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Thermal perceptions and microclimates of educational urban precincts in two different seasons in Melbourne

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Abstract: This paper assesses the levels of comfort within outdoor educational urban precincts in Melbourne. Three urban spaces, in relatively close proximity to each other were investigated in two different seasons: spring 2014 and summer 2015. In total, 368 and 413 comfort responses were collected in the spring and summer seasons, respectively. The preliminary results show the characteristics of thermal perceptions, using the 7-point scales of thermal sensation votes (TSV) and comfort scale 'affective evaluation'. In addition, the Physiological Equivalent Temperature (PET) index was also used to predict the thermal comfort for a large number of space users. While the mean temperature for spring was recorded as 21.55 °C, it reached up to 24.75 °C in summer. The overall thermal sensation votes for both seasons were toward the slightly warm side of the scale and its value moved from 0.47 in spring to 0.78 in summer. However, comfort responses, using 7-point comfort scale, on average, were from moderately to slightly comfortable conditions in spring, which changed to between just right and slightly uncomfortable conditions in summer. The changes found in the results of two seasons illustrate the extent of seasonal changes impacting thermal perceptions. Adopting the PET as a thermal comfort indicator, the results prove the reliability of this index for the study periods.

Keywords: Thermal comfort assessment; microclimates; urban precincts; outdoor environments.

1. Introduction

People's outdoor thermal comfort is influenced by surrounding microclimate, and people's usage of outdoor spaces is impacted by their thermal perceptions. Therefore, providing thermally comfortable open spaces for the users needs to be considered. Urban precincts may be considered as enclosures with different physical characteristics and focused activities. They provide much needed open outdoor areas, particularly in high density spaces. However, these open spaces are subject to a range of ecological issues, including but not limited to, urban heat island effects. In Australia, recent trends in urban planning suggest redevelopment of the urban precincts to minimise adverse environmental, social

and economic consequences such as climate change, energy consumption and pollution. Therefore, it is imperative to understand thermal comfort requirements during different times of a year to enhance the experience of users within outdoor environments. According to ASHRAE 55 (2010), thermal comfort is a "condition of mind which expresses satisfactions with the thermal environment".

1.1. Outdoor thermal comfort

Several thermal comfort indices and methodologies have been applied to investigate thermal comfort in outdoor settings. Both heat balance and adaptive based approaches have been developed and applied with some success in outdoor settings (Nikolopoulou and Lykoudis, 2006; Ng and Cheng, 2012). While the heat balance approach has been long used and still used to assess thermal comfort, there exist some shortcomings in terms of non-thermal factors that are addressed in adaptive theory.

To date, a number of studies have been conducted in Melbourne, Australia to analyse the thermal comfort requirements for different types of outdoor users (Spagnolo and de Dear, 2003; Loughnan *et al.*, 2012; Kenawy, 2013; Lam *et al.*, 2014). Each of these studies has focused on a population target with the view of characterising their thermal comfort conditions. Also, the thermal comfort conditions may vary depending on the season of the year as people can adapt to prevailing climate conditions (de Dear *et al.*, 1997; Lin *et al.*, 2011). The comfort requirements may also differ among various user groups; including, tourists, students and pedestrians. No study has considered outdoor thermal comfort assessment in educational precincts with a population consisting of university students and staff in Australia. While study of educational precincts is novel, the underlying concepts may be applied to any outdoor urban setting. The concept of educational precincts refers to those built environments that feature outdoor spaces, surrounded by educational buildings. These built environments give a sense of enclosure with different physical characteristics and focused activities. In Australia, recent trends of urban planning and management such as Melbourne @ 2030 (Victorian Government, 2008) suggest development of urban precincts to minimise adverse environmental, social and economic consequences (d'Argent, 2012). Some studies have focused on the temporal impact of physical characteristics of educational precincts on comfort conditions in other parts of the world (Wong *et al.*, 2007; Xi *et al.*, 2012).

This paper explores the effect of seasonal thermal conditions on the users' thermal perception in educational precincts in two seasons. The paper is based on a preliminary analysis of data collected for a doctoral study, which identifies some of the wider determinants of outdoor thermal comfort in educational urban precincts. The study aims to understand the ability of different thermal indices in the prediction of thermal comfort along with other cultural and social drivers, and site specific urban morphology in understanding thermal perception and microclimates in educational precincts. This paper is restricted to an initial exploration using the Physiological Equivalent Temperature (PET) index as the main yardstick of measure. This study also tries to inform the guideline used by universities on provision of thermally comfortable educational outdoor environments for university students and staff as well as other users.

