Outdoor Thermal Comfort Assessment: A Review on Thermal Comfort Research in Australia

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Abstract

Outdoor thermal comfort could significantly affect the usage and success of urban places. Accordingly, it is recommended to be considered in both urban design and planning projects. Urbanisation has been recognised as a major factor in elevated daily temperature values in Australia. This study aims to investigate the past and current position of outdoor thermal comfort studies in the Australian context. A critical review is conducted to examine the quality of thermal comfort assessment in Australia's cities. Twenty-five studies were reviewed to give a precise overview of past thermal comfort studies. The review scrutinises the focus of research, methodologies applied, data collection methods and results. This review helps main stakeholders in urban development better understand the evolution of outdoor thermal comfort with respect to liveability. In this line, where possible, the shortcomings are identified, certain solutions are provided and the need for further research is highlighted. In particular, future studies are necessary to cover missing geographical regions and ethnicities that are not considered in the existing literature. Furthermore, more psychological thermal adaptation studies are necessary, especially in transient thermal conditions. Qualitative analysis is also recommended to be incorporated in further studies in addition to considering the perceived environmental quality. The study serves as a reference to researchers, urban designers and planners to enhance their knowledge for achieving outdoor thermal comfort and understanding the gaps that need to be addressed in further studies.

Keywords: Thermal conditions; Outdoor thermal comfort; Thermal perception; Urban planning; Urban liveability

Nomenclature

aAT	Adjusted apparent temperature
aPMV	Adaptive predicted mean vote
AT	Apparent temperature
CTT_{out}	Critical thermal threshold
D ↓	Diffuse shortwave radiation
ET*	Effective Temperature
HEBIDEX	Heat Budget Index
IPCC	Intergovernmental Panel on Climate Change
K ↓, K ↑	Global shortwave radiation
L ↓, L ↑:	Longwave radiation
LCZ	Local climate zone
MOCI	Mediterranean Outdoor Comfort Index
mPET	Modified physiologically equivalent temperature

MTSV	Mean thermal sensation votes
NTT_{out}	Neutral thermal threshold
OUT_SET*	Outdoor Standard Effective Temperature
PET	Physiological Equivalent Temperature
PMV	Predicted mean vote
PT	Perceived Temperature
RH	Relative humidity
S_r	Solar radiation
SET	Standard Effective Temperature
STEBIDEX	Skin Temperature Energy Balance Index
T_a	Air temperature
T_g	Globe temperature
T_{mrt}	Mean radiant temperature
T_s	Surface temperature
T_{pref}	Preferred temperature
T_n	Neutral temperature
TDI	Thermal discomfort index
TOP	Operative Temperature
UTCI	Universal Thermal Climate Index
UHI	Urban heat island
V_a	Wind speed

1. Introduction

Recent changes in ecosystems have had a negative impact on the liveability of outdoor built environments [1]. The collective effects of these changes in urban outdoor spaces challenge effective urban planning which aims to create successful and usable outdoor spaces. Among the determinants of outdoor environment quality, a high priority is given to the thermal environment [2]. Hence, urban planners and designers attempt to explore the common grounds on which people perceive and interact with outdoor meteorological conditions. In fact, thermally comfortable urban environment can facilitate urban residents' interaction with their surrounding environment while meeting their everyday demands. Conversely, thermally uncomfortable environments may discourage participation in outdoor activities and raise indoor cooling energy consumption [3].

Therefore, the notion of thermal comfort theory as a universally recognised benchmark has been in use for several years to determine how residents may interact with the outdoor thermal environment. Thermal comfort definition is "…*that condition of mind that expresses satisfaction with the thermal environment*" [4, p. 7]. Two main models that underpin the knowledge of thermal comfort are the steady-state heat-balance theory model [5] and the adaptive models [6]. These models were initially developed for indoor air quality environment, and their application has been extended to the outdoor environment.

Australia is a leading country in developing thermal comfort theory and practice, mostly in interior conditions [7-16]. However, recently there has been a growing trend to assess outdoor thermal comfort [17] coinciding with rapid change in urban design patterns and population growth, and severe effects of climate change in Australian capital cities [18]. Australian capital cities are among the most fast-growing cities in developed countries, and there are growing concerns about thermal conditions in these cities [18-20]. Overall, certain evidence suggests that Australia is an exceptional case highlighting the need to take urgent decision and action against potential consequences.

In Australia, heatwaves are ranked as the third most severe natural disaster proceeded by floods and bushfires [21]. Hot weather is becoming more common and severe in Australia [22]. The 2003-2012 decade remains one of the country's warmest with a temperature anomaly of +0.44 ºC and all Australian capital cities recorded warmer-than-average maximum temperatures [23]. The latest report by the Intergovernmental Panel on Climate Change (IPCC) states that Australia will keep getting hotter, resulting in a need to use mechanical means to achieve comfortable temperature indoors [24]. The record 2012-2013 and 2013-2014 summer temperature reflect this shift to more hot weather events [23], including the January 2014 heatwave in southeast Australia [25]. The January 2019 heatwave is worth mentioning with respect to the duration and the average maximum temperature in Australia and Victoria, respectively [26]. The heatwave records surpassed those that occurred in 2009 [27]. The six days from 12 to 17 January 2019 are all within Australia's ten hottest days on record according to the Australian Bureau of Meteorology [26].

For all the reasons mentioned above, this study is an effort to shed light upon outdoor thermal comfort research in the Australian context. The aim is to review the quality of outdoor thermal comfort assessment in Australia’s cities. This review can further our understanding of Australians needs to better interact with outdoor environments and to show how past and current thermal comfort research can assist with improving urban liveability.

2. Methodology

This section explains the procedure followed to find, categorise and review the highly relevant sources for this review study. The procedure includes inclusion and exclusion criteria that applied in two stages.

2.1. Search procedure and selection criteria

The sources selected for this review study underwent two stages of examination as follows:

Stage I: to acquire the relevant English language literature for this systematic review, a desktop search of six major databases was conducted: Google Scholar, Scopus, PubMed, Wiley Online Library, Water Resource Abstracts (ProQuest), Web of Science and universities’ theses repositories. The keywords used were “*Australia*”, “*outdoor*”, “*thermal comfort*”, “*thermal perception*” and “*thermal preference*”. The desktop search resulted in 59 research outputs, including peer-reviewed journal articles, conferences papers and PhD theses. To make sure that highly relevant sources were captured, the references of selected sources’ references were also explored.

Stage II: at this stage, the sources that had highly relevant contents were shortlisted, and their full texts were downloaded. Notably, the sources that had not considered using thermal comfort index or only used simulation techniques were excluded. Studies that did not involve human subjects in their research design were also excluded. At the end of this stage, 25 research outputs remained for analysis.

2.2. Thermal comfort research language

The sections below describe the standard terminologies and definitions used in outdoor thermal comfort studies. These terminologies refer to thermal comfort indices and the concepts usedto describe people's thermal perceptions.

