Validation of the ability of outdoor thermal index on assessing the outdoor thermal comfort in hot-humid regions

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SUMMARY
This paper is to validate the ability of thermal index on assessing the outdoor thermal conditions and provide suggestions of improving thermal index and outdoor thermal environments. Field test including online measurement and questionnaire survey was carried out in different outdoor places in Hong Kong from March to December. Compared to places exposed directly to the solar radiant (OPEN area), places with ground beneath the elevated buildings (UEB area) could weaken the solar radiant and maintain the mean radiant temperature lower than 40.0℃. More than 90% of thermal conditions in UEB area and only 40.7% of those in OPEN area are accepted by subjects during the field test. The relationship between thermal sensation vote (TSV) and thermal comfort index UTCI (Universal Thermal Comfort Index) was fit cubic curve. TSVs stay at slightly cool with changing much when the UTCI is between 29.5℃ and 32.0℃, and stay hot once the UTCI is higher than 38.0℃. UTCI underestimates the effects of solar radiant on thermal perception when the UTCI is between 26.5℃ and 38.5℃ and underestimates the effects of wind speed when the UTCI is lower than 26.5℃. Neutral UTCI range between 29.5℃ and 32.0℃ with the mean radiant temperature lower than 40.0℃ is suggested for city planners to create comfortable outdoor spaces.

INTRODUCTION
Nowadays, comfortable outdoor thermal environment is becoming an essential factor for people to consider when planning for the outdoor activities and a determined factor influencing the quality of outdoor activities. Thus, the outdoor open space facilities are supposed to be designed thermally comfortable for attracting more people to enjoy the outdoor activities. However, before designing successful thermally comfortable outdoor environments, characteristics of outdoor thermal comfort required by human should be realized through assessing effects of the existing outdoor thermal condition on human thermal perceptions.

For providing a holistic view of the outdoor thermal conditions, a growing number of studies have been conducted in various kinds of outdoor spaces around the world in the last decades. Microclimate parameters, such as mean radiant temperature, wind speed, air temperature and relative humidity included in the outdoor spaces were proved to greatly affect the human thermal perceptions (Oliveira and Andrade 2007; Parsons 2014). In the earlier studies, their effects were presented as empirical formulas for predicting the thermal sensation at a specific outdoor space. Givoni et al. (2003) summarized the outdoor comfort studies in Japan and Israel and proposed a formula to describe the influences of air temperature, solar radiation and wind speed on the human thermal sensation. Nikolopoulou and Lykoudis (2006) investigated a wide variety of locations in European countries to testify the effects of various outdoor microclimate parameters on human thermal sensation. However, in the later studies, human thermal perception responding to an outdoor thermal condition was found to be influenced by the comprehensive effect of microclimate parameters and human physiological characteristics (Pickup and de Dear 2000; Brown and Gillespie 1986; Kenny et al. 2009). These comprehensive effects were abstracted to an equivalent temperature called thermal comfort index which is developed based on the human heat balance model. Such thermal comfort indices for widely use includes physiological equivalent temperature (PET) (Höppe 1999), OUT-SET® (De Dear and Pickup 2000) and recently developed universal thermal comfort index (UTCI) (Fiála et al. 2012). With the proposal of these thermal indices, they are widely used around the world for testing their reliability on describing the effects of outdoor microclimate parameters and human factors on human thermal sensations (Deb and Ramachandraiah 2010; Honjo 2009). However, human thermal sensations responding to the same values of thermal index are various in climate regions. For example, Edward (Cheng et al. 2012) and Tzu-Ping Lin (Lin and Matzarakis 2008) did field tests in subtropical regions like Hong Kong and Taiwan and found neutral PET of 28.0℃ in Hong Kong and that of 26.0℃ to 30.0℃ in Taiwan. However, according to the study in northern city of China by Dayi Lai (Lai et al. 2014) and that in European cities by Matzarakis (Lin, Matzarakis, and Hwang 2010; Krüger, Minella, and Rasia 2011), neutral PET in climate regions is between 11.0℃ and 24.0℃, much different from that in subtropical regions. This discrepancy furtherly proved the conception proposed by Nikolopoulou and Lykoudis (2006) that psychological adaptation such as individual thermal preference, experience and expectations play the vital role in determining human thermal sensation. Thus, outdoor thermal comfort is a complex issue relating to global climate situation, microclimate parameters and human physiological and psychological characteristics.

