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Spatial and activity preferences during heat stress conditions in Adelaide: towards increased adaptation capacity of the built environment

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Abstract

Outdoor thermal discomfort pushes citizens into air-conditioned buildings and causes increased demand for water and electricity in the majority of Australian urban heat islands. Citizens' spatial and activity preferences during heat stress conditions are under investigation in this paper. Citizens' outdoor activity choices in different thermal environments were surveyed in Adelaide from September 2013 to April 2014. The post-activity questionnaire survey of outdoor activities in Adelaide indicates that necessary, optional and social activities decreased during outdoor heat stress more than any other thermal conditions. Outdoor activities were chosen the most in neutral and warm thermal environments. Outdoor activity choices were affected significantly by the urban microclimate parameter of solar radiation. Tree canopy, shading (from buildings or temporary elements) and water features were the most attractive public space features for outdoor participants during heat stress conditions in Adelaide. Meanwhile, essential shopping and dining facilities and social events affect citizens' outdoor activity choices during heat stress conditions. Thus, increased green infrastructures and supportive land uses are a prerequisite of urban transformation towards high-performance built environment in the context of climate change.

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Keywords: Heat stress; outdoor preferences; high-performance public space; thermal discomfort

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1. Introduction

Australia is expecting a likely increase of 3.8°C in its surface temperature by 2090 [1, 2]. During summer, public spaces are frequently warmer than human thermal comfort standards in a majority of Australian Cities [1, 3]. The number of hot days with maximum temperature above 35°C increases from 15.3 in 30-year average to 18.3 in 3-years average in Adelaide [4]. Meanwhile, heat stress can reach up to 10°C in urban settings compared to their peri-urban surroundings – the phenomenon that is well known as the urban heat island effect [5-7].

In response to such substantial extra heat load in cities, citizens increasingly choose to attend air-conditioned buildings. Background research on Australian cities indicates that there is a strong positive (uphill) correlation between ambient temperature and electricity demand when the daily mean temperature is above 22 °C [8]. North American research confirms the high dependency of electricity demand to increased temperature in California with a slightly lower threshold of 18 °C. It also reveals that slightly lower negative (downhill) correlation exists between energy demand and increased temperature below 10 °C [9]. European research reveals that the lower threshold of energy demand temperature dependency varies from 15 °C in cold climates (Germany and Sweden) to 13 °C in temperate climates (Greece and Spain). The corresponding higher threshold is 22 °C in temperate climates [10, 11].

However, discharged heat – generated from indoor air-conditioning – causes ever-increasing outdoor temperatures. In this context, this paper examines the outdoor activity and spatial choices of citizens during heat stress conditions through an exploratory survey in Adelaide, South Australia. It aims to better understand the spatial configuration of high-performance public spaces in the context of climate change.

2. Outdoor activities and urban microclimates

The built environment can effectively alter outdoor activities and simultaneously, it is impacted by people's social and behavioural norms and actions [12, 13]. The concept of 'public space and public life' argues that vibrant public life is the result of quality public spaces and is also a significant contributor in shaping such quality [13-15]. While a comfortable thermal environment can enhance people's choices to attend outdoors, heat stress can cause significant discomfort – altering the frequency and patterns of outdoor activities.

Thermal comfort is defined as the state of mind that expresses satisfaction with the thermal environment [16]. While the surrounding built environment can justify the primary microclimate conditions for thermal comfort, it is the human's perception that justifies if the body is thermally comfortable or it is under thermal stress. Indoor thermal comfort studies result in the development of a number of steady state thermal comfort (SSTC) models, in which thermal comfort preferences are defined based on microclimate factors of air temperature, humidity, airflow and radiation in addition to human's metabolic rate and clothing isolation [17, 18]. However, advanced thermal comfort investigations indicate that the state of adaptation to outdoor microclimates is an influential factor in comfort sensations [19, 20]. Despite the SSTC models, which considers people as passive occupants of the space exposed to external microclimates, the adaptive thermal comfort (ATC) concept argues that thermal comfort contributing factors are beyond the physical environment.

