Thermal comfort differences between polycarbonate and opaque roofing material installed in bus stations of Malaysia

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Abstract

Bus shelter as a semi-outdoor space protects individuals from direct sun light, rain and wind. The roofing material of a bus stop has extreme influence on environmental and subjective conditions of persons within this space. In this study, the principal concentration is distinguishing the differences between installation of Polycarbonate plastic roofing material and that of opaque protection cover as two widespread roofing materials in obtaining human thermal comfort in equatorial climate of Malaysia. Hence, two bus stops, one covered by Polycarbonate translucent plastic and one with opaque concrete-based tile, were selected to evaluate their inner thermal comfort condition by measurement of four main microclimatic parameters (i.e. air temperature, wind velocity, humidity and mean radiant temperature) as well as subjective survey in a university campus using the Physiological Equivalent Temperature (PET) as thermal index. The study found that the Polycarbonate roofing material is not appropriate material for permanence in bus shelters of Malaysia neither objectively nor subjectively comparing with opaque protective cover. Additionally, it was revealed adoption greatly impacts individual thermal perception which should not be neglected in the examination of thermal comfort in non-indoor spaces.

Keywords: human thermal comfort, roofing materials, adaption, PET

Introduction

Concentration on assessing the quality of outdoor and semi-outdoor spaces due to rapid urbanization and climate changes has been raised in recent years. Indeed, quality of non-indoor environment greatly influences human contentment and performance, number of users and socio-economic status (Johansson, 2006). Of many factors affecting the quality condition of such places, thermal comfort is outstanding specifically in tropical climate.

According to study (Chun, & Kwok, 2004), semi-outdoor spaces are categorized into three parts. The first is located inside a building with interplay with outdoor environment. The second is connected to building with a cover protection. Finally, the last is complete placed in outdoor with a canopy in order to prevent persons from direct sun light. The most frequent semi-opened spaces in urban streets are belonged to the third category.

Bus stops are classified as semi-opened spaces that provide a passing circumstance for people. Hence, the experimented environmental condition under these locations is significant for exposed pedestrians who are not covered against the microclimatic factors. Therefore, microclimatic condition under bus stops affects thermal sensation of passengers. Although the evaluation of human thermal comfort condition underneath the bus shelter is consequential, the number of studies mainly focusing on above mentioned context is few.

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Among many elements of designing bus stops, the roofing material has profound effects on human thermal comfort. Selection of protective cover for bus shelters can alter the amount of absorbed long and short wave radiation by passengers' body. In this study, the differences between installation of Polycarbonate plastic roofing sheet and likewise opaque material as two common materials for performance in bus stops' roof in terms of thermal comfort of people are examined.

The usual procedure to evaluate thermal condition of semi-outdoor spaces is to statistically correlate the individuals' thermal sensation along with measuring the air temperature, air velocity, relative humidity and mean radiant temperature as the four main microclimate parameters (Chun, & Kwok, 2004; Pitts, & Bin Saleh, 2007). Even though assessing thermal comfort using modeling instead of experimental method is challengeable because it includes numerous basic research concepts, some studies conducted to evaluate thermal comfort condition in semi-opened spaces by the implementation of modeling (e.g. Turrin *et al.*, 2012; Ghaddar *et al.*, 2011).

One the primary study which mainly focused on the assessment of human thermal comfort within bus shelters was the study by Lin *et al.* (2006) who examined the role of passive design strategy in thermal comfort in Taiwan. They found that better covered bus stops prepare more comfortable thermal condition for passengers underneath these semi-outdoor spaces due to their ability to block more amount of solar radiation. Likewise, in the study by Metje *et al.* (2008), the pedestrians' comfort level in outdoor and semi-closed spaces at the university campus was evaluated conducting a field measurement a questionnaire survey concurrently. They found that wind speed and air temperature affect = human thermal comfort. However, it was difficult for respondents to distinguish the role of solar radiation and humidity in thermal comfort. They confirmed that in addition to microclimate parameters, subjective adaption extremely influences human thermal comfort. Similarly, in the research by Hwang and Lin, (2007), six distinctive semi-open locations were investigated in order to discover the thermal comfort demands for inhabitants in semi-closed areas. It was discovered in contrast to dwellers of easily restrained environments, inhabitants of hard conditions are more comfortable at higher temperature. Furthermore, they expressed that the potency of global radiation to modify the human thermal sensation is more powerful in comparison to air movement. Finally, they concluded that in hot and humid climate, enhancing wind speed and diminishing the amount of direct sun light in design concepts, can impressively improve the comfort level of individuals in semi-outdoor spaces.

Despite the interest of experts to assess the environmental comfort in tropical zones has been enhanced in recent years because of people's continuous involvement in the monotonous climate condition, the number of studies assessing thermal comfort conditions of outdoor and semi-closed in hot-humid climate is few (Johansson, & Emmanuel, 2006). Moreover, many researches which have been conducted in tropical and subtropical climates are concentrated on outdoors. Assessing thermal comfort conditions of semi-closed spaces is essential in order to comprehend the quality of such locations in tropical districts. Consequently, this study focuses on assessing human thermal comfort within bus stops with Polycarbonate plastic roofing material versus opaque protection cover.

Materials and methods

Study area

Malaysia is crescent-shaped that consists of two parts; Peninsular Malaysia and East Malaysia. This country is located in the South-East of Asia near to the equator and is separated by the South China Sea. The geographical coordinate lies on latitude 2° 30′N and longitude 112° 30′E (Islam *et al.*, 2011). Malaysia has a warm and humid climate throughout the year. However, it consists of wet and dry seasons, caused by Southwest and Northeast monsoon (Sanusi *et al.*, 2012). It has a yearly mean air temperature of about 27°C and relative humidity (RH) of 70–90% throughout the year (Sabarinah, & Hyde, 2002). Moreover, metrological data indicates that monthly mean of maximum air temperatures ranges from 33.5 °C in March and April to 31.9 °C in December, while monthly mean of minimum temperatures ranges from 23.1 °C in January to 24.3 °C in May.

This study was conducted at University Putra Malaysia (Latitude 3° 00′ N, Longitude 101° 45′ E) in three study areas. Study area A was covered by white Polycarbonate plastic roofing sheet and located near two stories buildings. It was oriented to the south and covered by an industrial concrete-based tile. As there was no effective shading casted by trees of buildings around the aforementioned place and consequently, sunlight could easily penetrate through the apportioned shade. Study area B was roughly 600 meters far from location A, and its orientation was similar to that of study area A. It had a white protective cover and the structure was metal with red color. Current study was restricted to 5 meters around the study areas as the regions of examination. Study area A and B were picked out to understand the differences between Polycarbonate roofing sheet as well as opaque material, while study area C was chosen as a control point to compare the distinct conditions of a place with or without Polycarbonate roofing sheet. By consequence, study area C was located near study area A in order to have the ability to compare a place shaded with Polycarbonate shield and a location without it as displayed in Figure 1.