Climate characteristics appearing at different seasons and climate regions could not be changed greatly right now by human activities. However, according to the study of Niu et al. (2015), the change of microclimate parameters caused significant differences in outdoor thermal comfort conditions within a prescient scale of 200 m. In other worlds, comfortable outdoor thermal conditions for pedestrian could be achieved through changing the microclimate parameters by different design of outdoor spaces (Krüger, Minella, and Rasia 2011). Besides, suitable thermal index should be used for accurate assessment of these comfortable or uncomfortable outdoor spaces. Then the improvement of outdoor spaces could be suggested.
However, according to the previous studies, weakness exists and needs to be addressed. First, psychological factors such as preference, experience and adaptation are proved to influence the human thermal perception, but how thermal perception is affected by these factors in not clear. Second, it’s inadequate to assess the thermal comfort of outdoor spaces purely according to thermal indices without figuring out the comfortable combination of wind speed, solar radiant, air temperature and humidity under values of thermal indices. The design strategies of outdoor spaces for controlling wind speed, solar radiant and air temperature at comfortable level are yet be enough and applicable. Third, test of thermal index’s ability to present actual effects of microclimate parameters on human perceptions is limited in existed studies. Sensitivity to change of microclimate parameters of human and that of thermal index are failed to be compared. Thus, suggestions for improving thermal index on what respects are not yet clarified.

Based on the above questions existed in the previous studies, this study carried out in outdoor spaces located at a university of Hong Kong, China is expected to: 1) investigate the influencing process of thermal preference on thermal sensation of subjects walking with low pace or sitting in Hong Kong, 2) compare the subjects’ thermal perceptions under thermal conditions presented by values of thermal comfort index UTCI in different outdoor spaces, 3) compare the sensitivity to microclimate parameters of human and that of UTCI for testing the ability of UTCI on reflecting actual effects of microclimate parameters on human perceptions, 4) clarify the neutral and comfortable outdoor thermal conditions and required wind speed, solar radiant and air temperature by subjects, 5) provide suggestions on improving UTCI in specific respects for better prediction of outdoor thermal comfort, 6) provide suggestions of optimal outdoor space design for city planners to refer.

METHODS

Field survey

The field studies consisted of online measurement and questionnaire survey were carried out in the selected sites between March 2016 and December 2016 covering summer and winter in Hong Kong, China, a subtropical city with relatively high temperature and humidity in the whole year. The study sites are located in a university campus shown as Fig. 1. Site 1 is called OPEN area, an open square exposed directly to the solar radiation during most of the daylight hours for most of the time in a year. Site 2 is called UEB area, an open ground floor beneath an elevated building. We set up a mini weather station shown as Fig.2 with six pyranometers and six pyrgeometers (manufactured by Kipp & Zonen Corp.) for measuring mean radiant temperature (Tmn, °C) and other sensors for measuring mean air temperature (Ta, °C), wind speed (WS, m/s) and relative humidity (RH, %). Subjects participated in the thermal comfort experiments were asked to record their perceptions to the outdoor microclimate conditions in the questionnaire. The subjects were mainly students and staffs in campus with the age between 18 and 35. Questionnaire included two sections: first section recorded subjects’ thermal sensations (7-point ASHRAE scales for thermal sensation vote: -3 for cold, -2 for cool, -1 for slightly cool, 0 for neutral, 1 for slightly warm, 2 for warm and 3 for hot), their preferences to the sun and wind and their overall comfort level (5-point scales for thermal comfort vote: -2 for very uncomfortable, -1 for uncomfortable, 0 for neutral, 1 for comfortable and 2 for very comfortable), and the second section collected subjects’ personal information, activity level and clothing status. 1177 effective questionnaires were collected in this study.

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\text{UTCI} = f(Ta; MRT; WS; RH) = Ta + Of set (Ta; MRT; WS; RH) \quad (1)
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Statistical analysis including Ridit (Relative to an identified distribution unit) analysis (Sermeus and Delesie 1996) and regression analysis were performed on on-site measured data and questionnaire data using SPSS 20.0 software. Ridit analysis is a nonparametric test used in this study to determine the difference of thermal sensations caused by subjects’ sun preference. The concept of Ridit analysis is to convert the discrete categorical variable into continuous variables, namely “Ridit value“. Each data set of discrete categorical variable has a “Ridit value“ with 95% confidence interval for comparison. Non-overlapped intervals indicate significant differences among original data sets. The larger Ridit value is, the higher level of this categorical variable is. The regression analysis is to test the prediction ability of thermal index on subjects’ thermal sensation or comfort vote through investigating the relationship between these two parameters.