2.2.1. Thermal comfort indices

The collective effect of study environmental variables (i.e. air temperature, relative humidity, wind speed, and mean radiant temperature) and two personal factors (i.e. clothing insulation and metabolic activity level) is calculated and expressed in the form of one thermal comfort index. Over one hundred thermal comfort indices have been used to assess and predict perceptions of comfort in thermal environments, most of these were designed to assess indoor conditions [28]. Among others, the main three thermal comfort indices, namely Physiological Equivalent Temperature (PET) [29], Universal Thermal Climate Index (UTCI) [28] and Outdoor Standard Effective Temperature (OUT_SET*) [30] are specifically designed for outdoor conditions and typically used in outdoor thermal comfort studies. Besides PET, UTCI and OUT_SET*, other common outdoor thermal comfort indices include apparent temperature (AT), adjusted apparent temperature (aAT), thermal discomfort index (TDI), Effective Temperature (ET*), Operative Temperature (TOP) and Perceived Temperature (PT). Some studies also used predicted mean vote (PMV) or adaptive predicted mean vote (aPMV), but

PMV's steady-state assumption could make it unreliable for fluctuating outdoor conditions [31]. In an early study, de Freitas [32] used the Skin Temperature Energy Balance Index (STEBIDEX) and Heat Budget Index (HEBIDEX) to define thermal sensation threshold levels, using the beachgoers in Caloundra as case studies.

Pickup and de Dear [30] extended the Standard Effective Temperature (SET) thermal comfort index in order to apply it in outdoor settings. This thermal index which still holds the basis of two-node model [33] have been used in various comfort research [34]. Recent studies mostly used PET or UTCI as outdoor thermal comfort indices. For a comprehensive review of thermal comfort indices, please refer to de Freitas and Grigorieva [35] and Coccolo, et al. [36].

2.2.2. Thermal perceptions

For the subjective perception for the outdoor thermal environment, the common terms used in thermal comfort surveys are provided in Table 1. The definitions of thermal preference, thermal sensation and thermal acceptability are derived from ISO 10551 [37].

Term	Description
Neutral temperature	A temperature at which most people feel neither cool nor warm. Here are two methods to define the neutral temperature: a) to define it by solving zero to the equation of linear regression between mean thermal sensation votes (MTSV) and index temperature values [17]; b) to define it using Probit analysis for two categories of "warmer than neutral" and "cooler than neutral" [38]
Preferred temperature	A temperature value at which people prefer neither warmer nor cooler environment. To define preferred temperature, the three-point scale of McIntyre [39] on thermal preference is split into the two categories of "change to cooler temperature" and "change to warmer temperature". Then, the preferred temperature is the temperature at which the Probit curves of "change to cooler temperature" and "change to warmer temperature" cross.

Thermal preference	A 3-point scale including “prefer warmer”, “no change” or “prefer cooler”, or a 7-point scale from “prefer much warmer” to “prefer much cooler” [37].
Thermal sensation	A 7-point scale from cold (-3) to hot (+3), with 0 being neutral [37].
Thermal acceptability	Thermal acceptability is indicated by generally acceptable or generally unacceptable [37].
Neutral thermal threshold (NTT_{out})	The NTT_{out} refers to the threshold temperature in which a significant decrease in outdoor activities occurs [40].
Critical thermal threshold (CTT_{out})	The CTT_{out} refers to the zero-activity threshold temperature [40].

Table 1. Various terms used to describe human thermal perceptions

3. Results

Following the application of the approach described in section 2.1, only 25 published research outputs (using observation and survey approach) were found to be suitable for our review and analysis. Apart from two studies published in 1985 [32] and 2003 [38], the other sources were released since 2012. Table 2 summarises the studies found to have the characteristics mentioned above.

Table 2 summarises these studies and compares their features. Further details of each study are provided in the subsequent sections. Four of these studies were published in the form of a doctoral thesis; others were presented in peer-reviewed journals (Table 2). However, for ease of access, where available, this review referred to the journal papers drawing on the Ph.D. theses reviewed. Comparison between these studies can reveal valuable information on the extent of variation, the aim and research approach in particular.

City	Season/ place	Method	Focus of the study	Sample size	Target population	Reference
Melbourne	Spring, summer, autumn, Educational precinct	Q, M, O	Exploring the adequacy of comfort standards in assessing people's thermal perceptions; the impact of contextual factors on thermal perceptions	1059 Male: 707 Female: 352	University students (i.e. overseas and local), academic and professional staff	[41-47]
Melbourne	Summer, Botanical garden(s)	Q, M, O,	Finding the specifications of thermal comfort and adaptation among visitors of Melbourne Botanical Gardens, in both heatwave and non-heatwave periods.	3241 Male: 1366 Female: 1875	Melbourne Botanical Garden's local and overseas visitors	[48-53]
Melbourne, Adelaide, Sydney	Spring, summer, autumn, Three city centres, 10 urban precincts, and 10 public spaces	Q (online & hardcopy), M, O, SD	Investigation of urban residents' outdoor activity choices	318 observation sets 108 (hard copy), 159 (online) Gender not recorded	Public	[40, 54-57]
Geelong	Summer, Street (during a cultural diversity festival parade)	Q, M	Examining the influence of cultural background on the thermal comfort perception	100 Gender sample size not recorded	Festival goers	[58]
Melbourne	Summer and winter, Federation Square	Q, M	Identification of climate and culture background role in thermal perceptions	1021 Gender sample size not recorded	Users of a busy plaza in Melbourne (locals & overseas)	[59]
Melbourne	Summer and winter, Federation Square and university campus	Q, M	The 2013 study identifies the climate and culture background role in thermal perceptions. The 2018 study identifies the different outdoor thermal comfort benchmarks for Melbourne in various seasons and public spaces	2123 Male:891 Female:1232	Pedestrians in plaza and university campus	[17, 60]
Melbourne, Adelaide	Summer, Outdoor spaces in Mawson Lake, Adelaide and Melbourne	Q, M	To identify thermally comfortable temperatures in outdoor settings	680 Gender not recorded	Pedestrians	[61]
Sydney	Winter, summer, Six semi-outdoor and outdoor spaces	Q, M	Evaluation of thermal comfort conditions in urban spaces by specifying seasonal neutral and preferred temperatures	1018 Gender sample size not recorded	Users of typical outdoor and semi-outdoor urban places in Sydney	[38]
Caloundra	All year round, Beachside	Q, M	Test the applicability of heat balance models under coastal conditions	179 Gender not recorded	Holidaymakers on a beachside	[32]

145 **Note: Q: questionnaire, M: measurement, O: observation, SD: secondary data**

146 **Table 2 Summary of Australian studies assessing outdoor thermal comfort using observation and survey**

3.1. The focus of study

A total of 25 studies that investigated outdoor thermal comfort in the Australian context have been identified in this study. Among these, 20 studies focused on Melbourne and Sydney, being the two major cities (Table 2). In Australia, these two cities had the largest increase in population between 2017 and 2018 of 119,400 and 93,400 for Melbourne and Sydney, respectively [62]. According to the latest census report, Melbourne and Sydney along with the other capital cities (i.e. Adelaide, Brisbane, Canberra, Perth, Darwin, and Hobart), accommodate 66.5% of the total population [63]. Due to this demographic status, these cities have experienced fundamental urban design reforms [64] and therefore, have severely faced issues rooted in urban heat island phenomenon and thermal discomfort [65]. According to these factors, the main outdoor thermal studies in Australia focused on capital cities.