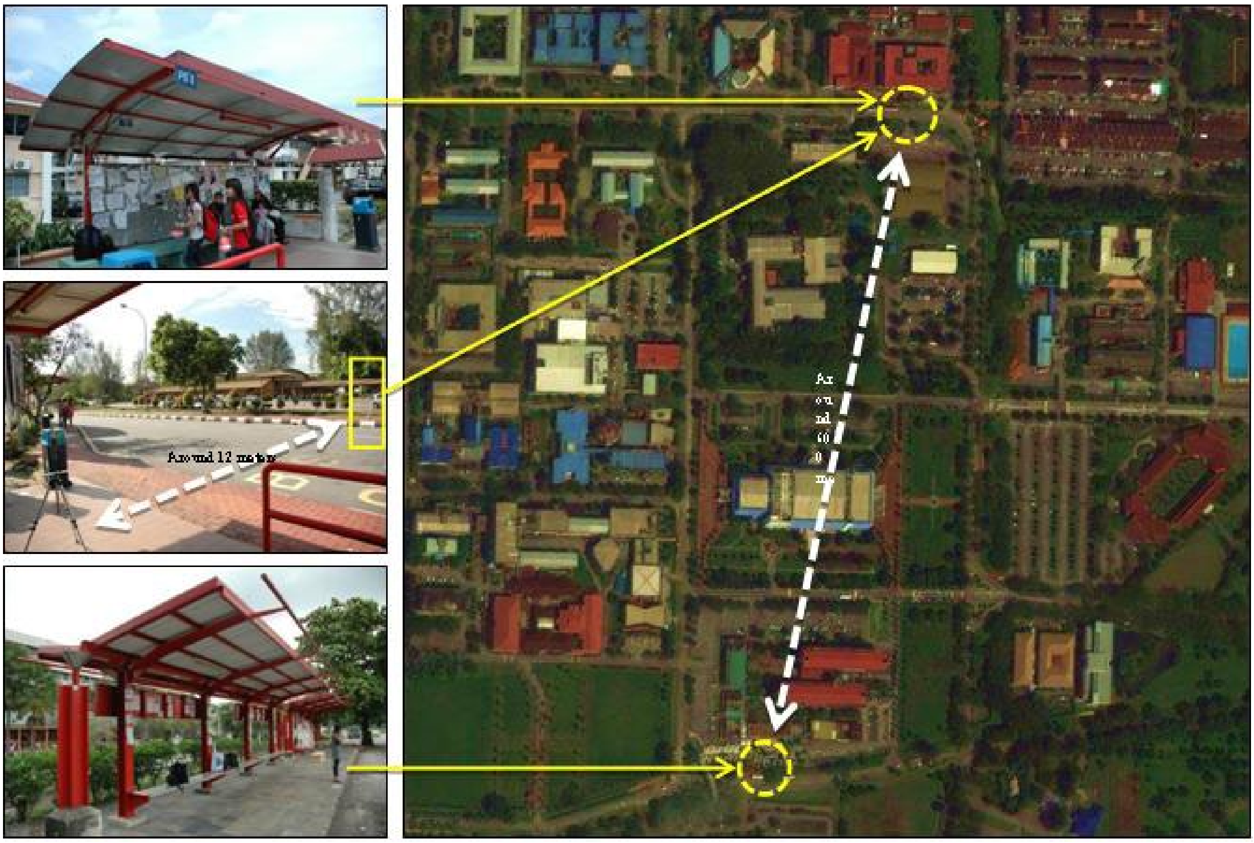

Figure 1. (A): Study area A, (B): Study area C and its distance from study area A, (C): Study area B, (D): Location of all the study areas and the distance between study areas A and B.

Physical measurement

A moveable mini-weather station named Delta Ohm data logger (HD32.3 device) (Delta Ohm SRL, 2009) was positioned in 1.1 m above the ground in order to save the values of air temperature (Ta), relative humidity (RH), wind velocity (v) and mean radiant temperature (Tmrt). The amount of cloud cover was acquired from the nearby metrological station. The measurement procedure and the instrument were in agreement with ISO 7726 (International Standard ISO7726, 1998) and it was set to record data at 10-min intervals between 9:00 AM and 4:00 PM. The selected measurement periods were five days in April 2012 (from 23 to 27 April) as well as five days in May 2012 (from 14 to 18 May). It was needed to record the values of globe thermometer temperature (°C), the air temperature (°C), and the air speed (m/sec). These were measured close to the globe thermometer for approximation of the average radiant temperature. Subsequently, the instrument could estimate the value of Tmrt automatically.

Thermal comfort index

Previous studies proposed OUT_SET and PET as the indices primarily designed to analysis human thermal comfort in open and semi-opened environments (Spagnolo, & de Dear, 2003). The current study implemented the PET as an appropriate thermal index for evaluating thermal comfort condition in equatorial zone. By definition, PET is "the air temperature at which, in a typical indoor setting (air temperature = mean radiant temperature, relative humidity = 50 %, wind speed = 0.1 m/s), the heat budget of the human body is balanced with the same core and skin temperatures as those under complex outdoor conditions" (Höppe, 1999). There are numerous benefits for carrying out the PET to appraise the thermal condition of outdoor and semi-outdoor spaces. The ability to help people for comparing their own experiences with real thermal condition (Höppe, 1999), make modern human-bio meteorological terminology apprehensible for unacquainted users (Li *et al.*, 2010), be presented in a familiar unit (i.e. °C) which is approved bioclimatic index to evaluate the thermal stress (Gulyas *et al.*, 2006), and the feasibility of computation by user-friendly software such as Rayman (Matzarakis *et al.,* 2007) are some prominent benefits of using the PET. Moreover, this thermal index is comprised in guideline 3787 of the German Association of Engineers (VDI, 1998). Finally, it was utilized in many studies in various climate conditions (such as Farajzadehand Matzarakis, 2012; Makaremi *et al.*, 2012; Krüger, & Rossi, 2011).

Rayman software

Rayman as the easy-use software estimates the short- and long-wave radiation fluxes (Matzarakis *et al.*, 2007). In order to approximate Tmrt in Rayman, it is required to import the global radiation (Gr), cloud cover (Cd), fisheye photographs, albedo, the Bowen ratio of ground surface and the Linke turbidity of air to contain the shading effect of the surrounding. Because of Rayman takes into consideration the radiation modification impacts of the composite surface construction very accurately, the trustworthy determination of the microclimatological modifications of diverse urban environments can be regarded as the chief benefit of the model (Gulyas *et al.*, 2006).