RESULTS

According to the measurement of microclimate variables during the field test, mean values of wind speed (WS), mean
radiant temperature ($T_{\text{mrt}}$) and air temperature ($T_a$) at one experiment day were calculated for investigating their distribution in UEB and OPEN area. The results are shown as Fig. 3. Since most of the measurements of microclimate variables in UEB and OPEN areas were carried out during the same time period at one day, $T_a$ in these two sites are almost the same seen from Fig. 3a. As for the wind speed observed from Fig. 3b, wind speed range in UEB area is from 0.5 to 3.0m/s, larger than that in the OPEN area from 0.5 to 1.8m/s. Fig. 3c reflects that $T_{\text{mrt}}$ in the UEB area does not exceed 40°C during the whole field test, while the $T_{\text{mrt}}$ in the OPEN area is much higher, reaching to almost 70.0°C at some days.

After understanding the thermal conditions in the UEB and OPEN areas, thermal perceptions of subjects responding to these different thermal conditions would be analysed in the following parts. Thermal conditions in UEB and OPEN areas were classified by different range of wind speed, WS less than 1.0m/s, WS between 1.0m/s and 2.0m/s and WS between 2.0m/s and 3.0m/s. With the control of wind speed, effects of sun radiant on the thermal perception would be evaluated and compared through the corresponded thermal sensations vote (TSV) obtained from questionnaire survey. According to the questionnaire survey, there is one important question asking subjects’ sun preference, which assumes that effects of sun radiant on subjects’ thermal perception might be influenced by subjects’ sun preferences. Thus, for testing this hypothesis, subjects under these classified thermal conditions were divided into groups preferring less sun, groups preferring no change of sun and groups preferring more sun, and their TSVs under the same thermal conditions were compared. The results are shown form Fig. 4, Fig. 5, Fig. 6 and Fig. 7.

Fig. 4 shows the percentage of different sun preference responding to the $T_{\text{mrt}}$ under WS less 1.0m/s, WS between 1.0m/s and 2.0m/s and WS between 2.0m/s and 3.0m/s in UEB area. Seen from Fig. 4, subjects preferring no change of sun possess more than 60% of the total under all thermal conditions, while subjects preferring less sun only possess less than 15% of the total. Thus, subjects preferring less sun in the UEB area would not be considered during the analysis. Besides, subjects preferring more sun only appear under the thermal conditions with $T_{\text{mrt}}$ no more than 32.5°C. Therefore, for testing the effects of sun preference on influencing the subjects’ responds to the sun radiant, TSVs of subjects preferring more sun and no change of sun under $T_{\text{mrt}}$ less than 32.5°C were compared as Fig. 5 shows. Fig. 5 is the plot of Ridit analysis, overlapped or non-overlapped error bars in this plot indicate whether there is significant difference among data sets consisted of ordered class variables. According to the results from Fig. 5, no significant difference is found among TSVs of subjects with different sun preference under either one of three wind speed ranges in the UEB area. However, subjects under wind speed more than 1.0m/s performed cooler feelings to the sun radiant than the subjects did under wind speed less than 1.0m/s. It is proved that in the UEB area, subjects’ responding to the sun radiant effects were little influenced by their sun preference but influenced by different range of wind speed. Thus, weak influence of sun preference on subjects’ thermal perception could be ignored in the UEB area.

Fig. 5 shows. Fig. 5 indicates that the effects of sun radiant on subjects’ thermal perception might be influenced by subjects’ sun preferences. Thus, for testing this hypothesis, subjects under these classified thermal conditions were divided into groups preferring less sun, groups preferring no change of sun and groups preferring more sun, and their TSVs under the same thermal conditions were compared. The results are shown in Fig. 7a shows. The results from the Ridit analysis shown as Fig. 7a indicate that the effects of sun radiant under such thermal conditions on subjects’ TSVs are

![Image](image.png)

**Figure 3.** Distribution of microclimate parameters in UEB and OPEN areas during the field test. a) Air temperature, b) Wind speed, c) Mean radiant temperature.

![Image](image.png)

**Figure 4.** Percentage of different sun preference under various wind speed ranges in UEB area. a) Wind speed less than 1.0m/s, b) Wind speed between 1.0m/s and 2.0m/s, c) Wind speed between 2.0m/s and 3.0m/s.