The two exceptions investigated outdoor thermal comfort in regional cities, being Caloundra [32], and Geelong [58]. In the first study, de Freitas [32] investigated the relationship between the body's heat balance and holidaymakers' thermal preference in a beach while undertaking the recreational activities. The second study [58] aimed to examine the influence of culture and environmental attitude on participants' thermal requirements in outdoor public places. The results demonstrated the impact of cultural diversity on thermal perception which is a crucial aspect to be considered in multicultural societies.

In a more comprehensive work executed by Spagnolo and de Dear [38], people's thermal comfort in various outdoor spaces was investigated in Sydney to determine the contextual-based thermal neutrality using different thermal indices. The work was a breakthrough in the field of outdoor thermal comfort, and the proposed protocol has been adopted by many researchers [66-69]. Spagnolo and de Dear [38] provided useful information on thermal perceptions based on predictions and suggested that indoor comfort thresholds are not directly applicable to outdoor environments.

In another effort to determine the thermal perception range for Australians, Loughnan, et al. [61] performed a comparative study between Melbourne and Adelaide. The study aimed to improve Australian bio-meteorological knowledge in an urban environment with respect to the concept of Water Sensitive Urban Design and thermal comfort [70]. However, research findings were limitedly disseminated, and no further details about this work were published. Similarly, the outdoor thermal perception range was identified for Melbourne and other areas with temperate oceanic (Köppen Cfb) climate conditions by multiple studies [17, 43, 47, 59, 60]. These studies estimated urban residents thermal comfort requirements and calibrated the PET ranges against them.

Besides thermal comfort surveys, outdoor activity choices under different summer conditions in Melbourne, Sydney and Adelaide were investigated using direct observation [40, 54]. A similar approach was adopted by Shooshtarian, et al. [42], who also considered how seasons and place characters influence usage patterns. Changes in activity choices reflect people's limit of outdoor thermal adaptation.

With an increasing number of outdoor thermal comfort studies, and placing stress on human parameters as an active recipient instead of passive [71], the attention is given to the requirements of specific outdoor space users with special comfort requirements including people with diverse cultural backgrounds [72]. In view of this, Kenawy [60] and Kenawy and Elkadi [59] performed comfort research in Melbourne to understand the cultural diversity impacts on the outdoor thermal comfort. The study was designed to find the impact and interaction between different factors including cultural and climatic background on thermal comfort and perception in outdoor places. These research findings are of particular importance for the context of Australia as a multicultural country as it seeks to ways of providing social inclusion for its residents [14, 73, 74]. The study was confined to two different outdoor places including an urban square and a university campus during summer and winter. The research findings could also be convenient for tourism decision-makers to consider the tourists' comfort requirements. Other studies identified that the weather conditions are ranked as the first or at most the second concern for the holidaymakers [32, 67].

The limitation identified in the previous studies on the special requirements of short-term visitors has been addressed by a work conducted in Melbourne's Botanic Gardens [51]. Multiple nationalities of visitors and diverse microclimates inside the garden offer further insight into how various factors affect outdoor thermal comfort [51]. Lam, et al. [50] compared thermal sensations of visitors who experienced heatwave conditions with those visitors under non-heatwave conditions, indicating the possible influence of thermal expectation. Furthermore, Lam, et al. [48] investigated the inter-daily variation of thermal perception before and after a heatwave. The results of the above studies contribute to the informed decision-making process for better management of recreational places, where the sites are frequently visited by tourists across Australia. These studies also promote a better understanding of the position of urban parks and gardens in the provision of human thermal comfort. The effects of urban design and elements in outdoor conditions have been the focus of various comfort-related studies [75-80].

Another study in Melbourne specifically focused on the impact of contextual factors on human-place-weather relationship in an educational precinct [44-46]. The results proved that there are multiple non-thermal factors that can modify the way outdoor users perceive comfort in outdoor spaces. Based on this result, it was suggested that current thermal comfort assessment methods are inadequate.

3.2. Target population

The reviewed studies involved collecting comfort data using participants' self-report judgment about outdoor thermal conditions (Table 2). The sample size of these studies ranged from 100 respondents [58] to 3241 respondents [50, 53]. Different outdoor places' users were considered in the reviewed studies. Public places' users were the most frequently used sample [54, 58-61], followed by holidaymakers and tourist [38, 50, 51], as well as university students and staff [17, 43, 60]. In four studies a distinction was made between local and overseas space users [44, 51, 59, 60] and their thermal responses were separately reported. In terms of gender frequency distribution, only several studies reported such a distribution as identified in Table 2 [44, 46, 49-51, 60]. It is clear from Table 2 that the samples in these studies were characterised by unbalanced ratios between genders. However, this gender ratio could be relevant to the actual representation of the targeted population. Various findings were reported in relation to the outdoor thermal comfort perception for different gender. Shooshtarian and Ridley [46] reported an insignificant correlation between gender and thermal perception. The authors added that both genders reported similar thermal perception and maintained this pattern throughout the study period. However, there was a significant gender difference in clothing choices. Opposite results were reported by Lam, et al. [51], as their study revealed that female visitors generally felt hotter than male visitors (higher mean thermal sensation) when the air temperature was 24.2 °C to 40.6 °C. However, there was no significant difference between the clothing worn by the different genders. These results were also in line with Kenawy [60], who found a significant association between gender and thermal sensation votes for both summer and winter seasons. The study also reported that female respondents were less tolerant of heat and cold stress, as they were having higher mean thermal sensation vote in both summer and winter.

3.3. Data collection methods

3.3.1. Questionnaire survey

The reviewed studies used a structured interview to collect data human place relationship. The data collected was generally grouped into four categories: personal details (e.g. age, gender, status of residency, clothing, position/activity), thermal perceptions (i.e. thermal sensation, thermal preference, thermal acceptance, overall comfort), thermal adaptive strategies, and place-related enquires (e.g. usage pattern and exposure before the survey). In Table 3, a summary of the items included in each of the four categories is presented. The number of questions in the questionnaires ranged from 3 to 14 questions. Except for the study in Caloundra, all other studies enquired demographic details, among which the main questions were the age group and gender.

There was a great variation in the structure of the questionnaire used in these studies, as it was aligned with the aim and focus of each study. However, certain sections remained constant in the administrated questionnaires. For thermal perception scales, all studies employed the ASHRAE thermal sensation scale [4] with seven choices (i.e. cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2) and hot (+3)); except two that used its 9 point version [32, 58].

