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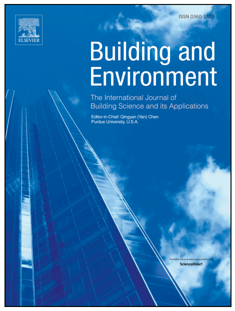

Effects of cultural diversity and climatic background on outdoor thermal perception at Melbourne city, Australia

Inji Kenawy, Hisham Elkadi

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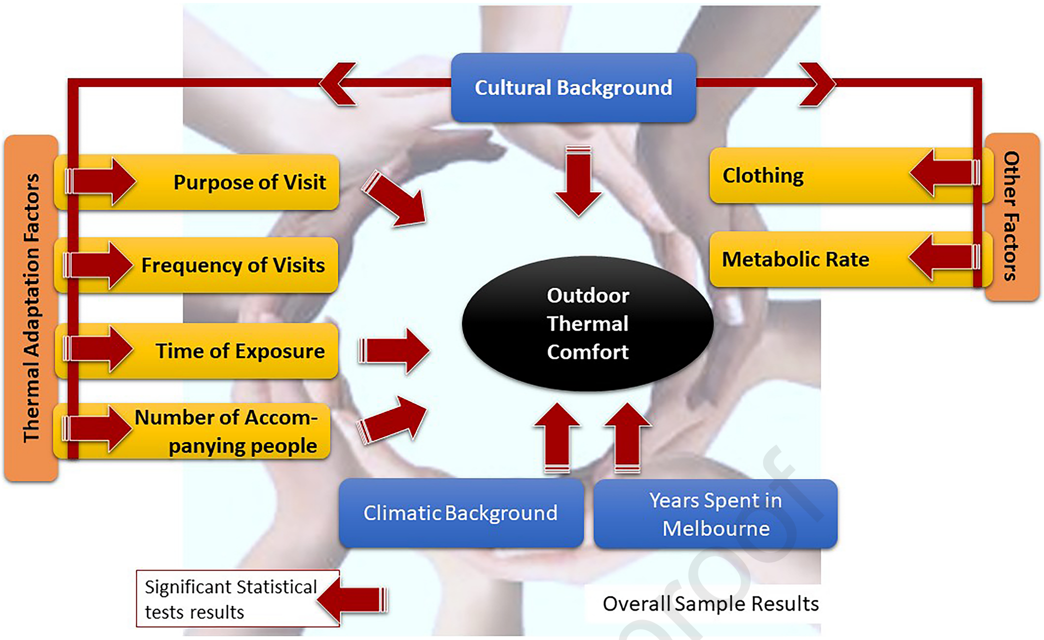
Cultural Background
Thermal Adaptation Factors
Purpose of Visit
Frequency of Visits
Time of Exposure
Number of Accom-
panying people
Outdoor
Thermal
Comfort
Clothing
Metabolic Rate
Other Factors
Climatic Background
Years Spent in
Melbourne
Significant Statistical
tests results
Overall Sample Results

Effects of cultural diversity and climatic background on outdoor thermal perception at Melbourne city, Australia.

Inji Kenawy[a], *Hisham Elkadi*[a]

[a] *School of Science, engineering and environment, University of Salford*

Abstract

Making cities and human settlements inclusive, safe, resilient and sustainable is one of the UN Sustainable Development Goals (SDG). This goal is particularly important in global cities where public places are shared with diverse communities. Successful design of shared, sustainable, and comfortable public places is, therefore, key to an inclusive and resilient urban future. Thermal comfort levels have proven to be a pre-requisite to the success in using public places, given its significant effect on their users' experience. However, in global multicultural cities, providing thermal comfortable public places is challenged by the diversity of their users. This paper aims to identify the effect of cultural diversity and climatic background of urban places' users on both their thermal perceptions and comfort levels. Field measurements were conducted in parallel to structured questionnaire and observations to interlink the empirical micrometeorological data with the subjective human assessments. The field empirical measurements took place during summer and winter along with a total of 2123 valid questionnaires and observations at two selected case study at Melbourne, Australia. Statistically significant variations in thermal sensation votes and thermal adaptation factors were found to be related to the users' cultural and climatic backgrounds. These findings showed the effect of the users' cultural and climatic background on their thermal sensation votes, and how it is crucial for these parameters to be taken into consideration while designing urban places within multicultural communities.

Keywords: Outdoor thermal comfort; Cultural diversity; Thermal comfort benchmarks; Thermal adaptation; Physiological Equivalent Temperature.

1. Introduction

It is believed that by 2030, 6 out of 10 people will be living in cities. The profiles of those cities' dwellers, across many parts of the World, are increasingly multi-cultural. It is almost unanimously agreed that our cities should therefore be inclusive, safe, resilient, and sustainable. This aim for any future development in our cities is visibly identified and explained in the UN SDG 11. In SDG11 description, inclusiveness and resilience of cities are not mutually exclusive; they are well interlinked [1]. Open spaces, the lungs of cities, are crucial not only as a place to demonstrate co-inhabiting and experiencing shared values but also for the mental and physical health of the population. This was clearly heightened during the current COVID-19 pandemic. Across the World, it is estimated that 47% of residents are within 400 meters walk to open spaces [1]. Ensuring thermal comfort among the culturally diverse users of open place would improve their experience and frequency of visits. It contributes to improving the quality of shared open places within global cities taking into consideration the multicultural nature of their residents. While different studies focused on assessing outdoor thermal comfort in various climatic regions, and considering various aspects physical, psychological and physiological factors [2-17], very few investigated the diversity of cultural and climatic backgrounds for users within the same region [18-21]. This gap has been highlighted in recent research [22]. This paper aims to investigate the influence of cultural and climatic backgrounds on outdoor thermal comfort within global cities. Melbourne, Australia has been repeatedly considered as one of the best liveable cities of the World. With its culturally diverse population [23]. Melbourne's World-renowned public places present excellent case studies for this paper. This empirical research applied both objective field measurements and subjective human assessment as the prevailing method used in outdoor thermal comfort studies [5, 10, 11, 15, 17, 24-33]. The discussion and the conclusion of the paper focus on thermal comfort in relatively large urban public places that attract visitors with diverse background where opportunities to manipulate design for various activities exist.

2. Material and methods

Comprehensive outdoor thermal comfort studies are examined by considering both objective measurements and subjective assessments. In this study, micrometeorological measurements took place on-site to provide a comprehensive evaluation of the thermal conditions for the selected case studies. Human monitoring data, on the other hand, was collected through a structured questionnaire and observations to assess human thermal perception for users taking into consideration their diverse cultural and climatic backgrounds.

Both subjective and objective data were simultaneously carried out at two different case studies that represent different typology and function of urban places. They were collected during summer and winter in January, February, July and August 2013 and 2014 from 9:00 am to 5:00 pm. This allowed examiniation of users' outdoor thermal perception in different functional and seasonal distributions. The following section gives an overview of the studied areas and details the data collected.

2.1 Study Areas

This paper examines outdoor thermal comfort perception among multicultural communities in a global city. Given the cultural diversity of its population and the vitality of its public open spaces to urban life, Melbourne provides an excellent case for this study. According to the Australian Bureau of Statistics, the net migration in 2019 contributed 60.2% to Australia's annual population growth [34]. In the same year, just under 30% of its estimated resident population (ERP) were born overseas [35]. From the eight capital cities in Australia, Sydney and Melbourne are considered the main two global cities in the country with ERP of 5,312,163 and 5,078,193 residents respectively. Melbourne has the highest growth rate of 2.3%, followed by Brisbane (2.1%) and Sydney (1.7%) [36]. This rapid rise in population growth fitted well with this paper that aims to contribute to the future sustainable development of global cities. The 2016 Census also showed that 40.2% of Greater Melbourne population were born overseas and 46.2% had both parents born overseas [23].

Melbourne is located between latitude 37°49’ South and longitude 144°58’ East. According to the Köppen- Geiger climatic classification, the city is categorised as temperate climate group (cfb) characterised by its uniform precipitation distribution and warm summers. Two case studies within Melbourne city are selected including an urban square and a university campus, presenting different functionality and usage. The Federation Square and Deakin University Burwood Campus were both selected to test the thermal sensation of culturally diverse users in different contexts, functions, and configurations. The selection of these two cases also allow testing the sensitivity of the results to different distinct population groups. Many multicultural events and festivals take place in the Federation square, reflecting the community and cultural life of Melbourne [37]. Since inaugurated in 2002, the square has received more than 100 million visits. In 2018-19, it hosted more than 2560 event days with an annual visitation of 9.7 million [38]. Burwood campus, the second case study, is the largest campus for Deakin University with 10,734 international students with different cultural backgrounds, representing 35% of the campus’ students population [39]. The activities taking place in urban squares and university campuses are classified as optional and necessary respectively [40]. Accordingly, involving both case studies also help to provide a basis for comparison and more accuracy in the generalisation of the results [41, 42].

