# Outdoor Thermal Comfort Assessment of Educational Precincts during Spring Time in Melbourne Australia

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# Outdoor Thermal Comfort Assessment of Educational Precincts during Spring Time in Melbourne Australia

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**Abstract**
Understanding the thermal effects of the built environment on the users' thermal perception and behavior, provides an insight into the suitability and usability of outdoor urban environments. This paper aims to address the extent to which thermal conditions can explain the thermal perception and users' behavior in an urban precinct. A field survey which included structured interviews using a standard questionnaire and observation of users' activities was carried out while the microclimate conditions were monitored. The survey was conducted in three study sites, with distinctive morphology and patterns of land use, across the RMIT University Campus City (RUCC) in Melbourne, Australia. This case study targets the university population of students, staff and visitors from different backgrounds. In total, 368 questionnaires were deployed during 21 days in November 2014. The preliminary results show that climatic conditions can significantly affect the users' thermal perception. This suggests the importance of considering passive design strategies in urban environments. Furthermore, the participants' climate/cultural background is recognized as a factor for thermal perception in an outdoor environment.
*Keywords: Thermal comfort; outdoor places; climate-sensitive urban design; microclimate*

## 1. INTRODUCTION

People who are exposed to outdoor conditions are directly influenced by microclimatic variables (Nikolopoulou and Lykoudis 2007). The usage of outdoor settings by people, may therefore, be highly dependent on climatic conditions. Assessment of these variables, will assist urban planners to increase the quality of urban life (Frank et al. 2003, Johansson 2006). This is underlined in Australia, where heat waves are considered to be the third most severe natural disaster, following floods and bushfires (Charleston 2012). Hot weather is becoming more common and severe in Australia (Climate Commission 2011). The 2003-2012 decade remains one of the country's warmest with a temperature anomaly of+0.44ºC and all Australian capital cities recorded warmer-than-average maximum temperatures (BoM 2014a). The latest report by the IPCC (2014) states that summer temperatures in Australia are predicted to rise leading to increased energy consumption to achieve comfortable temperatures indoors.

Meteorological parameters have been long associated with thermal perceptions in outdoor spaces (Mayer and Höppe 1987), nonetheless, the extent to which people perceive comfort differs according to the context, including, but not limited to, climate conditions, human parameters and spatial features (Brager and de Dear 1998, Aljawabra and Nikolopoulou 2010, Cohen et al. 2013).The reason to use the place or activities taking place outdoors also have been found to be a factor that can influence thermal perceptions (Thorsson et al. 2007, Spangenberg et al. 2008). Previous studies in public places of Japan (Thorsson et al. 2007), Morocco (Aljawabra and Nikolopoulou 2010) and Brazil (Spangenberg et al. 2008) found that the function of place impact usage pattern. Cultural factors including climate background can influence the way people perceive their surrounding thermal environment (Brager and de Dear 1998, Knez and Thorsson 2006, Aljawabra and Nikolopoulou 2010). Differing climate/geographical zones are also classified as different cultures (Knez and Thorsson 2006). The climate/cultural background was found to be a contributing factor in regards to thermal perception when the results of two studies in two different

cultures were compared (Knez and Thorsson 2008).

This study tries to understand the interaction of thermal and non-thermal factors, and people's thermal perceptions and usage pattern in educational precincts. Therefore, the main objectives of this paper are to (1): understand the effects of microclimate on outdoor users' thermal sensation votes (TSV) and usage pattern (2) evaluate the effect of cultural (climate) background on thermal perception (3) examine the applicability of two universal thermal indices in prediction of thermal comfort. The results of such studies can inform urban planners and designers when applying passive design strategies to outdoor settings. While there are some studies looking at educational precincts in various climates (Wong et al. 2007, Xi et al. 2012, Srivanit and Hokao 2013), no studies have been conducted in the oceanic temperate climate.