Calculating of Sky View Factor (SVF) is another advantage of Rayman. It can be computed by importing the fish eye prospect of specific location. Moreover, Rayman is able to evaluate the PET by importing the values of air temperature (Ta), relative humidity (RH), wind speed (v), human clothing and activity, and mean radiant temperature (Tmrt). In addition, Rayman can approximate the PET by knowing the value of global radiation (Gr) or importing date of year, time, location and cloud cover (Cd) (Li *et al.*, 2010).

Questionnaire survey

The main goal of subjective assessment was to find out the thermal sensation of passengers under bus stations with Polycarbonate and opaque roofing material in Tropical climate of Malaysia. Hence, 200 individuals were randomly asked to state their thermal sensation. Of them 100 persons were under bus shelter with Polycarbonate roofing material and the rest were within opaque protective cover. The questionnaire survey was administrated at the same time with recording the microclimatic factors. Because the study area C was just for controlling objective measurement, the questionnaire was not contributed in that place.

The first part of the questionnaire was allocated to personal characteristics of respondents. In this part, they were asked to state their age, gender, nationality and the time of staying in Malaysia in order to evaluate the effects of acclimatization. Furthermore, since a previous study (Schlink *et al.*, 2002) revealed that smoking, eating food and drink in 30 minutes before completing the questionnaire and suffering from some sorts of diseases may change the human perception about climate condition; some of questions were appertained to clarify these factors.

In the next part of the questionnaire, respondents were required to specify their type of clothing and level of activities based on some suggested options. The proposed clothing choices were some common types of garment for equatorial zones. Additionally, taking into account the level of activities is significant because it affects metabolic rates of body. Moreover, respondents were asked to determine their level of activities dependent upon some kinds of activities that are occurred in study area prevalently.

The last part of the questionnaire concentrated on the perception of outdoor thermal condition at the moment of field probe procedure. To approach this study, the respondents were requested to rate their sensation upon the main meteorological parameters (i.e. air temperature, relative humidity, air velocity and mean radiant temperature) on a five-point scale (i.e. -2 = cold; -1 = cool; 0 = neutral; 1 = warm; 2 = hot) and likewise thermal preferences (i.e. -2 = cooler; -1 = slightly cooler; 0 = no change;

1 = slightly warmer; 2 = warmer). To valid their rating, the results with the same values of thermal perception and thermal preferences (e.g. "I feel cold" and "I like to be cooler") were not considered in data analysis. Moreover, to indicate the role of each parameter in human thermal comfort, respondents were requested to specify their level of comfort about each factor in a five-point scale separately as well as their overall thermal comfort (i.e. -2 = very uncomfortable; -1 = uncomfortable; 0 = acceptable; 1 = comfortable; 2 = very comfortable). Correspondingly, it is significance to clarify the distinction between "Sensation" and "Preference". The sensation represents the human feeling, while, preference expresses the inclination of individuals for their coveted situation (Oliveira, & Andrade, 2007).

Results

Results of objective measurement

In order to analyze the thermal comfort condition of bus shelters, thermal perception range introduced by Lin and Matzarakis (2008) for sub-tropical climate was utilized. Hence, the PET values between 26° C and 30°C were regarded as the "neutral" thermal condition, while, the PET values corresponding to 22° C and 26° C as well as from 30° C to 34° C were considered as "acceptable" thermal conditions. Moreover, for simple understanding, the average values of each recorded microclimatic parameter are shown.

Table 1.Thermal perception range for sub-tropical climate introduced by Lin and Matzarakis.

Thermal perception	TPC for sub-tropical region (°C PET)
Very cold	<14
Cold	14-18
Cool	18-22
Slightly cool	22-26
Neutral	26-30
Slightly warm	30-34
Warm	34-38
Hot	38-42
Very hot	>42

Air temperature (Ta)

In April, the air temperature value in Polycarbonate station was higher than that of opaque shelter most times. The average values of air temperature at unshaded location were approximately similar to the recorded values for Polycarbonate shield during the noon. However, the air temperature values at unshaded zone were higher than those of bus stop with Polycarbonate roofing material at the initial hours of data collection. The air temperature values of unshaded location after increasing during the hottest time of day was decreased at the last hours of measurement and reached the second level after Polycarbonate cover during these times. Besides, the results showed that the difference between the air temperature's values for Polycarbonate location and unshaded location was not remarkable during the mid-hours of day in April. So, it can be concluded at the warmest times on this month, the effects of Polycarbonate roofing material on air temperature was slighter in comparison with adjacent uncovered location.

In May, the averaged air temperature values of unshaded location were often placed at the lower rank in comparison with those of Polycarbonate roofing material. The higher air temperature values for unshaded location were saved during the first hours of data collection. Based upon the scrutiny of study areas A and C on both April and May, it can be concluded the measured values of air temperature of the Polycarbonate location were not higher than the opaque. Furthermore, it was apperceived that the fluctuation of air temperature values at uncovered location was considerable, while, the trend of shaded locations (for both Polycarbonate and opaque stations) was understandable.

Although the saved values at the beginning hour of measurement were roughly the same for all study areas, the explicit higher air temperature values inside the Polycarbonate shield in contrast with opaque shelter were revealed hours by hours. This finding manifests the higher air temperature values were experienced within Polycarbonate shelter compared with opaque shield in equatorial climate. The averaged values of air temperature in April and May are shown in Fig. 2.

Relative humidity (RH)

In April, the appreciable higher saved humidity average values for Polycarbonate station were observed in the early hours of data collection. At the same time, the humidity at the bus stop covered by opaque material was positioned at the second level, above the unshaded location rank. However, starting from mid-day, the recorded relative humidity of all stations tended to decrease significantly and reached close values approximately. Synchronously, the average values of humidity at unshaded location gained the lowest level after opaque shelter and bus stop with Polycarbonate shield, respectively.

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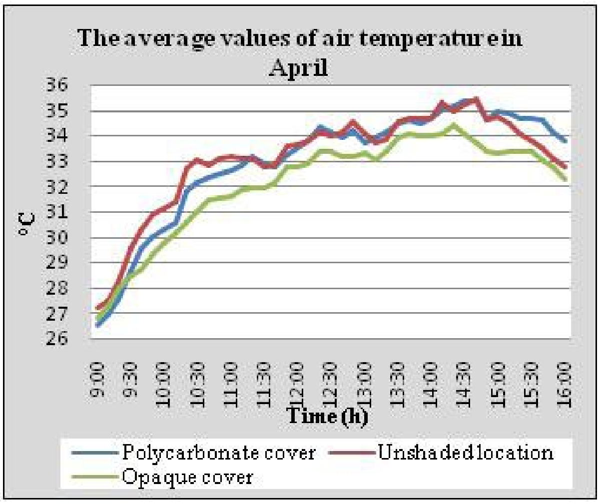