2. Method used for this study

The conditions of thermal comfort outdoor spaces were assessed according to a concurrent measurement of major microclimatic parameters: air temperature (Ta), wind velocity (Va), relative humidity (RH) and globe temperature (Tg), and a questionnaire survey on human thermal responses

using ISO standards (ISO 7730, 2006). The values of these parameters were measured using Testo 480 IAQ Pro Measurement Kit that was placed close to the participants, and the data logger was set to collect variables at 1-min intervals. The sensors were mounted on the kit's tripod at different heights: Ta (95 cm), RH (95 cm), Tg (95 cm) and Va (110 cm). Subjective assessment was conducted at the 3 sites to understand the effect of seasonal change on thermal comfort requirements. In each season 15 days were allocated to conduct field surveys in the study sites: from 9:00 am to 5:00 pm in November 2014 (spring time) and February 2015 (summertime). Also, a concurrent measurement of Ta and RH was carried out across the sties during each season using a stationary measuring system (HOBO Pro v2 temp/RH U23-00). The method used in this study is considered as a standard practice to assess outdoor thermal comfort that has been adopted in previous studies (Spagnolo and de Dear, 2003; Lin et al., 2011; Johansson et al., 2014)

2.1. Study sites

This study was conducted in Melbourne, which has an oceanic climate and Cfb according to the most updated Köppen-Geiger classification (Peel *et al.*, 2007). Melbourne has highly changeable weather conditions due to its specific location situated on the borderline of extremely hot inland region and cool southern ocean (BoM, 2014). The thermal variability is greatest in the spring and summer months due to the formation of cold fronts from the northwest, west and south. Three urban environments within an educational campus were selected as the case study for this research. The selection criteria were based on their characteristics representing common outdoor spaces with similar urban forms to those of the inner city of Melbourne. The study sites were situated in the heart of central Melbourne which is subject to UHI effects caused by surrounding high-rise buildings, densely urbanized hard surfaces with less evapotranspiration and crowded spaces with higher anthropogenic heat production (Coutts *et al.*, 2007). The majority of space users are university students and staff who belong to the young ages (18-35 years old) that use the sties either to pass by to another place, use the space for work or for leisure. All the sites were located in the premises of the RMIT University City Campus (RUCC) and their specifications are presented below:

- *Site 1:* University Lawn which is used as a recreational space by university students and staff. This venue has a varied surface coverage, water features and a natural green space. The compact design of University Lawn makes it representative of many recreational outdoor spaces in the inner city.

- *Site 2:* Ellis court in RUCC is differentiated from the other two sites as it acts a thoroughfare and a main path to other parts of the campus. This site includes a range of urban elements that collectively affect thermal conditions and resemble many other urban precincts in the City of Melbourne.

- *Site 3:* RMIT A'Beckett Urban Square is recreational space, which provides multi-functional courts for outdoor activities, green spaces and shading features. This site resembling many commercial outdoor settings in inner-city which is surrounded by high rise buildings and is open to the public. The microclimate conditions of these sites during the two field survey (Table 1) and in a 10 day period (Figure 1) are presented below. As can be observed, there were noticeable variations in the climate variables during the field survey in both seasons. However, the changes did not necessarily share a same trend in the three study sites.

Table 1: Summary of the climate variables monitored at study sites during the field survey (mobile weather station).

Site	Variable	Unit	Mean		Max		Min		Stdev	
			Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer
Site 1	T_a	˚C	22.51	22.21	28.96	27.80	17.35	18.75	2.05	2.15
	RH	%	40.43	55.63	63.59	72.51	26.92	40.14	6.95	7.68
	T_g	˚C	25.48	27.32	36.13	36.60	15.22	20.63	3.89	4.58
	SR	$W.m^{-2}$	701.47	502.14	1238.1	996.57	0.60	59.37	324.9 9	314.61
	V_a	$m.s^{-1}$	1.51	1.91	5.46	3.91	0.00	0.44	0.98	0.63
Site 2	T_a	˚C	23.50	29.18	36.18	34.52	14.97	23.08	6.11	3.011
	RH	%	34.72	48.47	58.13	72.52	16.45	28.19	11.19	13.05
	T_g	˚C	28.32	34.66	46.00	45.76	16	25.19	7.39	4.50
	SR	$W.m^{-2}$	433.14	517.51	1276.9	948.96	24.4	26.03	396.1 8	324.27
	V_a	$m.s^{-1}$	1.63	1.55	6.01	3.41	0.07	0.29	0.98	0.75
Site 3	T_a	˚C	18.96	24.34	26.39	29.13	14.31	19.55	2.43	2.40
	RH	%	49.24	60.34	71.16	80.85	30.38	37.42	6.56	9.87
	T_g	˚C	23.62	27.47	35.45	40.52	15.42	20.73	5.11	4.77
	SR	$W.m^{-2}$	410.19	352.18	1276.9	921.06	24.4	13.15	345.4 0	334.38
	V_a	$m.s^{-1}$	1.59	1.51	9.97	4.64	0.10	0.18	1.03	0.75