## 2. METHOD

### 2.1 Study sites

This study was conducted in the context of Melbourne which has an oceanic climate (Köppen-Geiger classification Cfb) characterized with warm to hot summers and cool winters (Peel et al. 2007). Melbourne has highly changeable weather conditions due to its specific location situated on the borderline of the extremely hot inland region and the cool southern ocean (BoM 2014). The thermal variability is greatest in the spring and summer months due to the formation of cold fronts. Three urban environments within an educational campus are selected as the case study for this research. These cases characterize common outdoor spaces with similar urban morphologies to those of the inner city of Melbourne. They vary in terms of function, morphology, size, location and potential users. The study sites are situated in the heart of central Melbourne which is subject to Urban Heat Island (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, Chen et al. 2013). All sites are located in the premises of the RMIT University City Campus (RUCC). Figure 1 illustrates the locations of the study sites in the Melbourne Central Business District (CBD), and Figure 1 is an aerial thermal image of the sites.

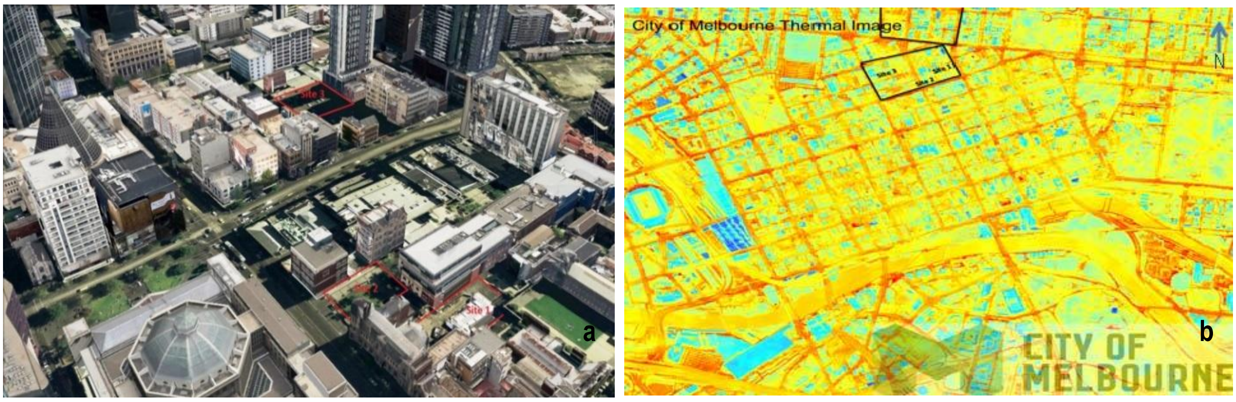


Figure 1 (a):The geographical distribution of the study sites within the RUCC using aerial map. Source: Google Maps (2014). (b): The thermal image of Melbourne CBD showing the hot spots within the inner city of Melbourne Source: City of Melbourne (2012).

Site 1: University Lawn located in the City Campus is used as a recreational space by university students and staff. This venue has a varied surface coverage; artificial grass, timber deck, 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 urban precincts in the City of Melbourne.

Site 3: RMIT A'Beckett Urban Square is a 2800 $m^2$ recreational project, which provides multi-functional courts for outdoor activities, green spaces and shading features. This site resembling many commercial outdoor settings in inner-city is intended to serve a wide range of users including students, staff, business population as well as visitors. The site is surrounded by high rise buildings and is open to public.

The study employed 3 techniques: physical measurement, questionnaire survey and observation at all 3 sites. To measure the microclimate conditions a stationary weather station was placed at each site to continuously recording during the 21 day study period in Spring 2014.