The cultural background as an indication of acclimatisation was also considered in some studies [46, 51, 58, 60]. Kenawy and Elkadi [58] compared the thermal comfort of respondents from various cultural backgrounds. Later, Kenawy [60] and Kenawy and Elkadi [59] extended this comparison to include the other categories. Lam, et al. [51] also examined the difference in the thermal comfort perceptions for visitors from Australia, Europe, North America and China. These studies found that acclimatization, thermal history and expectation would likely contribute to differences in thermal perception among respondents from various cultural backgrounds and climate zones.

Different studies use surveys to explore people’s thermal adaptive strategies. These adaptive strategies include changes in clothing [48, 50, 51], personal accessories (e.g. hat, umbrella) and behavioural adjustment, such as the length of stay outdoor and choices to move to shaded places [42]. Thermal perception in different seasons and study sites in the same city can also be used as an indicator of thermal adaptation [17, 43]. Other adaptive strategies are examined by asking respondents’ frequency of checking weather forecasts, as well as their subjective perception of urban site characteristics, including greenery and water features [57]. Overall, choices of thermal adaptive strategies depend on place character and seasons, which can inform outdoor space management.

Reference	**Personal details**	**Thermal perception scale**	**Place-related parameters**	**Thermal adaptive strategies**	**Number of questions**
Shooshtarian et al. [41-43, 45-47]	Gender, age group, activity, clothing, residency status, personal accessories, companionship,	**Thermal acceptance** (ASHRAE 7 points) **Thermal preference** (McIntyre 3 points) **Thermal sensation** (ASHRAE 7 points) **Overall comfort** (7 points) **Bedford preference** (3 points)	***What brings you here (in this particular outdoor place)?*** Having a break/ resting, getting fresh air, playing passage to another place, change of environment, having lunch/snack, read/write, meeting/waiting for someone, others (please specify) ***Which of the following statements about this particular place is close to your opinion:*** I agree/ disagree/ have no idea about the establishment of more natural green spaces in this place ***Which feature(s) do you find attractive in this place?*** Plants and exposure to nature, an environment with better ambient conditions, the beauty of the place compared to other environments, convenient access and closeness to my school/workplace, others (please specify) ***How often do you come to/pass this place?*** Daily, several times/week, a few times/week, a few times/ month, rarely, first time ***Where were you 15 minutes prior to this survey?*** Indoor non-ventilated space, indoor- conditioned space, outdoor-under shade, outdoor- exposed to sunlight ***If you were outdoors, how long have you spent in this particular outdoor place?*** Less than 5 minutes, 5-10 minutes, 10-30 minutes, more than 30 minutes ***Did you check the weather forecasts today before leaving home?*** *yes/no*	***What measures would you take to feel more comfortable?*** Use umbrella/hat, move to shade/sunlight, reduce/add clothing, no change, others (please specify)	14
Lam et al. [48-52]	Gender, age group, activity, clothing, residency status	**Thermal sensation** (ASHRAE 7 points) **Thermal preference** (McIntyre 3 points)	***For the last 5-10 minutes were you mainly in*** outdoor, exposed (in the sun), outdoor, shaded (including tree shade), indoor (no air conditioning), or air-conditioned? ***What is your main reason for visiting the garden? (Choose one option)*** relaxation, garden's scenery, time with family/friends, enjoy outdoors exercise, view plant species, other reasons (please specify).	***In which garden location would you like more shade?***	9
Kenawy and Elkadi [58]	Age, gender and cultural background	**Thermal sensation** (9 points) **Thermal preference** (McIntyre 3 points) **Perception of individual weather parameters** (air temperature, humidity, wind speed and solar intensity)	N/A	N/A	N/A
Kenawy and Elkadi [17]	Age, gender, clothing, activities	**Thermal sensation** (ASHRAE 7 points)	Time of response, the location of respondents in the place, and sky conditions	Not specified in questionnaire. However, thermal adaptation was indicated by difference in thermal perception in various	N/A

		Thermal preference (McIntyre 3 points)		seasons and survey locations (public square vs university campus)	
Sharifi et al. [56]	Age, activity	**Thermal sensation** (ASHRAE 7 points)	- Questions on frequency of necessary, optional and social activities - Thermal sensation vote across different activities - Outdoor activity choices in different thermal conditions - Effective climate factors in outdoor attendance	- A question about weather information updating - A question about spatial preferences during heat stress conditions - A question on heat-health awareness	11
Sharifi [57]	Gender, age, activity	**Thermal sensation** (ASHRAE 7 points)	***How often do you attend public spaces in the Adelaide metropolitan area?*** Daily, two-three times/ week, once a week, once-twice/ month, rarely, never	***How often do you check the weather predictions (from radio, TV, phone apps, etc)?*** *Several times/day, daily, once a week, only when going outdoors, two-times/week, never* ***Which feature of visited public spaces did attract you during last year very hot days?*** *Open grass cover, open-air hard landscape, shade from tree canopies/temporary structures/buildings, outdoor air conditioners, water features, shopping /dining/sport/swimming facilities, social events.*	11
Loughnan et al. [61]	NS	**Thermal sensation** (ASHRAE 7 points)	N/A	N/A	N/A
Spagnolo and de Dear [38]	Gender, activity, clothing	**Thermal sensation** (ASHRAE 7 points) Thermal preference (McIntyre 3 points)	N/A	N/A	5
de Freitas [32]	Gender	**Thermal sensation** (9 points) Thermal pleasantness (5 points)	N/A	N/A	3

Table 3. Structure of the questionnaires used in thermal comfort studies in Australia

3.3.2. Measurement and instrumentation

Table 4 summarizes the data collection methods, devices used and analytical models for outdoor thermal comfort studies in Australia. Most studies stated the model of the instrument used, except for Loughnan, et al. [61] and Kenawy and Elkadi [58]. Although these studies used different models of weather stations, many of them measured the basic parameters for thermal comfort, including air temperature, relative humidity, wind speed and mean radiant temperature or solar radiation. Most studies used either PET, UTCI or OUT_SET* in their analysis. Rayman Pro was usually used to calculate the thermal comfort indices. The AT is another common index used when wind speed or T_{mrt} data are unavailable. The measurement height of sensors is generally around 1.1 m to 1.5 m, which corresponds to the centre of gravity of the human body [34]. Notably, Kenawy [60] and Kenawy and Elkadi [17, 59] used a mobile cart to measure meteorological variables at different heights, for example at 0.1, 0.6, 1.1 and 1.7m above the floor respectively (representing lying, sitting and standing people).

All the reviewed studies measured air temperature and relative humidity. The measurement probes measuring both variables were reported to be placed inside radiation shield in three studies. Five studies did not use radiation shield, whereas seven studies did not mention whether the probes were shielded or not. It would be good to put temperature sensor in some kinds of shield to protect it from direct solar radiation loading. However, in direct sunlight with little wind, the temperature inside the shield might be higher than the actual ambient temperature [81]. This radiative forcing on sensor-shield system could lead to systematic error in air temperature measurement, which might require correction [81, 82].

