ACCEPTED VERSION

Ehsan Sharifi, Alpana Sivam and John Boland

Resilience to heat in public space: a case study of Adelaide, South Australia

Journal of Environmental Planning and Management, 2016; 59(10):1833-1854

© 2015 University of Newcastle upon Tyne

"This is an Accepted Manuscript of an article published by Taylor & Francis in ***Journal of Environmental Planning and Management*** on 02 Dec 2015 available online: http://dx.doi.org/10.1080/09640568.2015.1091294

PERMISSIONS

http://authorservices.taylorandfrancis.com/sharing-your-work/

Accepted Manuscript (AM)

As a Taylor & Francis author, you can post your Accepted Manuscript (AM) on your personal website at any point after publication of your article (this includes posting to Facebook, Google groups, and LinkedIn, and linking from Twitter). To encourage citation of your work we recommend that you insert a link from your posted AM to the published article on **Taylor & Francis Online** with the following text:

"This is an Accepted Manuscript of an article published by Taylor & Francis in [JOURNAL TITLE] on [date of publication], available online: ***http://www.tandfonline.com/****[Article DOI]."*

For example: *"This is an Accepted Manuscript of an article published by Taylor & Francis Group in Africa Review on 17/04/2014, available online:****http://www.tandfonline.com/10.1080/12345678.1234.123456***.

N.B. Using a real DOI will form a link to the Version of Record on **Taylor & Francis Online**.

The AM is defined by the **National Information Standards Organization** as:
"The version of a journal article that has been accepted for publication in a journal."

This means the version that has been through peer review and been accepted by a journal editor. When you receive the acceptance email from the Editorial Office we recommend that you retain this article for future posting.

Embargoes apply if you are posting the AM to an institutional or subject repository, or to academic social networks such as Mendeley, ResearchGate, or Academia.edu.

Embargo

Journal of Environmental Planning and Management 12 months

3 August 2017

http://hdl.handle.net/2440/106581

Sharifi, E., Sivam, A., & Boland, J. (2016). Resilience to heat in public space: a case study of Adelaide, South Australia. *Journal of Environmental Planning and Management, 59*(10), 1833-1854. doi: 10.1080/09640568.2015.1091294

Resilience to Heat in Public Space: a Case Study of Adelaide, South Australia

Ehsan Sharifi [a], Alpana Sivam [b] and John Boland [c]

[a, c] School of Information Technology and Mathematical Sciences, Division of Information Technology, Engineering and the Environment, University of South Australia, Adelaide, Australia
[b] School of Natural and Built Environment, Division of Information Technology, Engineering and the Environment, University of South Australia, Adelaide, Australia

(Received 28 October 2014; final version received 30 August 2015)

ABSTRACT: *During summer heatwaves, heat load exacerbate in urban heat islands (especially in hot climates) and threatens public life in cities. This paper examines the links between urban microclimates, outdoor thermal discomfort and public life through an exploratory case study. Heat resilience is highlighted as the ability of the space to support its normal activities when experiencing out-of-comfort temperatures. It also reports on the correlations between heat sensitive outdoor activities and urban greenery in three disparate case studies in Adelaide.*

Results indicate that necessary and optional activities start to decline after the apparent temperature reaches the threshold of 28-32°C, while activities in public spaces with more urban greenery show higher resilience to heat stress. Research findings propose heat resilience as a quality indicator in public space and support the application of urban greenery to make urban settings more resilient to heat stress.

Keywords: Summer heatwave, heat resilience, outdoor thermal discomfort, heat stress, outdoor activities

1. Introduction

Summer heatwaves are now more frequent and extended in Australian cities. Australia experienced seven extreme heatwaves in 1908, 1939, 1960, 1973, 2004, 2009 and 2013 (BoM 2008, Nairn and Fawcett 2013). Today there is no doubt about the significant damage of summer heatwaves on natural ecosystems and public health especially in hot and temperate climates (Montero, Miron et al. 2013). During summer heatwaves, public spaces are frequently warmer than human's thermal comfort level in a majority of Australian Cities (BoM 2008, Ricketts and Hennessy 2009, Williams, Nitschke et al. 2012). Such extended heat stress in public space is argued to be partially the result of urban structure, land cover, lifestyle and lack of urban greenery in cities.

The excess heat load in urban settings can reach up to 10°C compared to their peri-urban surroundings. In response to such substantial extra heat load in cities, citizens increasingly move into air-conditioned buildings during hot summer days to benefit from the indoor thermal comfort. However, exhausted heat generated from indoor air-conditioning causes an ever-increasing outdoor temperature (Ichinose, Matsumoto et al. 2008). Such anthropogenic (human-made) heat is cited as a key contributor to the artificial heat load in cities, which is well known as the urban heat island effect (Oke 2006, Gartland 2008, Erell, Pearlmutter et al. 2011).

The urban heat effect exists across climate zones and in some cases, such as in cold climates and during winter, it can be beneficial. However, it exacerbates the sensible and latent heat load[i] during summer heatwaves in hot and temperate climates. The excess urban heat stress affects citizens' health, especially in regards to more vulnerable groups such as the elderly and children during summer heatwaves (Hu, Becker et al. 2007). Amplified heat stress during summer heatwaves causes more than 1000 extra annual deaths and contributes significantly to heat-related morbidity in Australia (McMichael, Woodruff et al. 2003, Kirch, Menne et al. 2006, Nitschke, Tucker et al. 2007, Wendt, Van Loon et al. 2007, Williams, Nitschke et al. 2012, Williams, Nitschke et al. 2012, Major Cities Unit 2013, Steffen, Hughes et al. 2014).

Australia is expecting a likely increase of 2-5°C in its surface temperature by 2070 (Ricketts and Hennessy 2009, OECD 2010). The combination of summer heatwaves and the urban heat island effect has increased the risk to public life and health.

This paper examines the links between urban microclimates, thermal discomfort and outdoor activity patterns through an exploratory case study in Adelaide, South Australia. Outdoor thermal discomfort indices have been reviewed to find the most appropriate indicator of thermal stress for the current case study. Microclimate and activity data were collected during a year starting in February 2013 and is analysed through correlation and regression analysis to identify the outdoor heat-activity interactions. Heat resilience is highlighted as the ability of the space to support its normal activities when experiencing out-of-comfort temperatures. We also report on the correlations between heat sensitive activities and urban greenery in three disparate case studies in Adelaide.

2. Urban microclimates and outdoor activities

Lack of outdoor activities in modern cities is argued to be the result of poor public spaces (Jacobs 1961, Gehl and Gemzoe 2001, Madanipour 2003, Jacobs 2004, Lang 2005, Moughtin and Shirley 2005). The vitality of human activities in public space is the core concept of significant and contemporary public life studies (Whyte 1980, Gehl 1987, Lang 1987, Moughtin 2003, Burton and Lynne 2006, Dobbins 2009). The underlying argument is that the built environment can significantly affect outdoor activities and simultaneously, it is impacted by people's social and behavioural norms and actions (Lang 2005, Gehl 2010). Therefore, 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 (Gehl 1987, Lillebye 2001, Bosselmann 2008, Gehl 2010).

While a comfortable thermal environment can enhance people's choices to spend more time outdoors, excess heat load can cause significant discomfort, altering the frequency and patterns of outdoor

---

[i] Sensible heat refers to the energy, which directly changes the temperature of a substance, whereas latent heat refers to the energy, which changes the state of a substance without causing any temperature differences such as water evaporation.

activities. Thus, the spatial configurations, contributing to urban microclimates have the ability to alter the vitality and utilisation of public space by providing thermal comfort and consequently facilitating optional outdoor activities. Urban structure, surface materials and landscape are examples of such urban microclimate contributing factors.

2.1 Urban microclimates

Urban microclimates are the complex outcome of spatial and climatic variables and can affect outdoor activity patterns, especially when there is a factor of choice (Gehl 1987, Bosselmann, Arens et al. 1995, Gehl 2010, Nikolopoulou 2011). However, recent studies on urban microclimates focus more on the physicality of the space (Shashua-Bar, Tzamir et al. 2004, Johansson 2006, Lin, Matzarakis et al. 2010, Correa, Ruiz et al. 2012), rather than discussing how physical attributes of spaces can alter outdoor activities.

Gehl (1987) argues that optional activities are the only ones that are influenced (notably) by urban microclimates. As such, Gehl suggests that to make vibrant public spaces, particular focus is needed on supporting optional 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 a classical study of the social life of small public spaces, it is concluded that sun-activity correlations of outdoor activities are temperature dependent (Whyte 1980). Focusing on the dynamic effect of sun and shadow patterns on social life of Seagram Plaza, Paley Park (New York City) and Farragut Square (Washington), Whyte suggests that the humans’ need for solar exposure is dependent on the perceived temperature and the level of outdoor thermal comfort.