### 2.2 Measurements and instrumentation

In this study physical measurements, observation and questionnaires were conducted at the 3 sites. Physical measurements consisted of two measurement systems: (1) mobile measurement in which four environmental variables used to calculate the thermal comfort: air temperature ($T_a$), wind velocity ($V_a$), relative humidity (RH) and globe temperature ($T_g$) were recorded, and (2) stationary loggers that concurrently took the measurement of $T_a$ and RH at the three sites. For mobile measurement a portable Testo 480 IAQ Pro Measurement Kit was used and global temperature ($T_g$) was registered by Silicon Pyranometer Smart Sensor. The mobile weather station was placed close to the participants and the period of measurement was from 9:00 am to 5:00 pm, the time when the study sites were most frequented by users. The measuring interval was one minute and readings were logged by the Testo 480 data logger and H21-002- HOBO Micro Station. The requirements of the measuring range and the accuracy of the instruments comply with ISO 7726: 1998 (ISO 7726 1998) and ASHRAE 55 (2010). This study employed Physiological Equivalent Temperature (PET) (Mayer and Höppe 1987) and Universal Thermal Comfort Index (UTCI) (Jendritzky et al. 2001) indices to predict the thermal comfort at the given outdoor environments. Rayman Software Package V 1.2 (Matzarakis et al. 2007) and BioKlima V 2.6 (Jendritzky et al. 2012) were used to calculate PET and UTCI values, respectively.

### 2.3 Questionnaire survey

A questionnaire survey was concurrently preformed while taking the measurement of environmental variables to understand the actual thermal perceptions in urban precincts. The structure of questionnaire consists of three parts: personal details, thermal perceptions and thermal adaptation. Supplementary observations were also carried out by the researcher to record the participants' characteristics in order to minimize the response time and reduce the rejection rate. On average, the questionnaire took less than five minutes to complete. The personal details included age, gender and the cultural (climate) background. The participants' thermal sensation vote (TSV) were obtained using an ASHRAE 7-point scale (ASHRAE 55 2010). The scale is ranked from +3 (hot) to -3 (cold) with 0 that denotes the neutral conditions (not warm and not cool). The participants' reason to use the site was also noted to understand the function of the study location. The supplementary observation covered the information on the personal factors and the sub-areas. Participants were mostly university students, academic and professional staff. The participants were briefed about the objectives of the study with an information sheet which was approved by RMIT University Ethics Committee.

### 2.4 Observation

Unobtrusive observation was also used as a standard practice to assess the interaction between climate conditions and people's attendance and usage. Observation of usage pattern in the study sites can be linked to thermal conditions to understand the possible impact of thermal factors on usage of outdoor environments. Unobtrusive observation was employed in previous studies (Thorsson et al. 2007, Aljawabra and Nikolopoulou 2010, Égerházi and Kántor 2011). The observation was conducted simultaneously with field measurement every 30 minutes for two days at each study site, making 34 cases of observation over the 6 days at the three sites.

## 2.5 Analysis

Data was collected from 368 participants spread across the 3 sites. Statistical analysis was conducted to evaluate the effect of microclimate conditions on thermal perception and to investigate the factors contributing to the perception and usage pattern of users in open urban precincts. These tests included descriptive analysis along with inferential methods. Due to the normal distribution of the thermal responses and the type of data gathered, parametric tests were applied. PET and UTCI indices were calculated, and put into 1°C intervals (bins) as suggested by de Dear and Fountain (1994) to to reduce the effect size of individual differences in the given environment on the overall thermal sensation. The mean thermal sensation vote (MTSV) was calculated to describe the impact of thermal conditions on a large number of people rather than an individual's thermal perception. SPSS Statistical Software Package V. 22 and Microsoft Spread sheet Excel 2010 was employed to conduct the analysis and to plot the figures and tables.

## 3. RESULTS AND DISCUSSION

### 3.1 Microclimatic conditions

The weather during the study period was changeable with a considerable fluctuation in meteorological conditions measured by both the mobile and stationary weather stations. The variation in the observed values also indicates the extent of variability in daily and inter-seasonal microclimate conditions of Melbourne. The air temperature, at the same hours (9:00 am to 5:00 pm), ranged from 14.72℃ to about 34℃ and relative humidity varied from 18% up to 75%. The three sites exhibited broadly similar temperatures profiles; with the main difference being Site 3 was slightly lower than those measured in Site 1 and 2 (Figure 2, Table 1). Mean global horizontal solar radiation was higher at Site1 compared to Sites 2 and 3. Table 1 presents the basic statistics for the climatic conditions during the field survey in the three study sites.