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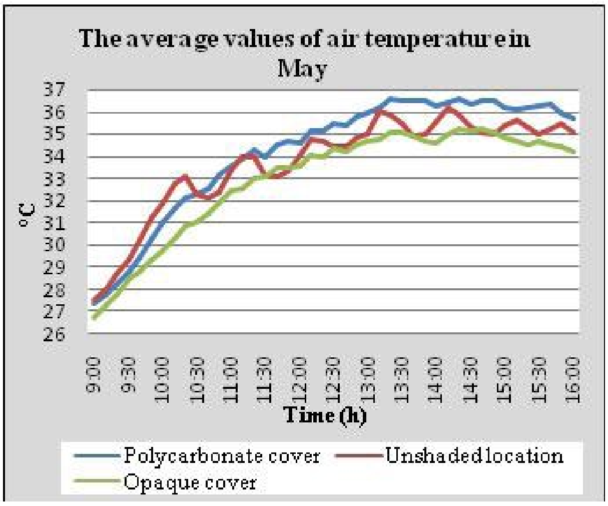

Figure 2. The recorded averaged values of air temperature at three study areas (1) 23 - 27 April 2012 and (2) 14-18 May 2012.

In May, the mean humidity values of the beginning hours of microclimate measurement had similar tendency like the last month. In other words, humidity at Polycarbonate shelter positioned the highest level at the first hour of data collection. Contemporaneously, the relative humidity of bus stop with opaque roofing material recorded the partially similar values to unshaded location. However, the humidity values of opaque station after reducing tended to increase until the last hours of measurement. On the other hand, humidity values of Polycarbonate station placed in the last position from the mid-time of data collection. However, although unshaded location was gained the second rank at the same time, its recorded values vacillated several times. It can be concluded that humidity values of the bus stop covered by opaque materials were higher than the rest of study areas in most of the times. In Figure 3, the average values of humidity in April and May are illustrated.

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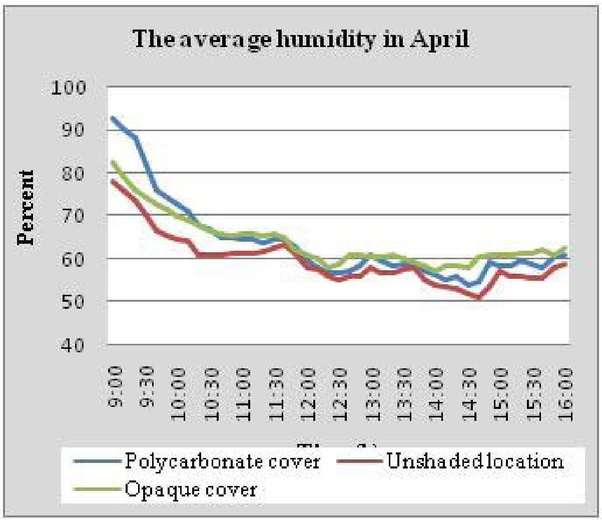

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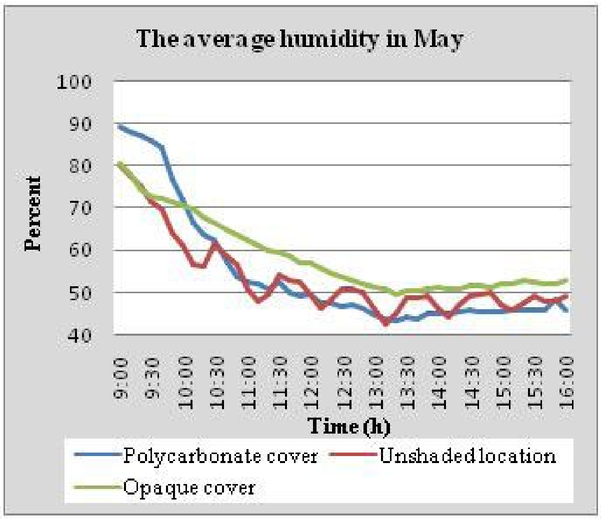

Figure 3. The recorded averaged values of humidity at all the study areas; (1): 23-27 April 2012, (2): 14-18 May 2012.

Wind velocity (v)

To assess the wind speed results, the influence of study areas' protection was dominant. In other words, the unshaded location which was not covered with any protection material experienced more powerful air movement. In April, the average values of wind speed revealed that unshaded location gained the first rank. Subsequently, the bus station with opaque cover and Polycarbonate roofing material placed on the next levels, respectively. In detail, although the air movement values for all locations fluctuated several times, the tendency of wind speed values for the three study areas was to increase from beginning to end of measurement time.

In May, the general trend of saved wind speed values was similar to the previous month. It means considering the different values, the wind speed values of all locations after declining the initial hours of data collection, raised slightly till the last times of measurement. In May, like the wind speed ranking in April, unshaded location, opaque shield and station protected with Polycarbonate material positioned on the first, second and the last levels, respectively. In addition, the maximum air movement values of each location were increased in May. The well-protected locations were faced less strong wind speed. Hence, the unshaded location in both months gained the highest position comparing to Polycarbonate shelter and opaque protection cover. The recorded average values of wind speed in April and May are shown in Figure 4.

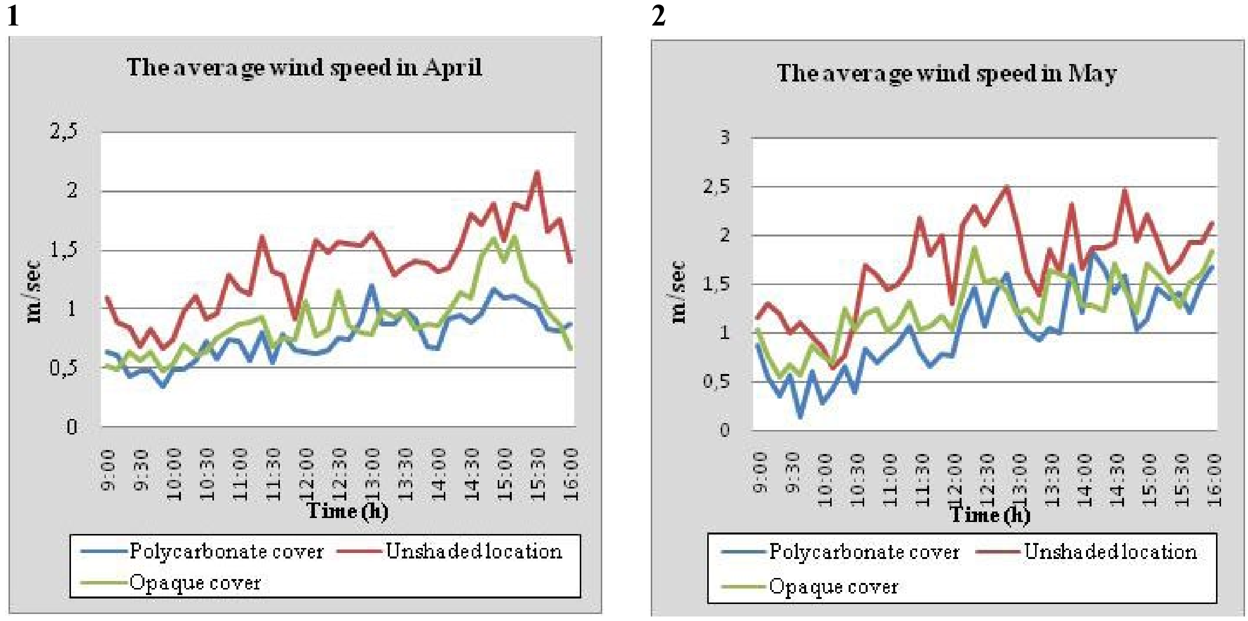

Figure 4. The recorded average values of wind velocity at all the study areas; (1): 23-27 April 2012, (2): 14-18 May 2012.