2.2 Outdoor thermal comfort

Outdoor thermal comfort is a factor which affects outdoor activities in public space (Gehl 1987, Bosselmann, Arens et al. 1995, Nikolopoulou, Baker et al. 2001, Eliasson, Knez et al. 2007). In general, thermal comfort is defined as the state of mind that expresses satisfaction with the thermal environment (ASHRAE 2013). While the surrounding built environment can justify the primary microclimate conditions for thermal comfort, it is the human’s brain that identifies if the body is thermally comfortable or it is under heat stress. Focusing on the effect of microclimates on humans, a number of indoor thermal comfort investigations have been undertaken since the 1960s (Olgyay and Olgyay 1963, Auliciems 1969, Fanger 1982, Oke 1988, Givoni 1998). 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 (Stathopoulos, Wu et al. 2004, Walton, Dravitzki et al. 2007).

While many studies of outdoor thermal comfort concentrate on physical factors of microclimate (Walton, Dravitzki et al. 2007), more advanced investigations indicate that the state of adaptation to outdoor microclimates is an influential factor in comfort sensations (Nikolopoulou and Steemers 2003, Lin 2009). Despite the SSTC models, which considers people as passive occupants of the space exposed to external microclimates, the adaptive thermal comfort argues that thermal comfort contributing factors are beyond the physical environment. The extent of feeling of comfort is a dependent variable of physical, psychological and psychological factors of the human-climate systems. 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 (Nicol 1993, Nikolopoulou 2004, Szokolay 2008).

People adapt themselves to microclimate conditions by selective activities such as clothing and sunlight exposure-prevention (Spagnolo and de Dear 2003, Nikolopoulou and Lykoudis 2007), while the level of social activities can also influence the outdoor thermal comfort sensation (Aljawabra and Nikolopoulou 2010). The adaptive thermal comfort (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 (Cooper 1982, Szokolay 2008), adaptive actions (e.g. clothing), and general expectations of the climate (de Dear, Leow et al. 1991, Nikolopoulou and Lykoudis 2007, Wang, Zhang et al. 2010, Candido 2011).

In the study of commonly used outdoor thermal comfort indices, physiological equivalent temperature (PET), temperature-humidity index and wind chill index are being compared with actual thermal sensation votes, indicating that regardless of the thermal comfort calculation method, expressed outdoor thermal comfort correlates significantly with the site mean temperature and adjusting the indicators gives a small improvement in the indices (Tseliou, Tsiros et al. 2010). The application of the ATC concept (based on mean monthly temperature differences) in different climate conditions such as winter time in cold climate or summer time in hot climates is still under investigation (van Hoof and Hensen 2007).

2.3 Thermal-load dependency of human activities

Indoor thermal comfort research indicates that there is no need for thermal adjustment for sedentary and light activities for temperatures below 24-25°C. However, productivity and performance starts to decline for equivalent temperatures above 36°C (relative humidities above 74% and dry bulb temperature above 30°C (Lin and Chan 2009, Parsons 2009).

In this context, the questions for this paper are: To what extent do out-of-comfort temperatures affect outdoor activities in public spaces of a city with a temperate climate such as Adelaide? What urban surface covers can facilitate more outdoor activities in heat stress conditions? Such heat-activity investigation supports vitality and usability enhancement of public spaces, especially during the stressed microclimates of summer heatwaves.

3. Materials and methods

Public life in contemporary cities involves a variety of users with diverse expectations of climate and cultural responses to combat heat stress in public space. Citizens perform a diverse range of choices during heat stress conditions, ranging from preventing outdoor attendance to wet sports and indoor shopping.

Two major investigations of public space and public life in Adelaide have been conducted based on pedestrian flow and stationary outdoor activities in ideal climate conditions (Gehl 2002, Gehl 2011). The climate and weather conditions are considered as controlled variables, and data was collected during sunny spring or autumn days when the temperature varied between 18°C and 28°C. Building upon the existing public life studies in Adelaide, we investigated outdoor neutral temperature thresholds for three public spaces in Adelaide, using direct observations and microclimate measurements. The selected case studies represent three typical public spaces in regards to their microclimates and embodied activity patterns. The selected public spaces for this study are:

- Rundle Mall – an open-air pedestrian-oriented shopping street. It has a wide range of surrounding land uses;
- Hajek Plaza – a hard-landscaped public space located in the Adelaide Festival Centre
- Hindmarsh Square – a soft-landscaped green public space surrounded by office buildings and a few dining facilities.

The selected public spaces are located within a one-kilometre distance from each other in Adelaide central business district (see Figures 1 and 2).

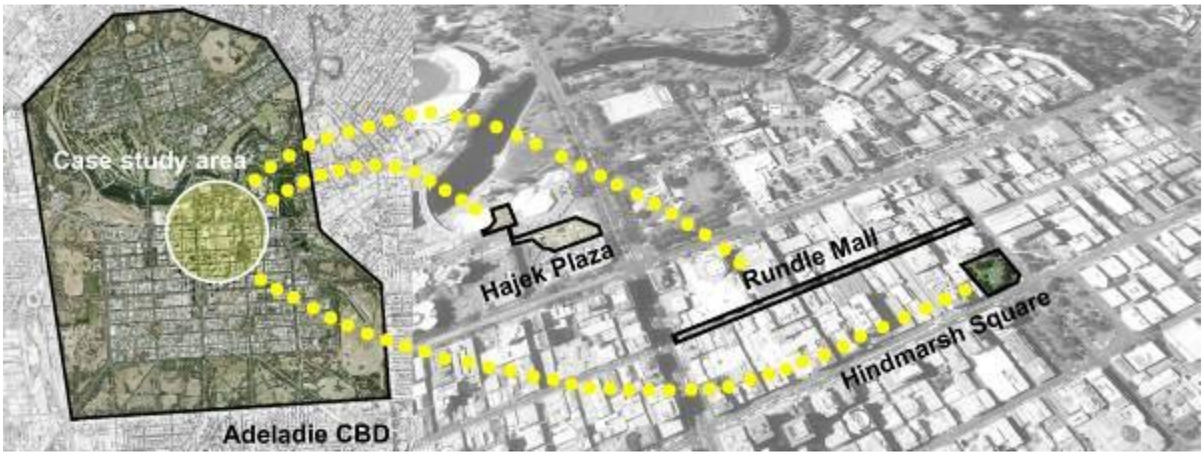


Figure 1. Rundle Mall, Hajek Plaza and Hindmarsh Square are located within one-kilometer distance from each other in Adelaide central business district.

Figure 2. Hajek Plaza, Rundle Mall and Hindmarsh Square have diverse physical and activity characteristics.

3.1 Thermal-load measurement

The SSTC models result in corresponding thermal comfort standards such as ISO 7730 and ASHRAE, mainly concentrate on indoor microclimates and passive human participations. The SSTC standards predict the mean thermal sensation of large populations, based on thermal comfort indices such as predicted mean vote (PMV) and standard effective temperature (SET). Such SSTC thermal comfort indicators are commonly used in building air-conditioning and ventilation design. Considering the physiological and psychological variables of outdoor thermal comfort, outdoor thermal comfort is commonly predicted based on dry-bulb temperature, vapour pressure (or relative humidity), air velocity, and net radiation absorption[ii] in SSTC models.

The current case study focuses on general trends of heat sensitivity of outdoor activities. Therefore, physiological and psychological factors of participants were not taken into consideration. It was assumed that the randomly observed participants represent a sample of the general public in Adelaide (who use the public spaces). Each space was observed for more than 80 times during a year starting in February 2013 to ensure the validity of data. During each round of observation, which lasts for ten minutes, citizens' outdoor activity patterns were coded into necessary, optional and social activities and printed on prepared field study maps.

[ii] Net radiation absorption is a function of surface temperature differences between the target object (in this case the human body) and the surrounding mean radiant temperature (MRT) and thermal conductivity of insulations (in this case clothing) (Bradshaw 2010).

Microclimate data including temperature, humidity and wind speed is collected before and after each activity observation via three fixed weather data loggers[iii], installed in permanently shadowed areas, exposed to wind flow and 1.5m above the ground surface. A portable weather station was used to ensure the calibration of data loggers[iv]. Hygrometer data loggers had been installed at the observation point before our observations started (they had been calibrated with the portable weather station unit). Local weather data was obtained from the Australian Bureau of Meteorology, Kent Town Station.