Accordingly, thermal comfort is perceptual and varies depending on the psychological condition of participants, their expectations and adaptation level, their physiological conditions and the microclimate of the space in which they are placed [21-23]. People adapt themselves to microclimate conditions by selective activities such as clothing and sunlight exposure-prevention [24, 25], while the level of social activities can also influence the outdoor thermal comfort sensation [26]. The ATC concept is multi-variable and complex and discuss thermal comfort not only dependent on microclimate physical factors, but also dependent on demographic characteristics such as gender and age, health, psychological states such as happiness and stress [22, 27], adaptive actions (e.g. clothing), and general expectations of the climate [25, 28-30].

Gehl [15] argues that only optional activities (in which there is a strong factor of choice) are influenced (notably) by urban microclimates. As such, it is suggested that to make vibrant public spaces, particular focus is needed on supporting optional outdoor activities. However, Gehl's studies on quality of public space and public life considered climate (long-term) and weather (short-term) as controlled variables to investigate public life in ideal weather conditions (respective case studies are done on sunny days in spring and autumn). In this context, the questions for this paper are: what outdoor activities are sensitive to heat stress in public space? Moreover, what public space features can attract outdoor activities during heat stress conditions. Such heat-activity investigation supports vitality and usability enhancement of public spaces. It also provides guidelines to increase the adaptive capacity of public spaces to heat stress.

3. Materials and methods

A self-completion questionnaire has been used to survey Adelaide citizens' choices of outdoor activities during a year concludes to the data of survey completion (January to August 2014). The questionnaire aims to test and validate the activity observation findings via ten multiple-choice questions and one optional open question. The participants were accessed through two separate channels of postal addresses and online social network.

- A package including cover letter, research information sheet, a copy of the questionnaire and a prepaid return envelope were distributed to postal addresses in the City of Adelaide. As the minimum acceptable response number had been set to 100, the hard-copies will be distributed to 500 postal addresses (assumed response rate of 20%). The questionnaire was designed to take approximately 15 minutes to be completed (simple random sampling).
- An identical online copy of the survey was envisaged to broaden the surveyed population to the Adelaide metropolitan area. This online questionnaire was distributed through researcher's social network and email. The first layer of recipients is asked not to fill, but to nominate potential participants and redistribute the online survey. The questionnaire is prepared in Google Forms identical to the hard-copy questionnaire. The second layer of recipients browsed through the online survey via the provided link (http://goo.gl/forms/9EHlqhMedv) and answer the questions by selecting their activity and space choices during one year ending on the date of survey completion. The expected return rate for the online questionnaire was set to 100 (snowball sampling).

3.1. Survey design

The questionnaire was designed in a brief format to address the required criteria exclusively through close questions through multiple choice activity preferences with the option to add comments at the end of each question. The questionnaire included a participant's information sheet, a question on frequency of public space usage, four questions on outdoor activity choices during last year in different thermal conditions, a question on frequency of weather information updating, a question on other microclimate parameters affecting outdoor activity choices, a question on spatial preferences during heat stress conditions, a question on heat-health awareness, a data monitoring question on age-range and an open question on participants further suggestions. A choice of "none of above" and a choice of "other" were designed for a majority of questions, in which respondents were able to enter their additional comments.

Respondents were not identifiable in the design of the questionnaire. They are asked for their city of living (Adelaide) for data validity and age group for data separation and analysis. No name, address, and gender were recorded as they are not relevant to the project scope and no further questions from participants were envisaged in research scope. At the end of the survey, there was an option for the respondents to contact the researcher via email address to be forwarded the research outcomes.

3.2. Response rate

Baurch [31] suggests that questionnaire survey average response rate may vary from low value of 10% in ethics research to high value of 60% in other human-related research. For focused populations, the acceptable response rate may be 60% ± 20, whereas, it is acceptable to have the response rate of 36% ± 13 for general population social research [31]. Nevertheless, the actual response rate may be affected by survey presentation, demographical specifications of respondents, control rate, required time allocation and seasonal climate at the time of distribution. Therefore, the initial response rate of 20% had been set at the time of questionnaire distribution.