![Image](image.png)

**Figure 5.** Ridit values of thermal sensation votes of subjects with different thermal preference.
neither influenced by the different wind speed range or the different sun preference. When the $T_{mrt}$ in OPEN area gets higher than $33.5^{\circ}C$, TSVs of subjects preferring less sun and no change of sun were compared as Fig. 6 shows. The same findings are obtained from Fig. 7b that different sun preference and different wind speed range play the weak roles on influencing the TSVs of subjects responding to the sun radiant. Thus, based on the above analysis in the UEB and OPEN areas, effects of sun preference on the subjects’ thermal responding to the sun radiant were proved to be weak, which could be ignored in the following analysis. However, different wind speed range in the UEB area played more significant role on influencing the subjects’ thermal responding to the sun radiant when compared with that in the OPEN area did.

![Figure 6](image1)

**Figure 6.** Percentage of different sun preference under various wind speed ranges in OPEN area. a) Wind speed less than 1.0m/s, b) Wind speed between 1.0m/s and 2.0m/s.

![Figure 7](image2)

**Figure 7.** Ridit values of TSVs of subjects with different sun preference in OPEN area with different $T_{mrt}$. a) $T_{mrt}$ no more than $33.5^{\circ}C$, b) $T_{mrt}$ higher than $33.5^{\circ}C$.

Subjects’ thermal sensation and thermal comfort under different thermal conditions are results of synthetic effects of microclimate variables and human factors such as clothing insulation, metabolic rate and physiological characteristics of subjects. Such synthetic effects could be expressed by an equivalent temperature called universal thermal comfort index (UTCI). Then this equivalent temperature obtained from a specific thermal condition is correlated with the corresponded thermal sensation vote of subject to the same thermal condition. This process is to test the reliability of UTCI on forecasting the real thermal sensation or thermal comfort of subject. Thus, thermal conditions with different wind speed range in UEB and OPEN areas were transformed to values of UTCI, and the mean values of subjects’ TSVs with 95% confidence interval were determined under every temperature interval with a bins width of 1 $^{\circ}C$ UTCI. The results are shown as Fig. 8.

![Figure 8](image3)

**Figure 8.** Distribution of MTSV with 95% confidence interval under values of UTCI in UEB and OPEN areas. a) UEB area, b) OPEN area.

Seen from Fig. 8, thermal conditions in UEB and OPEN areas during the field test are expressed by UTCI values from 16.5 $^{\circ}C$ to 38.5 $^{\circ}C$ and 20.5 $^{\circ}C$ to 48.5 $^{\circ}C$, respectively. The overlapped UTCI range in these two sites is from 20.5 $^{\circ}C$ to 38.5 $^{\circ}C$, TSVs forecasted by this range of UTCI are supposed to be the same in spite of the different wind speed range or different experiment sites. However, TSVs under this UTCI range variate between slightly cool (TSV from -1.5 to -0.4) and slightly warm (TSV from 0.6 to 1.5) in the UEB area and between neutral (TSV from -0.5 to 0.5) and warm (TSV from 1.6 to 2.5) in the OPEN area. Besides, there is a significant increase of TSVs from neutral to warm once the UTCI is higher than 26.5 $^{\circ}C$ in the OPEN area, unlike the slight change of TSVs from neutral to slightly warm in the UEB area. Thus, UTCI range from 20.5 $^{\circ}C$ to 38.5 $^{\circ}C$ is divided into two ranges by UTCI of 26.5 $^{\circ}C$ for exploring the reason caused the significant difference among TSVs in UEB and OPEN areas. One hypothesis is proposed that difference among TSVs in the OPEN and UEB areas under the same range of UTCI is caused by the effects of different strength of microclimate variables on the subjects.