3.2 Heat index and apparent temperature

It is widely argued that the outdoor thermal environment cannot be explained only by dry-bulb temperature (Nikolopoulou, Baker et al. 1999, Spagnolo and de Dear 2003, Nikolopoulou 2004, Erell, Pearlmutter et al. 2011). A primary temperature-humidity index (THI) has been introduced by Thom (1959). The THI gives an equivalent temperature in degree centigrades based on dry-bulb temperature and relative humidity. The THI is claimed to be a suitable measure for humans' thermal-load (or discomfort) in public space (Thom 1959) and can be calculated as:

$$\mathrm{THI} = T - (0.55 - 0.0055\ \mathrm{RH}) \times (T - 14.5)$$

The effect of wind flow is neglected in the THI. However, wind flow is a prominent factor in people outdoor living in the case of Adelaide especially during summer (BoM 2008, Nairn and Fawcett 2013). Apparent Temperature (AT) is also used as an indicator of the perceived equivalent temperature by humans. The benefit of AT to THI is the consideration of human biology (by using skin vapour pressure instead of relative humidity) and wind flow in thermal comfort calculation. Steadman defines AT based on dry-bulb temperature, vapour pressure and wind speed (Steadman 1979, Steadman 1984), and applies the AT in the study of semi-outdoor thermal comfort in Sydney, Australia (Steadman 1994):

$$\mathrm{AT} = T + 0.33 \times \mathrm{VP} - 0.70 \times \mathrm{WS} - 4.00$$

where T = dry bulb temperature (°C)
VP = water vapor pressure (hPa) [representing humidity]
WS = wind speed (m/s) at an elevation of 10 meters

The vapor pressure can be calculated from the temperature and relative humidity using the equation:

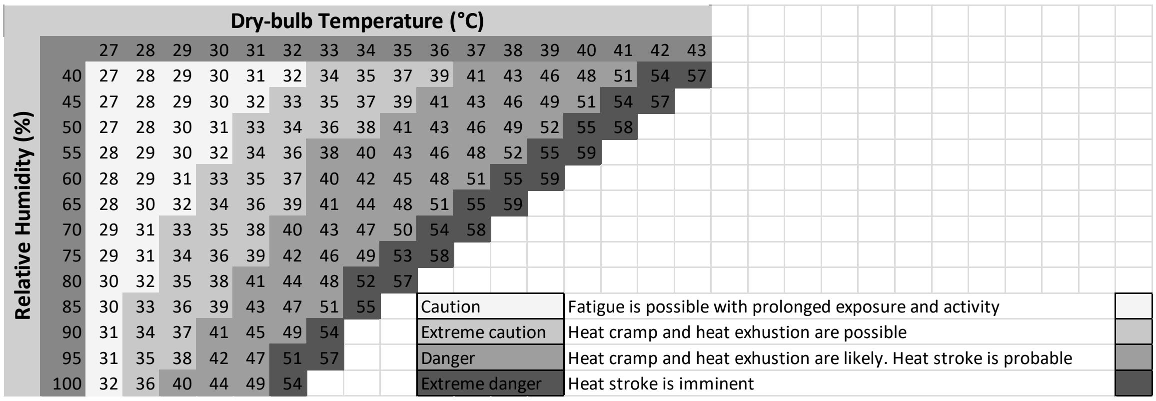
$$\mathrm{VP} = \mathrm{RH} / 100 \times 6.105 \times \exp\left(17.27 \times T / (237.7 + T) \right)$$

where RH = Relative Humidity (%)
exp (x) = exponential function = e^x
e (Euler number) = 2.718281828

[iii] EXTECH RHT20: temperature resolution 0.1°C; temperature accuracy ±1°C; relative humidity resolution 0.1 %RH; relative humidity accuracy ±3%.

[iv] Kestrel 4000: temperature resolution 0.1°C; temperature accuracy ±0.5°C; relative humidity resolution 0.1 % RH; relative humidity accuracy ±3%; wind speed resolution 0.1m/s; wind speed accuracy 3%.

Table 1. Apparent temperature (AT) for heat stress conditions based on dry-bulb temperature and relative humidity in calm weather (NWS, 2014)



Relative Humidity (%)	Dry-bulb Temperature (°C)																
	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
40	27	28	29	30	31	32	34	35	37	39	41	43	46	48	51	54	57
45	27	28	29	30	32	33	35	37	39	41	43	46	49	51	54	57	
50	27	28	30	31	33	34	36	38	41	43	46	49	52	55	58		
55	28	29	30	32	34	36	38	40	43	46	48	52	55	59			
60	28	29	31	33	35	37	40	42	45	48	51	55	59				
65	28	30	32	34	36	39	41	44	48	51	55	59					
70	29	31	33	35	38	40	43	47	50	54	58						
75	29	31	34	36	39	42	46	49	53	58							
80	30	32	35	38	41	44	48	52	57								
85	30	33	36	39	43	47	51	55									
90	31	34	37	41	45	49	54										
95	31	35	38	42	47	51	57										
100	32	36	40	44	49	54											

Caution	Fatigue is possible with prolonged exposure and activity	░
Extreme caution	Heat cramp and heat exhustion are possible	▒
Danger	Heat cramp and heat exhustion are likely. Heat stroke is probable	▓
Extreme danger	Heat stroke is imminent	█

The AT is also known as heat index and humidex. Table 1 shows the AT values related to heat stress conditions based on temperature and the relative humidity in calm weather (WS<1 m/s). Outdoor thermal discomfort also depends on activity rate and clothing insulation of space participants (Nikolopoulou 2004, Nikolopoulou and Lykoudis 2006). However, clothing and activity factors may vary significantly based on the level of individual thermal adaptation. Since the focus of the current case study is on a large number of public space participants, activity and clothing factors are not taken into consideration. AT is used as the official thermal comfort indicator by the Australian Bureau of Meteorology and, therefore, is taken in this research as the closest indicator of outdoor thermal comfort in Adelaide.

3.3 Data collection framework

Case studies were monitored from February 2103 to April 2014. The long duration of data collection facilitated a well-distributed activity observation in a wide range of apparent temperature and different seasons (temperature between 18°C and 42°C).

Microclimate indicators and activity patterns in each public space were observed and mapped in 10-minute intervals during hourly periods. Observations were limited to working hours between 10 am to 5 pm during weekdays to ensure the consistency of the collected data. Activity patterns and users of the public spaces change significantly during weekends, and this weekly change represents different characteristics for the selected public spaces (weekend activities can still inform some aspects of the public life but are out of the scope of this study). Therefore, weekends and public holidays are not included in the final data. Rainy and stormy days were also excluded.

Frequency and location of walking, working, sitting, standing, lying down, meeting, eating, children playing, sport, music playing and socio-cultural activities were recorded on observation sheets, and then transferred to data sheets. Based on the adopted theory of public space and public life (Gehl and Svarre 2013), activity patterns were categorised into necessary (including walking and working), optional (including standing, sitting, lying down, and individual eating and sport) and social activities (including group playing, eating and cultural activities) for data analysis. Activity patterns in Hindmarsh Square, Rundle Mall and Hajek Plaza were monitored, coded and mapped in different seasons to ensure that seasonal changes in activity patterns do not significantly affect the results.

Because of the differences in the function of selected public spaces, it is not accurate to compare the number of users and their activity patterns across the cases. The focus is on the comparison between activity patterns during heat stress and average thermal conditions in each case study. Therefore, the proposed spatial heat resilience of each space is based on a comparison between its normal and heat stress conditions and the normalised results are being compared to investigate which space has the higher heat resilience.

3.4 Correlation, and linear regression analysis

Data was analysed via scattergrams, correlational and linear regression analysis to investigate the effect of AT on outdoor activity patterns. Correlation analysis (also known as contingency test) is one of the most common statistical tests to identify connections in quantitative research. Correlation coefficient value (varies between 0 and ±1) shows the strength and direction of the relationship between variables (Bryman 2008, Neuman 2011). Correlation coefficient (r) values closer to +1 represent stronger positive relationships between the two variables, while closer r-values to -1 indicate strong negative dependency (i.e. variable A decreases with increase in variable B) and r-value = 0 indicate no connection.

Linear regression is used to explore probability and in-detail dependency among two observed variables including the direction and significance of dependency (Bryman 2008, Neuman 2011). Regression analysis shows how and to what extent certain changes in an independent variable can alter the dependent variable. It helps to define the conditional expectation of dependent variables when the independent variable is being specified. Therefore, linear regression analysis can be a prediction tool for the dependent variable, when predictor (independent) variable(s) is known. However, regression analysis does not perform optimally, when variables with small effect or causality are explored through observational data.

