The influence of perceived environmental quality on thermal comfort in an outdoor urban environment during hot summer

Kevin Ka-Lun Lau¹,²,³, Chun Yin Choi¹
¹ Institute of Future Cities, The Chinese University of Hong Kong, Hong Kong
² CUHK Jockey Club Institute of Ageing, The Chinese University of Hong Kong, Hong Kong
³ Institute of Environment, Energy and Sustainability, The Chinese University of Hong Kong, Hong Kong
Email: kevinlau@cuhk.edu.hk

Abstract. Thermal comfort in outdoor spaces is essential for human health and human wellbeing. A comfortable outdoor space enhances urban livability and sustainability. Previous studies on outdoor human thermal comfort highlighted that apart from the microclimate conditions, the psychological and physiological factors play an important role in human thermal comfort. The influence of environmental quality on human thermal comfort is being examined in this paper. A survey with a total of 1842 thermal comfort responses was conducted during a hot summer in Hong Kong. Perceived aesthetic and acoustic quality votes are strongly associated with Thermal Sensation Votes (TSV). Thermal Comfort Votes (TCV) in the satisfied aesthetic group and the satisfied acoustic group are significantly higher than that in the not satisfied group. A sensation of comfort was confirmed by 39.8% and 38.4% of participants in the satisfied aesthetic group and the satisfied acoustic group, while only 22.2% and 23.9% of the members of the not satisfied group felt comfortable. The study suggested that the perceived environmental qualities are highly associated with thermal sensation and thermal comfort, and a beautiful and quiet environment can improve the thermal comfort and thermal tolerance.

Keywords: perceived environmental quality, outdoor thermal comfort, aesthetic, acoustic

1. Introduction

Well-designed outdoor spaces in an urban environment are important for health and well-being in urban living. A comfortable outdoor environment can enhance the livability, encouraging the use of spaces and community development. To achieve a comfortable outdoor design, the consideration of thermal comfort is inevitable. The design of urban geometry and greenery can enhance the thermal comfort and users’ thermal experience [11]. For outdoor urban environments, the urban microclimate conditions may only account for 50% of the variance in human thermal comfort, while psychological factors account for as much [8]. The psychological adaptation makes a complex relationship between subjective thermal comfort and objective micrometeorological conditions. The objectives of this study are to examine the effects of environmental qualities on thermal comfort, and the relationship between aesthetic and acoustic quality,
and thermal perception. Subjective thermal assessment and meteorological measurements was conducted in outdoor urban environments during hot summer in Hong Kong in 2017.

2. Methodology

2.1 Description of the study sites

Questionnaire surveys were conducted in 15 designated sites in Hong Kong during summer in 2017. The 15 designated sites include different environmental and morphological settings, which includes residential estates, pedestrian streets, and an urban park.

2.2 Meteorological measurements

To examine the relationship between subjective thermal perception and objective thermal conditions, the thermal comfort survey was conducted simultaneously with micrometeorological measurements nearby. TESTO480 data logger and probes for air temperature, globe temperature, relative humidity and wind speed were used for the mobile meteorological stations nearby the survey locations. The globe temperature was measured by using a 38mm-black painted ball with an emissivity of 0.95, which has been widely used for predicting mean radiate temperature in recent decades [5][7]. Universal Thermal Climate Index (UTCI) was used as a thermal comfort indicator based on human thermophysiology, which predicted human responses to outdoor climatic conditions [2]. The UTCI model considers human physiology, climate conditions, and also the human behavioral characteristics, such as clothing insulation. The UTCI model has been widely used in outdoor thermal comfort studies. The software BioKlima was used to calculate UTCI.