To test such hypothesis, the strength of microclimate variables (WS, $T_{mrt}$, Ta and Relative humidity) in two sites are compared under UTCI range between 26.5 $^{\circ}C$ and 38.5 $^{\circ}C$. For more accurate comparison between UEB and OPEN areas, thermal condition with wind speed between 2.0m/s and 3.0m/s in the UEB area is not discussed since there is no such wind level in the OPEN area. Under this UTCI range, thermal conditions with wind speed less than 1.0m/s and wind speed between 1.0m/s and 2.0m/s in the UEB and OPEN areas are compared and discussed respectively. The results are presented through box-plots (Fig. 9), showing the dispersion and range of air temperature, mean radiant temperature and relative humidity in UEB and OPEN area. It’s obvious to see the higher $T_{mrt}$ in OPEN area than that in the UEB area in spite of the different wind speed. UTCI range between 26.5 $^{\circ}C$ and 38.5 $^{\circ}C$ includes wide range of $T_{mrt}$ from 25.0 $^{\circ}C$ to 58.5 $^{\circ}C$. However, subjects under relative low $T_{mrt}$ felt much cooler than subjects did under high $T_{mrt}$. UTCI is not as sensitive as subjects to the wide range of $T_{mrt}$, causing the significant difference among TSVs under the same UTCI values. UTCI presenting the synthetic effects of multiple factors on thermal perceptions should be improved focusing on the relationship between UTCI and $T_{mrt}$.
When the UTCI range is between 20.5°C and 26.5°C, no significant difference among TSVs of subjects under thermal condition with wind speed less than 1.0m/s in UEB and OPEN areas was found. For further validation of prediction ability of UTCI on TSVs, regression analysis was carried out between UTCI values and corresponded mean values of TSVs. With the curve estimation, quadratic model was found perfectly describe the relationship between UTCI and TSVs in UEB and OPEN areas respectively. The results are shown as Fig. 10, very different from the linear regression analysis in the previous research.

Neutral UTCI is defined by neutral TSV from -0.5 to 0.5 based on the regression models. Thus in the UEB area, the neutral UTCI ranges are 18.5°C to 32.0°C under wind speed less than 1.0m/s, 27.5°C to 37.5°C under wind speed between 1.0m/s and 2.0m/s, and 29.5°C to 34.5°C under wind speed between 2.0m/s and 3.0m/s. The overlapped UTCI range from 29.5°C to 32.0°C is defined as the neutral UTCI range in the UEB area whatever the wind speed is in such area.

Seen from Fig. 10b, in the OPEN area, thermal conditions are described by UTCI values from 20.0°C to 50.0°C, wider than that in the UEB area. Although there is the same UTCI range in the UEB and OPEN areas, quadratic models presenting the relationship between TSV and UTCI in the OPEN area are different from those in the UEB area. According to these curves in Fig. 10b, unlike the change rule of TSVs with the increase of UTCI in UEB area, TSVs in the OPEN area increase rapidly when the UTCI increase from 22.0°C to 38.0°C and keep constant at thermal sensation of hot when the UTCI is higher than 40.0°C. However, the discrepancy between curves caused by different wind speed ranges in the OPEN area is not as notable as that between curves in the UEB area. Neutral UTCI ranges obtained from these curves are from 23.0°C to 27.0°C under wind speed less than 1.0m/s and from 21.0°C to 28.0°C under wind speed between 1.0m/s and 2.0m/s. Thus, the overlapped UTCI range from 23.0°C to 27.0°C is defined as neutral UTCI range in the OPEN area, lower than that in the OPEN area.

Based on the results from Fig. 10, values of UTCI during the field test were not smaller than 14.0°C and larger than 58.0°C. When the UTCI is relatively low between 14.0°C and 26.0°C or higher than 38.0°C, TSVs of subjects would stay at a specific sensation scale without changing much with the increase of UTCI. Thus, a hypothesis is proposed that the relationship between UTCI and actual TSVs should be fit cubic curve in spite of different outdoor places. However, because of the limitation of the experiment in this study, this hypothesis would be tested in the future study.

Except for the TSV, thermal comfort vote (TCV) is another important index describing subjects' thermal perceptions for assessment of outdoor thermal conditions. Thus, the distribution of TCVs under different thermal conditions in the UEB and OPEN areas was carried out as the Fig. 11 shows. In the UEB area, thermal conditions were classified by UTCI less than 20.5°C, UTCI higher than 20.5°C but lower than 26.5°C and UTCI higher than 26.5°C but lower than 38.5°C under different wind speed ranges. The similar classification of thermal conditions was carried out in the OPEN area. Through observing the distribution of TCVs under the overlapped UTCI range from 20.5°C to 38.5°C in the UEB and OPEN areas, over 90.0% of the subjects felt neutral (TCV=0) to uncomfortable (TCV=-1) to very uncomfortable (TCV=-2) in the OPEN area. The results could be explained by the previous analysis, much higher TSVs in OPEN area than that in the UEB area caused by different $T_{\text{air}}$ under this UTCI range.
Under the persistent increase of UTCI higher than 38.5°C in the OPEN area, over 95% of subjects felt uncomfortable (TCV=−1) to very uncomfortable (TCV=−2). When the UTCI is lower than 20.5°C in the UEB area, percentage of subjects feeling comfortable decreased while that of subjects feeling uncomfortable increased. In spite of such change, still over 70% of subjects felt neutral to comfortable under this UTCI range. The results from Fig. 11 indicate that distribution low of TCVs in both UEB and OPEN areas is not influenced by different wind speed ranges, unlike that of TSVs. Thus, without considering the effects of different wind speed ranges on TCV, all thermal conditions in UEB area described by UTCI from 16.5°C to 38.5°C are thought to be acceptable. However, since the sensitivity of subjects to the higher Tmrt in the OPEN area, only the thermal conditions described by UTCI from 20.5°C to 26.5°C could be thought comfortable in spite of the same range of UTCI from 20.5°C to 38.5°C in OPEN area as that in the UEB area.