Two statistical functions indicate the goodness-to-fit of a regression model. The coefficient of determination, also known as R-squared (R^2), indicates how well data fits a statistical model. In a linear regression model, R-squared equals to the square value of correlation coefficient (r) value ($R^2 = r^2$). Therefore, R-squared may vary between 0 and +1 and closer R-squared values to +1 indicate higher goodness-to-fit of the model to the existing data.

The significance level of the model, also known as the p-value, reveals the consistency and validity of the model. The p-value is being compared to a threshold value, which is commonly suggested to be between 0.05 and 0.1 in social sciences (Bryman 2008, Neuman 2011). The p-values less than 0.05 in regression analysis indicate that there is less than 5% chance that the two variables are not related. Thus when the *p*-value is smaller than 0.05, the regression model is considered as a reliable model to predict future scenarios with more than 95% validity.

3.5 Neutral thermal threshold (NTT) in public space

Thermal comfort standards indicate that there are temperature ranges, in which the need for thermal adjustment is perceived to be neutral by most of the space participants (more than 80%) in the actual thermal voting system (ASHRAE 2013). Such neutral temperature range is being used by microclimate engineers to set the indoor air-conditioning systems.

Neutral thermal threshold (NTT) in the current research refers to the higher threshold of outdoor thermal neutrality. The high threshold of the neutral temperature is commonly suggested to be 24-25°C for indoors (ASHRAE 2013), European studies suggest up to 10°C variation in outdoors' neutral temperature high limit (Nikolopoulou and Lykoudis 2006). An investigation in Sydney suggests that the average outdoor neutral temperature high limit is 26.2°C (Spagnolo and de Dear 2003).

Despite the neutral temperature, which is resulted by the thermal sensation voting system, the NTT is determined based on the observation of thermal sensitivity of outdoor activities. The observation data is preferred for the calculation of NTT since the progressive outdoor activity-comfort research suggests that thermal adaptation occurs more frequently and significantly outdoors (Nikolopoulou 2004, Lin, de Dear et al. 2011, Chen and Ng 2012) and such thermal adaptation can be highly complex. Such significant rate of thermal adaptation occurs due to a higher degree of freedom, alternative choices and flexible climate expectations compared to what may be experienced indoors.

The NTT indicates the temperature threshold, after which significant decline in outdoor activities occurs (the causes of such outdoor activity decline are not focused). The NTT may be identified as the breakpoint in the temperature-activity regression model. Segmented regression analysis (also known as piecewise regression) is the mathematical method to identify the breakpoint in the temperature-activity model. Segmented regression analysis is used when there are at least two different identifiable patterns in the data distribution. In this method, the scatterplot diagram of the regression model is visually observed by the researcher to identify the possible breakpoint(s). Then the regression analysis is being conducted for data between the identified segments. The test is being repeated using slightly higher and lower possible breakpoints and the respective regression models are being compared to identify the model, which represents the best goodness-to-fit with the lowest *p*-value and highest R-squared value (R^2). The breakpoint of the best-to-fit model is the most accurate value in the segmented regression model, and in this study indicates the NTT.

3.6 Canopy and surface cover reconstruction

Urban surface cover (i.e. outdoor surfaces up to the canopy of trees) were reconstructed via desktop extraction of visible land cover from Google Earth images. The proportional coverage of trees, grass, concrete, paving, asphalt, surface water, sand and vacant land in each public space was calculated via i-

Tree Canopy V6.1. The i-Tree Canopy is a land cover estimation tool, being used by United States Department of Agriculture (USDA) Forest Service and is available at http://www.itreetools.org/canopy. The i-Tree tool uses ESRI shape files and Google Earth maps to classify land cover surface materials. The land cover calculation in i-Tree Canopy is based on the supervised classification of sample benchmarks, selected randomly by the software. To evaluate the proportion of canopy cover in this case study, 100 sample points were classified in each public space. Due to the land cover class limitation in i-Tree Canopy (maximum six layers) public space features with similar thermal characteristics were grouped.

4. Results

Distribution of activity patterns in Hajek Plaza, Rundle Mall and Hindmarsh Square is presented in Figure 3. A primary comparison of the results reveals the relatively significant amount of necessary activities in Rundle Mall compared to the other two public spaces. This prominent rate of necessary activities is related to daily walking journeys through the pedestrian mall, as well as shopping activities. On the other side of the range is Hajek Plaza, which is located near the riverbank, far from necessary everyday activities.

Rundle Mall also experiences a lower maximum temperature compared to Hajek Plaza and Hindmarsh Square (max AT of 35°C compared to 42°C in Hajek Plaza and 39°C in Hindmarsh Square). Considering the similar timeframe of observations, such cooler microclimate may have two contributors: air-conditioning of numerous shops, projecting to the outdoor space through the open doors (to keep indoor temperature below the NTT = 24°C) and shading effect of surrounding buildings and trees (in the course of observation majority of activities occur in front of shop openings and shaded areas during out-of-comfort hot temperatures).

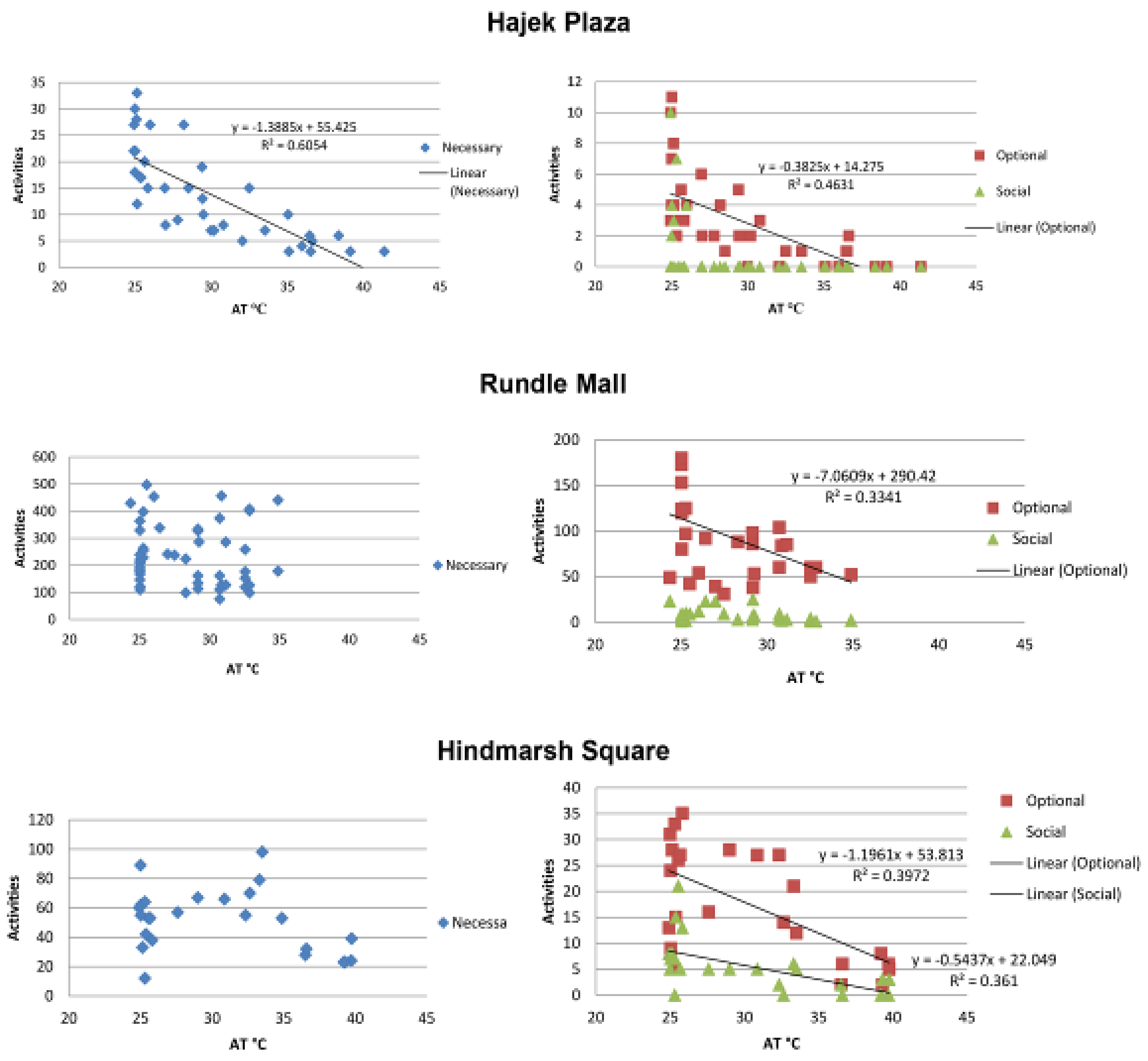


Figure 3. Observed necessary, optional and social activities in Hindmarsh Square, Rundle Mall and Hajek Plaza between February 2013 and March 2014

4.1 The Effect of AT on Necessary Activities

Figure 3 illustrates that necessary activities in Rundle Mall are distributed randomly in the thermal spectrum. For example, necessary activities vary between 100 and 500 at the ideal AT = 25°C as well as AT > 32°C. In other words, necessary activities are not dependent on AT in the Rundle Mall. Nevertheless, observation reveals that the pattern of walking in Rundle Mall is shifting towards shaded areas for the temperatures above 28°C.