Mean radiant temperature (Tmrt)

In April, the Tmrt values of unshaded location were considerably higher than other locations. In other words, despite the average of Tmrt at unshaded position was fluctuated many times, it tended to increase significantly from the early hour of measurement to the final hour and, eventually, falled down remarkably and reached the close Tmrt values of the bus stop protected by Polycarbonate material. Moreover, the recorded Tmrt under Polycarbonate shelter was comparatively higher than those saved within opaque protection cover. This may because of the physical characteristics of semi-transparent material that passes some amount of light beams. It can be noticed that this finding shows Polycarbonate roofing materials are not effective as opaque roofing sheet to block the sun lights at the warmest hours of day in outdoor and semi-outdoor spaces. Furthermore, it was found significant differences between Tmrt and Ta. Comparing with the average of Mean Radiant Temperature and the average of air temperature in the three study areas in April, it was found that the Tmrt values were remarkably higherthan Ta in all locations, particularly at noon.

In May, the trend of mean radiant temperature was similar to that in April, but the maximum value for all locations was considerably higher than their recorded values in May verse vice the minimum mean radiant temperature values. Tmrt values in unshaded location after increasing considerably, especially during the midday, diminished substantially at the final hours of data collection. Also, the Tmrt for the three locations was roughly in the close values at the beginning of the measurement. Likewise, although the Polycarbonate location was placed the upper level than opaque shelter, the different values between these mentioned locations were reduced in May comparing to April.

Comparing the average of Tmrt and Ta in May, it can be concluded that the Tmrt of the bus stop protected by Polycarbonate and opaque were remarkably higher than those of Ta values. For unshaded location, this comparison was very significance and the measured Tmrt was notably higher than Ta.

Eventually, it can be noticed that Tmrt of unshaded location in both months was exceptionally higher than the other study areas. In addition, the bus station with Polycarbonate and opaque roofing material were placed in the next ranks, respectively. This shows that efficiency of Polycarbonate roofing material for obstruction of the direct or reflected sun light is weaker comparing with opaque materials. The average of mean radiant temperature values in April and May are presented in Figure 5.

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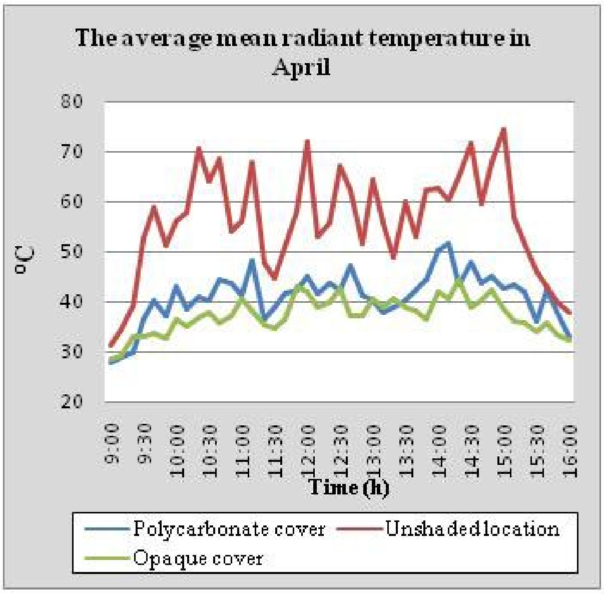

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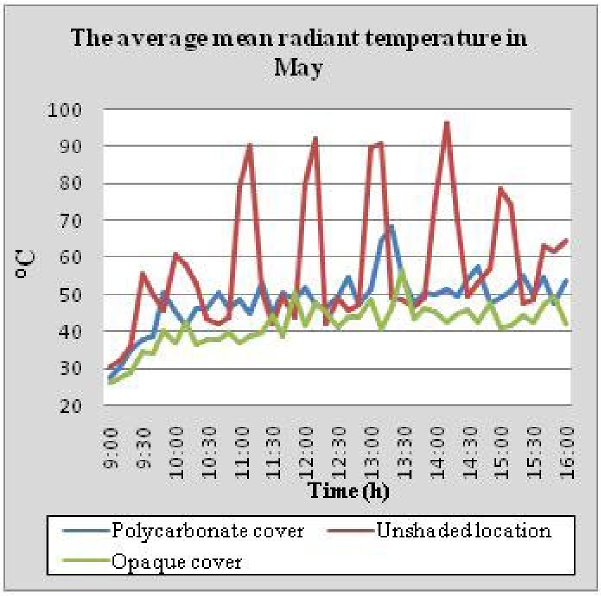

Figure 5. The recorded average values of humidity at all the study areas; (1): 23-27 April 2012, (2): 14-18 May 2012.

Physiological Equivalent Temperature (PET)

The approach to estimation of PET using Rayman is based on inputting values of air temperature, relative humidity, wind velocity, mean radiant temperature, cloud cover and sky view factor as well as geographical coordinates of examinated location, date and the day of year. By using fish-eye photograph, the SVF values of the study areas A, B and C were calculated 0.312, 0.284 and 0.979, respectively.

In April, the calculated average PET showed that during the initial minutes of data collection (i.e. from 9:00 AM to 9:20 AM), the thermal condition of all study areas were in the "neutral" level. However, the "acceptable range" was experienced in the bus stop with Polycarbonate roofing material until 10:00 AM. In the next two hours, "warm" condition was perceived in this location; while the "hot" level was comprehend several times between 12:00 PM and 15:30 PM. It can be concluded that the bus stop covered by Polycarbonate material did not provide acceptable condition for users in most of the times. Moreover, the range of "acceptable" condition in the study area with opaque roofing material was felt till 11:30 AM and during the last half an hour of the measurement (i.e. from 15:30 PM to 16:00 PM). Furthermore, "warm" environmental condition was frequently dominated during the rest of measurement time. Nevertheless, the recorded values of PET demonstrated that the bus stop with opaque material supplied better thermal condition compared with Polycarbonate shelter. By contrast, apart from beginning time of measurement, "acceptable level" of thermal perception never sensed at unshaded location because PET values went beyond the level of "very hot" condition several times. Consequently, it can be deduced shading has a fundamental role in thermal condition in outdoor and semi-outdoor spaces of equatorial zones during the day-time.