2.1.1 Federation Square

This urban square is one of Victoria's main and most visited meeting place. It is situated in the intersection of two main linear paths in the Central Business District (CBD) of Melbourne city (37.8178°S, 144.9687°E). The square covers an area of 3.2 hectares and can accommodate 15000 people at one time. The main irregular shaped plaza is surrounded by key buildings with various cultural and entertaining functions. The flooring is mainly paved with sandstone cobblestones, with very limited green infrastructure.

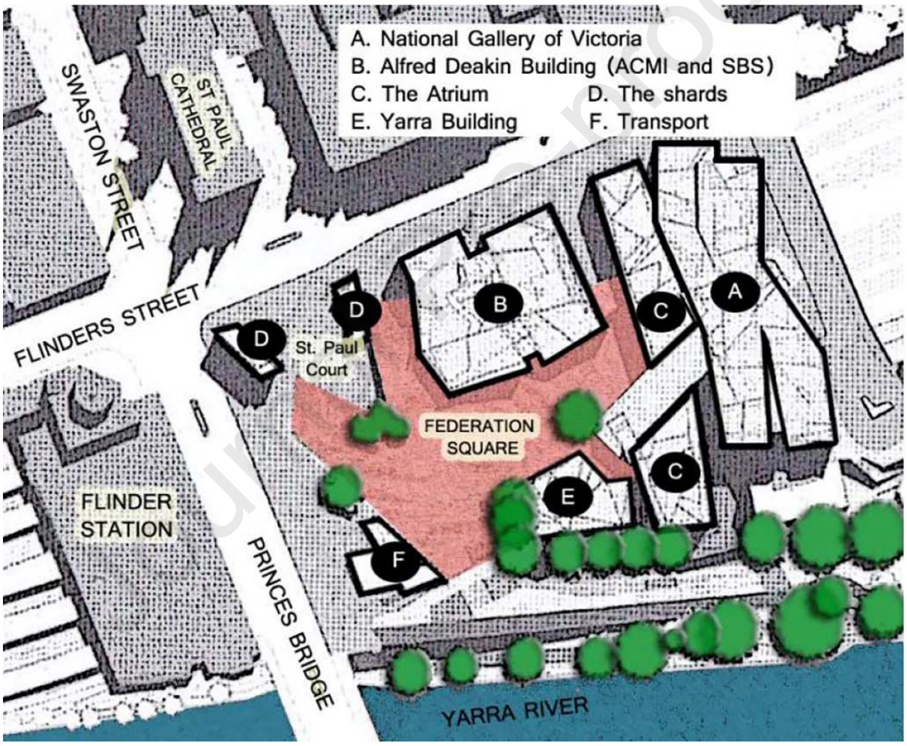

Figure 1 Federation Square layout - Source: [20]

2.1.2 Deakin University, Burwood Campus

Burwood campus is the largest and busiest campus of Deakin University, accommodating around 26,000 students and 1500 staff members. The campus is situated at Melbourne's eastern suburb of Burwood (37.8479°S, 145.1143°E) and covers an area of 27 hectares. Given the vast scale of the campus, the field study focused on the main central courtyard surrounded by the library, the learning spaces, the food outlet and the student life department.

Unlike the Federation square, Burwood campus is characterised by its generous green areas and its flooring is mainly paved with concrete.

Figure 2 Burwood Campus layout - Source: [20]

2.2 Micrometeorological Objective Measurements

The objective measurements intended to record the different micrometeorological variables that are used in the calculation of the outdoor thermal comfort index. This study used the Physiological equivalent temperature (PET) as its unit of analysis given that it is the most commonly employed and endorsed index in outdoor thermal comfort studies [24-26, 43]. PET is defined as the air temperature in a typical indoor setting at which the heat balance of the human body is maintained by skin temperature, core temperature, and sweat rate equal to those under the conditions to be assessed [44]. This heat balance model of the human body is expressed in

Celsius and calculated using the Rayman software, v1.2. The input data required in the calculation are ambient air temperature (Ta in °C), Relative humidity (RH in %), Wind speed (V in m/s), Mean radiant temperature (T_{mrt} in°C), cloud cover (octas), respondents' age and gender [45, 46].

The mean radiant temperature (T_{mrt}) is a critical parameter in PET calculation, given its significant effect on the energy balance and thermal comfort of the human body [47, 48]. It is defined as the 'uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure' [49]. Different methods are used in estimating T_{mrt} including the integral radiation measurements, the globe thermometer and the Rayman 1.2 software. This study used the globe thermometer method -equation 1- which reported a relatively small difference in accuracy when compared to more complicated methods based on integral radiation measurements and angular factor [50].

$$Tmrt = \left(\frac{(Tg+273)^4 + (1.1*10^8\ Va^{0.6}\ )(Tg-Ta)}{\varepsilon D^{0.4}}\right)^{1/4} - 273$$

Where: Tg is the globe temperature (°C), D is globe diameter (m) (= 0.038 m black tennis table ball covering a thermocouple wire in this study), and ε is emissivity (= 0.95 for black coloured globe). The field micrometeorological measurements comprised Ta in ◦C, V in m/s, RH in %, globe temperature (Tg in ◦C) and solar radiation (R in w/s^2) [24, 31, 51, 52]. The globe temperature was used in calculating the mean radiant temperature (Tmrt) being a critical parameter in the PET calculations. The measurements were conducted in both case studies using two Mobile Architecture and Built Environment Laboratory (Mabel) thermal comfort carts. The carts were placed in sunny and shaded areas. The carts measure thermal conditions in line with the procedures and protocols given by ASHRAE 55-92R and ISO 7726 standards [53]. They are designed to measure thermal conditions at four different height

LO, MID, HI and HEAD; at 0.1, 0.6, 1.1 and 1.7 meters above the floor respectively. These heights correspond to the ankles, waist, head of a seated person, and head of a standing person. Data loggers for both carts were programmed to record all the measured data at 1- and 15-minutes intervals. All equipment have been tested and calibrated before the survey to guarantee the accuracy and reliability of the measured data. At the start of each field survey, they were also allowed 15 minutes of response time before the data recording. In addition to the carts accuracy, their mobility allowed to be distanced within a maximum of three meters from the questionnaires' respondents as recommended by Ng and Cheng [54]. The comfort carts specifications and calibration are detailed in previous studies as summarised in Table 1 [20, 51]. Supplementary climatic variables including cloud cover and water vapour pressure were also obtained from the nearby Melbourne (Olympic Park) weather station [54].

Sensor	**Specifications**	**Calibration**
Three x OMEGA 44032 linear thermistor composite for air temperatures	- interchangeability 0.1°C - time constant 1 sec	- 6-point water bath calibration between 10 and 35°C - reference temperature from Cassella Assmann Aspirated psychrometer mercury-in-glass thermometer (47911)
Three x OMEGA 44032 linear thermistor composite for globe temperatures	- interchangeability 0.1°C - time constant circa 10 minutes	- 6-point water bath calibration between 10 and 35°C - reference temperature from Cassella Assmann Aspirated psychrometer mercury-in-glass thermometer (47911)
Three x TSI omidirectional anemometers (model number 8475)	- Time constant adjustable 0.2 to 2 sec with default setting 0.2 sec. - range = 0.05-2.5 m/s - accuracy = 3% of reading	- Factory calibrated at TSI's wind tunnel - reference anemometers are traceable to NIST standards - calibration procedures compliant with ISO 9001 and ISO 10012 - TSI calibration certificates are appended to the equipment manual.
One HyCal integrated circuit humidity sensor (IH-3605-B)	- repeatability 0.5%rh at 25°C - total accuracy 2%rh at 25°C - hysteresis 0.8% of span max - time constant 15 sec at 25°C	The linear calibration function used in the MABEL data loggers was derived from equilibration of the sensor in the

		sealed atmosphere above three different saturated salt solutions using the HyCal portable calibration cells (HC-60 series, prepared in compliance with ASTM standard E104-85): - Lithium Chloride solution for 11.3%rh at 25°C - Potassium Carbonate solution for 43.16%rh at 25°C - Sodium Chloride solution for 75.29%rh at 25°C

Table 1 MABEL comfort carts sensor specifications and calibration [20].

2.3 Subjective Assessment

The subjective thermal comfort perception for users was assessed based on randomly distributed questionnaires and observations that were conducted in parallel to the objective micrometeorological measurements. Various aspects were considered in the questionnaire given the variety of personal, behavioural, and psychological factors affecting thermal perception. The questionnaire was divided into three main sections. The first section was concerned with users' personal characteristics and demographic information including their age, gender, country of origin, and duration of living in Australia. The second section involved psychological aspects involving their activities, reasons and duration of visiting the place. The users' thermal perception votes were also examined through the ASHRAE 7-points scale - Cold, cool, slightly cool, neutral, slightly warm, warm, hot - being the most commonly used scale in outdoor thermal comfort studies. The users' expectations, preferences and acceptability were also recorded using the McIntyre scale - cooler, no change, warmer. The users' outfits were recorded and converted to clothing levels [54]. The activities were also converted to metabolic rates of 1, 1.2, and 2 met for users' sitting, standing and walking respectively. These calculations were adopted from the ASHRAE-Standard55 [55] and ISO-7730 [56]. Observations also took place simultaneously to record additional data including the date and time, the location of the respondents within the urban place, and the sky conditions.