From the 500 hard-copy questionnaires, the total number of 108 were returned. Thus, the actual response rate is 21.6%. The actual response rate of 21.6% is marginally higher than the expected response rate of 20%. Also, it is very close to the suggested 23% for the lower limit of response rate for general population social research. Total 159 online questionnaires were received from January to August 2014 (One questionnaire was taken out from the data set due to the age of respondent being less than 18). This led to the actual response rate of 31.8%. The actual response rate of 31.8% is higher than the expected response rate of 20%. It is in very close to the average ideal response rate of 36% for general population social research. In total 1000 surveys were distributed, of which 267 were returned. Therefore, the overall response rate equals to 26.7%, which is in the range of ideal response rate of 36% ± 13 for general population social research.

3.3. Statistical validity test

The chi-square test is a statistical method to test whether there are differences in the data distribution in two or more categorical data groups. A chi-square test assumes that data of the two groups are independent and normally distributed. When p-value ≥ 0.05, then the data does not suggest that the two discrete data groups have statistically significant differences. The chi-square test is performed using the MS Excel data analysis tool for questionnaire survey data in this paper. It is used to test and discuss outdoor heat-activity choices of citizens of Adelaide via online and hard copy self-completion questionnaire surveys.

4. Results

Citizens of Adelaide were asked to choose their outdoor activities during a year concluded to the completion of the questionnaire. Based on the adopted theory of ‘public space and public life’, outdoor activities are coded as follows [32]:

- Walking and working are coded into necessary activity category
- Standing, sitting, eating, drinking, laying down, jogging, cycling, and other individual exercises are coded into optional activity category
- Playing (children), group sports, meeting others and attending social or cultural activities are coded into social activity category

Table 1. Annual outdoor attendance rate of questionnaire survey participants in Adelaide.

	Online	Hard- copy	Total
At least once a week	79.9%	80.6%	80.2%
At least once a month	94.3%	99.1%	96.7%
Rarely	5.7%	0.9%	3.3%

The Chi-square test reveals that there are no meaningful statistical differences between the two data collection methods regarding public space usage ($p = 0.076$). Nearly 80% of respondents reported that they had used public space at least once a week while almost all the respondents (96.7%) attended outdoors actively at least once a month (see Table 1). Therefore, the randomly selected sample population does present public space users in Adelaide. Meanwhile, 83% of the respondents check the weather predictions at least once a day. Adding the population who check the weather when going outdoors increase weather awareness rate of the respondents to 89%. Therefore, the survey respondents are assumed to have proper weather information before attending outdoors.

4.1. Comparison of online and hard-copy heat-activity choices

Outdoor activity choices of respondents were collected in four ordinal thermal environments. Such ordinal thermal environments are based on how respondents felt outdoors and were divided into hot, warmer than preferred, thermally comfortable and cooler than preferred categories (The fifth scale – cold - was not included in the questionnaire due to the research scope and focus on the heat stress). A reference temperature range was given on the questionnaire for each thermal sensation category, and the participants were asked to note their thermal preferences if different from the given range.

The chi-square test confirms that there is no statistical significance between online and hard-copy responses regarding activity preferences in different thermal conditions ($p=0.088$). Therefore, the responses can be grouped for heat-activity analysis. Descriptive charts of outdoor activity choices are presented in Fig.1 and reveal that online and hard-copy responses have less than 15% variation in each category.