Wind speed measurement can produce issues if the anemometer is not sensitive to low wind speed, such as two-dimensional cup anemometers (used in six studies) and impeller-type anemometers (used in six studies). In outdoor settings where wind direction varies greatly, omni-directional anemometer (used by Shooshtarian and Rajagopalan [43], Kenawy and Elkadi [17] and Spagnolo and de Dear [38]) would be preferred over one-directional anemometer. Alternatively, vane mount on a tripod can be used to change the instrument direction to face the prevailing wind (e.g. Kestrel portable weather stations used in Lam, et al. [51]).

Those studies that estimated T_{mrt} mostly used the globe thermometers method, but the diameter of globes used varied. For example, past studies have used 150-mm black globe [41-43, 45-50, 52], 40-mm black globe [54, 55], 38-mm black globe [17, 60] and 25-mm black globe (calibrated against 150-mm black globe) [48-50, 52]. In other outdoor studies [83, 84], 40-mm grey globe thermometers (RAL 7001) were often used instead of the 150-mm black globe. The globe diameter will likely affect its response time. Ideally, the T_{mrt} estimated through T_g from globe thermometers should be calibrated with integral radiation measurements at each study location (e.g. using three net radiometers measuring three-dimensional radiation fields) [34] In this way, the accuracy of T_{mrt} calculated from globe thermometers can be improved. As the three net radiometers method can be expensive, Spagnolo and de Dear [38] suggested using radiation sensors measuring two hemispheres, one facing upward and the other downward. They adopted a T_{mrt} formula consisted of direct, diffuse, reflected short-wave radiation and infrared fluxes. This particular method can simplify the measurement procedure and produce more accurate T_{mrt} measurement than the black globe method.

Reference	Devices used	Index used	Software used
Shooshtarian et al. [41-43, 45-47]	**T_a, RH, V_a:** Weather station - Testo 480 IAQ Pro **T_g:**150-mm diameter black globe thermometer **S_r:** Silicon Smart HOBO S-LIB-M003 sensor **T_s:** HOBO Pendant UA-001-64	PET, OUT_SET*, UTCI	Rayman Pro 2.1
Lam et al. [48-52]	**T_a, RH:** Vaisala HMP155A Probe **V_a:** Met One 014A-L anemometer **T_g:**150-mm diameter black globe thermometer with Omega 44031 precision thermistor inside **S_r:** Apogee SP-212 Amplified Pyranometer Kestrel 4400 Heat Stress trackers were also used to measure **T_a, RH, V_a**, and **T_g** (25-mm black globe)	UTCI, AT	Rayman Pro 2.1
Sharifi et al. [54, 55]	**T_a, RH:** EXTECH RHT20 **T_a, RH, V_a:** Kestrel 3000 and Kestrel 5500 **T_g:** EXTECH HT30 (40-mm black globe)	UTCI, PET, SET, OUT_SET*, AT, aAT, aPMV	Rayman Pro 2017, UTCI calculator on http://www.utci.org/, SET values estimated based on regression analysis between AT and UTCI
Sharifi et al. [40]	**T_a, RH, V_a:** EXTECH RHT20, Kestrel 4000	AT	Not specified
Kenawy and Elkadi [17, 60]	The Mobile Architecture and Built Environment Laboratory (Mabel) thermal comfort carts, with Campbell Scientific CR23X data logger **T_a:** OMEGA,44032 linear thermistors **RH:** HyCal integrated humidity sensor (IH-3605-B) **V_a:** Digital TSI anemometers with omnidirectional hot wire type of anemometer probes **T_g:** OMEGA,44032 linear thermistors inside 38-mm diameter black table-tennis ball	PET	Rayman version 1.2
Loughnan et al [61]	**T_a, RH, V_a,, T_g, S_r**: portable weather station (model not specified)	Air temperature	Thermal comfort calculator
Kenawy and Elkadi [58]	**T_a, RH, V_a, S_r**: portable weather station (model not specified)	PMV	Not specified
Spagnolo and de Dear, [38]	**T_a**: Omega 44032 linear composite thermistor **RH:** HyCal IH-3605B solid sate hygrometer **V_a,**: TSI 8475-150 omnidirectional heated-sphere anemometer, Mini-Rimco 3-cup photochopper anemometer **K ↓, K ↑,D ↓:**LiCor LI-200SA Silicon pyranometer **L ↓, L ↑:**Eko MS-201 pyrgeometer	PET, OUT_SET*, PT, TOP, ET	WinComf© software (ET* & OUT_SET*), Source code from Jendritzky and Staiger (PT), Program from Peter Hoeppe (PET)
de Freitas [32]	**T_a, RH:** aspirated Assmann psychrometer **T_S:** Ultrakust Type 4444-1 equipped with a T_S sensing **V_a:** Casella cup anemometer **S_r:** Kipp, Moll thermopile	Skin Temperature Energy Balance Index (STEBIDEX), Heat Budget Index (HEBIDEX)	Using equations presented in the paper

Note: T_a: air temperature (°C), RH: relative humidity (%), V_a: wind speed (m/s), T_g: Globe temperature (°C), T_S: surface temperature (°C), T_{mrt}: mean radiant temperature (°C), S_r: Solar radiation (W/m^2), K ↓, K ↑: Global shortwave radiation (W/m^2), D ↓: Diffuse shortwave radiation (W/m^2), L ↓, L ↑: Longwave radiation (W/m^2)

Table 4. Summary of characteristics of data collection methods used in thermal comfort studies

3.3.3. Observation

Past Australian studies have examined the impact of urban morphology (e.g. aspect ratio and street orientation) [85, 86], tree shade [85-88] and water-sensitive urban design [89] on outdoor thermal comfort, using thermal indices such as PET and UTCI. However, these studies do not involve human subjects in their research design. For the purpose of this review, we focus on observation studies where researchers stand aside and observe how people interact with outdoor built environments.

Apart from thermal comfort surveys and microclimate measurement, direct observation is another method to investigate people's activity pattern associated with different physical attributes of spaces and outdoor thermal conditions. In direct observation studies, it is not necessary to interfere with subjects during observation. This method could lead to accurate activity pattern results because people's behaviour might change when researchers involve the subjects in their investigation.

Previously, the relationship between outdoor thermal conditions (e.g. UTCI) and pedestrians' outdoor neutral thermal threshold (NTT_{out}) was examined in Adelaide, Sydney and Melbourne [40, 54-56, 90]. Pedestrian activity patterns could be necessary (e.g. walking and working), optional (e.g. standing and sitting) and social (e.g. group activities) [40]. The upper threshold of outdoor thermal neutrality was 25 °C, 26 °C and 30 °C for Melbourne, Sydney and Adelaide, respectively [55]. In these three cities, people were still able to maintain thermal comfort by changing clothing and activity rate when UTCI was 22 °C– 34 °C [54]. However, UTCI beyond 34 °C saw a decline in optional and social activities, and the zero-activity threshold was reached at UTCI = 48 °C (i.e. critical thermal threshold - CTT_{out}), indicating the limit of behavioural heat adaptation [54]. Both NTT_{out} and CTT_{out} illustrates the level of heat resilience in urban open space, which has an important implication for urban planning.