3. Results

3.1. Micrometeorological measurements

As explained in the previous section, two MABEL comfort carts were used in recording the micrometeorological measurements. The minimum and maximum air temperature values at Federation square were 19.3°C and 28.8°C respectively during summer and 9.5°C and 17°C respectively during winter. According to the PET classification of Melbourne city, these values lies between slightly cool and slightly warm thermal sensation on the 7 points ASHRAE scale during summer and between almost cool and slightly cool during winter [51]. At Burwood campus, the air temperature values were having minimum and maximum of 17.5°C and 34.6°C respectively during summer and 7.3°C and 18.4°C respectively during winter. These values cover a broader PET range when compared to their equivalents at the Federation square. They lie between slightly cool and warm during summer and between cool and slightly cool during winter. The summary of the descriptive statistics of the main measured variables during summer and winter at Federation square and Burwood campus are presented in Table 2.

		Summer (n= 120 Fed.Sq., 97 Burwood C.)					Winter (n=114 Fed.Sq., 112 Burwood C.)				
		Air temp. (°C)	**Wind speed (m/s)**	**Relative humidity (%)**	**Global radiation (W/m^2)**	**Diffuse radiation (W/m^2)**	**Air temp. (°C)**	**Wind speed (m/s)**	**Relative humidity (%)**	**Global radiation (W/m^2)**	**Diffuse radiation (W/m^2)**
Federation square	Mean	23.6	0.44	55.4	400.9	422.2	13.6	0.9	55.3	283.7	297.7
	Std.D	2.1	0.15	10.2	257.2	281.5	1.5	0.3	6.4	139	144.4
	Min	19.3	0.15	31.6	45.8	36.9	9.9	0.4	41.4	11.4	0.13
	Max	28.8	0.77	82.9	903	951	17.1	1.5	66.2	482.5	512.7
Bu	Mean	24.7	0.9	47.9	683.4	781.1	12	0.6	66.1	234.9	247.1

	Std.D	4.4	0.4	19.3	142.4	165	2.6	0.25	12	119	136.7
	Min	18	0	8	328	337	6	0	18	17	5
	Max	35	2	85	879	985	18	1	96	434	470

Table 2 The descriptive statistics for the main measured micrometeorological variables at Federation square and Burwood campus.

3.2. Respondents' profile

Minimum reliable sample sizes for this study were calculated to be 118 and 139 respondents following work by Cochran [57] and Green [58] respectively. In this study, a total of 1021 and 1102 valid questionnaires were collected at Federation square and Burwood campus respectively. The pattern of usage and attendance at Federation square during summer and winter differed between the weekdays and weekends. During winter, the attendance was almost similar, however, during summer at the weekends' attendance was almost double the weekdays. This distinguished difference indicates that summer weather is encouraging the users to visit the square and practice different optional activities during their weekends. The distribution of the sample in relation to the places and seasons is detailed in Table 3.

Category	**Summer**		**Winter**		**Total**	
	n	**%**	**N**	**%**	**n**	**%**
Federation Square	523	24.6%	498	23.5%	1021	48.1%
Burwood Campus	623	29.3%	479	22.6%	1102	51.9%
Total	1146	53.9%	977	46.1%	2123	100%

Table 3 Distribution of sample in relation to places and seasons

Given the aim of the paper, it has been crucial to identifying the respondents' distribution based on their cultural and climatic background. The paper uses the Australian government cultural classification of immigrants [59]. The ten categories are Oceania and Antarctica, North-West Europe, Southern and Eastern Europe, North Africa and The Middle East, South-East Asia, North-East Asia, Southern and Central Asia, Americas, and Sub-Saharan Africa. According to the questionnaire's responses, a percentage of 50.7% were native Australian from the different states. The respondents from other cultural backgrounds represented 49.3% of the total sample. The most dominant cultural groups were from North-West Europe and

North-East Asia. They represented 12.2% and 11.5% of the total respondents respectively. The Sub-Saharan Africa group had the least attendance rate in the sample with a percentage of 1.4%. The distribution of respondents in both case studies based on their cultural background during summer and winter as shown in Table 4.

Cultural background for respondents	**Federation Square**				**Burwood Campus**				**Both studies**				**Total**	
	Summer		**Winter**		**Summer**		**Winter**		**Summer**		**Winter**			
	n	**%**	**n**	**%**	**n**	**%**	**N**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Australia	189	36.1	241	48.4	394	63.2	252	52.6	583	50.9	493	50.5	1076	50.7
North-West Europe	165	31.5	62	12.4	14	2.2	19	4	179	15.6	81	8.3	260	12.2
Southern & Eastern Europe	26	5	2	0.4	10	1.6	6	1.3	36	3.1	8	0.8	44	2.1
North Africa & Middle East	17	3.3	13	2.6	17	2.7	25	5.2	34	3.0	38	3.9	72	3.4
South-East Asia	28	5.4	32	6.4	42	6.7	50	10.4	70	6.1	82	8.4	152	7.2
North-East Asia	26	5	64	12.9	85	13.6	69	14.4	111	9.7	133	13.6	244	11.5
Southern & Central Asia	26	5	31	6.2	32	5.1	35	7.3	58	5.1	66	6.8	124	5.8
Americas	26	5	28	5.6	9	1.4	10	2.1	35	3.1	38	3.9	73	3.4
Sub-Saharan Africa	3	0.6	10	2	9	1.4	8	1.7	12	1.0	18	1.8	30	1.4
Oceania & Antarctica	17	3.3	15	3	11	1.8	5	1	28	2.4	20	2.0	48	2.3
Total	523	100	498	100	623	100	479	100	1146	100	977	100	2123	100

Table 4 Distribution of sample in relation to the users' cultural backgrounds during summer and winter

The effect of climatic background on outdoor thermal sensation is also considered in this study. The respondents were categorised based on their backgrounds according to the main Köppen-Geiger climate classification [60]. The interstate respondents from other states within Australia were considered in the analysis as users with Australian cultural origins, yet different climatic backgrounds than those from Melbourne's temperate climate. As per Table 5, many of the respondents were coming from a temperate climatic background.

Climatic background for respondents	**Federation Square**				**Burwood Campus**				**Both case studies**				**Total**	
	Summer		**Winter**		**Summer**		**Winter**		**Summer**		**Winter**			
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**

Tropical	55	10.5	69	13.9	68	10.9	83	17.3	123	10.7	152	15.6	275	13.0
Dry	34	6.5	42	8.4	24	3.9	25	5.2	58	5.1	67	6.9	125	5.9
Temperate	386	73.8	332	66.7	452	72.6	297	62	838	73.1	629	64.4	1467	69.1
Cold	48	9.2	55	11	79	12.7	74	15.4	127	11.1	129	13.2	256	12.1
Total	523	100	498	100	623	100	479	100	1146	100	977	100	2123	100

Table 5 Distribution of sample in relation to the users' climatic backgrounds during summer and winter

Other parameters including age and gender were also reported. However, given the main aim of this paper, they were only considered in the calculation of the PET.

3.3. The effect of cultural and climatic backgrounds on outdoor thermal comfort benchmarks

3.3.1. Thermal sensation votes and cultural/climatic backgrounds

Overall, the thermal sensation votes (TSV) of the respondents derived from their response to the ASHRAE 7-points scale. Their votes for the neutral (TSV=0), cold (TSV<0), and warm (TSV>0) directions represented 14.7%, 53% and 32.2% respectively of the overall sample. When considering the cultural backgrounds of the respondents, a clear distinction could be noticed. As shown in Figure 3, the users who were originally from Sub-Saharan Africa, South East Asia, North Africa and Middle East, Southern Central Asia and North-East Asia, voted towards the cold direction of the scale. However, those originally from North-West Europe and South-East Europe voted towards the hot direction of the scale. Those from Australia and Oceania showed quite balanced similar TSV as the users' neutrality feeling in the middle of the scale. The results were also consistent during summer and winter showing that the respondents from NW Europe had less tolerance to heat stress during summer. On the contrary, the respondents from South East Asia showed the least tolerance to cold weather conditions.