2.3 Thermal comfort questionnaire

The thermal comfort surveys were conducted from 10:00 to 16:00 on clear summer days. A total of 1,842 effective responses were conducted and used for the following statistical analyses. The survey included the questions for thermal perception and perceived environmental quality. A seven-point scale was adapted for evaluating thermal sensation and mapped directly to the ASHRAE seven-point thermal sensation scale (i.e. -3 (Cold) to +3 (Hot), while 0 is neutral sensation) [1]. A four-point Likert scale was adapted for evaluating thermal comfort, from -2 (very uncomfortable) to +2 (very comfortable) without a neutral option [8]. To express satisfaction with aesthetics and acoustics, a five-point Likert scale was used, from -2 unsatisfactory to +2 satisfactory with a neutral option. The question of thermal preference gave the three options ‘cooler’, ‘no change’, and ‘warmer’ [8].

2.4 Statistical analysis

Descriptive statistics were used for getting a summary of respondents’ characteristics and micrometeorological conditions. Scatter plot and bar charts were used to examine the relationship between subjective thermal perception and objective meteorological parameters and examine the effects of environmental quality on the thermal perception. The Spearman rank-order correlation test was used to determine the correlation between perceived aesthetic/ acoustic quality and thermal perception. The Kolmogorov-Smirnov (KS) test was used to compare the probability distribution between satisfied environmental quality groups and not satisfied environmental quality groups. A conservative level of significance of 0.05 was adopted for this statistical testing. Linear regressions were produced by using the binned data, with 1°C UTCI binning. Linear models were used for evaluating the relationship between thermal perception and satisfaction of environmental quality and comparing the relationship between thermal perception and UTCI in the environmental quality satisfaction group and not satisfaction group. All statistical analyses were performed using the ‘R’ programming language [10].
3. Results

3.1 Descriptive statistics

A total of 1,842 questionnaire survey responses were obtained. 45% of respondents were male, 55% female. 64.4% of respondents were in an air-conditioned environment 15 minutes before the survey, while the remaining 35.6% of the respondents were in a non-air-conditioned environment 15 minutes before the survey. Approximately half of the respondents were walking before the survey, 32.6% were standing, and 12.7% were sitting. For the age distribution, 25.6% of respondents were under 18 years of age, while 29.7% of respondents were Young adults (18-34 years old), 18.5% of respondents were middle adults, and 25.7% of respondents were old adults (above 55 years old).

The air temperature range during our measurements is from 29.8 to 38.9 °C, which is a typical hot summer in Hong Kong. The relative humidity ranged from 55.2% to 76.4%. The wind speed was between 0.6 and 1.6 m/s. The UTCI calculated by our micrometeorological measurements ranged from 34.0 °C to 44.7 °C. 67.2% of the surveys were conducted in a ‘strong heat stress’ environment (UTCI, 32 - 38 °C), while 32.8% of the surveys were conducted in a ‘very strong heat stress’ environment (UTCI, 38 - 49 °C), the heat stress classification following Brode’s model [3].

3.2 Relationship between thermal perception and satisfaction of perceived aesthetic

Figure 1a shows that there was a strong linear relationship (R^2 = 0.84) between the percentage of comfort and mean aesthetic vote (AeSV) as calculated for 1°C UTCI binning. The respondents satisfied with a higher aesthetic quality of the environment tended to have higher probability of feeling comfortable. The association between thermal comfort vote (TCV) and AeSV is significant as the Spearman rank-order correlation coefficient shows: (p) is 0.191 (p < 0.0001, S = 8.426 x 10^8). The result of the correlation test suggests that the more satisfaction with aesthetic quality, the more thermally comfortable participants felt.

Figure 1c shows that the linear relationship between the mean thermal sensation vote (TSV) and aesthetics is strongly negative (R^2 = 0.8). According to the Spearman correlation test, the correlation between TSV and AeSV is marginally insignificant (p = -0.0402, p = 0.0843, S = 8.426 x 10^8). The respondents more satisfied with the aesthetic quality of the environment tended to vote a lower TSV.