In another Melbourne study, the usage pattern characteristics in different seasons were examined by counting the number of people and their activities every 30 minutes, together with mobile weather station measurement [42]. They found that Melbourne people tend to modify their usage patterns and behaviours depending on seasonal weather conditions. The frequency of visit, length of stay outdoor, type of visitors and activities, as well as adaptive thermal measures all differed between spring, summer and autumn. Moreover, the influence of weather conditions on people's usage pattern was more evident in autumn. This influence of seasonal change on usage pattern could be due to changes in people's thermal expectation and thermal preference [43].

Apart from meteorological conditions, the type of public space also affects pedestrian activity patterns. In particular, Sharifi, et al. [40, p. 1833] defined heat resilience as 'the ability of the space to support its normal activities when experiencing out-of-comfort temperatures'. In observing the user pattern of different urban space, the heat resilience of urban green space was higher than other public space, and the hard landscape was largely avoided by pedestrians during heat stress conditions [56]. In brief, outdoor activity pattern can be used to assess people's thermal adaptation behaviour and preference of place usage in different outdoor thermal conditions.

3.4. Study areas and methods for thermal comfort assessment

Past Australian studies have used both microclimate observation and surveys to examine outdoor thermal comfort. More than half of these studies focused on Melbourne, Victoria (Köppen Cfb); several studies focused on Adelaide, South Australia (Köppen Csa) and Sydney, New South Wales (Köppen Cfa) (Figure 1). One study was in Caloundra, Queensland (Köppen Csb), 90 km north of Brisbane. Table 5 summarizes the neutral PET or UTCI range in different outdoor thermal comfort survey studies in Australia. Most studies used linear regression analysis between thermal indices and mean thermal sensation votes (MTSV) to derive the neutral range of thermal indices. This neutral thermal index range reveals the thermal comfort range in different study sites and cities, which is determined by solving the linear regression equation with MTSV of ±0.5 [17]. Most past Australian studies used PET and UTCI to derive this thermal neutral range, but some studies only used air temperature [61]. In another Sydney study, the OUT_SET* threshold limit values are shown to differ between people with different metabolic rates (spectator: 1.2 mets, tourist: 2.2 mets and athlete: 9 mets) [91]. All studies examined the thermal neutral range during summer, and only a few studies investigated the thermal neutral range in winter [17, 38], spring and autumn [45]. The winter thermal neutral range was higher than that of summer in both Melbourne [45] and Sydney studies [38]. Melbourne people’s preferred wind speed was also higher in summer (4.51 m/s) and spring (2.04 m/s) compared with autumn (1.25 m/s) [41]. The thermal neutral PET range in Melbourne botanic gardens [53] is wider than the Federation Square and university campuses in Melbourne [17, 45], suggesting that people are more likely to feel neutral in urban green space. Our analysis shows that even within the same climate zone, there is an intra-urban difference in thermal comfort requirement depending on the site characteristics.

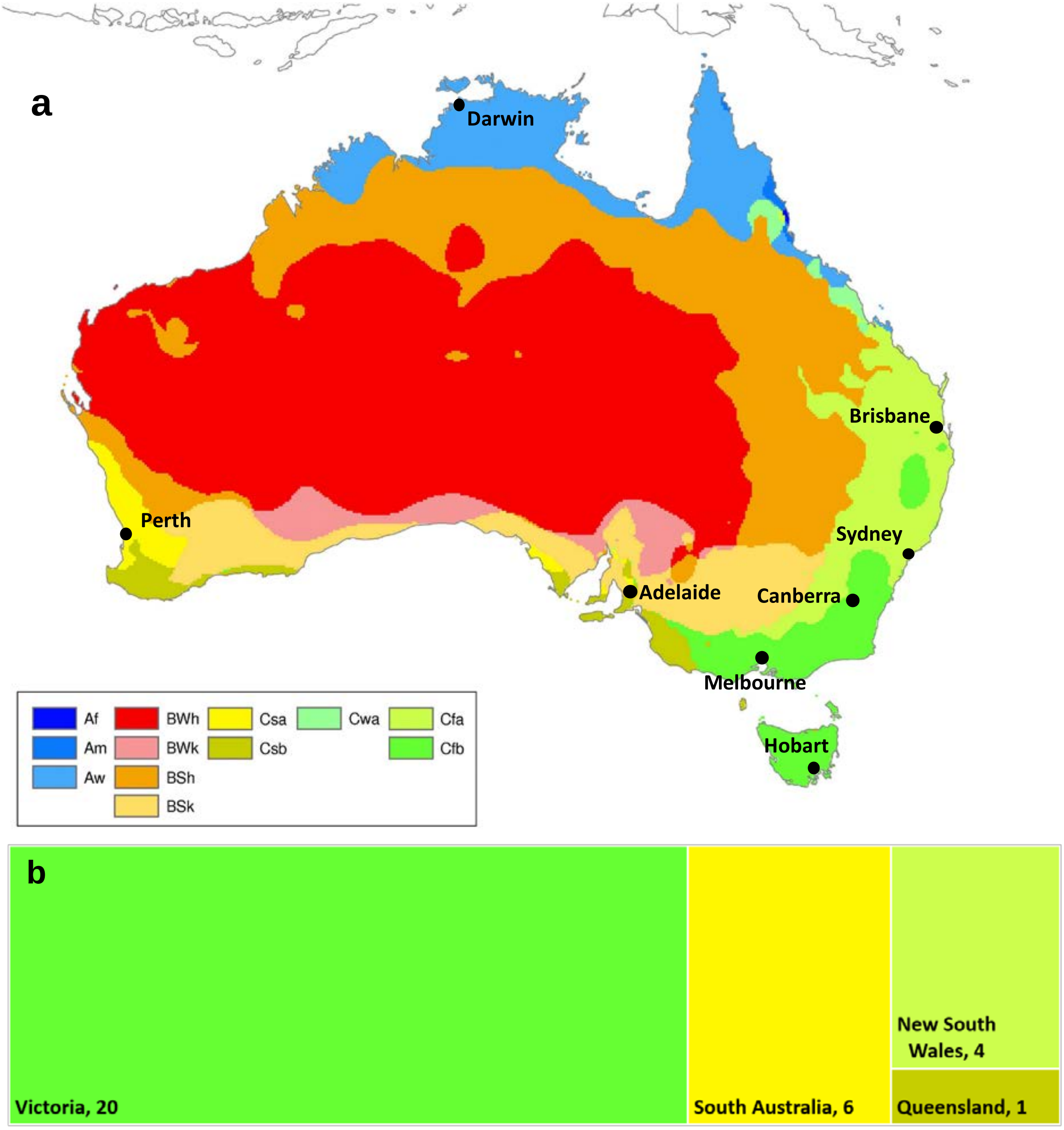

Figure 1a) Australia capital cities according to Köppen climate zones [adapted from 92]; b) number of outdoor thermal comfort studies according to the states of Australia. Note that some studies have multiple study sites.