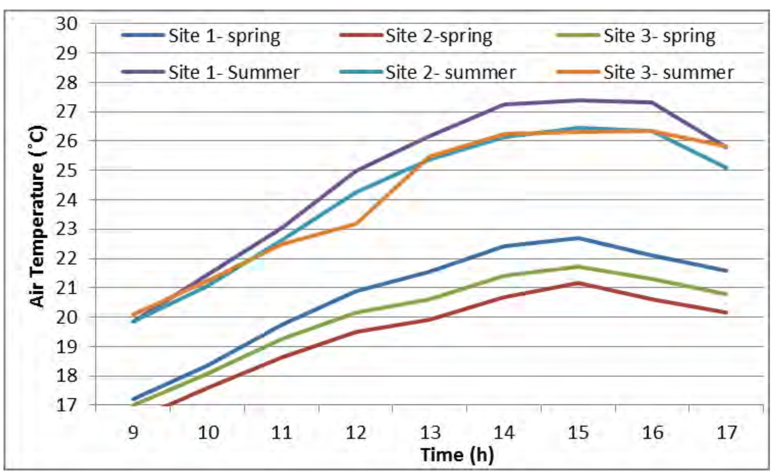

Figure 1: Thermal conditions of the three study sites (Ta) in two seasons (Stationary station).

2.2. Outdoor thermal index, PET

Among several thermal comfort indices, the Physiological Equivalent Temperature (PET) was used in the study. This index is specifically designed for outdoor conditions and has been recently adopted in many

outdoor comfort studies. PET is expressed in degrees centigrade and easy to be understood by designers and urban planners. Use of this index eases the comparison between the results of this study and those of others. Also, the results in the form of PET can be integrated with other PET-based studies to form a global database on thermal comfort requirements.

PET is built up on the basis of Munich Energy-balance Model for Individuals (MIMI) in 1987 and is technically linked with the Gagge's two-node model parameters (Höppe, 1999). The theory behind this index is to transfer the actual thermal conditions in an equivalent indoor setting, where similar thermal perception is assumed (Thorsson *et al.*, 2007a) and therefore is fit to be used outdoors (Chen and Ng, 2012). PET was calculated using Rayman Software Package 1.2 that assumes the constant values for the level of activity (80 W) and clothing insulation (0.9 *Clo* for spring and 0.5 *Clo* for summer). Also, Mean Radiant Temperature (T_{mrt}) is also calculated to be input into Rayman software using T_a, T_g and V_a (ISO 7730, 2006). Tmrt indicates the radiative exchange between the human body and the given environment (Thorsson *et al.*, 2007b). To reduce the effect size of individual differences the calculated PETs were put into 1 ˚C intervals (bins) and thermal sensation votes (TSVs) were averaged against each interval called mean thermal sensation vote (MTSV) (de Dear and Fountain, 1994).

2.3. Thermal perceptions

The participants in this study were among university students and staff who were asked to complete a questionnaire that took less than five minutes with 14 questions. They were briefed about the aim of research before participating in the survey. Two descriptors of thermal perceptions were used in this study: thermal sensation and thermal comfort. The subjective perception was measured using two 7-point scales: thermal sensation and comfort scale 'affective evaluation that was tailored to 7-point to match with thermal sensation points. The TSV was judged on the ASHRAE 7-point scale (ASHRAE 55 2010) and has a range of "cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2) and hot (+3)". The comfort 7-point scale, which is an extension of 4-point scale of ISO 10551 (1995), ranges from "very uncomfortable" (1), "moderately uncomfortable"(2), "slightly uncomfortable"(3), "just right"(4) to "slightly comfortable"(5), "moderately comfortable" (6) and "very uncomfortable"(7) that correspond to the thermal sensation scale.