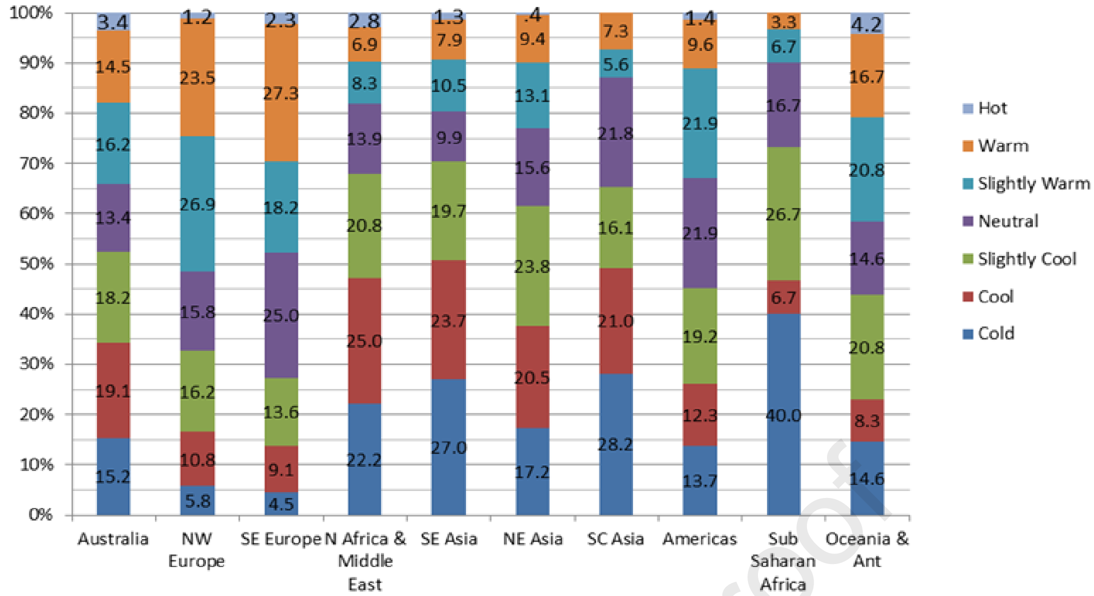

Figure 3 Distribution of TSV according to the respondents' cultural backgrounds

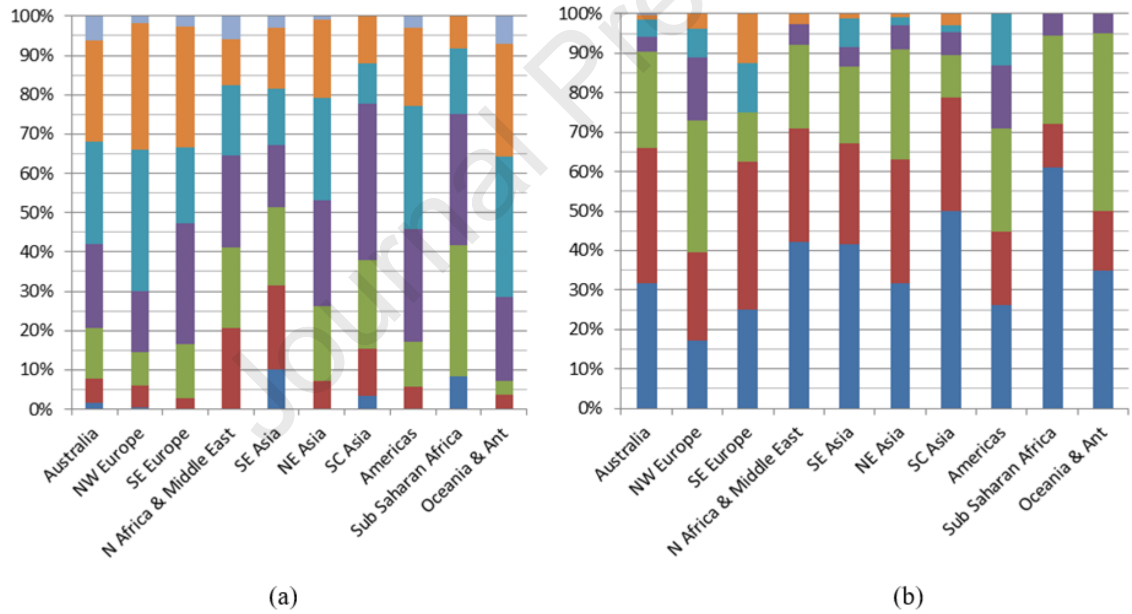

Figure 4 Distribution of TSV according to culture origin during (a) summer and (b) winter

To further investigate the influence of cultural backgrounds on users' thermal sensation, a Kruskal-Wallis test was employed. The test indicated a statistically significant result in TSV across the different cultural groups, X^2 (9, N= 2123) = 199.604, p < 0.01. The thermal sensation is therefore influenced by the cultural origins with an effect size equal to $X^2/(N-1)$

where X^2=199.604 and N=2123 of 0.094. This value indicates that 9.4 % of the variability in TSV could be explained by the cultural backgrounds of respondents.

When employing the same test for both case studies individually, similar statistical significance of Chi-square of X^2 (9, N= 1021) = 182.038, $p < 0.01$ and X^2 (9, N= 1102) = 73.644, $p < 0.01$ with an effect size of 17.8% and 6.7% were obtained for Federation square and Burwood campus respectively.

The test was also repeated for both summer and winter indicating a statistical significance of X^2 (9, N= 1146) =117.423, $p < 0.01$ and X^2 (9, N= 977) =148.782, $p < 0.01$ respectively. The effect size showed that the variability in TSV is accounted by different culture origins during winter more than summer with values of 15.2% and 10.3% respectively. Statistical significances were repeated when the test was employed to include different case studies during both seasons. At Federation Square, the values of Chi-square tests were X^2 (9, N= 523) = 84.036, $p < 0.01$ and X^2 (9, N= 498) = 88.479, $p < 0.01$ with calculated effect size of 16.1% and 17.8% for summer and winter respectively. The corresponding value of Chi-square tests at Burwood campus are X^2 (9, N= 623) =49.404, $p < 0.01$ and X^2 (9, N= 479) =59.463, $p < 0.01$ with an effect size of 7.9% and 12.4% during summer and winter respectively. The means for thermal sensation votes (MTSV) for the respondents having different cultural background during summer and winter were calculated as shown in Table 6.

Race groups	**Summer**			**Winter**		
	Mean	**N**	**Std. Deviation**	**Mean**	**N**	**Std. Deviation**
Australia	.6604	583	1.39	-1.7972	493	1.15
North-West Europe	.8436	179	1.21	-1.1481	81	1.3
Southern & Eastern Europe	.6944	36	1.21	-1.2500	8	1.83
North Africa & Middle East	-.0294	34	1.51	-2.0000	38	1.139
South-East Asia	-.3857	70	1.70	-1.8537	82	1.29
North-East Asia	.3514	111	1.23	-1.8195	133	1.06
Southern & Central Asia	-.2241	58	1.26	-2.1061	66	1.22
Americas	.5714	35	1.2	-1.2895	38	1.37

Sub-Saharan Africa	-.2500	12	1.29	-2.2778	18	1.02
Oceania & Antarctica	1.0357	28	1.14	-1.8000	20	1.01
Total	.5279	1146	1.39	-1.7646	977	1.20

Table 6 MTSV for respondents having different cultural background during summer and winter

Being also concerned with the respondents' climatic background, another Kruskal-Wallis test was employed to identify its effect on their TSV. The test also indicated a statistically significant result in TSV across the different climatic groups, X^2 (9, N= 2122) =103.663, p < 0.01. Similar significant differences were repeated for each case study, with Chi-square of X^2 (3, N= 1020) =18.422, p < 0.01 and X^2 (3, N= 1102) =41.644, p < 0.01 for Federation square and Burwood campus respectively. The calculated effect sizes are 4.9%, 1.8% and 3.8% for the overall sample, Federation square and Burwood campus. The MTSV for the respondents having different climatic backgrounds during summer and winter are shown in Table 7.

Climatic classification		**Summer**			**Winter**		
		Mean	N	Std. Deviation	Mean	N	Std. Deviation
Overall Sample	Tropical	-.2764	123	.96	-1.8553	152	.7
	Dry	.1276	58	1.11	-1.9612	67	.54
	Temperate	.6742	838	.87	-1.7437	628	.38
	Cold	.4798	127	.87	-1.6041	129	.61
	Total	.5230	1146	.94	-1.7575	976	.5
Federation Square	Tropical	-.0909	55	1.25126	-1.4928	69	1.42068
	Dry	.1176	34	1.32035	-1.9286	42	.92110
	Temperate	.6865	386	1.17227	-1.6193	331	1.09826
	Cold	.6458	48	1.22890	-1.5455	55	1.06837
	Total	.5641	523	1.22130	-1.6197	497	1.13337
Burwood Campus	Tropical	-.4265	68	1.61445	-2.1566	83	1.14212
	Dry	.0833	24	1.47196	-1.9600	25	1.30639
	Temperate	.6704	452	1.49492	-1.8923	297	1.25546
	Cold	.4304	79	1.28785	-1.7027	74	1.27923
	Total	.4976	623	1.52036	-1.9123	479	1.24618

Table 7 The mean TSV for different climatic background during summer and winter

To further distinguish the relationship between the effect of the respondents' climatic backgrounds, and the MTSV for the different cultural groups, a cross tab is employed. As shown in Table 8, the respondents who are originally from Australia, Oceania, NW Europe and SE Europe, are principally from the temperate climatic region. This could explicate their low tolerance to heat stress and vice versa for cold conditions. The respondents who were originally from SE Asia and SC Asia belong to tropical regions which explains their high tolerance to heat stress and vice versa for cold conditions. At Burwood campus, most of the respondents originally from the Americas and NE Asia were from cold regions, which explains their high tolerance to cold conditions, especially during winter.