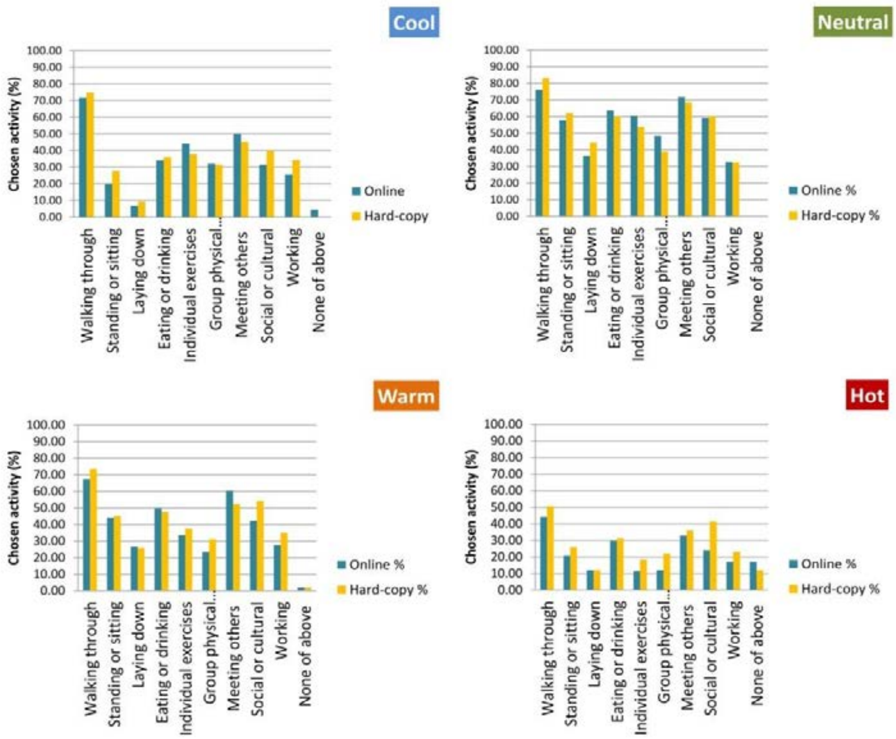

Fig. 1. Descriptive charts of outdoor activity choices in four sensible thermal environments ($N_{online}=159$, $N_{hard\text{-}copy}=108$).

Fig.2 reveals that a higher number of outdoor activities occurred in neutral temperatures when respondents felt thermally comfortable compared with hot, warm and cool conditions. The total number of activity choices are calculated based on declared choices that respondents had made in a year concluding to the questionnaire survey. As such, results do not reflect the total number of outdoor activities for each respondent, but the choices of outdoor activities. For example, despite probable multiple outdoor walking activities in the past year, only one walking score could be recorded for an identical respondent in hot weather conditions. The hot thermal environment was avoided by citizens with the considerable decline rate of 45% compared with the neutral thermal conditions.

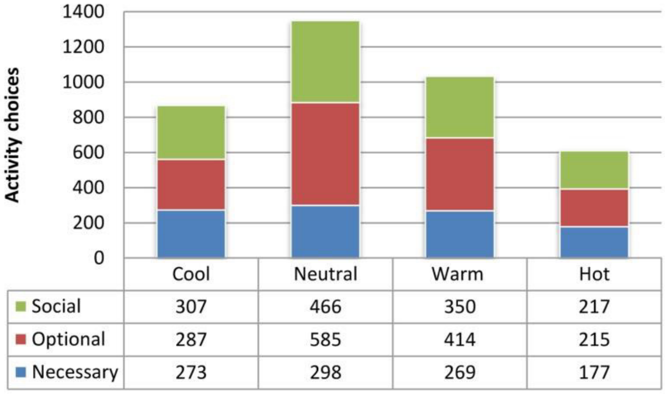

Fig. 2. Outdoor activity choices in hot, warm, neutral and cool outdoor thermal conditions in Adelaide (N=267)

4.2. Heat sensitivity of necessary activity choices

Necessary activities tend to be the highest during neutral thermal conditions. Necessary activity choices in warm and cold thermal environment have marginal differences to neutral thermal conditions (less than 10%). However, necessary activity choices have a significant 41% decrease in sensible heat stress conditions. Meanwhile, 40 respondents expressed that they had not done any outdoor activities during heat stress conditions (15% of the whole sample population).

The outdoor walking rate of 79% decreases to 73% in cool thermal conditions, 70% in warm thermal conditions and 46.8% during heat stress conditions. Similarly, the outdoor working rate of 32.6% decreases to 29.2 % in cool thermal conditions, 30.7% in warm thermal conditions and 19.5% during heat stress conditions. Overarching outdoor activity decrease rate is 10% for cool, 8% for warm and 41% for hot thermal environments compared with neutral conditions. Therefore, optional activities were the least favourite during heat stress conditions.

The rate of no outdoor activity (during a year) in hot thermal conditions is even more significant. Some 13.9% of the studied population revealed that they had no outdoor activities during heat stress conditions while such critical zero-activity situation occurs only for 2.6% of the population in cool and 1.9% of the population in warm outdoor thermal conditions. No outdoor zero-activity was chosen by the participants during neutral (comfortable) thermal conditions. As such, necessary activity choices decrease during outdoor heat stress more than any other thermal conditions and are sensitive to heat stress in public space.