3. Results

3.1. Characteristics of the sample size

In total 781 thermal responses were collected from two field surveys conducted during 18 days from November 2014 to February 2015 at the study sites. In the spring, of the total 368, male and female participants were accounted for 67% (N= 246) and 33% (N= 122), respectively. The same percentages were also observed in the summer, where out of 413 participants, 69% (N= 257) and 38% (N=142) were male and female, respectively. Also, over 54% and 63% of participants were within the range of less than 18 to 30 years old in the spring and summer, respectively. The age group distribution indicates the type of the study site users who were mostly young people.

3.2. Thermal sensation votes

While the mean temperature for spring was recorded at 21.55 °C and reached up to 24.75 °C in summer, the distribution of TSVs shows relatively alike trends (Figure 2). However, the percentage of

votes to the right side of the scale (warmer conditions) was always higher (60.10 %) in summertime compared to the conditions in the spring (53.80%). Likewise, for the left side of the scale (cooler conditions), spring's TSVs outnumbered that of summertime. The overall TSV (the arithmetic average of thermal votes) for both seasons were toward the slightly warm side of the scale and its value moved from 0.47 in spring to 0.78 in summer. However, comfort responses, using a 7-point comfort scale, on average, were from moderately to slightly comfortable conditions in spring, which changed to between just right and slightly uncomfortable conditions in summer.

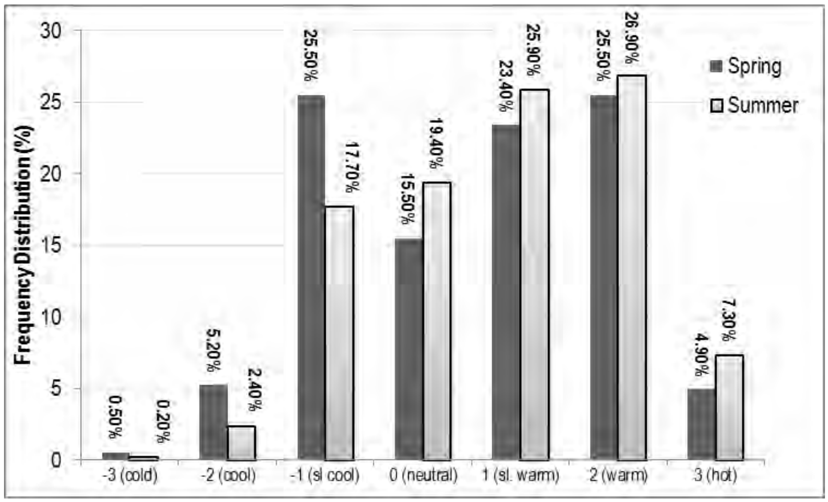

Figure 2: Distribution of thermal sensation votes in two seasons.

3.3. Actual and Predicted thermal perception

To validate the accuracy of predicted thermal comfort conditions, mean thermal sensation votes (MTSV) were plotted against predicted PET values. As shown in Figure 3, the prediction power of PET noticeably changed during the two seasons (R^2= 0.77 in spring to R^2=0.93 in summer, $P<0.05$). Also, the findings suggest the fact that while in summer above 90% of the variation in the users' thermal sensation is explained by the thermal conditions, in spring users were less sensitive to weather conditions and other non-thermal factors matter. In the two seasons an increase in PET values caused TSVs shifted towards the warmer end of the scale.

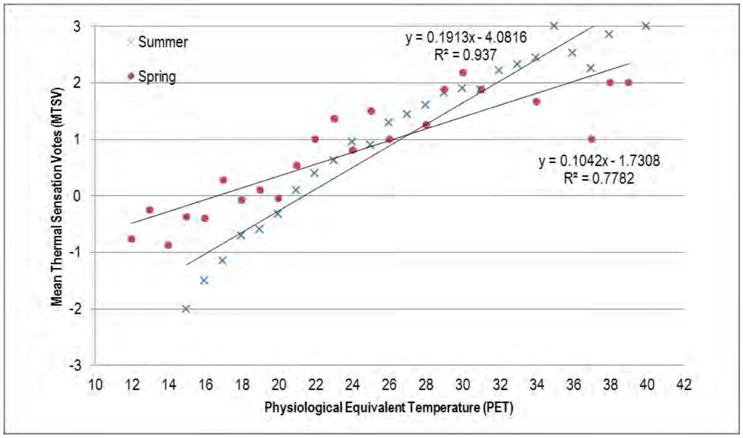

Figure 3: The dependence of actual thermal sensation (MTSV) on predicted thermal comfort (PET) in two seasons.