CONCLUSIONS
Based on the 1117 questionnaire surveys and measurement of microclimate variables, different thermal conditions and subjects’ thermal perceptions were found in the UEB and OPEN areas. Synthetic effects of these conditions and human factors on subjects’ thermal perceptions are described through UTCI values and TSVs or TCVs from the questionnaire survey. The major achievements on assessing the outdoor comfort through the comparison between UTCI and TSVs or TCVs are as follows. Besides, major factor among outdoor thermal variables influencing the thermal perception is figure out. According to the study, subjects’ preferences to the sun radiant and wind speed have weak effects on subjects’ perceptions to the outdoor thermal conditions, which could be ignored. The following conclusions are all based on this finding.

Tmrt in the UEB area is not exceeding 40.0°C, thermal sensations of subjects to such Tmrt reduce with the increase of wind speed from 0.5m/s to 3.0m/s. However, in the OPEN area with Tmrt higher than 40.0°C, there is no significant variation of thermal sensation of subjects to Tmrt with the increase of wind speed from 0.5m/s to 1.8m/s. This wind speed under OPEN area is not enough for balancing the effects of high Tmrt on thermal sensation.

Under the same UTCI range from 26.5°C to 38.5°C in UEB and OPEN areas, higher TSVs in OPEN area than that in the UEB area is caused by the significant higher Tmrt in the OPEN area. Other thermal variables being equal in UEB and OPEN areas, this UTCI range includes wide range of Tmrt to which subjects could be more sensitive than UTCI itself does. Effects of Tmrt on thermal sensation are underestimated by UTCI when its value is higher than 28.5°C.

Compared with previous studies, the relationship between TSV and UTCI values is better described by quadratic regression models in this study instead of linear regression models. In the UEB area, when the UTCI is relatively low from 14.0°C to 26.0°C, subjects hold their TSVs on a lower and stable level with the increase of the UTCI. While in the OPEN area with the UTCI range higher than 38.0°C, TSVs of subjects change much slightly at the hot level with the increase of UTCI. From these quadratic regression lines, wind effects on TSVs of subjects are found to be underestimated by UTCI which value is lower than 26.0°C, subjects are more sensitive to the wind speed than UTCI does under such values of UTCI.

In the hot-humid region such as Hong Kong, where the hot season lasts from March to November, outdoor place like UEB area with low Tmrt and strong wind is recommended for bring subjects comfortable or neutral feelings. While in the OPEN area where high Tmrt appeared for the most of the time, only when the UTCI is lower than 28.0°C, subjects would feel comfortable or neutral. UTCI presenting the synthetic effects of outdoor thermal conditions and human factors on thermal perceptions is an appropriate index for forecasting the TSV. However, it underestimates the effects of sun radiant on thermal perception under the UTCI values between 26.0°C and 38.0°C, and wind speed effects when UTCI values are lower than 26.0°C. UTCI should be improved focusing on revising the effects of microclimate parameters on thermal perceptions.

Based on this study, subjects who go for a walk or sit somewhere in Hong Kong would stay hot and uncomfortable once the UTCI value is higher than 38.5°C and stay slightly cool and acceptable once the UTCI value is lower than 26.5°C. Neutral thermal sensation happens under the UTCI between 29.5°C and 32.0°C in the UEB area but between 23.0°C to 27.0°C in the OPEN area. Lower range of neutral UTCI in OPEN area is required because of the high Tmrt there. Therefore, air movement increasing and sunshine eliminating design strategies could be carried out in outdoor spaces based on these UTCI ranges.

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