4.3. Heat sensitivity of optional activity choices

Optional activity choices tend to be the most favourite during neutral thermal conditions. Optional activities in warm and cool environments have a higher decrease rate compared with necessary activities. Such outdoor activity decrease rate is 29% for warm, 51% for cool and 64% for hot outdoor thermal conditions. Therefore, optional activities were the least favourite in cool and heat stress conditions. Three participants (1.89% of the population) did outdoor swimming during heat stress conditions that are classified in optional activity category.

Similar fluctuation (to necessary activities) occurs in a majority of optional activity sub-classes including standing, sitting, eating, drinking, laying down and individual exercises. Combined standing and sitting activity rate decreased from 59.5% in the neutral thermal environment to 44.6% in warm thermal conditions, 23.2% in cool thermal conditions and 22.8% during heat stress conditions. Outdoor eating and drinking rate of 62.2% decreases to 49.1 % in warm thermal conditions, 34.8% in cool thermal conditions and 30% under heat stress conditions.

Laying down had the least activity choice rate among other optional activities and reached its lowest rate in cool outdoor environments (7.9%). However, the hierarchy of optional activity choices shifts in the favour of cool thermal environments for individual physical activities. Individual physical activity choice rate of 57.7% in neutral thermal environment decreases to 41.6% in cool thermal conditions, 35.2% in warm thermal conditions and 14.2% during heat stress conditions. Such popularity of physical activities in cooler thermal environments can be justified by the physiological need of the human body to generate internal heat in cool thermal conditions. As such, a majority of optional activity choices (excluding laying down outdoors) decrease during outdoor heat stress more than any other thermal conditions and are sensitive to heat stress in public space.

4.4. Heat sensitivity of social activity choices

Social activities tend to be the highest during neutral thermal conditions. Social activity choices in warm and cold thermal environment have less than 10% differences to each other (25% and 34% respectively). However, social activities had a significant 53% decrease in heat stress conditions compared with neutral thermal environments.

Meeting others outdoors had the highest popularity among social activity sub-classes. The rate of 70.4% for meeting activities in neutral thermal environments decreases to 57.3% in warm thermal conditions, 48.3% in cool thermal conditions and 34.1% during heat stress conditions. Attending social or cultural events had the rate of 59.6% in neutral thermal environments that decreased to 47.2% in warm thermal conditions, 34.8% in cool thermal conditions and 31.1% during heat stress conditions. Here the decrease rate for cool and heat stress conditions are very close.

Group physical activities had the least popularity among other social activities in Adelaide. The corresponding ideal rate of 44.6% in neutral thermal environment decreased to 31.8% in cool thermal conditions, 26.6% in warm thermal conditions and 16.1% during heat stress conditions. Similar to individual physical activities (sub-class of optional activities), group physical activity choices were more favourite in neutral and cool thermal environments due to the physiological characteristics of human participants. As such, social activity choices decrease during outdoor heat stress more than any other thermal conditions and are sensitive to heat stress in public space.

4.5. Spatial preferences during outdoor heat stress

Spatial preferences of citizens are analysed in two parts: influential microclimate parameters and spatial preferences during heat stress. Respondents were asked to indicate climate factors that can affect their decision for outdoor attendance. Fig.3 reveals that urban microclimate parameters of sunshine intensity, wind speed and humidity have a similar effect on outdoor attendance as rainfall. Rain is highlighted as the most common barrier to optional activities in background studies [15, 33, 34]. Thus, participants' outdoor activity choices were affected significantly by major urban microclimate parameters of solar radiation, wind speed and humidity (temperature was excluded in this question because thermal preferences of participants were asked in other questions).