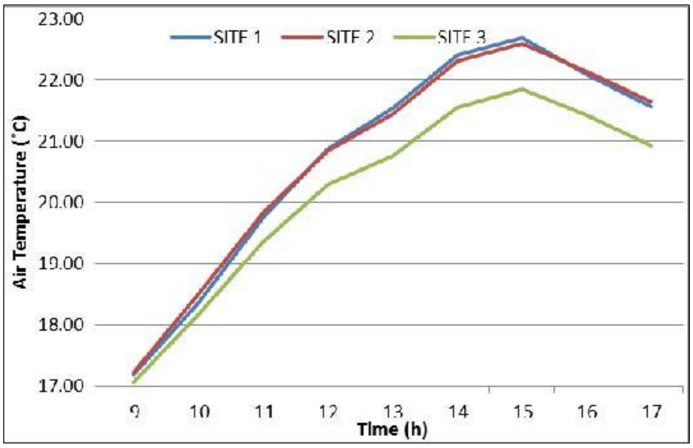


Figure 2. The averaged variation of $T_a$ values during 10 days of field survey within the three study sites (stationary loggers).

**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 |
|---|---|---|---|---|---|---|
| | $T_a$ | °C | 22.51 | 28.96 | 17.35 | 2.05 |
| | $RH$ | % | 40.43 | 63.59 | 26.92 | 6.95 |
| *Site 1* | $T_g$ | °C | 25.48 | 36.13 | 15.22 | 3.89 |
| | $SR$ | W.m$^{-2}$ | 701.473 | 1238.1 | 0.6 | 324.99 |
| | $V_a$ | | 1.51 | 5.46 | 0.00 | 0.98 |
| | $T_a$ | °C | 23.50 | 36.18 | 14.97 | 6.11 |
| | $RH$ | % | 34.72 | 58.13 | 16.45 | 11.19 |
| *Site 2* | $T_g$ | °C | 28.32 | 46 | 16 | 7.39 |
| | $SR$ | W.m$^{-2}$ | 433.14 | 1276.9 | 24.4 | 396.18 |
| | $V_a$ | | 1.63 | 6.01 | 0.07 | 0.98 |
| | $T_a$ | °C | 18.96 | 26.39 | 14.31 | 2.43 |
| | $RH$ | % | 49.24 | 71.16 | 30.38 | 6.56 |
| *Site 3* | $T_g$ | °C | 23.62 | 35.45 | 15.42 | 5.11 |
| | $SR$ | W.m$^{-2}$ | 410.19 | 1276.90 | 24.4 | 345.40 |
| | $V_a$ | | 1.59 | 9.97 | 0.10 | 1.03 |

### 3.2 Questionnaire survey

As indicated, a total 368 questionnaires were collected during 9 days of field survey in November 2014 at the three study sites. Male and female participants accounted for 67% (n= 246) and 33% (n= 122) of the study sample, respectively. The largest proportion of the participants belonged to the 18-30 age group which accounts for 52% of the sample size, followed by 31-45 who are about 30% of the total sample population. Most of the respondents were by themselves when they were present at the three sites; they were not part of a group. Table 2 specifies the characteristics of the participants during spring time.

**Table 2. Personal details of the participants for the spring obtained from the questionnaire survey and the complementary observation.**