In May, based upon the average values of PET, all examination areas were experienced the "neutral" thermal condition at the first twenty minutes of collection time. This trend was varied time-by-time. The average of PET recorded in the bus stop with Polycarbonate roofing material revealed "hot" condition was governed from 9:40 AM to 12:30 PM and, afterward, "very hot" level was the predominant condition in this place. However, "acceptable" condition was sensed between 9:20 AM and 9:40 AM for twenty minutes. This finding disclosed the recorded average values of PET in May were above than those in April.

The "acceptable" condition most of the time roughly was experienced at the bus stop with opaque roofing material condition until 10:40 AM. After perceiving "warm" condition between 10:50 AM and 12:00 PM, "hot" thermal environment was sensed oftentimes in the rest of data collection time at the aforementioned examination area. It can be concluded that despite raising the average values of PET in May comparing with previous month, the opaque shelter had better thermal condition than bus stop protected by Polycarbonate cover. At the same period, except fluctuation in some minutes, unshaded location was experienced "very hot" thermal level. Indeed, this location due to the lack of any protection far exceeded the acceptable range in both May and April. This finding showed the significant role of shading at open-spaces in decreasing the amount of sun light.

The average values of PET confirmed that opaque protection cover provides better thermal condition even in warmer month comparing with Polycarbonate protection cover. Moreover, it was demonstrated that shading has profound role in thermal comfort perception in outdoor and semi-outdoor spaces.

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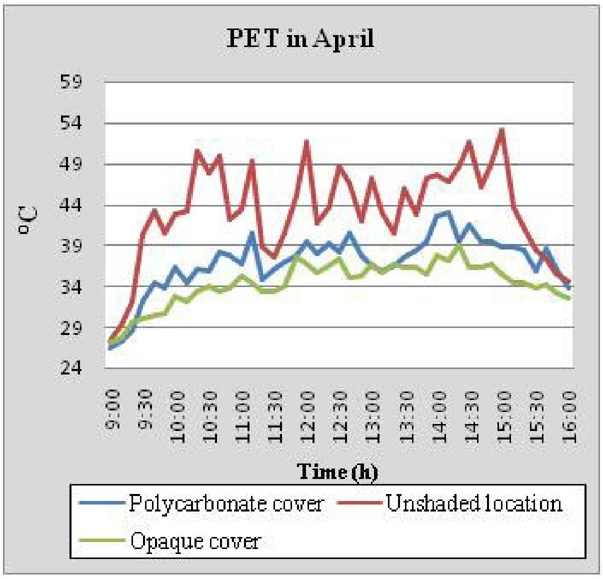

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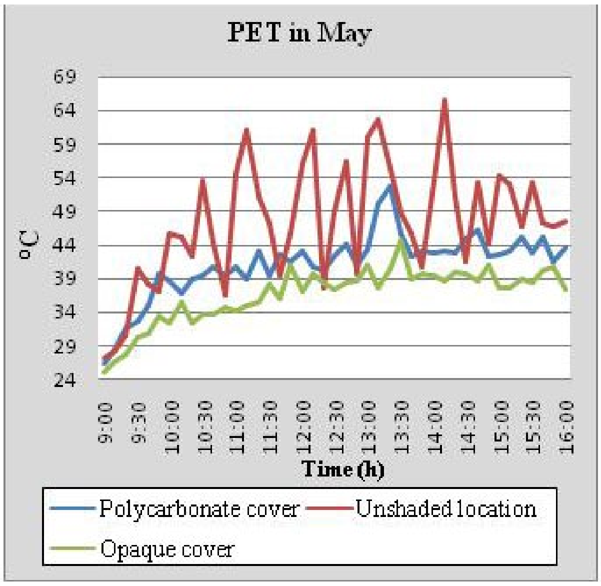

Figure 6. The average of calculated PET at three locations; (1): 23-27 April 2012, (2): 14-18 May 2012.

Subjective results

The questionnaire survey was contributed among 200 participants to evaluate their thermal perceptions and preferences in the study areas. 122 females (61%) and 78 males (39%) were accomplished the questionnaires. Besides, the numbers of international and local persons were 72 (36%) and 128 (64%), respectively. This shows that the majority of participants were local students. Also, only international students who have stayed in Malaysia more than 6 months before completing the questionnaire were considered as the selected respondents due to the effect of acclimatization (ASHRAE, 2004). The independent sample T-Test was done in order to analyze the statistical results.

Air temperature

Most of respondents felt air temperature as warm or hot in both study areas. In contrast, no person expressed air temperature as cool in the study area A, while, the percentages of persons who stated the condition as cool and neutral were 5% and 15% in the study area B, respectively. Moreover, the majority of respondents (65%) preferred air temperature to be slightly cooler, while only a small portion (13.5%) wanted "no change" or "warmer" conditions.

There was no significant difference between the air temperature preferences of individuals in both study areas (P-Value = 0.054 > 0.05). The respondents generally desired cooler air temperature. In contrast, there was a significant difference between the air temperature sensation of respondents inside the bus stations with Polycarbonate shield and opaque roofing cover (P-Value = 0.004 < 0.05). It is concluded that the feeling of air temperature among respondents within the first and second study areas was antithetic.

Based on the subjective outcomes, individuals within study area B sensed the better condition in terms of air temperature in comparison with ones within the study area A. Although there was no remarkable disagreement with the human air temperature preferences of ones in both locations, opaque cover prepared better air temperature comfort condition for passengers.

Wind

The majority of the participants (53%) felt air movement as neutral, while the sensation of weak wind speed placed in the second rank in the two stations. Furthermore, the percentage rates of attended persons under polycarbonate roofing material were higher in both locations (56% for the "neutral wind speed" and 31% for "weak air movement"). On the other side, only 16% of individuals stated that their wind speed sensations were "strong" or "very strong" in all the study areas. As to the wind speed preference, "slightly stronger" and "no change" gained the topmost result rank among whole of answerers by 43% and 33%, respectively.

There was a significant difference between the wind speed sensation of persons under the bus stops with Polycarbonate shield and the bus station covered by opaque material (P-value = 0.021 and 0.021 < 0.05). By contrast, there was no significant difference between wind speed preferences of respondents in the two study areas (P-value = 0.083 > 0.05). This outcome expresses those passengers in both study areas mostly preferred slightly stronger air movement.

