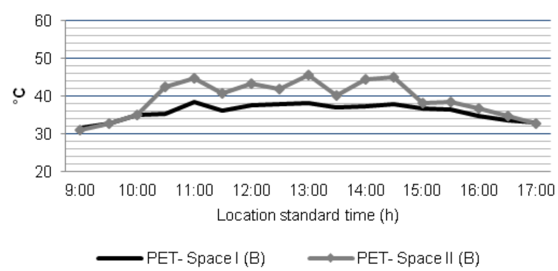
Regarding the comparison between the values of air temperature and mean radiant temperature in Study Area B, it can be observed that the difference between the values of Ta and Tmrt were smaller in the early morning and late afternoon than that of during the noon hours. As a result of high amount of solar radiation in central pergola (Space II, B), there was a significant difference between the values of Tmrt and Ta.

3.3 Calculated thermal conditions (PET)

Finally, PET values for both locations were evaluated according to the thermal comfort classification for (sub)tropical regions [1]. The results present that an acceptable range of thermal comfort (less than 34 °C) only existed during the early morning (9-10 am) and late afternoon (4-5 pm). However, the duration of acceptable thermal conditions extended from 10 to 11 am in the locations with high shading level (See Fig 3). The study also found that the time period of 11 am to 4 pm is considered having the lowest level of thermal comfort due to the high amount of solar radiation. It is essential to note that the thermal measurement of this study was based upon the daytime period (9 am- 5 pm) which is considered as the peak hours of the worst conditions.



(a)



(b)

Fig 3. Variation of calculated PET,
(a) Study Area A, Space I and Space II,
(b) Study Area A, Space I and Space II

As illustrated, the recorded values of air temperature (Ta) showed very small differences between the selected locations (with a maximum value of about 3 °C) although there was a considerable difference in thermal comfort conditions and their corresponding PET values (with a maximum value of about 18 °C) between the areas. It is demonstrated that, during the measurement process, the variation of the thermal index PET was mostly affected by Tmrt rather than Ta.

Hence, this fact verifies and approves that air temperature alone is inappropriate indicator for the evaluation of thermal comfort in outdoor spaces. Meanwhile, these results complement the finding of previous studies [1,13,14] indicating the stronger effect of mean radiant temperature on thermal comfort values than air temperature in an outdoor environments within the hot climatic conditions. It should be noted that, air flow can decrease the values of PET although, solar radiation play more important role than wind speed when calculating PET. The findings also illustrate that the use of trees and vegetations lead to a reduction in the PET values of area by protection from direct solar radiation.

Correspondingly, shading is the noticeable characteristic of the vegetation that leads to a moderate reduction in the Ta while the value of mean radiant temperature is strongly reduced [1,2,5,11]. Accordingly, the locations which are protected by the shade of surrounding buildings and plants show tendency to be slightly cooler than the others due to their lower exposure to direct solar radiation. Hence, high shading level is required in outdoor environments to increase thermal comfort and extend the continuity of the acceptable thermal conditions during the day.

4. Discussion and Conclusion

Consequently, it is argued that the use of plants and vegetation surfaces, the circumstances of location to be provided with shade of surrounding objects and suitable shade structures are substantially influential to create comfortable comfortable outdoor spaces. Evaluating the thermal conditions highlight the important effect of Tmrt on the variation of the thermal index PET especially during the noon time. As elaborated in the field measurement analysis, consideration of the aforementioned issues increases the duration of acceptable conditions within outdoor spaces. Thereby, it is concluded that the outdoor spaces must be created in accordance with the climatic conditions of each particular region to enhance the quality of outdoor life. It is recommended to architects, planners and urban designers to consider the respective facts in the design process of shaded outdoor spaces in order to achieve the thermal comfort level specifically in hot and humid climate.

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5. References

1. Lin, T., A. Matzarakis, RL. Hwang, (2010). Shading effect on long-term outdoor thermal comfort. *Building and Environment*, 45(1): p. 213-221.

2. Makaremi, N., E. Salleh, M.Z. Jaafar, A.H. Ghaffarian Hoseini, (2012). Thermal Comfort Conditions of Shaded Outdoor Spaces in Hot and Humid Climate of Malaysia, *Building and Environment,* 48: p. 7-14.

3. Nikolopoulou, M., S. Lykoudis, (2007). Use of outdoor spaces and microclimate in a Mediterranean urban area. *Building and Environment*, 42(10): p. 3691-3707.

4. Ahmad, K. S., (2003). Comfort in urban spaces: defining the boundaries of outdoor thermal comfort for the tropical urban environments. *Energy and Buildings, 35:* p. 103–110.

5. Gaitani, N., G. Mihalakakou, M. Santamouris, (2007). On the use of bioclimatic architecture principles in order to improve thermal comfort conditions in outdoor spaces. *Building and Environment*, 42(1): p. 317-324.

6. Malaysian Meteorological Department, [Online], Available: http://www.met.gov.my [7 April 2009].

7. Mayer, H., P. Höppe, (1987). Thermal Comfort of Man in Different Urban Environments. *Theoretical and Applied Climatology*, 38: p. 43-49.

8. Höppe P., (1999). The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology*, 43: p. 71-75

9. Matzarakis, A., H. Mayer, M.G. Iziomon, (1999). Applications of a universal thermal index: physiological equivalent temperature. *International Journal of Biometeorology*, 43: p. 76-84.

10. Matzarakis, A., F. Rutz, H. Mayer, (2007). Modelling radiation fluxes in simple and complex environments—application of the RayMan model. *International Journal of Biometeorology,* 51(4): p. 323-334.

11. Streiling, S., A. Matzarakis, (2003). Influence of singular trees and small clusters of trees on the bioclimate of a city – a case study. *Journal of Arboriculture,* 29: p. 309-316

12. International Standard ISO 7726, (1998). Ergonomics of the Thermal Environment-Instruments for Measuring Physical Quantities. *International Organization for Standardization,* Geneva, Switzerland.

13. Herrmann, J., A. Matzarakis, (2012). Mean radiant temperature in idealized urban canyons – Examples from Freiburg, Germany. *International Journal of Biometeorology*, 56: p. 199-203.

14. Fröhlich, D., A. Matzarakis, (2011). Hitzestress und Stadtplanung - Am Beispiel des „Platz der alten Synagoge“ in Freiburg im Breisgau. Gefahrstoffe – *Reinhaltung der Luft,* 71: p. 333-338.