| | | *Site 1* | | *Site 2* | | *Site 3* | | *Total* |
|---|---|---|---|---|---|---|---|---|
| | | *No* | *Percentage* | *No* | *Percentage* | *No* | *Percentage* | *Percentage* |
| **Gender** | **Male** | 64 | 59.30 | 95 | 68.3 | 87 | 71.9 | 66.84 |
| | **Female** | 44 | 40.70 | 44 | 31.7 | 34 | 28.1 | 33.15 |
| | **Total** | 10 | 100 | 13 | 100 | 121 | 100 | |
| **Age** | **<18** | 1 | 0.90 | 1 | 0.7 | 5 | 4.10 | 1.90 |
| | **18-30** | 31 | 28.70 | 79 | 56.8 | 82 | 67.80 | 52.17 |
| | **31-45** | 51 | 47.20 | 36 | 25.9 | 22 | 18.20 | 29.61 |
| | **46-60** | 17 | 15.70 | 15 | 10.8 | 11 | 9.10 | 11.68 |
| | **>60** | 8 | 7.40 | 8 | 5.8 | 1 | 8.0 | 4.61 |
| **Companionship** | **1** | 66 | 61.1 | 93 | 66.9 | 50 | 41.3 | 56.8 |
| | **2** | 37 | 34.3 | 37 | 26.6 | 37 | 30.6 | 30.2 |
| | **>2** | 5 | 4.6 | 9 | 6.5 | 34 | 28.1 | 13 |

The overall TSV distribution among the participants in spring shows that their perception is close to neutral conditions (Figure 3). The mean value of 0.50 (Stdev= 1.39) for thermal sensation indicates the comfortable conditions and no thermal stress was experienced by the users in the study outdoor environments in the shoulder season of spring. This result also suggests a good tolerance of the study users to the spring thermal conditions in the oceanic temperate climate in the outdoors.

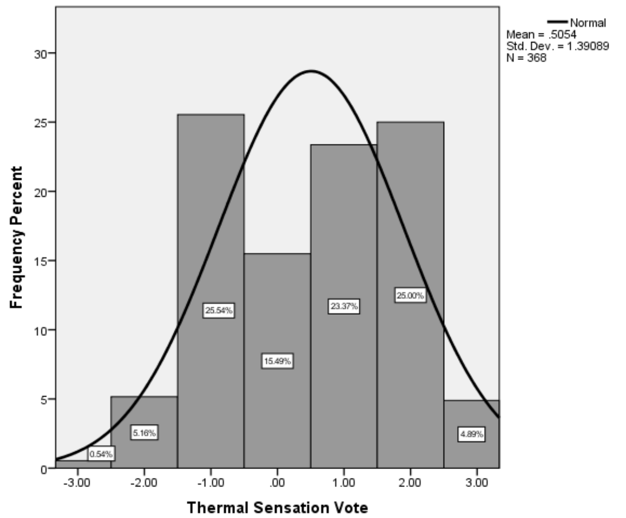


Figure 3. Histogram chart of the overall TSV distribution in RUCC in spring.

### 3.3 Thermal conditions and thermal sensation

Four environmental variables that are known for thermal perceptions along with solar radiation intensity were tested to understand the strength of the relationship between climatic conditions and mean thermal sensation. The relationship and explanatory effect within the measured climatic conditions and mean thermal sensation was investigated. Results of a Pearson's correlation and simple linear regression tests suggest a high correlation between the variables in the investigation and the mean thermal perception (Table 3). According to the results, while the Ta, Tmrt and Sr were positively correlated to MTSV (P<0.01, r= 0.93, 0.68, 0.58), RH and Va were found to have negative correlation with MTSV (P<0.01, r=-0.74, -0.24). Except wind speed, all the variables tested had significant explanatory effect on MTSV with varying effect sizes (Table 3).

**Table 3. The correlation between the climate variables and thermal sensation vote.**

| | | $T_a$ | RH | $V_a$ | $T_{mrt}$ | Sr |
|---|---|---|---|---|---|---|
| MTSV | Pearson's correlation (r) | 0.93** | -0.74** | -0.24 | 0.68** | 0.58** |
| | Sig. (2-tailed) | 0.00 | 0.00 | n.s | 0.00 | 0.00 |
| | Coefficient of determination ($r^2$) | 0.86** | 0.55** | 0.05 | 0.47** | 0.34** |
| | Sig. (2-tailed) | 0.00 | 0.00 | n.s | 0.00 | 0.00 |

**. Correlation is significant at the 0.01 level (2-tailed).

### 3.4 Actual and predicted thermal comfort

After determining the correlation of individual climate variables and mean thermal sensation, the collective effect of climate variables on thermal sensation to determine a predictive model of microclimate and thermal perceptions was investigated. The Physiological Equivalent Temperature (PET) and the Universal Thermal Comfort Index (UTCI) were plotted against MTSV the RUCC as a whole (Figure 4). The line of best fit regression was then used to characterize the explanatory power of the collective effect of microclimatic variables on thermal sensation.