On the other side of the range, the decrease in necessary activities in Hajek Plaza is significantly high, starting at NTT = 25°C. With an average 30 space participants (walking through space), Hajek Plaza loses 4.6% of its necessary activities for each 1°C increase of AT. This decrease of necessary activities has the correlation coefficient (*r*) value of -0.77 to AT. It means that this constant decrease of necessary activities in Hajek Plaza has a strong dependency on AT (*r*-values more than 0.7 are mathematically interpreted as strong dependency, and the negative value shows the negative or downhill dependency).

In the linear regression model of the number of necessary activities and AT, the *p*-value is less than 0.001. Thus, based on the observed data and the regression model Hajek Plaza is projected to have no necessary activities in AT > 40°C (the prediction matches the observed data with no participants in the space at AT = 40°C and above).

Figure 4. Rundle Mall keeps its minimum level of social activities, after its NTT of 30°C with the aid of shadow patterns, outdoor air-conditioning support and event management for Fringe Festival, February 2014.

In Hindmarsh Square, the decrease in necessary activities is less significant than Hajek Plaza starting at NTT = 32°C when citizens avoid walking through Hindmarsh Square. Research in Japan (Ichinose, Matsumoto et al. 2008) confirms that a larger proportion of people stays indoors in air-conditioned shopping areas or walk-through buildings to reach their destinations in such heat stress conditions. Necessary activities in Hindmarsh Square have the *r*-value of -0.88 to AT above 32°C. It indicates a strong negative (downhill) dependency of necessary activities to out-of-comfort microclimates. In the regression model *p*-value (significant f) is 0.002, which shows that the model in Figure 5 can be used to predict necessary activities in Hindmarsh Square for AT above 32°C. As such, starting with the average of 73 necessary activities at NTT = 32°C, Hindmarsh Square loses 9.3% of its necessary activities for every 1°C increase in AT. The regression model also reveals that at AT = 43°C, Hindmarsh Square will not have any necessary activities. However, because of cooler materials, good shadow coverage and tree canopy, AT in Hindmarsh Square was 39.3°C when Adelaide CBD was experiencing 43°C on 16 January 2014.

The projected necessary activity rate depends on the assumption that the form of relationship is maintained at higher temperatures. The estimation of future activity patterns may experience another step change (i.e. sudden drop in a new breakpoint) at higher temperatures since the AT is becoming extremely uncomfortable for humans in AT ≥ 40°C. A possible step change in activities during extreme heat stress conditions could make Hajek Plaza completely vacant, Rundle Mall a very costly space to operate and Hindmarsh Square very hard to access. Such probable (and experienced) step change refers to the prominent avoidance of outdoor activities resulting from the extreme heat stress in public space. In such circumstances, citizens do not participate in Hajek Plaza at all; Rundle Mall electricity consumption for air-conditioning goes far beyond business as usual scenario; and to access Hindmarsh Square people are required to walk over extremely hot asphalt for a short distance.

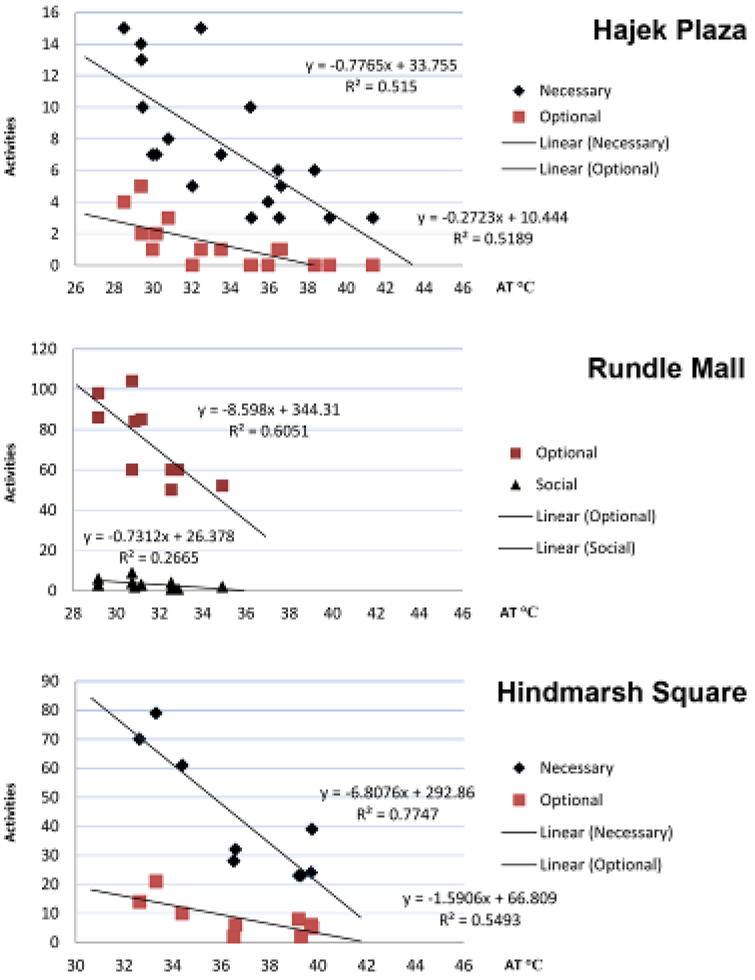


Figure 5. Necessary and optional activities in Hindmarsh Square, Rundle Mall and Hajek Plaza start to decline after specific NNT. The NNT is the least in Hajek Plaza and the most in Hindmarsh Square.

4.2 *The Effect of AT on Optional Activities*

According to the theory of public space and public life, optional activities are the most vulnerable outdoor activities to urban microclimates. Although the maximum vibrancy of optional activities is happening around AT = 25°C in all three case study public spaces, a random distribution of optional activities is identifiable until the AT reaches a specific threshold in each public space (see Figures 3 and 5). The recorded NTT is 32°C in Hindmarsh Square, 29°C in Rundle Mall and 27°C in Hajek Plaza. After this NTT, a consistent decline in optional activities begins. The decline of optional activities in

Hindmarsh Square has the *r*-value of -0.74 to AT > 32°C (indicating significant negative dependency). The *r*-value of optional activities is -0.77 to AT > 29°C in Rundle Mall, and -0.72 to AT > 27°C in Hajek Plaza.

A linear regression model of optional activities and AT in the three public spaces indicates that Hindmarsh Square will lose all its optional activities at AT = 42°C (see Figure 5 and Table 2). This critical zero-activity condition is expected to occur in Rundle Mall at 40°C and in Hajek Plaza at 38°C. It needs to be considered that, when Adelaide experienced above 43°C temperatures during the observation time, Rundle Mall and Hindmarsh Square never reached their critical zero-activity conditions. However, Hajek Plaza experienced AT > 38°C many times with no observed optional activities in the 12 rounds of ten-minute observations (see Figure 5).

4.3 The Effect of AT on Social Activities

As Figure 3, Figure 5 and Table 2 show, the distribution of social activities does not have any meaningful correlations to AT < NTT. In higher temperatures, when a public space reaches its NTT, this lack of correlation continues to occur in Hindmarsh Square and Hajek Plaza. However, the analysis reveals moderate dependency of social activities to the AT in Rundle Mall (*r*-value = -0.51), and it gives us the ability to predict via a regression model (*p*-value = 0.01). The model reveals that Rundle Mall will lose its social activities for AT > 36°C, which is not a confident statement. In reality, Rundle Mall does keep its social activities in almost a constant minimum level after its NTT = 30°C. However, this minimum number of social activities needs the support of shadow patterns and in some cases the mechanical support of air-conditioning and event management.