Relative Humidity

40% of respondents in location B felt atmosphere humidity dry, while the difference of responses for presented persons within location A was inconsiderable by 32%, 31% and 30% for neutral, dry and damp, respectively. Besides, 33% of people inside the Polycarbonate protection cover noticed that "slightly dry" were their preference condition for relative humidity. On the other hand, 44% of respondents in the other station desired atmosphere humidity to be "slightly damp".

It can be concluded that there was no significant difference between the humidity sensation of passengers in study area A and B (P-value = 0.103 > 0.05). It indicates that people sensed relative humidity in both bus stops in approximately similar condition. By contrast, there was a significant difference between the humidity preference of respondents in the study areas (P-value = 0.011 < 0.05). This result stated that the human preferences within the location A was "dry" condition, while the trend of persons under the station B was "damp" environmental humidity.

Solar radiation

51% of all respondents declared that solar radiation was bright. Additionally, 29% of respondents at the study area A noticed the "very bright" solar radiation as their second sensation choice, while the "neutral" option obtained this level for 22% of individuals in study area B. This finding is in agreement with the physical property of Polycarbonate plastic, as a translucent material that passes the light and the opaque substance that blocks the beams. Despite the first solar radiation preference of40% of respondents under Polycarbonate cover was equal for both "no change" and "slightly darker", the most preferred choice of persons within opaque shield was "slightly darker".

There was no significant difference between solar radiation sensation of individuals in both study areas (P-value = 0.086 > 0.05). Additionally, it was revealed that there was no significant difference between the solar radiation preferences of passengers presented under bus stop with Polycarbonate roofing material and opaque protection cover (P-value = 0.267 > 0.05).

Overall thermal comfort

The final part of the questionnaire was allocated to participants' request for stating their overall thermal comfort in a five-point scale. According to the results, although most respondents said that the overall thermal comfort condition was "acceptable" in each study area by 47% for the bus stop with Polycarbonate protection cover and 53% for the study area with opaque roofing material, the declaration of "uncomfortable" overall thermal comfort in the study area Awas more distinctive by 32% of respondents, while the "comfortable" condition was much sensed in station with opaque shelter by 25% of respondents. It was concluded that the presented passengers under opaque protection cover felt better condition than those within the station covered by Polycarbonate roofing material. Meanwhile, the most choices for acceptable and comfortable condition were noticed during the early hours (i.e. 9-11 AM) and the last hours (i.e. 3-4 PM) of the measurement.

There was a significant difference between overall thermal comfort sensation of respondents within two groups in both bus stations covered by Polycarbonate and opaque material (P-value = 0.024 < 0.05). Although the most preferred choice for both groups in terms of overall thermal comfort was "acceptable", the percentage of persons who declared overall thermal comfort condition as "comfortable" was more in the station covered by opaque material. The most "uncomfortable" overall thermal condition in the study area protected by Polycarbonate material was expressed to be during 12-14 pm, whereas, the major selected choice at the same time in station with opaque shelter was "acceptable". The results of overall thermal comfort are shown in Figure 7.

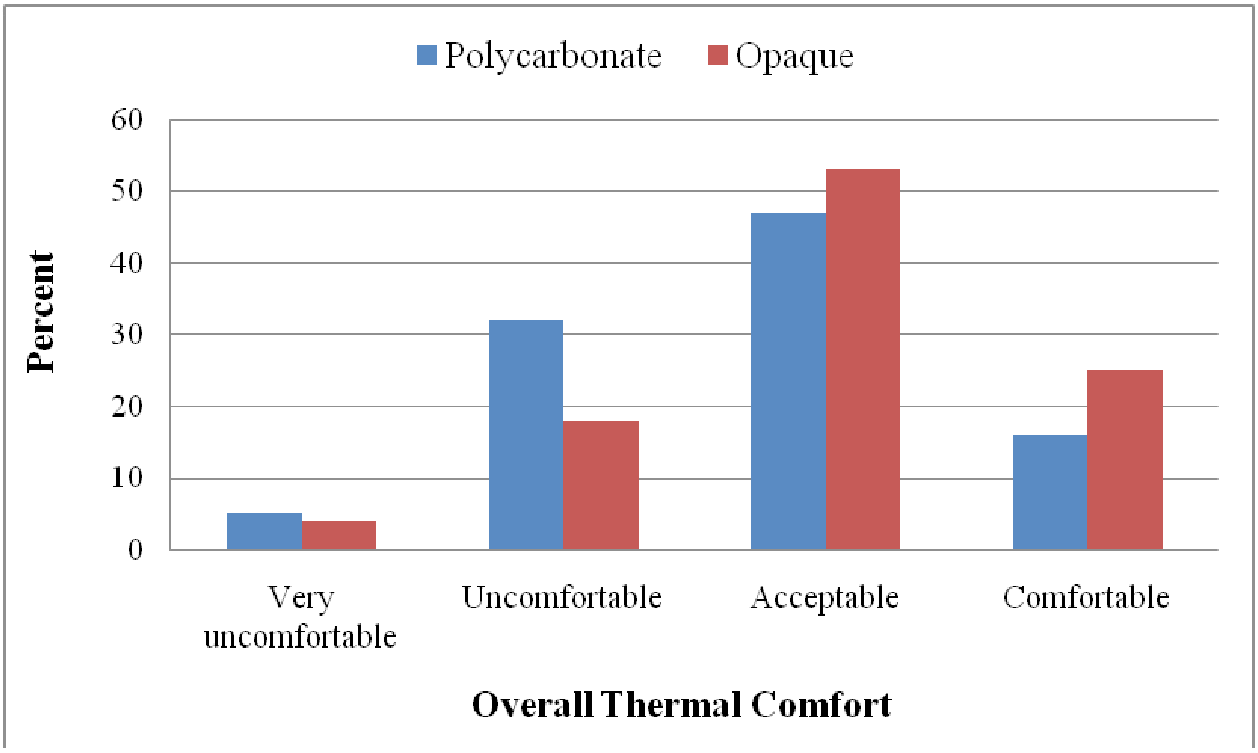

Figure 7. The overall thermal comfort rates under Polycarbonate shelter and opaque protection cover.

Discussion

Most respondents felt air temperature as warm and hot. However, the majority of respondents in both study areas preferred air temperature decline. Meanwhile, many felt relative humidity in dry condition inside the opaque shelter, whereas, the humidity sensation of people in Polycarbonate shield fluctuated from dry to damp conditions. Nevertheless, the distinctive preference of passengers under opaque shelter was much wet condition in contrast with those under Polycarbonate cover who wanted to much dry condition. These finding showed that the characteristic of roofing material can influence the air temperature perception as well as relative humidity preference of human in semi-outdoor spaces. Additionally, despite there was no significant difference between wind speed preferences of respondents in the study areas; their air movement sensation was significantly difference. Also, as there was no significant difference between solar sensation as well as preference of people among the two study areas, the material of roof did not greatly affect the perceptions and preferences of respondents as to solar radiation.