Study site/reference	**Köppen climate zone**	**Neutral PET/UTCI range (°C) (MTSV ± 0.5)**			**Analytical model**
		Summer	Winter	Other	
Federation Square and Deakin Burwood campus, Melbourne [17]	Cfb	17-22.9 (PET)	20-28.4 (PET)	N/A	Linear regression (LR) MTSV vs PET bn (0.5 °C)
Education Precinct (RMIT University),	Cfb	16.5-24.5 (PET)	N/A	14.9-23.6 (PET, Spring)	Linear regression Spring: y=0.1149PET-2.2116

Melbourne [43, 45]				21.5-28.7 (PET, Autumn)	Summer: y = 0.1251PET-2.5615 Autumn: y = 0.14PET-3.5144
Mawson Lake, Adelaide [61]	Csa	25-30.6 (air temperature)	N/A	N/A	Not specified
Melbourne (location unspecified) [61]	Cfb	19.9 - 23.2 (air temperature)	N/A	N/A	Not specified
Melbourne Garden, Melbourne [53]	Cfb	6.8*-21.1 (PET) 11.2-23.2 (UTCI)	N/A	N/A	Linear regression Y=0.0699PET-0.9783 Y= 0.0836UTCI-1.4389
Cranbourne Garden, Melbourne [53]	Cfb	10.7-27.7 (PET) 14.6-24.1 (UTCI)	N/A	N/A	Linear regression Y=0.0589PET-1.1319 Y=0.1004UTCI-2.205
Melbourne and Cranbourne Garden, Melbourne [49]	Cfb	14.6-24.1 (UTCI)	N/A	N/A	Linear regression Y=0.1047UTCI-2.0257
Semi-outdoor locations, Sydney [38]	Cfa	21.5-24.0 (PET)	26.4-32.4 (PET)	N/A	Probit analysis

* The PET linear regression line does not touch MTSV = -0.5, survey results indicate that MTSV = -0.5 reached at 13 °C PET.

Table 5 A comparison of modified neutral PET/UTCI range for various study sites in Australia

4. Discussion

4.1. Need to develop a guideline for thermal comfort studies

Currently, the assessment of outdoor thermal comfort follows the universal standards [4, 93, 94] that are designed for indoor conditions. However, their adequacy for outdoor conditions and certain contexts are challenged by several researchers. Researchers believe that a universal standard might not be as useful as a local thermal comfort that has the luxury of accounting contextual factors in the assessment of thermal comfort conditions. As a result, developing and compliance by local standards is becoming more favoured relative to a universal standard due to our improved understanding of the impact of contextual factors and thermal adaptation on the perception of outdoor thermal comfort [95].

With the increase in the number of studies investigating outdoor thermal comfort conditions in Australia, there is a huge potential to develop a local thermal comfort standard for outdoor settings. Such a standard can be used as a benchmark against which property managers can measure up thermal comfort conditions of their managed outdoor spaces.

Developing a local thermal comfort standard seems to be in direct relation with adopting a standardised assessing procedure. Comfort data that is derived from the application of uniform assessing procedure is generally more reliable and can provide a higher level of confidence about comfort conditions of various thermal environments. The need for a standardised assessing procedure was first suggested by Johansson, et al. [34] and was followed by other researchers in different contextual conditions [96]. To date, most of the efforts in this respect have been geared towards the development of thermal comfort index such as Mediterranean Outdoor Comfort Index (MOCI) [97] and modified physiologically equivalent temperature (mPET) [98].

4.2. Gaps, limitations and future directions

Past Australian studies have made some advancement in how different factors affect outdoor thermal comfort, including culture, demography and urban configurations. However, several gaps are identified in the literature that warrant further study. First, certain regions and ethnicities in Australia are not well-studied. Second, the timescale and mechanism of outdoor physiological adaptation need further research, particularly in cases of transient thermal comfort. Third, the mechanism behind the interaction between thermal perception and other human senses (e.g. visual, acoustic) requires greater understanding, together with the influence of psychological adaptation. Fourth, few Australian studies have used qualitative methods to assess outdoor thermal comfort. Future research directions to address these gaps are discussed below.

Australia encompasses many climate zones, but for the most past Australian studies focused on Victoria, South Australia and New South Wales. Outdoor thermal comfort studies are missing in several major cities and climate zones in Australia, including Perth and Brisbane. Many studies also focus on capital cities in each state and territory. Regional studies (including rural areas) that had different urban development patterns may warrant different comfort level, which requires further study.

Australia is proud of its multicultural society, and as a result besides climate zones, future studies should also examine the differences in comfort requirements between different ethnic groups ;for instance, aboriginal people. In addition to European ethnicities, comfort requirements of Asians and the Aboriginals are also worth studying. It is because differences in thermal history, acclimatisation, cultural background and body could affect thermal perceptions among these groups.

Previous Australian studies have examined how physiological variables affect indoor thermal comfort [99, 100]. However, limited outdoor studies have used the same approach to investigate physiological heat adaptation and their impact on outdoor thermal comfort. The lack of such studies is possibly due to the cost and difficulty to measure physiological variables in transient outdoor environment. Recently, the University of New South Wales researchers from Project Coolbit has combined physiological measurement from Fitbit and thermal comfort survey to assess spatio-temporal distribution of outdoor thermal comfort [101, 102]. Future studies can continue to examine whether the timescale of heat acclimatization and thermal comfort differ for people who exercise outdoor.

Transient thermal comfort has gained interest in outdoor thermal comfort research in recent years [103-105]. It would be interesting to adopt the framework of alliesthesia [106] to examine the thermal comfort of people who transit from indoor environment to semi-outdoor or outdoor settings. Alliesthesia refers to the phenomenon that ‘a given stimulus can induce a pleasant or unpleasant sensation depending on the subject’s internal state’ [107, p. 1107]. During summer, any expectation of the prospect of a cooler environment could induce thermal comfort [38]. Moreover, researchers can use transect data to obtain transient thermal comfort [108]. In certain shopping districts, pedestrians can move in and out of air-conditioned shopping malls, which means they might not be able to reach the minimum 30 minutes residency time suggested by Krüger, et al. [109]. Indeed, it would be interesting to carry out studies under such conditions, thereby evaluating the time-exposure effect on the prediction bias of thermal sensation.