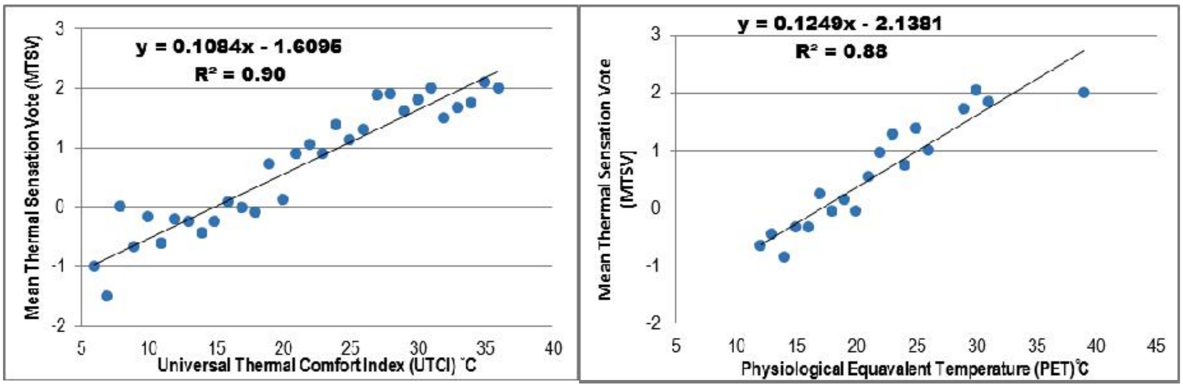


**Figure 4. (a) The association between calculated thermal comfort (UTCI) and (MTSV). (b) the association between calculated thermal comfort (PET) and MTSV.**

$$MTSV = 0.124 \times PET - 2.13 \quad \textbf{Eqs. 1}$$

$$MTSV = 0.108 \times UTCI - 1.609 \quad \textbf{Eqs. 2}$$

As it can be seen in the figure above, the regression lines can explain 88% (PET) and 90% (UTCI) of variation found in the users' thermal judgment (P<0.05). Two predictive equations were also obtained from the regression that can be used to estimate thermal sensation for a large number of users in the study urban precincts in springtime (Equation 1, 2 The analytical results also reveal the goodness of application of the two thermal indices in the context of the study with a slightly better performance of UTCI (Figure 4). Substituting zero into Eqs (1) and (2), MSTV=0, denoting neutral conditions, the thermal neutrality for the users of academic precincts in the spring is obtained (17.11 ℃ and 14. 84℃ for PET and UTCI, respectively). Furthermore, the Pearson's correlation test results show 93% and 95% relationship between MTSV and PET and UTCI, respectively.

### 3.5 The usage pattern and thermal conditions

The impact of climate conditions on outdoor usage pattern at the sites was investigated. The frequency of attendance, obtained from the unobtrusive observation (at 30 minute intervals in which the number of users was counted for 1 minute period), was correlated against the meteorological parameters using Pearson's correlation test. Pearson's correlation test was used to understand the strength of relationship between the climate parameters and the users' attendance in the study sites. The variables tested were air temperature, relative humidity, wind speed, solar radiation and calculated radiant temperature. Among the tested variables only the mean radiant temperature

(Tmrt) was significantly correlated to the users' frequency of attendance (N= 102, r= 0.20, p <0.05). Furthermore, it was found that in spring time the RH and Ta were respectively linked to the frequency of attendance in the study precinct in negative and positive directions (r= 0.15 and -0.17). A simple linear regression model was also calculated to predict the effect of thermal conditions on the use of outdoor spaces. The results showed that none of meteorological parameters could explain the variation found in the users' attendance at spring time. This is mainly due to the mean user's TSV indicating no thermal stress during the spring time, according to the field survey. It also suggests that the usage of outdoor environments in spring time is independent of thermal conditions.