Culture Origins	Köppen-Geiger Climatic Classification			
	Tropical	Dry	Temperate	Cold
Australia	0.00%	4.65%	95.26%	0.09%
North-West Europe	0.00%	0.00%	93.46%	6.54%
Southern & Eastern Europe	0.00%	0.00%	79.55%	20.45%
North Africa & Middle East	0.00%	55.56%	44.44%	0.00%
South-East Asia	100.00%	0.00%	0.00%	0.00%
North-East Asia	0.00%	0.00%	23.05%	76.95%
Southern & Central Asia	69.35%	16.94%	13.71%	0.00%
Americas	31.51%	10.96%	0.00%	57.53%
Sub-Saharan Africa	26.67%	20.00%	53.33%	0.00%
Oceania & Antarctica	12.50%	0.00%	87.50%	0.00%

Table 8 Cross tab between different culture and climatic groups

	Federation Square				Burwood Campus			
Culture	Tropical	Dry	Temperate	Cold	Tropical	Dry	Temperate	Cold
Australia	0%	11.2%	88.8%	0%	0%	.3%	99.5%	.2%
North-West Europe	0%	0.%	94.3%	5.7%	0%	0%	87.9%	12.1%
Southern & Eastern Europe	0%	0%	82.1%	17.9%	0%	0%	75%	25%
North Africa & Middle East	0%	40%	60.0%	0%	0%	66.7%	33.3%	0%
South-East Asia	100%	0%	0%	0%	100%	0%	0%	0%
North-East Asia	0%	0%	34.8%	65.2%	0%	0%	16.2%	83.8%
Southern & Central Asia	61.4%	14%	24.6%	0%	76.1%	19.4%	4.5%	0%
Americas	38.9%	11.1%	0%	50%	10.5%	10.5%	0%	78.9%
Sub-Saharan Africa	30.8%	15.4%	53.8%	0%	23.5%	23.5%	52.9%	0%
Oceania &	12.5	0%	87.5%	0%	12.5%	0%	87.5	0%

Antarctica	%						%	

Table 9 Cross tab between different culture and climatic groups in Federation Square and Burwood Campus

The numbers of years spent in the current regions within Australia were also investigated. Five categories were identified including less than 6 months, from 6 months to 1 year, more than 1 year to 5 years, more than 5 years to 20 years and more than 20 years. A Kruskal-Wallis test was employed to assess the relationship between the numbers of years spent in Australia and TSV. Statistically significant Chi-square results of X^2 (4, N = 2123) = 50.047, $p < 0.01$, X^2 (4, N = 1021) = 63.433, $p < 0.01$ and X^2 (4, N = 1102) = 45.65, $p < 0.01$ were obtained for the overall sample, Federation square and Burwood campus respectively.

3.3.2. Neutral PET and cultural diversity

The neutral PET is one of the main reported outdoor thermal benchmarks, it represents the temperature at which the respondents would have a neutral thermal sensation. To calculate its value by the linear regression between MTSV and PET. The MTSV is calculated for each 0.5°C PET interval. The neutral PET has been calculated in a previous study by solving the fitted equation that derived from the strong linear regression having MTSV=0. This value was found to be 20.4°C, 20°C and 24°C for the overall sample, summer and winter respectively [51].

Given the aim of this study and the statistically significant effect of cultural background on outdoor thermal sensation, neutral PET values were also calculated for the respondents having different cultural origins. These values were assessed using the simple linear regression on MTSV for each culture's respondents as a function of the measured PET as shown in Figure 5.

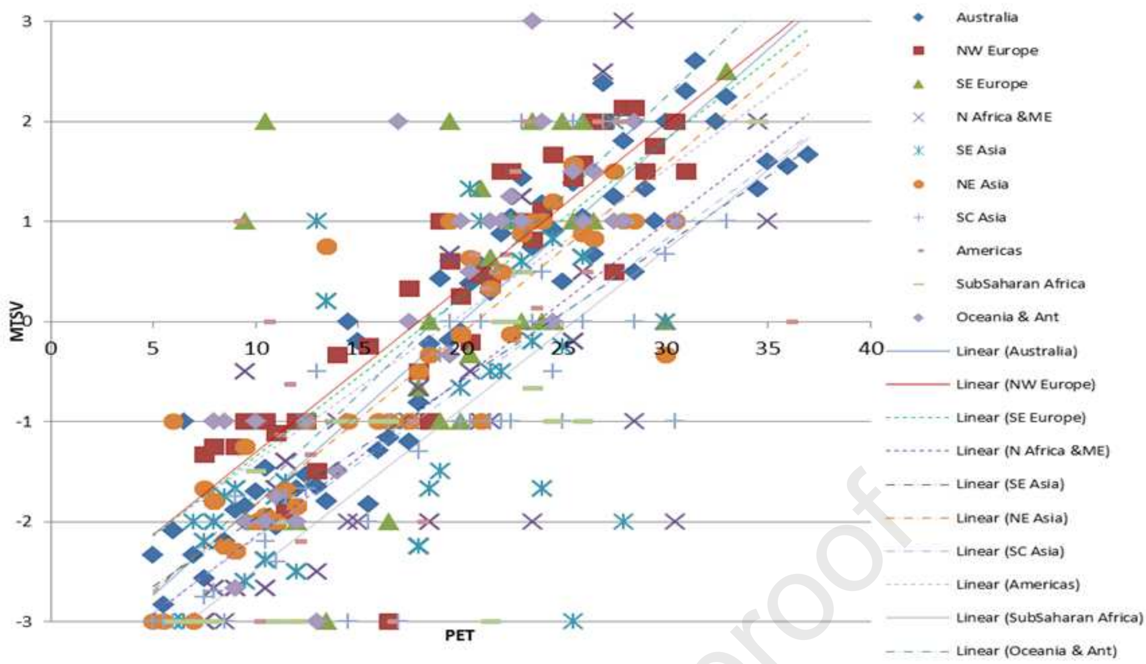

Figure 5 Regression model between MTSV and PET for different cultural groups

The fitted regression lines that resulted from the relation between MTSV and PET for each cultural group are represented by the equations shown in Table 10. The neutral temperature and the neutral PET range values were then calculated by solving the fitted equations having MTSV equals zero, -0.5, and 0.5 respectively. It is noted that the neutral PET range is not much reported in similar previous studies, however, it is an easy method that could be used to understand the outdoor thermal comfort ranges in cities.

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Culture	**Best fitted regression equation (MTSV=)**	**R squared & Significance**	**Neutral PET (MTSV = 0)**	**Neutral PET range (MTSV = ±0.5)**		**Thermal Acceptability Range (MTSV = ±0.85)**	
Australia	0.182PET - 3.644	0.897, p<0.01	20 °C	17.3 °C	22.8 °C	15.4 °C	24.7 °C
NW Europe	0.164PET - 2.950	0.846, p<0.01	17.9 °C	14.9 °C	21.0 °C	12.8 °C	23.2 °C
SE Europe	0.158PET – 2.927	0.378, p<0.01	18.5 °C	15.4 °C	21.7 °C	13.1 °C	23.9 °C
N Africa & ME	0.156PET – 3.713	0.599, p<0.01	23.8 °C	20.6 °C	27.0 °C	18.4 °C	29.3 °C
SE Asia	0.137PET – 3.336	0.509, p<0.01	24.4 °C	20.7 °C	28.0 °C	18.1 °C	30.6 °C
NE Asia	0.171PET – 3.540	0.822, p<0.01	20.7 °C	17.8 °C	23.6 °C	15.7 °C	25.7 °C
SC Asia	0.149PET – 3.652	0.73, p<0.01	24.5 °C	21.2 °C	27.9 °C	18.8 °C	30.2 °C

Americas	0.145 PET – 2.845	0.502, p<0.01	19.6 °C	16.2 °C	23.1 °C	13.8 °C	25.5 °C
Sub-Saharan Afr.	0.160PET-4.084	0.703, p<0.01	25.5 °C	22.4 °C	28.7 °C	20.2 °C	30.8 °C
Oceania & Ant.	0.198PET – 3.705	0.748, p<0.01	18.7 °C	16.2 °C	21.2 °C	14.4 °C	23 °C

Table 10 Neutral PET, Neutral PET range, and thermal acceptability range for different cultural groups

3.3.3. Thermal acceptability range and cultural diversity

Thermal acceptability range (TAR) is the limit of temperature accepted by 80 or 90% of the respondents. It is calculated from the quadratic polynomial fitting the acceptability percentages in 1°C PET intervals. This benchmark for Melbourne was calculated to range between 15 to 29.9°C and between 20 and 24°C having the acceptability percentages 80% and 90% respectively [51]. In this study, TAR is calculated for the respondents taking into account their cultural background. Acceptability level of 88% has been also reported to minimise the data range and account for a greater variation of outdoor thermal conditions[30].