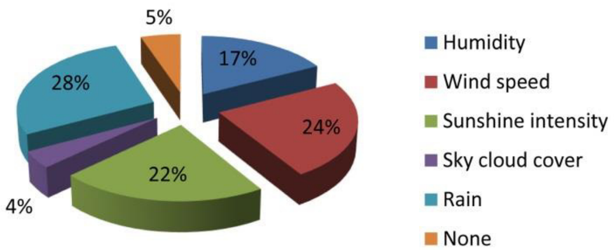

Fig. 3. Effective climate factors in outdoor attendance of survey respondents in Adelaide (N=270)

Randomly selected citizens of Adelaide were asked to choose their outdoor spatial preferences during heat stress conditions in the questionnaire survey. The chi-square test of online (N=159) and hard-copy (N=108) data reveals that there are no statistically significant differences between the mean values (p = 0.068). As Fig.4 illustrates, grass cover and social events were more popular in the hard-copy questionnaire, while buildings' shading was more popular in the online method. Nevertheless, the two data sets can be merged for further analysis.

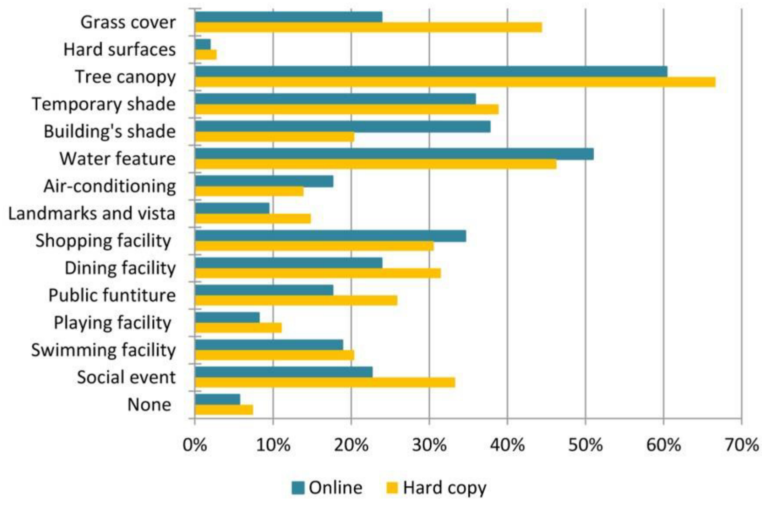

Fig. 4. Results of online and hard-copy questionnaire survey regarding spatial feature popularity during heat stress conditions in Adelaide (N_{online}=159, $N_{hard\text{-}copy}$=108)

Fig.5 presents merged results of spatial feature preferences in Adelaide (during heat stress conditions). Tree canopy was the most attractive public space feature for outdoor participants. With the preference rate of 62.9%, tree canopies were chosen by more citizens compared with any other public space features. With 13.8% less popularity, water features had the preference rate of 49.1%. Such preference rate was 37.1% for temporary shading, 32.2% for grass coverage and 30.7% for buildings' shading (in land cover feature class). In public space supportive feature class, shopping facilities had the preference rate of 33%. The preference rate was 27% for dining facilities and 21% for swimming facilities. Regarding public space management, social and cultural events had the preference rate of 27% during heat stress conditions.

Outdoor air-conditioning attracted 16.1% of survey respondents. Landmarks and vista were among the attractive features of public space for 11.6% of respondents and playing facilities attracted 9.4% of surveyed population. However, hard landscapes were highly avoided by citizens and had the lowest preference rate of 2.2% during heat stress conditions.