The descriptive statistics for the time spent outdoors at each site are given in Figure 5. While most of users at Site 1 and 2 stayed for only a short time (less than 5 minutes and 5 to 10 minutes), users at Site 3 stayed for a longer time. This could be explained by Site 3 having a wider range of facilities including basketball courts, BBQ facilities and more seating options.

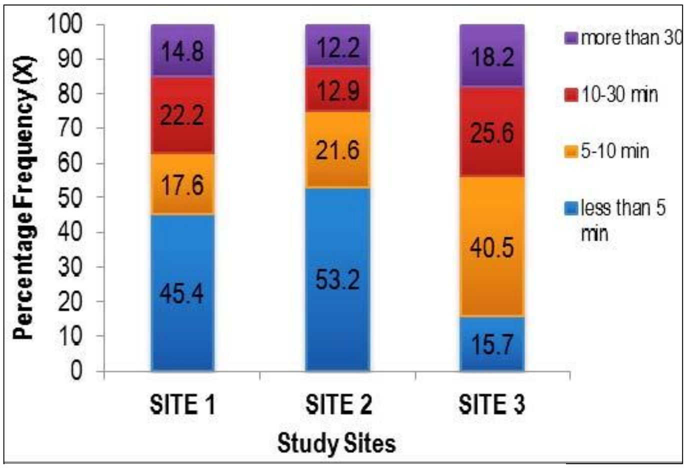


Figure 5. The length of stay in the study sites.

The General Linear Model was used to investigate the impact of time spent outdoor on thermal perception (Table 4). The results indicate the time spent time is a significant factor that influences thermal perception (P<0.05). The p-value of the corrected model, which is statistically significant, also reports the collective effects of thermal conditions (PET) and spent time in the place on the participants' thermal sensation.

**Table 4. General linear model on association between MTSV and time spent in the place.**
**Tests of Between-Subjects Effects**

Dependent Variable: M TSVs

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 231.110[a] | 4 | 57.778 | 44.253 | .000 |
| Intercept | 133.202 | 1 | 133.202 | 102.021 | .000 |
| PET | 220.560 | 1 | 220.560 | 168.930 | .000 |
| Time spent | 12.211 | 3 | 4.070 | 3.117 | .026 |
| Error | 472.639 | 362 | 1.306 | | |
| Total | 795.000 | 367 | | | |
| Corrected Total | 703.749 | 366 | | | |

a. R Squared = .328 (Adjusted R Squared = .321)

### 3.6 Thermal sensation and climate/cultural background

This study used the main five Koppen-Geiger climate categories (Peel et al. 2007) to understand the effect of cultural background on thermal sensation. The polar climate, however, was excluded from accounting as no individual was interviewed from this category. Participants were asked to indicate

their last residency on questionnaire. Table 5 and Figure 6 present the basic statistics of the participants with the climate diverse backgrounds and the quality of their thermal sensation.

**Table 5. The characteristics of population sample from different cultural background.**

| Culture | N | Mean | Std.D |
|---|---|---|---|
| *Tropical* | 67 | 0.09 | 1.15 |
| *Arid* | 44 | 0.09 | 1.32 |
| *Temperate* | 227 | 0.06 | 1.30 |
| *Cold* | 29 | 1.03 | 1.42 |