Figure 2a shows that the slope of the linear regression between UTCI and mean TSV for the aesthetic satisfaction group (m = 0.03) is lower than that for the not aesthetic satisfaction group (m = 0.054). The thermal sensitivity of the respondents in the aesthetic satisfaction group is lower than that of the not aesthetic satisfaction group. Figure 2c shows that the percentage of thermal comfort in the aesthetic satisfaction group is generally higher than that for the not aesthetic satisfaction at an equal UTCI, except for the point at 43.5 °C, which suggests that this outlier may be due to the insufficient response under extreme heat stress (n = 16). The Kolmogorov-Smirnov test shows that the distribution of TCV between aesthetically satisfied group and aesthetically not satisfied group is significantly different (D = 0.17645, p-value < 0.0001). 39.8% of respondents with a satisfied aesthetic quality felt comfortable, while only 22.2% of respondents with a not satisfied aesthetic quality felt comfortable. 80.8% of the respondents with a satisfied AeSV would prefer a cooler temperature, while 16.1% desire no change and 3.1% would prefer a warmer temperature.

88.7% of the respondents with a not satisfied AeSV would prefer a cooler temperature, while 8.2% desire no change and 3.1% would prefer a warmer temperature. The Kolmogorov-Smirnov test shows that the distribution of thermal preference vote between satisfied AcSV group and not satisfied AeSV group is significantly different (D = 0.079187, p-value = 0.0078).
3.3 Relationship between thermal perception and satisfaction of perceived acoustic

Figure 1b shows that the linear relationship between mean acoustic vote (AcSV and the percentage of comfort is strong ($R^2 = 0.88$) and positively associated. At the same UTCI, the respondents with a higher acoustic quality vote tended to present a higher probability of feeling comfortable. The Spearman rank-order correlation between TCV and acoustic quality vote is positive ($\rho = 0.163$, $p < 0.0001$, $S = 8.716 \times 10^9$), which means the higher the satisfaction with acoustic quality, the higher the thermal comfort level. Figure 1d shows that the linear relationship between mean thermal sensation and mean AcSV are strong ($R^2 = 0.92$) and negatively associated. The Spearman rank-order correlation between TCV and acoustic quality vote are negative ($\rho = -0.083$, $p = 0.0004$, $S = 1.238 \times 10^9$). The respondents more satisfied with the acoustic quality of the environment tended to vote for a lower TSV.

Figure 2b shows that the slope of the linear regression between UTCI and mean TSV for the acoustic satisfaction group ($m = 0.037$) is lower than that for the not aesthetic satisfaction group ($m = 0.055$). The respondents satisfied with acoustic quality are less sensitive to the UTCI change compared with the respondents not satisfied with acoustic quality. Figure 2d shows that the percentage of thermal comfort in the acoustic satisfied group is higher than that for the not acoustic satisfied group, except for the points at 37.5 °C. The Kolmogorov-Smirnov test distribution shows that the TCV in the acoustically satisfied group and the acoustically not satisfied group are significantly different ($D = 0.14539$, $p$-value < 0.0001). 38.4% of respondents satisfied with the acoustic quality felt comfortable, while only 23.9% of respondents not satisfied with acoustic quality felt comfortable.
82% of the respondents with a satisfied AcSV would prefer a cooler temperature, while 14.6% desire no change and 3.4% would prefer a warmer temperature. 78.6% of the respondents with a not satisfied AcSV would prefer a cooler temperature, while 9.5% desire no change and 2.9% would prefer a warmer temperature. The Kolmogorov-Smirnov test distribution shows that the thermal preference votes of satisfied AcSV group and not satisfied AcSV group are significantly different ($D = 0.055102$, p-value = 0.1466).