The results reveal that Hajek Plaza has already met its critical thermal conditions and loses all its embodied activities due to the excess heat load, whereas Hindmarsh Square and Rundle Mall have a few degrees left to reach their critical thermal conditions. Such thermal adaptation capacity is supported by self-shading of trees and buildings, softer landscapes (and the mechanical support of indoor air-conditioning). The envisaged critical zero-activity condition depends on the assumption that the form of relationship is maintained at higher temperatures.

Urban microclimate literature indicates the contribution of open space cover surfaces on the thermal environment especially in lower vertical elevations than 1.5m. The probability of any correlations between heat resilience and land cover classes is evaluated in next stage.

4.4 Urban surface cover materials and AT

Surface cover materials reconstruction via i-Tree Canopy shows that 65% of Hindmarsh Square is covered with grass and trees, while this percentage is 20% of Rundle Mall and only 1% for Hajek Plaza (see Table 3). Hard surfaces (including asphalt, concrete and paving; 6% under shadow) cover 33% of Hindmarsh Square, while this percentage is 79% in Rundle Mall (27% under shadow), and 71% in

Hajek Plaza (9% under shadow). Surface water covers less than 1% in Hindmarsh Square and Rundle Mall and does not exist in Hajek Plaza.

Table 2. Statistical significance (p-value) and correlational coefficient (r-value) of activities to Apparent Temperature (AT) after the Neutral Thermal Threshold (NTT)

r-value (correlational analysis)	Necessary activities for AT > NTT	Optional activities AT > NTT	Social activities AT > NTT
p-value (regression analysis)			
AT in Hindmarsh Square, NTT = 32°C	$r = -0.88$	$r = -0.74$	$r = -0.17$
	$p = 0.002$	$p = 0.02$	$p = 0.66$
AT in Rundle Mall, NTT = 30°C	$r = 0.22$	$r = -0.77$	$r = -0.51$
	$p = 0.31$	$p < 0.001$	$p = 0.01$
AT in Hajek Plaza, NTT = 28°C	$r = -0.71$	$r = -0.72$	$r =$ N/A (div/0)
	$p < 0.001$	$p < 0.001$	$p =$ N/A

Results of urban canopy and land cover surfaces are presented in Table 3. Hindmarsh Square has the highest rate of urban greenery including tree canopy and grass cover. Tree canopy is 34% at Hindmarsh Square; while in Rundle Mall, trees cover 20% of the space and in Hajek Plaza only 1%. Furthermore, 31% of Hindmarsh Square is covered by grass while the grass cover is almost zero in Rundle Mall and Hajek Plaza.

The average tree canopy is 27% in Adelaide (Madew, Trowell et al. 2014). Therefore, only Hindmarsh Square has a higher ratio of urban greenery than average in Adelaide. Considering the dominance of hard surfaces in conventional public spaces of Adelaide and the inclusion of inner-city parklands in the calculated average, we assume that Rundle Mall may represent the average tree canopy, Hindmarsh Square represents high tree canopy and Hajek Plaza represents very low tree canopy. Under investigation is any probable correlation between the ratio of urban greenery and the outdoor activity patterns during heat stress conditions.

5. Resilience to heat in public space

Thermal Resilience has been used in architecture and engineering to indicate the ability of a system (e.g. building or structure) to resist the excess heat load (Lomas and Giridharan 2012). Accordingly spatial heat resilience (SHR) is proposed to indicate the ability of the space to maintain its normal activity patterns during out-of-comfort thermal conditions. Therefore, SHR deals with both typology and frequency of outdoor activities. It is assumed that the distribution of necessary, optional and social activities in public spaces and the number of participants in controlled timeframes can be proper indicators for heat resilience in the case study public spaces. Thus, it is suggested that high NTT values indicate high SHR in open space.

Table 3. Surface cover materials in Hindmarsh Square, Rundle Mall and Hajek Plaza in 2013, calculated in iTree Canopy

		Tree and Shrub	Shade	Concrete and Paving	Asphalt and Bitumen	Surface Water	Grass and Bare Ground
Hajek Plaza	Sample Points	1	9	62	0	0	28
	% Cover	1.00±1.00	9.00±3.00	62.00±4.85	0.00±0.00	0.00±0.00	28.00±4.49
Rundle Mall	Sample Points	20	27	52	0	1	0
	% Cover	20.00±4.00	27.00±4.44	52.00±4.92	0.00±0.00	1.01±1.01	0.00±0.00
Hindmarsh Square	Sample Points	34	6	16	11	1	31
	% Cover	34.30±4.77	6.06±2.47	16.20±3.70	11.10±3.16	1.01±1.01	31.30±4.66

5.1 SHR of different activity patterns

The SHR of necessary activities is higher in public spaces, supported by other land uses (e.g. Rundle Mall), shadow coverage and a medium rate of urban greenery. Necessary activities in Rundle Mall are less affected by the AT, mainly due to the support of other factors such as citizens’ daily walking journeys and shopping habits. The comparison between surface cover materials and NTT of activity patterns reveals that necessary activities in greener spaces have a high SHR value. For example, Hindmarsh Square shows a high NTT of 32°C, which is sufficient to support a reasonable amount of activities on the majority (more than 85%) of Adelaide’s summer days. However, necessary activities in public spaces with very low supporting land uses, shadow coverage and urban greenery (such as Hajek Plaza) have the least SHR with 4°C lower NTTs and higher decline in activity rates for respective AT > NTT. Therefore, hard surfaced and poorly shadowed public spaces lose their necessary activities earlier and more significant than greener and well-shadowed settings.

Optional activities resilience to heat stress is higher in greener public spaces with higher NTT (in Hindmarsh Square NTT = 32°C) and less activity decline at higher temperatures (see Figure 3 and Table 2). Medium size green areas represent the best SHR value for optional activities. Well-supported public spaces (by surrounding land use) have an acceptable SHR value (in Rundle Mall NTT = 30°C) and represent the lowest rate of optional activity decline. Space users who have to keep to their necessary daily activities at higher temperatures, start to refuse optional attendance in spaces with less greenery. Optional activities in hard-landscaped public spaces have the least NTT (in Hajek Plaza NTT = 28°C) and activities start to disappear (with zero values) from the public space right after the NTT reaches a mean value of zero at 38°C.

5.2 Boundaries of Necessary and Optional Activities in Higher Temperatures

A comparison between the behaviour of necessary and optional activities for ATs above the NTT in Figure 3 and Figure 5 reveals that necessary activities in Hindmarsh Square and Hajek Plaza fluctuate similarly to optional activities at AP > NTT (even with a higher *r*-value). The comparison indicates that the boundaries between necessary and optional activities can shift based on the space functions. This means that walking, which is a necessary activity in Rundle Mall, looks more like an optional activity in Hajek Plaza and Hindmarsh Square.

The argument becomes more tangible when we consider that necessary activities become optional in the places where alternative choices are available. For example, when there are other routes to work, home or school or alternative work areas are available, the choices of outdoor activities can alter based on the thermal environment. This activity-shift effect in higher temperatures reveals that activities in spaces with less supportive land uses and shading from buildings and trees are far more sensitive to heat stress compared to well supported public spaces.

5.3 SHR and urban greenery

Hindmarsh Square has the best heat resilience performance with high NTT and SHR values (average of all activities). It also has the highest soft-landscaped area (covered by tree canopies or grass). Although, this primary result cannot be generalised, due to the limited number of observed public spaces, it supports the vitality of increase in urban greenery for quality public spaces.

There is a growing literature, supporting the positive influences of greenery on outdoor activities and public health (McMichael 2003, Ryan and Wayuparb 2004, Santos 2005, Kirch, Menne et al. 2006, Leary 2007, Helfer 2008, Kjellstrom, Holmer et al. 2009, Humphreys 2010, Booth 2012). The urban greenery is argued to promote health, well-being and social safety in the living environment (Groenewegen, Van Den Berg et al. 2006, Van Dillen, de Vries et al. 2012, Nordbo, Karsisto et al. 2015). Besides the effect of urban greenery on air quality, noise reduction, well-being and social safety, the existence of natural elements in public space is highlighted as an effective factor in outdoor thermal adaptation (Nikolopoulou 2004). The existence of urban greenery is referred as the factor of ‘naturalness’ in adaptive thermal comfort discussions.

Increasing urban greenery improves the adaptive capacity of public spaces and their embodied outdoor activities to heat stress by reducing the heat load (and moderating humidity in drier climates) as well as providing appropriate shading under tree canopies. There is strong research evidence that increased vegetation reduces the heat load on pedestrians (see for example Afshari 2012, Bencheikh and Rchid 2012, Correa, Ruiz et al. 2012, Sharifi and Lehmann 2014, Ong 2015). Depending on the greenery attributes, such heat mitigation effect may range from shading to radiant heat reduction (particularly if replacing otherwise hard pavement). Improvements in thermal comfort and outdoor activities are expected as a result.