Culture	Best fitted regression equation (Acceptability Rate=)	TAR (Acceptability Rate= 80%)		TAR (Acceptability Rate= 88%)	
Australia	$0.002x^2 - 0.0875x + 1.069$	15.2 °C	28.5 °C	19.9 °C	23.9 °C
NW Europe	$0.0022x^2 - 0.0824x + 0.9416$	15 °C	22.4 °C	NA	NA
SE Europe	$0.0036x^2 - 0.1517x + 1.5546$	12.8 °C	29.3 °C	14.3 °C	27.8 °C
N Africa & ME	$0.0031x^2 - 0.1433x + 1.6322$	14.6 °C	31.6 °C	16.3 °C	29.9 °C
SE Asia	$0.0023x^2 - 0.1028x + 1.1482$	13°C	31.7 °C	15.1 °C	29.6 °C
NE Asia	$0.0032x^2 - 0.127x + 1.2718$	12.2 °C	27.5 °C	14 °C	25.7 °C
SC Asia	$0.0024x^2 - 0.1095x + 1.3515$	16.4 °C	29.2 °C	20.1 °C	25.5 °C
Americas	$0.0008x^2 - 0.0482x + 0.9066$	25.2 °C	35.1 °C	NA	NA
Sub-Saharan Afr.	$0.0009x^2 - 0.0403x + 0.6318$	17.8 °C	27.0 °C	NA	NA
Oceania & Ant.	$0.0044x^2 - 0.1686x + 1.6776$	13.6 °C	24.7 °C	15.5 °C	22.8 °C

Table 11 TAR for different cultural groups

Another less recommended way of calculating TAR, is based on the assumption that 80% of thermal acceptability corresponds to the MTSV of ±0.85 on the ASHRAE scale [28, 61]. The values obtained from substituting MTSV = ±0.85 in the linear equations are shown in Table 10.

3.4. The effect of thermal adaptation factors

Thermal comfort conditions in outdoor places allow for adaptive opportunities to be developed to their full extent, physically, physiologically and psychologically [62]. Accordingly, when assessing outdoor thermal comfort, it is necessary to consider the personal and adaptation parameters. The relationship between outdoor thermal comfort and adaptation factors was carefully investigated, considering the respondents' cultural backgrounds. The investigated thermal adaptation factors involved the impact of the purpose of visit, frequency of visits, time of exposure, number of accompanying people, and years spent in Australia.

3.4.1. Purpose of visit

Ten different purposes of visit were reported by the respondents including participating in a social event, reading, escorting a person or dog, sitting as a consumer, selling something, watching, meeting, sitting free or lying down, buying something, and circulating or exercising. Percentages of almost 50%, 20%, 14% and 11% were sitting free, watching, circulating or exercising and meeting respectively. The rest of the users were distributed among the other activities with a percentage of almost 7.5%.

A Kruskal-Wallis test showed a significant difference of TSV across the different purpose of visit of X^2 (9, N= 2123) =118.107, $p < 0.01$. The same significance of X^2 (8, N= 1021) = 47.206, $p < 0.01$ and X^2 (9, N= 1102) = 92.947, $p < 0.01$ were found when repeating the test to Federation square and Burwood campus respectively.

3.4.2. Frequency of visits

Five answers were identified in the questionnaire to gather the frequency of visits for the users. Percentages of 54.5%, 15.1%, 13.5%, 8.5% and 8.4% were visiting both case studies weekly, yearly, monthly, for the first time and daily respectively. Given the function type of Federation square received more variability in the responses.

Statistically significant differences of TSV across the different frequency of visits of X^2 (4, N = 1021) = 22.712, $p < 0.01$ and X^2 (4, N = 977) = 20.121, $p < 0.01$ were detected by Kruskal-Wallis tests for the Federation square and overall winter responses respectively. Burwood campus and the overall summer responses indicated non-significant results of X^2 (4, N = 1102) = 3.839, $p > 0.05$, and X^2 (4, N = 1146) = 3.242, $p > 0.05$ respectively.

3.4.3. Time of exposure

The time of exposure is another factor affecting TSV. The distribution of the time of exposure indicated percentages of 4.1%, 36.7%, 24.4%, 20.6% and 14.3% for staying in the place for less than 15 minutes, 15 min.- 1 hour, 1-3 hours, 3-5 hours, and more than 5 hours respectively. More variability was found at Burwood campus as almost 60% of the respondents at Federation square stayed from 15 minutes- 1 hour.

The employed Kruskal-Wallis test indicated a statistically significant difference of X^2 (4, N = 2123) = 12.951, $p < 0.05$, X^2 (4, N = 1021) = 11.913, $p < 0.05$ and X^2 (4, N = 1102) = 15.196, $p < 0.01$ for the overall sample, Federation square and Burwood campus respectively. This significance indicates that the time of exposure is significantly related to the users' thermal sensation.

3.4.4. Number accompanying people

The number of users accompanying the respondents were also gathered and percentages of 31 %, 37.2% and 31.8% of users were found to be visiting the places alone, with one person and with more than two persons respectively. The Chi-square test employed to understand the effect of the number of accompanying persons on the TSV, indicated a significance of X^2 (12, N = 2122) = 39.029, $p < 0.01$, X^2 (12, N = 1020) = 28.356, $p < 0.01$ and X^2 (12, N = 1102) = 24.778, $p < 0.05$ for the overall sample, Federation square and Burwood campus respectively. The variance in TSV has then significantly proven to be accounted by the number of accompanying people, however, the Cramer V effect was found to be quite small 0.096.

3.5. The effect of Cultural background on thermal adaptation factors

Kruskal-Wallis tests were employed to assess the relationship between the cultural origins and the thermal adaptation factors identified before. The results of the tests are shown in Table 12.

Thermal adaptation factor	**Overall sample**	**Federation square**	**Burwood Campus**
Purpose of visit	X^2 (9, N = 2123) = 24.709, $p < 0.05$	X^2 (9, N= 1021) = 15.189, $p > 0.05$	X^2 (9, N= 1102) = 13.23, $p > 0.05$
Frequency of visit	X^2 (9, N = 2123) = 28.858, $p < 0.01$	X^2 (9, N= 1021) =42.857, $p < 0.01$	X^2 (9, N= 1102) =14.326, $p > 0.05$
Time of exposure	X^2 (9, N = 2123) = 94.289, $p < 0.01$	X^2 (9, N = 1021) = 21.206, $p > 0.05$	X^2 (9, N = 1102) = 9.808, $p > 0.05$
Number of accompanying people	X^2 (9, N = 2122) = 24.275, $p < 0.05$	X^2 (9, N = 1020) = 28.401, $p < 0.01$	X^2 (9, N = 1102) = 11.989, $p > 0.05$

Table 12 Kruskal-Wallis results for the relation of cultural background and thermal adaptation factors.

A non-significance Chi-square was found at Burwood campus showing that the variances of the purpose of visits cannot be explained by the users' cultural backgrounds. However, significant results were found for the overall sample.

3.6. The effect of Cultural background on other factors

Clothing and metabolic rates are the two main factors affecting TSV. Accordingly, this part is assessing their effect on TSV, and whether they are influenced by the respondents' cultural backgrounds.

3.6.1. Clothing

Simple regression test revealed that 29.3% of the variability in TSV are accounted for by clothing. To identify the relation between clothing and the users' cultural backgrounds, Kruskal-Wallis tests were employed. A significant relation was found between the cultural background and the clothing worn by the respondents of X^2 (9, N= 2123) =124.812, $p < 0.01$. The calculated effect size indicates that 5.9% of the variance in clothing is explained by the users' cultural background. CLO means shown in Table 13, indicate that the users originally from NW Europe and SE Europe wore lighter clothes and vice versa for those from NE Asia, SE Asia and N Africa & ME.

Race groups	Mean CLO	N	Std .D.	Race groups	Mean CLO	N	Std .D.
Australia	.6333	1076	.25	North-East Asia	.7522	244	.25
North-West Europe	.5676	260	.25	Southern & Central Asia	.6848	124	.25
Southern & Eastern Europe	.5418	44	.24	Americas	.6742	73	.29
North Africa & Middle East	.7078	72	.22	Sub-Saharan Africa	.6187	30	.22
South-East Asia	.7383	152	.26	Oceania & Antarctica	.6035	48	.22

Table 13 CLO means for the different cultural backgrounds

3.6.2. Metabolic rate

The relation between the metabolic rate and the TSV were also examined through a Kruskal-Wallis test. A significant difference in TSV for different metabolic rates was distinguished X^2

(6, N= 2122) = 111.144, p < 0.01. The test revealed that 5.2% of the variance in TSV is explained by the metabolic rates for the respondents. An employed chi-square test indicated a significant relation between cultural background and metabolic rate of X^2 (27, N= 2122) =133.925, p < 0.01. However, the Cramer's V was 0.145 which is quite a small effect size.

4. Discussion

The analysis for this paper is focusing on the effect of both cultural and climatic backgrounds of users on their outdoor thermal perception and comfort. A statistically significant relation was found between TSV collected in the questionnaire and cultural backgrounds of the users. The calculated effect size indicated that 9.4%, 17.8% and 6.7% of the variability in TSV could be explained by the users' cultural backgrounds for the overall sample, Federation square and Burwood campus respectively. The lowest effect size at Burwood campus could be explained by its functional nature where necessary activities are located and accordingly, less design quality could be acceptable [40]. The higher value of calculated effect size during winter indicate that the effect of the cultural background of the respondents on their TSV is raised under cold conditions.