Figure 2. Scatterplots between mean TSV and UTCI for ‘Satisfactory’ and ‘Not Satisfactory’ groups for (a) Aesthetic and (b) Acoustic. Scatterplots between percentage of thermal comfort and UTCI per 1°C UTCI binning for ‘Satisfactory’ and ‘Not Satisfactory’ group for (c) Aesthetics and (d) Acoustics

4. Discussion

This study examines the effect of aesthetic and acoustic quality on thermal perception in outdoor environments. The results show that the satisfactions of aesthetic and acoustic qualities are significantly associated with the subjective thermal perception. Respondents with a satisfaction with aesthetics or acoustics tended to report a cooler sensation and vice versa. The thermal sensitivity of respondents with a satisfaction with aesthetics or acoustics is lower than that of the respondents with a non-satisfaction with aesthetics or acoustics. In the same thermal environment, the respondents who indicated satisfaction with aesthetic or acoustic quality were more likely feeling comfortable than the respondents who indicated non-satisfaction with aesthetics or acoustics. A previous study suggested that the influence of pleasant aesthetics has a positive effect on satisfaction of comfort [4]. The present study consistently suggests that aesthetic comfort is highly positively associated with the perception of thermal comfort. Previous studies reported
that noise level is associated with thermal discomfort [6] [10]. The present study shows similar findings, i.e. that the respondents in a perceived noisy environment may tend to feel more thermally uncomfortable and feel hotter.

A previous study suggested that psychological adaptation plays an important role on the response to the micrometeorological change, which affects how people perceive the environment [4][9]. Humans have high tolerance to micrometeorological conditions in outdoor environments since they are adaptive to the environment or the perceived environmental quality. To enhance the thermal comfort in a particular high-density urban outdoor environment, it might not be possible to change the meteorological conditions significantly. The thermal comfort can be enhanced by improving the environmental quality. Therefore, the knowledge of the relationship between perceived environmental qualities and thermal comfort is indispensable for building a more comfort outdoor spaces, and to further promote the use of outdoor spaces. Further work is required to determine the effects of others environmental qualities on outdoor thermal comfort.

References

[1] ASHRAE. (2010). ANSI/ASHRAE Standard 55-2010: Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.

[2] Blażejczyk, Krzysztof & Jendritzky, Gerd & Bröde, Peter & bullet, Dusan & Fiala, Dusan & bullet, George & Havenith, George & bullet, Yoram & Epstein, Yoram & Psikuta, bullet & Kampmann, Bernhard. (2013). An introduction to the Universal Thermal Climate Index (UTCI). Geographia Polonica. 86. 5-10. 10.7163/GPol.2013.1.

[3] Bröde P, Fiala D, Blażejczyk K, Holmér I, Jendritzky G, Kampmann B, Tinz B, Havenith G, 2012. Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). International Journal of Biometeorology 56(3): 481-494.

[4] Castaldo VL, Pigliautile I, Rosso F, Cotana F, de Giorgio F, Pisello AL, 2018. How subjective and non-physical parameters affect occupants’ environmental comfort perception. Energy and Buildings 178: 107-129.

[5] D’Ambrosio Alfano, Francesca & Malchaire, Jacques & Palella, Boris & Riccio, Giuseppe. (2014). WBGT Index Revisited after 60 years of Use. Annals of Occupational Hygiene. 58. 955-970. 10.1093/annhyg/meu050.

[6] Fanger PO, Breum NO, Jerking E, 1977. Can colour and noise influence man's thermal comfort? Ergonomics 20(1): 11-18.

[7] Fountain, M. (1987). Instrumentation for thermal comfort measurements: The globe thermometer. UC Berkeley: Center for the Built Environment. Retrieved from https://escholarship.org/uc/item/1qx8c7sm.

[8] Marcel Schweiker, Xaver Fuchs, Susanne Becker, Masanori Shukuya, Mateja Dovjak, Maren Hawighorst & Jakub Kolarik (2017) Challenging the assumptions for thermal sensation scales, Building Research & Information, 45:5, 572-589, DOI: 10.1080/09613218.2016.1183185

[9] Nikolopoulou M, Steemers K, 2003. Thermal comfort and psychological adaptation as a guide for designing urban spaces. Energy and Buildings 35(1): 95-101.

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

[11] Yang, Wonyoung. (2017). Effects of Noise on Indoor Thermal Sensation and Comfort. KIEAE Journal. 17. 83-89. 10.12813/kieae.2017.17.1.083.