6. Conclusions

‘Public life changes constantly in the course of the day, week, month and over a year’ (Gehl and Svarre 2013, p 12). Nevertheless, the complex interaction between public space and public life supports diversity, flexibility and adaptability of local communities and their outdoor activities (Stathopoulos, Wu et al. 2004, Lin 2009, Nikolopoulou 2011). This case study supports the concept that urban microclimates influence public life by altering typology, duration, and frequency of outdoor activities in heat stress scenarios. Studying the dynamics of thermal discomfort in the current case study indicates that:

- The neutral thermal thresholds (NTT) for heat sensitivity in the studied public spaces vary from 28°C to 32°C.
- Optional activities (i.e. sitting, standing, eating, playing and sport) are highly sensitive to heat stress and start to decrease after the public space reached its NTT.
- Necessary activities (i.e. walking between home and work or for daily shopping) have more resilience to heat stress and start to decline after higher NTTs compared to optional activities especially in public spaces with more diversity of functions and supportive land use.
- Necessary and optional activity patterns are dependent on shading effect during heat stress conditions
- Social activities (i.e. group activities, cultural activities such as music playing) are more sensitive to time and organisational adjustments than heat stress, nevertheless, still follow necessary activities thresholds.
- Activity patterns in public spaces with more urban greenery and shadow coverage are more resilient to heat stress compared to hard-landscaped areas.

With a better understanding of the relationship between urban space, microclimates and public life, it is possible to develop prototypes of public spaces that respond to both functional demands and local microclimates (Lehmann and Thornton 2015). Urban greenery and shadow coverage can facilitate more diverse and extended activities in public space especially at higher temperatures. Thus, an increase in the tree canopy, softer landscapes and shadow coverage are suggested to achieve higher spatial heat resilience (SHR) in public space. Increased greenery leads to improved thermal comfort, which increases resilience to heat stress. Thermal load on outdoor participants decreases in heat resilient public spaces, resulting in more vibrant and healthier public life in cities.

Research findings propose heat resilience as a quality indicator for public space and support the application of urban greenery to make cities more resilient to heat. The neutral thermal threshold (NTT) is the suggested benchmark for public life vitality assessment at high temperatures since it indicates the extent of public life resilience to heat stress. In the context of climate change, heat resilience in public space can support more vibrant, healthy and safer urban environments in existing and future cities. Such spatial heat resilience supports the usability of outdoor spaces by local communities in hot scenarios.

7. Research Limitations and Further Opportunities

This research is based on observational data and spatial microclimate measurement. It also focuses on a limited number of public spaces in Adelaide. Further research can include more public spaces to increase the ability to generalise the results. Also, public spaces in other cities are the subject of further analysis via a similar method as people responses to urban microclimate are highly contextual. The use of radiant temperature in thermal discomfort calculation is another opportunity for further research.

8. Acknowledgments

This paper draws on the work of the authors at the University of South Australia. It is a part of an ongoing research project on Urban Microclimates of Australian Cities, supported by the CRC for Low Carbon Living and the cities of Adelaide, Sydney and Melbourne. The research is approved by UniSA’s Human Research Ethics Committee (PR 31464). We appreciate the generous and constructive assistance of the editorial board of Journal of Environmental Planning and Management and the anonymous reviewers in finalising this manuscript.

9. References

Afshari, H. 2012. "Design Fundamentals in the Hot and Humid Climate of Iran: The Case of Khoramshahr." *Asian Culture and History* 4(1): 65.

Aljawabra, F. and M. Nikolopoulou 2010. "Influence of hot arid climate on the use of outdoor urban spaces and thermal comfort: Do cultural and social backgrounds matter?" *Intelligent Buildings International* 2(3): 198-217.

ASHRAE 2013. *Standard 55 - Thermal Environmental Conditions for Human Occupancy*. Atlanta, American Society of Heating, Refrigerating and Air-conditioning Engineers INC.

Auliciems, A. 1969. "Effects of weather on indoor thermal comfort." *International Journal of Biometerorology* 13: 147-162.

Bencheikh, H. and A. Rchid 2012. "The Effects of Green Spaces (Palme Trees) on the Microclimate in Arides Zones, Case Study: Ghardaia, Algeria." *Energy Procedia* 18(0): 10-20.

BoM 2008. *Climate of Australia*. Melbourne, Australian Bureau of Meteorology, Commonwealth of Australia.

Booth, C. 2012. *Solutions to climate change challenges in the built environment*
edited by Colin Booth ... [et al.]. Ames, Iowa :, Wiley-Blackwell.

Bosselmann, P. 2008. *Urban Transformation: Understanding City Design and Form*. Washington DC, Island Press.

Bosselmann, P., E. Arens, K. Dunker and R. Wright 1995. "Urban Form and Climate." *Journal of American Planning Association* 61(2): 226.

Bradshaw, V. 2010. Human Comfort and Health Requirements. *The Building Environment: Active and Passive Control Systems*. V. Bradshaw, Wiley: 3-36.

Bryman, A. 2008. *Social Research Methods*. Oxford, Oxford University Press.

Burton, E. and M. Lynne 2006. *Inclusive Urban Design: Streets for Life*. Oxford Elsevier, Architectural Press.

Candido, C. 2011. "Adaptive Comfort: Passive Design for Active Occupants." *Environment Design Guide*(69): 1-5.

Chen, L. and E. Ng 2012. "Outdoor Thermal Comfort and Outdoor Activities: A Review of Research in the Past Decade." *Cities* 29(2): 118-125.

Cooper, I. 1982. "Comfort Theory and Practice: Barriers to the Conservation of Energy by Building Occupants." *Applied Energy* 11(4): 243-288.

Correa, E., M. A. Ruiz, A. Canton and G. Lesino 2012. "Thermal Comfort in Forested Urban Canyons of Low Building Density. An Assessment for the City of Mendoza, Argentina." *Building and Environment* 58: 219-230.

de Dear, R. J., K. G. Leow and S. C. Foo 1991. "Thermal Comfort in the Humid Tropics: Field Experiments in Air Conditioned and Naturally Ventilated Buildings in Singapore." *International Journal of Biometeorology* 34(4): 259-265.

Dobbins, M. 2009. *Urban Design and People*. Hoboken, Wiley.

Eliasson, I., I. Knez, U. Westerberg, S. Thorsson and F. Lindberg 2007. "Climate and Behaviour in a Nordic City." *Landscape and Urban Planning* 82(1): 72-84.

Erell, E., D. Pearlmutter and T. Williamson 2011. *Urban Microclimate: Designing the Spaces between Buildings*. London, Earthscan.

Fanger, P. 1982. *Thermal Comfort: Analysis and Applications in Environmental Engineering*, Danish Technical Press.

Gartland, L. 2008. *Heat Islands: Understanding and Mitigating Heat in Urban Areas*. Washington, DC, Earthscan.

Gehl, J. 1987. *Life between Buildings: Using Public Space*. New York, Van Nostrand Reinhold.

Gehl, J. 2002. *Public Spaces and Public Life: City of Adelaide*. Adelaide, Planning SA.

Gehl, J. 2010. *Cities for People*. Washington, DC, Island Press.

Gehl, J. 2011. *Public Spaces and Public Life Survey: City of Adelaide 2011*. Adelaide, Adelaide City Council.

Gehl, J. and L. Gemzoe 2001. *New City Spaces*. Copenhagen, The Danish Architectural Press.

Gehl, J. and B. Svarre 2013. *How to Study Public Life*. Washington DC, Island Press.

Givoni, B. 1998. *Climate Considerations in Building and Urban Design*. New York, Van Nostrand Reinhold.

Groenewegen, P. P., A. E. Van Den Berg, s. S. De Vrie and R. A. Verheij 2006. "Vitamin G: Effects of Green Space on Health, Well-being, and Social Safety." *BMC Public Health* 6(1).

Helfer, S. 2008. "Plant health in private urban gardens." *Turkish Journal of Botany* 32(6): 485-488.

Hu, W., N. Becker, T. McMichael and S. Tong 2007. "Heat-related Mortality during Summer in Sydney, Australia, 1990-2004." *Epidemiology* 18(5): S113-S114.

Humphreys, S. 2010. *Human rights and climate change*
[electronic resource]
edited by Stephen Humphreys ; with a foreword by Mary Robinson. New York :, Cambridge University Press.