The comfort level was also cross-tabulated against PET for the two seasons (Figure 4). The results of simple linear regression show a weak relationship between the concept of comfort and thermal conditions in spring (R^2= 0.14, P<0.05) and summertime (R^2= 0.13, P<0.05). The results also show that comfort conditions were equally a function of thermal conditions in the two seasons.

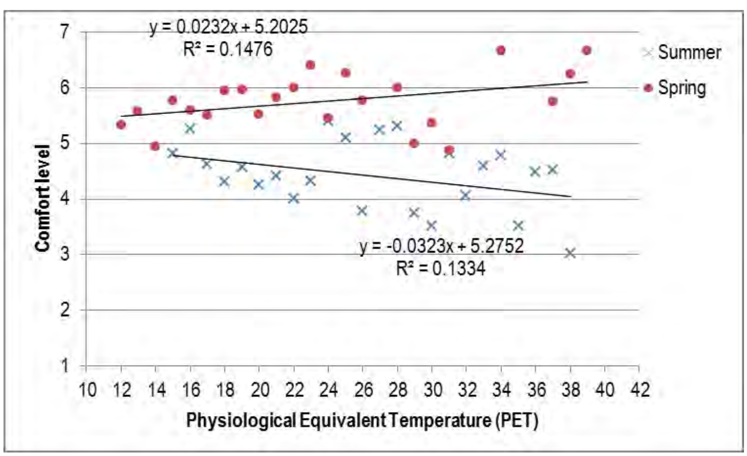

Figure 4: Cross-tabulation of comfort levels and predicted thermal comfort (PET) in two seasons.

4. Discussion

The requirements of thermal comfort in outdoor spaces vary depending on some factors including seasonal change. This study evaluates the impact of seasonal change on the thermal perceptions to understand the essence of changes across the two seasons. In doing so, two comfort field surveys were conducted in a spring (November 2014) and in summer (February 2015). In total, 368 and 413 comfort

responses were collected in the spring and summer seasons, respectively. The overall TSVs for both seasons were toward the slightly warm side of the scale and its value moved from 0.47 in spring to 0.78 in summer. These findings suggest the impact of seasonal change on the outdoor thermal perceptions, yet in small grades, in two subsequent seasons.

Cross-tabulating TSV with PET values indicates the strong impact of climate conditions on thermal sensation. However, this impact was proved to be varying across the seasons; more effective in summer and less in spring. The varying effect of climate conditions on TSV implicates the role of seasonal change on outdoor users' thermal perception; where the comparatively severe thermal conditions in summer induced higher sensitivity to thermal conditions among users. The results of cross-tabulation between PET and comfort levels points to the difference between the concept of comfort and thermal sensation. This difference is already recognised in a study in Queensland (de Freitas, 1985) where the holiday makers had different thermal preference and comfort compared to what they indicated as thermal sensation. This difference also underlines the importance of other non-thermal factors contributing to the status of comfort in outdoor spaces (Brager and de Dear, 1998).

5. Conclusion

The outcome of the present study contributes to empirical data used to assess thermal comfort in outdoor areas in a temperate climate such as Melbourne. Despite the growing demand for understanding the dynamic of thermal comfort, such empirical data are yet to be investigated and the links to urban planning yet to be explored. This shortcoming has been also recognised in the previous studies (Spagnolo and de Dear, 2003; Kenawy, 2013) that suggest further studies are required to shed light on different aspects of thermal comfort in outdoor conditions. The preliminary findings of this study illustrate the role of other players in achieving comfort in outdoor environments. Furthermore, the likelihood of changes in comfort conditions throughout a year calls for the need for standard assessment of thermal comfort during different seasons. This, together with results of previous studies can lead to defining the requirements of thermal comfort in urban spaces and setting up of a standardised approach to measuring thermal comfort in the outdoors. The empirical findings of the research also raise the awareness for the use of climate sensitive design principles, which allows spatial managers to maximize the use of comfortable outdoor environments including educational precincts. Further studies are highly recommended to gain an insight into the dynamic of the concept of comfort in use of outdoor spaces; the factors that are influential in thermal perceptions.

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