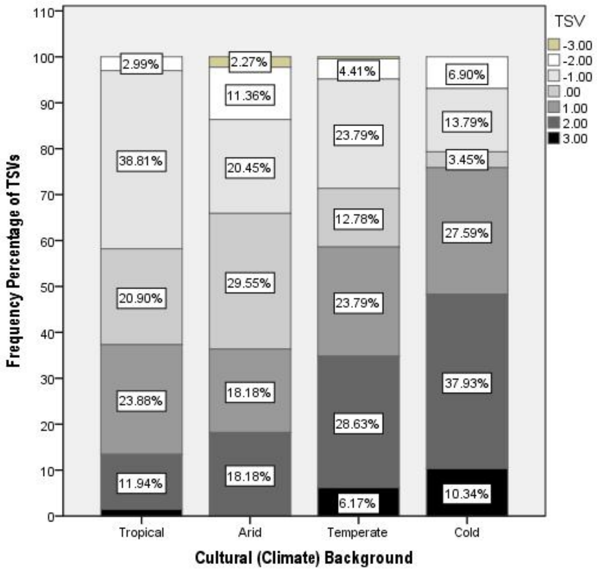

Figure 6. Distribution of thermal votes among different climate background groups.

In the climate conditions of springtime, a large proportion of people from cold regions voted for the warm side of the TSV scale (above 75.86%) as opposed to the thermal votes from people of tropical regions (35.82%) followed by the people of the temperate regions (58.59%). Furthermore, excluding the people from the cold regions, the remaining respondents felt the spring climate very close to the neutral conditions. A general univariate linear model was used to determine the significance of climate background impact on participants' thermal sensation. This model considers the effect of independent variable of climate background which covariates in line with climate conditions (PET values). The results clearly indicate that the climate background is a significant predictor of thermal votes (Table 6). The p-value of corrected model (P<0.05) also confirms the explanatory collective effects of climate conditions and climate background on MTSV.

**Table 6. General linear model on association between MTSV and climate background.**
**Tests of Between-Subjects Effects**

Dependent Variable: M TSVs

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 219.066[a] | 4 | 54.766 | 47.764 | .000 |
| Intercept | 110.671 | 1 | 110.671 | 96.521 | .000 |
| PET | 190.322 | 1 | 190.322 | 165.988 | .000 |
| Climate code | 23.498 | 3 | 7.833 | 6.831 | .000 |
| Error | 415.069 | 362 | 1.147 | | |
| Total | 719.500 | 367 | | | |
| Corrected Total | 634.135 | 366 | | | |

a. R Squared = .345 (Adjusted R Squared = .338)

## 4. DISCUSSION

Use of outdoor places is highly dependent on the surrounding thermal conditions experienced by the users. This study evaluates the relationship of the thermal perception of users of educational precincts with the two categories of the measured microclimatic variables and non-thermal factors such as cultural/climate background and the time spent outdoor. The climate conditions during the survey were found to have a great variation. Of 368 thermal responses, a large proportion voted for the conditions that are close to neutral conditions using the ASHRAE 7-point thermal sensation scale. The results prove that the explanatory power of the two studied thermal comfort indices on MTSV variation is stronger than that of each environmental variable. Hence they are reliable

enough to apply in the context of Melbourne with the degree of 88% and 90% for PET and UTCI, respectively. The results also indicate that the reason to use the place and more specifically the length of time spent in the location can influence the thermal perception in the environment. The analytical results confirmed the findings of Kenawy and Elkadi (2013) study in which the thermal perception was a function of climate and cultural background in a public square. However, the use of place was found to be independent of thermal conditions in the study environments. This trend was also identified in the previous studies in urban spaces (de Freitas 1985, Thorsson et al. 2007, Spangenberg et al. 2008), However, the results are in disagreement with the those of some other studies where the reasonable evidences of significant causality were found between the microclimate conditions and the people's attendance (Zacharias et al. 2004, Nikolopoulou and Lykoudis 2007, Eliasson et al. 2007, Lin et al. 2013). One possible explanation can be made with regards to the time of observation when no severe weather conditions occurred in spring. The methodology is being repeated in the summer and autumn periods at the RUCC sites.

## 5. CONCLUSION

The results of field studies, such as these, can supply urban designers who are considering the use of passive design strategies in outdoor environments, with the appropriate local seasonal comfort range. Furthermore, they can contribute to a climate sensitive design plan which allows spatial managers to maximize the use of comfortable outdoor environments.

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