The MTSV at Federation square during summer indicated that the respondents who were originally from Oceania and Ant., America, NW Europe and Australia were the least tolerant to the heat stress with values of .8576, 0.6520, 0.6463, and 0.5370 respectively. On the contrary, those originally from Southern & Central Asia, NE Asia were the most tolerant to the heat stress with values of .3104 and .4226. During winter, the respondents who were originally from SC Asia, SE Asia, NW Europe and Australia were most tolerant to cold conditions with similar means values of -1.56220, -1.5803, -1.5841 and -1.5896. Those from Sub-Saharan Africa, NE Asia, and SE Europe were the least tolerant to cold conditions with values of -1.8255, -1.7839 and -1.7086 respectively. At Burwood campus, the respondents who were originally from NW Europe were found to be the least tolerant to heat stress followed by those from Oceania, Antarctica, and Australia with MTSV values of .776, .6032 and .5983. during the same season, those originally from Asia were the most tolerant to heat stress. During winter, the respondents who were originally from SC Asia were the least tolerant to cold conditions (-2.1568), followed by SE Asia (-1.9985). In contract, those originally from Oceania and Antarctica were found to be the most tolerant during winter (-1.4214). It is also observed from the linear regression results that the users that are originally from Oceania followed by NW Europe are the least tolerant to the heat stress. The users from Australia and SE Europe are having very close votes under hot weather; however, the users from the SE Europe group are more tolerant to the cold conditions. Conversely, the users originally from Sub-Saharan Africa, SE Asia and SC Asia are the more tolerant to the heat stress followed by the users from N Africa & ME. The investigation of the different ethnic group was also found to be significant in other studies [22, 63, 64].

When investigating the effect of climatic background on TSV, it was also found to be significant, yet having an effect size of 4.9%. It is noted that the effect size found for the climatic background is lower than its equivalent for the cultural background. This could be explained by the fact that the cultures involve climatic past experience among other factors affecting the TSV including clothing traditions, time of exposure preferences, and other related cultural customs and preferences. It is observed that the respondents from tropical climatic backgrounds were most tolerant to heat stress followed by those from the dry regions during summer. During winter, the respondents originally from cold regions were found to be the most tolerant to cold conditions, followed by those from temperate, tropical and dry regions. The results show small differences between the means at Federation square and Burwood campus during summer, where the respondents originally from tropical regions are the most tolerant to the heat stress followed by the dry, temperate and cold regions. However, the tolerance of those from tropical climatic background to cold conditions varies between the two case studies. It is noticed that people who live in cool conditions enjoy feeling warm, while in a warm climate enjoyment corresponds to cool conditions, which is in line with other studies [65]. The number of years spent in Australia was also found to be a significant factor affecting the variance in TSV. The variances in TSV were also found to be accountant of the variance in thermal adaptation factors including the purpose of visit, time of exposure and number of accompanying people. These results are in line with similar studies [15, 62, 66-69]. The frequency of visits was also found to be statistically affecting TSV during winter but not summer. These findings were in line with other studies [28].

5. Conclusion

This paper examines the effect of cultural diversity and climatic background of urban places' users on both their thermal perceptions and comfort levels. Both objective measurements and subjective assessments took place in parallel in two case studies at Melbourne during summer and winter. Total of 1021 and 1102 valid questionnaires and observations were collected at Federation square and Deakin University Burwood campus respectively. A statistically significant relation was found between the users' collected TSV and their cultural backgrounds. The means for TSV of different cultural groups in the different seasons shown in Table 6 indicate that during summer the users from Oceania and Antarctica are the least tolerant to the heat stress. This group is followed by North-West Europe, South-East Europe, and Australia. On the other side, the users from South East Asia, Sub-Saharan Africa, and Southern &Central Asia users are the most tolerant of the heat stress. During winter Sub-Saharan Africa, Southern &Central Asia and North Africa and Middle-East are the less tolerant of the cold conditions. North-West Europe, South-East Europe, and Australia and Oceania are the most tolerant of the cold conditions. Another statistically significant result was found when investigating the relationship between the climatic background and TSV. From the means, it is noticed that people who live in cool conditions enjoy feeling warm, while in a warm climate enjoyment corresponds to cool conditions. The relation between the cultural background of the users and thermal adaptation factors was also assessed. The findings indicated that these factors were all significantly affected by the users' cultural backgrounds for the overall sample and Federation square users, yet not for those at Burwood campus. Again, this could be explained by the functional nature of the place as an educational institution.

The paper shows that the successful design of a public place should consider personal and adaptation parameters of users. Urban designers should take into consideration the different thermal adaptation factors as well as the individual characteristics for the users including their cultural and climatic backgrounds to design urban places that would comfortably accommodate the varied thermal sensation of their users. In global cities, such as Melbourne, where users of public places are predominantly diverse in their cultural background, designers should carefully provide a variety of spaces that would cater to these variations. Sheltered and warm spaces, for example, could be placed next to open airy places. The use of temporary, flexible, and mobile shading devices and canopies would be welcomed in such public places. Orientation, configuration, façades and floor materials, green infrastructure, water bodies and other place characteristics could all be designed with such conclusion in mind.

References

[1] UN, Make cities and human settlements inclusive, safe, resilient and sustainable, 2020.

[2] B. Yang, T. Olofsson, G. Nair, A. Kabanshi, Outdoor thermal comfort under subarctic climate of north Sweden–A pilot study in Umeå, Sustainable cities and society 28 (2017) 387-397.

[3] I.V. Bajšanski, D.D. Milošević, S.M. Savić, Evaluation and improvement of outdoor thermal comfort in urban areas on extreme temperature days: Applications of automatic algorithms, Building and Environment 94 (2015) 632-643.

[4] E. Krüger, F. Minella, F. Rasia, Impact of urban geometry on outdoor thermal comfort and air quality from field measurements in Curitiba, Brazil, Building and Environment 46(3) (2011) 621-634.

[5] L. Zhao, X. Zhou, L. Li, S. He, R. Chen, Study on outdoor thermal comfort on a campus in a subtropical urban area in summer, Sustainable cities and society 22 (2016) 164-170.

[6] S. Thorsson, T. Honjo, F. Lindberg, I. Eliasson, E.-M. Lim, Thermal comfort and outdoor activity in Japanese urban public places, Environment and Behavior 39(5) (2007) 660-684.

[7] J. Spagnolo, R. De Dear, A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia, Building and environment 38(5) (2003) 721-738.

[8] S.B. Ali, S. Patnaik, Thermal comfort in urban open spaces: Objective assessment and subjective perception study in tropical city of Bhopal, India, Urban climate 24 (2018) 954-967.

[9] A. Middel, N. Selover, B. Hagen, N. Chhetri, Impact of shade on outdoor thermal comfort—a seasonal field study in Tempe, Arizona, International journal of biometeorology 60(12) (2016) 1849-1861.

[10] M.H. Elnabawi, N. Hamza, S. Dudek, Thermal perception of outdoor urban spaces in the hot arid region of Cairo, Egypt, Sustainable cities and society 22 (2016) 136-145.

[11] W. Yang, N.H. Wong, G. Zhang, A comparative analysis of human thermal conditions in outdoor urban spaces in the summer season in Singapore and Changsha, China, International journal of biometeorology 57(6) (2013) 895-907.

[12] W. Yang, N.H. Wong, S.K. Jusuf, Thermal comfort in outdoor urban spaces in Singapore, Building and Environment 59 (2013) 426-435.

[13] N. Makaremi, E. Salleh, M.Z. Jaafar, A. GhaffarianHoseini, Thermal comfort conditions of shaded outdoor spaces in hot and humid climate of Malaysia, Building and environment 48 (2012) 7-14.

[14] E.L. Krüger, B. Givoni, F.A. Rossi, Outdoor comfort study in Curitibia, Brazil: Effect of gender, body weight and age on the thermal comfort, Adapting to Change: New Thinking on Comfort, Network for Comfort and Energy Use in Buildings, London, 2010.

[15] S. Shooshtarian, I. Ridley, The effect of physical and psychological environments on the users thermal perceptions of educational urban precincts, Building and Environment 115 (2017) 182-198.

[16] P.K. Cheung, C. Jim, Determination and application of outdoor thermal benchmarks, Building and Environment 123 (2017) 333-350.

[17] T.P. Lin, R. de Dear, R.L. Hwang, Effect of thermal adaptation on seasonal outdoor thermal comfort, International Journal of Climatology 31(2) (2011) 302-312.

[18] I. Knez, S. Thorsson, Thermal, emotional and perceptual evaluations of a park: cross-cultural and environmental attitude comparisons, Building and Environment 43(9) (2008) 1483-1490.

[19] F. Aljawabra, M. Nikolopoulou, Thermal comfort in urban spaces: a cross-cultural study in the hot arid climate, International journal of biometeorology 62(10) (2018) 1901-1909.

[20] I. Kenawy, Cultural diversity and thermal comfort in outdoor public places, Deakin University, Australia, 2013.