Those persons came daily or several times per week had a high tolerance for acceptable thermal condition. This finding is in agreement with previous findings (e.g. Nikolopoulou, & Steemers, 2003; Liu *et al.*, 2012) and expressed that psychological adaptions modify human's expectation and likewise their satisfaction level. In other word, the experience can directly influence the personal expectation. Finally, it can be mentioned that no significant difference was in overall thermal comfort based on the gender comparison.

Uncomfortable condition in the station covered by Polycarbonate roofing material was appeared to be from 12 to 14 PM, while the passengers under opaque shelter noticed overall thermal comfort condition as acceptable. It means that the physical property of Polycarbonate material in transmitting the sun light leads to increasing of the percentage of discomfort. The opaque material which blocks the solar radiation beams prepares acceptable condition for users during the warmest time of day. This result emphasizesthe fundamental role of shading in improving the level of thermal satisfaction in semi-outdoor spaces during the daytime. Besides, very comfortable status was found at the initial hours of data collection likewise the latest hours when the low intensity of solar radiationoccurs. Hence, this finding illustrates the important role of solar radiation in human thermal comfort satisfaction in equatorial zones.

Based on the average values of PET implemented to assess thermal comfort condition of the three study areas, it was found that the "neutral" range of thermal condition was just existed at the initial minuets of data collection both in April and May for all studied locations. However, regarding "acceptable" time, the longer period in the bus stop covered with opaque material was observed. Moreover, acceptable condition duration in April was longer comparing that in May for aforesaid study area. Likewise, warm thermal situation governed frequently in the rest of time in study area B for April and May. This finding expresses better overall thermal conditions underneath of opaque shelter than Polycarbonate protection cover as well as unshaded location. Similarly, unshaded place gained the least level as to overall thermal comfort because itgoes beyond the "very hot" range severally. This finding revealed that shading has essential influence on evaluating thermal comfort in non-indoor spaces. Finally, on the basis of assessing thermal condition under Polycarbonate shield, it can be said that except the first half an hour of measurement most of the time warm condition and hot thermal situation was experienced in April and May, respectively. This showed that thermal condition under Polycarbonate shelter was better than unshaded location, but, not than opaque shield. The PET values recorded in the bus stop with Polycarbonate protection cover often placed in "hot" range in April as well as "very hot" rang in May. Furthermore, this location met the less fluctuation comparing with close unshaded zone. This finding showed that the overall thermal comfort in the study areas had a predictable trend.

Additionally, very small difference in air temperature values of the three study areas and their various values of PET revealed that solely assessment of air temperature is not enough for evaluating overall thermal comfort in semi-outdoor and outdoor spaces. Hence, it can be inferred that the most effective factor in overall thermal comfort in such places is mean radiant temperature. This finding is in agreement with the prior studies which noticed that the impact of mean radiant temperature on outdoor circumstance in hot climatic condition is more profound than air temperature values (Cheng *et al.*, 2011; Lin, 2009; Hwang, & Lin, 2007).

It was illustrated that man-made structure has different influence on thermal comfort. In other words, the opaque materials which block the sun beams prepares better thermal condition than Polycarbonate shield which transmits some part of solar radiation fluxes. This finding confirms previous study which expressed that the artificial elements create different thermal circumstance in non-indoor locations (Xi *et al.*, 2012).

Comparative analysis between questionnaire survey and measurement field

According to the objective analysis, the neutral and acceptable range of comfort thermal perception for the three study areas was different. Indeed, the satisfaction range mostly occurred in the beginning minutes for study areas A and C and in the initial hours as well as the last thirty minutes of measurement for study area B. The remainder times of data collection were divided into warm, hot and very hot thermal condition ranges based on the daytimes and examination locations. Besides, the numbers of “uncomfortable” rates in study area B were less than study area A. Hence, it was deduced that people accepted thermal condition even in unacceptable thermal condition level. This finding is in accordance with previous studies which expressed that an individual’s adaption with microclimatic circumstance happens frequently in non-indoor places and thermal endurance of people in this kind of location is high (Hwang, & Lin, 2007, Walton *et al.*, 2007).

Furthermore, measurement field revealed that the bus stop covered by opaque material experienced better thermal condition based on the average PET values. Likewise, the results of subjective assessment showed that the percentage of “comfortable” rates in this location was more than those of Polycarbonate shelter. By contrast, the percentage of “uncomfortable” as well as “very uncomfortable” thermal rates for the bus stop with opaque roofing sheet was less than rates in the other bus station. Hence, it is concluded that the bus stop with opaque protection cover provided more desirable thermal condition rather than the bus station with Polycarbonate protection cover.

Additionally, the influence of subjective assessment was emphasized by tolerance of respondents with warm or hot thermal comfort condition. The results of this study demonstrated that subjective parameters have a consequential role in assessing thermal comfort. Indeed, evaluating thermal comfort in open and semi-opened spaces without considering adaption factors is not admissible and only conduction field of measurement cannot reflect the actual thermal condition of specific location. This finding is in agreement with many other studies which focus the significance of adaption in examination of overall thermal comfort condition of individuals in non-indoor environments (Mahmoud, 2011; Hwang *et al.*, 2010; Nikolopoulou, & Lykoudis, 2007).

Eventually, the results revealed that people in Malaysia can endure in higher values of PET comparing the proposed thermal range for subtropical climate of Taiwan. In other words, the psychological, physiological and behavioral adaption of occupants in specific location leadsto specific thermal satisfaction range. This outcome is in accordance with a prior study which emphasized the role of environmental and cultural attitudes in examination of human thermal comfort (Knes, & Thorsson, 2006).

Conclusion

There was a significant difference between human thermal comfort condition under installation Polycarbonate and opaque roofing sheet on bus stops of Malaysia. The objective analysis showed considerable discrepancy between actual thermal condition as well as thermal sensation of respondents on the basis of subjective analysis in both study areas. Correspondingly, it isfound that thermal condition underneath the bus stop with opaque protection cover is in better condition both objectively and subjectively than that covered by Polycarbonate roofing plastic sheet.

The findings indicate that subjective parameters play a fundamental role in evaluating thermal comfort in semi-opened spaces. It means that the psychological adaption can improve thermal sensation of individuals in unacceptable climatic condition due to effects of acclimatization and experiences.

It is demonstrated the important effects of Tmrt on evaluating thermal comfort in non-indoor spaces. Shading enhances human thermal comfort in non-indoor places because of decreasing the Tmrt. Hence, Polycarbonate plastic roofing materials which transmit some parts of sun beams provide the lower level of thermal comfort for users. Also, this studyshows thatmere consideration of air temperature is not reliable for assessing human thermal condition.

The acceptable thermal range for participants in this study is higher than previously determined levels obtained for Taiwan. Hence, it can be concluded that each resident in each region has the individual thermal range which may not the same as that for other zones.

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