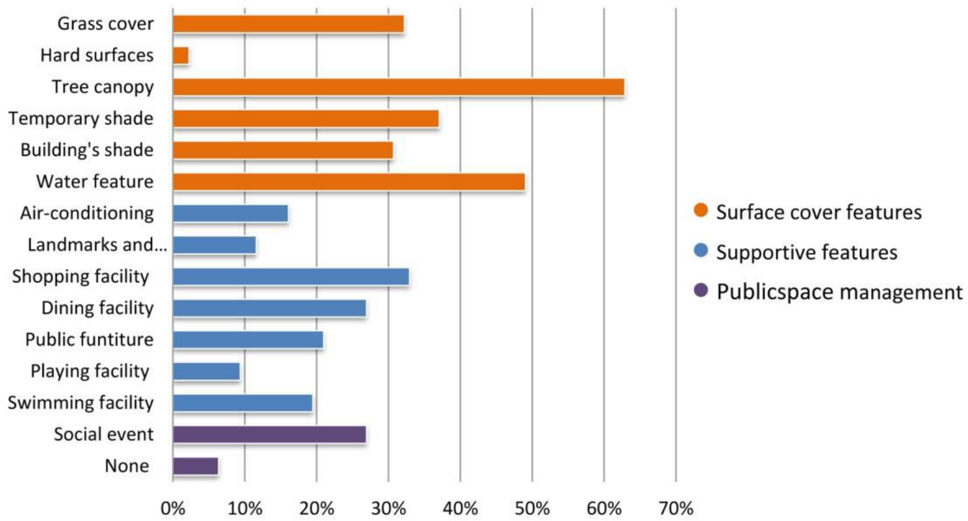

Fig. 5. Merged results of spatial feature popularity during heat stress conditions in Adelaide (N=267)

Meanwhile, 6.4% of respondents expressed that no spatial feature can attract them to attend outdoors during heat stress conditions. Comparing this preference rate with the expressed 13.9% zero-activity rate in hot thermal environments underlines that, regardless of public space features and facilities, there are some citizens who avoid outdoor heat stress. The difference between no-preference rate (6.4%) and zero-activity rate (13.9%) during heat stress condition highlights the freedom and complexity of outdoor activity choices among citizens.

5. Further discussion

Necessary, optional and social activities were more chosen during thermally comfortable and slightly warm conditions. Table 2 reveals that except individual and group physical activities, the least activity decrease rate occurred in warm thermal environments (less than 30% decrease rate). Sedentary activities such as standing, sitting, laying down, eating, drinking and attending social or cultural events are less favourite during cool conditions, when more active outdoor activities such as walking, working, individual exercise and group sport are preferred by respondents.

Hot environments were avoided by citizens especially when there was a strong factor of choice such as optional activities with 63.8% activity decrease compared with the neutral thermal environment. Necessary activities including walking and working had the least decrease average rate of 40.6% in hot thermal environments. Planned optional and social activities such as eating, drinking, meeting and attending social or cultural events have the second lowest decrease rate during heat stress conditions (average rate of 50.2%). However, optional and social activities which could be easily relocated indoors or postponed such as individual exercise, sport, laying down, standing and sitting are highly sensitive to heat stress.

Table 2. Decrease rate in necessary, optional and social activities in different thermal conditions compared with neutral environment

Classification	Decrease rate	Cool	Neutral	Warm	Hot
Necessary	Walking through	7.6%		11.4%	40.8%
	Working	10.3%		5.7%	40.2%
Optional	Standing or sitting	61.0%		25.2%	61.6%
	Laying down	80.2%		34.0%	69.8%
	Eating or drinking	44.0%		21.1%	51.2%
	Individual exercises	27.9%		39.0%	75.3%
Social	Group physical activity	28.6%	N/A	40.3%	63.9%
	Meeting others	31.4%	Reference	18.6%	51.6%
	Social or cultural event	41.5%		20.8%	47.8%
	Necessary	8.4%		9.7%	40.6%
Overall	Optional	50.9%		29.2%	63.8%
	Social	34.1%		24.9%	53.4%

A majority of outdoor activities in hot thermal conditions are limited to necessary walking and planned social activities. During heat stress conditions, optional activities are the least probable to occur outdoors. Also, cool sensible temperatures cause the outdoor activities to shift towards necessary and planned social activities with less decrease rate than the hot conditions (necessary activities are likely to be close to ideal conditions in cool thermal conditions).

6. Conclusions

Heat-activity survey findings reveal that almost all the necessary, optional and social activities are heat-sensitive. Outdoor activities decrease significantly during heat stress compared with neutral (comfortable) thermal conditions. Optional activities have the highest rate of heat-sensitivity. Tree canopies are the most attractive public space features during heat stress conditions in Adelaide. Shading, soft landscapes, and water features are preferred in hot microclimates. However, hard landscapes are highly unattractive and are likely to be avoided by citizens. Nevertheless, public space supportive features and management can extend the attractiveness of public space under heat stress conditions. In the context of climate change, high-performance public spaces can facilitate more vibrant outdoor living in cities. Such heat resilient public spaces support the usability of outdoor spaces by local communities in hot scenarios.

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