[21] I. Kenawy, H. ElKadi, The impact of cultural and climatic background on thermal sensation votes, the 29th international PLEA conference, Sustainable Architecture for a Renewable Future, Munich, Germany, 2013.

[22] X. He, L. An, B. Hong, B. Huang, X. Cui, Cross-cultural differences in thermal comfort in campus open spaces: A longitudinal field survey in China's cold region, Building and Environment 172 (2020) 106739.

[23] ABS, 2016 Census QuickStats, 2019. https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/2GMEL?opendocument. 2020).

[24] F. Salata, I. Golasi, R. de Lieto Vollaro, A. de Lieto Vollaro, Outdoor thermal comfort in the Mediterranean area. A transversal study in Rome, Italy, Building and environment 96 (2016) 46-61.

[25] S.Q. da Silveira Hirashima, E.S. de Assis, M. Nikolopoulou, Daytime thermal comfort in urban spaces: A field study in Brazil, Building and Environment 107 (2016) 245-253.

[26] W. Liu, Y. Zhang, Q. Deng, The effects of urban microclimate on outdoor thermal sensation and neutral temperature in hot-summer and cold-winter climate, Energy and Buildings 128 (2016) 190-197.

[27] K. Pantavou, G. Theoharatos, M. Santamouris, D. Asimakopoulos, Outdoor thermal sensation of pedestrians in a Mediterranean climate and a comparison with UTCI, Building and Environment 66 (2013) 82-95.
[28] W. Yang, N.H. Wong, S.K. Jusuf, Thermal comfort in outdoor urban spaces in Singapore, Building and Environment 59(0) (2013) 426-435.
[29] N. Kántor, L. Égerházi, J. Unger, Subjective estimation of thermal environment in recreational urban spaces—part 1: investigations in Szeged, Hungary, International Journal of Biometeorology 56(6) (2012) 1075-1088.
[30] T.-P. Lin, A. Matzarakis, Tourism climate and thermal comfort in Sun Moon Lake, Taiwan, International journal of biometeorology 52(4) (2008) 281-290.
[31] L. Chen, Y. Wen, L. Zhang, W.-N. Xiang, Studies of thermal comfort and space use in an urban park square in cool and cold seasons in Shanghai, Building and Environment 94 (2015) 644-653.
[32] P. Cohen, O. Potchter, A. Matzarakis, Human thermal perception of Coastal Mediterranean outdoor urban environments, Applied Geography 37(0) (2013) 1-10.
[33] S. Shooshtarian, C.K.C. Lam, I. Kenawy, Outdoor thermal comfort assessment: A review on thermal comfort research in Australia, Building and Environment (2020) 106917.
[34] ABS, Annual population change, 2020. https://www.abs.gov.au/Ausstats/abs@.nsf/7d12b0f6763c78caca257061001cc588/fa9c11f1913bdafcca25765100098359!OpenDocument#:~:text=In%20the%20year%20ending%2031%20December%202019%2C%20net%20overseas%20migration,to%20Australia's%20annual%20population%20growth. 2020).
[35] ABS, Australia's population: over 7.5 million born overseas, 2020. https://www.abs.gov.au/ausstats/abs@.nsf/lookup/3412.0Media%20Release12018-19#:~:text=More%20than%207.5%20million%20people,the%20Australian%20Bureau%20of%20Statistics. 2020).
[36] ABS, Key statistics, 2020. https://www.abs.gov.au/ausstats/abs@.nsf/mf/3218.0. 2020).
[37] K. Brennan, Federation Square–a place for the people, Journal of Place Management and Development (2010).
[38] Fed-square, ANNUAL REPORT 2018-2019, Fed Square Pty Ltd, Australia, 2019.
[39] Deakin-SIPU, Deakin Statistics Summary 2018, 2018. https://www.deakin.edu.au/__data/assets/pdf_file/0005/2018048/Deakin-stats_2018.pdf.
[40] J. Gehl, Life between buildings: using public space, Island press2011.
[41] J. Rowley, Using case studies in research, Management research news (2002).
[42] M.W. Lewis, Iterative triangulation: a theory development process using existing case studies, Journal of operations Management 16(4) (1998) 455-469.
[43] P.K. Cheung, C.Y. Jim, Subjective outdoor thermal comfort and urban green space usage in humid-subtropical Hong Kong, Energy and Buildings 173 (2018) 150-162.
[44] P. Höppe, The physiological equivalent temperature – A universal index for the biometeorological assessment of the thermal environment, International Journal of Biometeorology 43 (1999) 71–75.
[45] A. Matzarakis, F. Rutz, H. Mayer, Modelling radiation fluxes in simple and complex environments—application of the RayMan model, International Journal of Biometeorology 51 (4) (2007) 323–334.
[46] A. Matzarakis, F. Rutz, H. Mayer, Modelling radiation fluxes in simple and complex environments: basics of the RayMan model, International journal of biometeorology 54(2) (2010) 131-139.
[47] H. Mayer, P. Höppe, Thermal comfort of man in different urban environments, Theoretical and Applied Climatology 38 (1987) 43–49.
[48] J.C. Spagnolo, R.J. de-Dear, A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia, Building and Environment 38 (2003) 721-738.

[49] ASHRAE, ASHRAE Handbook of Fundamentals, American Society of Heating Refrigerating and Air-Conditioning Engineers, Atlanta, 2001.
[50] S. Thorsson, F. Lindberg, I. Eliasson, B. Holmer, Different methods for estimating the mean radiant temperature in an outdoor urban setting, International Journal of Climatology (27) (2007) 1983–1993.
[51] I. Kenawy, H. Elkadi, The outdoor thermal benchmarks in Melbourne urban climate, Sustainable cities and society 43 (2018) 587-600.
[52] K. Li, Y. Zhang, L. Zhao, Outdoor thermal comfort and activities in the urban residential community in a humid subtropical area of China, Energy and Buildings 133 (2016) 498-511.
[53] ISO, International Standard 7726, thermal environment-instruments and method for measuring physical quantities, International Standard Organization, Geneva 2002.
[54] E. Ng, V. Cheng, Urban human thermal comfort in hot and humid Hong Kong, Energy and Buildings 55 (2012) 51-65.
[55] ASHRAE-Standard55, Standard 55: Thermal environmental conditions for human occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, USA, 2004.
[56] ISO-7730, Moderate thermal environments — determination of the PMV and PPD indices and specification of the conditions for thermal comfort., International Standards Organization, Geneva, 1994.
[57] W.G. Cochran, Sampling techniques, John Wiley & Sons2007.
[58] S.B. Green, How many subjects does it take to do a regression analysis, Multivariate behavioral research 26(3) (1991) 499-510.
[59] ABS, 1269.0 - Standard Australian Classification of Countries (SACC), Second Edition 2019. https://www.abs.gov.au/ausstats/abs@.nsf/0/3E3848A2DCF7FF4FCA25744B001535DB?opendocument. 2020).
[60] M. Kottek, J. Grieser, C. Beck, B. Rudolf, F. Rubel, World map of the Koppen-Geiger climate classification updated, Meteorologische Zeitschrift 15(3) (2006) 259-64.
[61] ISO-7730, Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, Geneva, International Standard Organization, 2005.
[62] M. Nikolopoulou, Outdoor Comfort, in: K. Steemers, M.A. Steane (Eds.), Environmental Diversity in Architecture, Spon Press, USA and Canada, 2004, pp. 101-120.
[63] I. Knez, S. Thorsson, Influences of culture and environmental attitude on thermal, emotional and perceptual evaluations of a public square, International journal of biometeorology 50(5) (2006) 258-268.
[64] D. Brychkov, Y. Garb, D. Pearlmutter, The influence of climatocultural background on outdoor thermal perception, International journal of biometeorology 62(10) (2018) 1873-1886.
[65] M. Nikolopoulou, K. Steemers, Thermal comfort and psychological adaptation as a guide for designing urban spaces, Energy and Buildings 35 (1) (2003) 95-101.
[66] T.P. Lin, Thermal perception, adaptation and attendance in a public square in hot and humid regions, Building and Environment 44(10) (2009) 2017–2026.
[67] X. Chen, P. Xue, L. Liu, L. Gao, J. Liu, Outdoor thermal comfort and adaptation in severe cold area: A longitudinal survey in Harbin, China, Building and Environment 143 (2018) 548-560.
[68] S.L. Heng, W.T. Chow, How 'hot'is too hot? Evaluating acceptable outdoor thermal comfort ranges in an equatorial urban park, International journal of biometeorology 63(6) (2019) 801-816.
[69] C.K.C. Lam, Y. Luo, W. Lin, J. Hang, Short-term thermal adaptation and outdoor thermal comfort in Southern China: a case study of high-intensity outdoor training in summer, Geophysical Research Abstracts, 2019.

Highlights

- Different cultural backgrounds significantly affect how users perceive thermal comfort.
- Cultural and climatic background affect thermal adaptation factors.
- Outdoor thermal comfort benchmarks for the different cultural backgrounds support urban strategies to design comfortable outdoor places.
- Further studies required to cover missing interaction of other comfort requirements including acoustics and other geographic contexts.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.