To quantify the effect of urban morphology characteristics on outdoor thermal comfort. Recent studies have also adopted local climate zone (LCZ) schemes [103, 110]. LCZ schemes reflect built type (low-rise to high-rise) and land cover type (e.g. vegetation and water) of a neighbourhood [111]. Through the LCZ approach, it is possible to derive the spatial characteristics that have the main influence on outdoor thermal comfort [110]. Despite these advantages, there remain some concerns about whether applying the LCZ concept at the micro-scale is valid, given that the source area for outdoor thermal comfort and local-scale approaches are fundamentally different in terms of influences for all the relevant climate variables. Other study limitation includes limited samples in certain LCZ classes. LCZ classification becomes problematic when study areas have diversified visual outlook and heterogenous urban morphology. In such areas, further study is required to understand the influence of site-related physiological, psychological, social and meteorological factors on outdoor thermal comfort, as well as seasonal differences. To overcome issues related to LCZ application to human scale, researchers have explored alternative methods by developing miniaturized weather stations which could be directly worn by pedestrian [103, 105, 112-114] or set on bicycles [89, 115, 116] or cars [117, 118].

In an urban environment, there is a complex interplay between thermal comfort and multi-sensory stimulus. Recent studies have focused on how perceived environmental quality (such as visual, acoustic, air quality and olfactory) interacts with thermal perception [119, 120]. Apart from physiological reasons, the phenomenological view of embodiment and multi-sensory perception can also be a possible factor [121]. Over similar UTCI range, people's thermal sensation was shown to be higher at higher incoming solar radiation [52], indicating a potential interaction between people's visual comfort and thermal perception. Perceived acoustic environment and aesthetic quality also influenced outdoor thermal perception, suggesting possible psychological pathways in explaining how people perceive outdoor thermal comfort [119, 120]. Current studies mainly reveal the association between perceived environmental quality and thermal comfort, but more studies are necessary to understand the underlying mechanism of such association.

Most Australian studies have used quantitative approaches to assess outdoor thermal comfort, whereas few studies have employed qualitative approaches. Future studies could adopt qualitative approaches to assess outdoor thermal comfort, which shed light on the spatial attributes of urban places and people's synesthetic experience of these places [122]. This subjective experience can potentially influence people's thermal perception, which is difficult to capture through quantitative methods.

Direct observation has the advantage of not interfering with subjects, but it could have selection bias. For instance, people who choose to come out during extreme heat conditions might be more heat resilient and not representing the general public. Future direct observation studies can record people’s adaptive behaviour, such as the use of hat and umbrella, as well as gender and age differences in outdoor activity patterns. Researchers could also develop choice experiments with respect to thermal comfort, particularly on how microclimate-related stress influences outdoor space users’ behaviour, such as the length of stay at one location. This result could potentially inform how much energy is ‘wasted’ because people choose to spend their time indoor in air-conditioned buildings or cars [54], rather than walking or using public transit to their destination. This resulted in waste heat from air-conditioning that further exacerbates urban heat island effects. By promoting the heat resilience in a public space, it achieves the co-benefits of more liveable neighbourhood, more healthy population and less energy consumption.

Other examples of qualitative assessment methods include “thermal walk” [123], “cognitive microclimate map” [122] and “photographic comparison” [124]. Thermal walk uses thermal notation to assess changes in people’s thermal perception and reasons associated with those changes along a transect [122]. In addition, cognitive maps provide a general picture of people’s thermal perception in a neighbourhood, thereby highlighting places that elicit long-term thermal discomfort. By assessing the visual aspect of photo and spatial characteristics of places shown in photos, photographic comparison presents a complementary visual appraisal approach in outdoor thermal comfort survey [124]. In brief, employing both quantitative and qualitative approaches can provide a more in-depth understanding on people’s perception of thermal comfort in outdoor settings.

5. Conclusion

This study presented a critical review of outdoor thermal comfort within urban context in Australia. The focus on Australian context derived from the rapid urbanisation and population growth in its capital cities, as well as the presence of severe heat waves that are considered as one of its major natural disasters. The selected reviewed papers resulted from two stages. The first stage involved a search in six credible academic databases. Publications identified from this stage were then filtered and those focusing on simulation techniques only and those disregarding thermal comfort indices were excluded, resulting in 25 publications. From the search, it was clear that outdoor thermal comfort studies in Australia are limited which exposes the need for additional research. Most of the selected studies focused on urban space within Melbourne and Sydney having temperate oceanic Köppen Cfb, and humid subtropical climate Köppen Cfa, respectively. Few studies investigated thermal comfort in South Australia and Queensland classified as hot-summer Mediterranean climate Köppen Csa, and warm-summer Mediterranean climate Köppen Csb, respectively. The main studies in Sydney focused on determining the contextual based thermal neutrality using different thermal indices. The outdoor activity choice under different meteorological conditions during summer were also examined in Sydney, Melbourne and Adelaide. In Melbourne, multiple studies focused on identifying thermal comfort requirements. These studies used both subjective thermal comfort assessment and objective meteorological field observation and used the PET or UTCI as the thermal index to report thermal comfort data. Direct observation was used to identify the impact of seasons and urban characteristics on usage patterns, showing that changes in activity choices reflect people's limit for outdoor thermal adaptation. The impact of contextual factors on the human-places-weather relationship was also investigated in educational precincts. Several studies investigated the effect of climate and cultural background on outdoor thermal comfort perception, including the thermal requirement of short-term visitors. Thermal adaptive strategies were examined in most Melbourne studies.

The selected studies used microclimate monitoring and questionnaire surveys in order to collect meteorological conditions and humans' perception of outdoor thermal environments. The structure of the questionnaire varied according to the main aim of the studies. However, the main data collected involved demographic details, thermal perceptions, thermal adaptive strategies and place related enquires. Most of the studies adopted the 7-points ASHRAE scale to determine thermal perceptions. The environmental variables recorded in the reviewed studies, included air temperature, relative humidity, wind speed, mean radiant temperature and solar radiation., PET, UTCI and OUT_SET* were commonly used as thermal comfort indices. Direct observation is another method that was used in some of the studies to investigate the users' activity pattern within urban places. The observation focused on noticing users' activity and usage patterns, as well as various thermal adaptation strategies. The neutral PET/UTCI ranges was calculated by different reviewed studies, using different analysis, including linear regression and probit analysis.

From reviewing the outdoor thermal studies in Australia, different recommendations are suggested. Firstly, it is necessary to develop a local standard for assessing thermal comfort. This is because adopting universal standards is found to be limiting the impact of contextual factors and thermal adaptation on outdoor thermal comfort perception. Having such a local standard, at least for different climatic zones, could provide higher levels of confidence in assessing thermal comfort conditions. Secondly, further research is needed to cover the regions and ethnicities that were not considered in the existing literature. Thirdly, more psychological thermal adaptation analysis and studies are suggested especially in transient thermal conditions as the Australian urban design patterns advocate such spaces. Lastly, qualitative analysis is recommended to be added in future studies. The interaction between perceived environmental quality (e.g. visual and acoustic environment) and outdoor thermal comfort can be further examined

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