Ichinose, T., F. Matsumoto and K. Kataoka 2008. Counteracting Urban Heat Islands in Japan. *Urban Energy Transition: From Fussil Fuels to Renewable Power*. D. Peter. Amsterdam, Elsevier: 365-380.

Jacobs, J. 1961. *The Death and Life of Great American Cities*. New York Random House Inc.

Jacobs, J. 2004. "The Greening of the City." *New York Times Magazine*(Journal Article): 22.

Johansson, E. 2006. "Influence of Urban Geometry on Outdoor Thermal Comfort in a Hot Dry Climate: A Study in Fez, Morocco." *Building and Environment* 41(10): 1326-1338.

Kirch, W., B. Menne and R. Bertollini 2006. *Extreme Weather Events and Public Health Responses*. Dordrecht, Springer

Kjellstrom, T., I. Holmer and B. Lemke 2009. "Workplace Heat Stress, Health and Productivity: An Increasing Challenge for Low and Middle-Income Countries during Climate Change." *Global Health Action* 2(1): 1-7.

Lang, J. 1987. *Creating Architectural Theory: the Role of the Behavioral Sciences in Environmental Design*. New York, Van Nostrand Reinhold Co.

Lang, J. 2005. *Urban Design: A Typology of Procedures and Products*. Oxford Elsevier, Architectural Press.

Leary, N. 2007. *Climate change and vulnerability*
edited by Neil Leary ... [et al.]. Sterling, VA :, Earthscan.

Lehmann, S. and K. Thornton 2015. Applying Low Carbon Principles to Shift Urban Design paradigms in the Asia-Pacific Region towards Green Urbanism. *Low Carbon Cities: Transforming Urban Systems*. S. Lehmann. London, Routledge: 394-421.

Lillebye, i. 2001. The Architectural Significance of the Street as a Functional and Social Arena. *The Sustainable Street: the Environmental, Human and Economic Aspects of Street Design and Management*. C. Jefferson, J. Rowe and C. Brebbia. Southampton, WIT Press: 3-44.

Lin, R. T. and C. C. Chan 2009. "Effects of Heat on Workers' Health and Productivity in Taiwan." *Global Health Action* 2(1): 1-7.

Lin, T.-P., R. de Dear and R.-L. Hwang 2011. "Effect of Thermal Adaptation on Seasonal Outdoor Thermal Comfort." *International Journal of Climatology* 31(2): 302-312.

Lin, T. P. 2009. "Thermal Perception, Adaptation and Attendance in a Public Square in Hot and Humid Regions." *Building and Environment* 44(10): 2017-2026.

Lin, T. P., A. Matzarakis and R. L. Hwang 2010. "Shading Effect on Long-term Outdoor Thermal Comfort." *Building and Environment* 45(1): 213-221.

Lomas, K. J. and R. Giridharan 2012. "Thermal Comfort Standards, Measured Internal Temperatures and Thermal Resilience to Climate Change of Free-Running Buildings: A Case-Study of Hospital Wards." *Building and Environment* 55(0): 57-72.

Madanipour, A. 2003. Why are the Design and Development of Public Spaces Significant for Cities? *Designing Cities: Critical Readings in Urban Design*. A. R. Cuthbert. Oxford, Blackwell: 140-151.

Madew, R., V. Trowell, Y. Lynch, J. Byrne, C. Lorimer, A. Kachenko, T. Astell-Burt and X. Feng 2014. Where are All the Trees? An Analysis of Tree Canopy Cover in Urban Australia. Institute of Sustainable Future, UTS, Sydney, 202020 Vision.

Major Cities Unit 2013. State of Australian Cities, Deparment of Infrastructure and Transport.

McMichael, A., R. Woodruff, P. Whetton, K. Hennessy, N. Nicholls, S. Hales, A. Woodward and T. Kjellstrom 2003. Human Health and Climate Change in Oceania: A Risk Assessment. Canberra, Commonwealth of Australia.

McMichael, T. 2003. *Human Health and Climate Change in Oceania*. Canberra, Commonwealth Department of Health and Ageing.

Montero, J. C., I. J. Miron, J. J. Criado, C. Linares and J. Díaz 2013. "Difficulties of defining the term, "heat wave", in public health." 23(5): 377-379.

Moughtin, C. 2003. *Urban Design: Street and Square*. Amsterdam Elsevier, Architectural Press.

Moughtin, C. and P. Shirley 2005. *Urban Design: Green Dimensions*. Boston, Architectural Press.

Nairn, J. R. and R. Fawcett 2013. *Defining Heatwaves : Heatwave Defined as a Heat-Impact Event Aervicing All Community and Business Sectors in Australia*. Adelaide, Centre for Australian Weather and Climate Research.

Neuman, W. L. 2011. *Social Research Methods: Qualitative and Quantitative Approaches*. Boston, Pearson/Allyn & Bacon.

Nicol, F. 1993. *Thermal Comfort: A Handbook for Field Studies toward an Adaptive Model*. London, University of East London.

Nikolopoulou, M. 2004. Outdoor Comfort. *Environmental Diversity in Architecture*. K. Steemers and M. A. Steane. London, Spon (E&F): 101-119.

Nikolopoulou, M. 2004. "Outdoor comfort." *Environmental Diversity in Architecture*: 101.

Nikolopoulou, M. 2011. Urban Open Spaces and Adaptation to Climate Change. *Applied Urban Ecology*, John Wiley & Sons, Ltd: 106-122.

Nikolopoulou, M., N. Baker and K. Steemers 1999. "Improvements to the globe thermometer for outdoor use." *Architectural Science Review* 42(1): 27-34.

Nikolopoulou, M., N. Baker and K. Steemers 2001. "Thermal Comfort in Outdoor Urban Spaces: Understanding the Human Parameter." *Solar Energy* 70(3): 227-235.

Nikolopoulou, M. and S. Lykoudis 2006. "Thermal Comfort in Outdoor Urban Spaces: Analysis Across Different European Countries." *Building and Environment* 41(11): 1455-1470.

Nikolopoulou, M. and S. Lykoudis 2007. "Use of Outdoor Spaces and Microclimate in a Mediterranean Urban Area." *Building and Environment* 42(10): 3691-3707.

Nikolopoulou, M. and K. Steemers 2003. "Thermal comfort and psychological adaptation as a guide for designing urban spaces." *Energy and Buildings* 35(1): 95-101.

Nitschke, M., G. R. Tucker and P. Bi 2007. "Morbidity and Mortality during Heatwaves in Metropolitan Adelaide." *The Medical journal of Australia* 187(11-12): 662-665.

Nordbo, A., P. Karsisto, L. Matikainen, C. R. Wood and L. Järvi 2015. "Urban Surface Cover Determined with Airborne Lidar at 2 m Resolution – Implications for Surface Energy Balance Modelling." *Urban Climate* 13: 52-72.

OECD 2010. *Cities and Climate Change*, Organisation for Economic Cooperation and Development (OECD).

Oke, T. R. 1988. "Street Design and Urban Canopy Layer Climate." *Energy and Buildings* 11(1–3): 103-113.

Oke, T. R. 2006. "Towards Better Scientific Communication in Urban Climate." *Theoretical and Applied Climatology* 84(1): 179-190.

Olgyay, V. and A. Olgyay 1963. *Design with Climate: Bioclimatic Approach to Architectural Regionalism*. Princeton, N.J Princeton University Press.

Ong, B. L. 2015. The Green Plot Ratio and the Role of Greenery in Low Carbon Living. *Low Carbon Cities*. S. Lehmann. New York, Routledge: 349-360.

Parsons, K. 2009. "Maintaining Health, Comfort and Productivity in Heat Waves." *Global Health Action* 2(1): 1-7.

Ricketts, J. and K. Hennessy 2009. Climate change in
southern South Australia
and western Victoria Aspendale VIC, CSIRO and Australian Bureau of Meteorology.

Ryan, P. and N. Wayuparb 2004. "Green Space Sustainability in Thailand." *Sustainable Development* 12(4): 223-237.

Santos, M. A. 2005. "Environmental Stability and Sustainable Development." *Sustainable Development* 13(5): 326-336.

Sharifi, E. and S. Lehmann 2014. "Comparative Analysis of Surface Urban Heat Island Effect in Central Sydney " *Journal of Sustainable Development* 7(3): 23-34.

Shashua-Bar, L., Y. Tzamir and M. E. Hoffman 2004. "Thermal Effects of Building Geometry and Spacing on the Urban Canopy Layer Microclimate in a Hot Humid Climate in Summer." *International Journal of Climatology* 24(13): 1729-1742.

Spagnolo, J. and R. de Dear 2003. "A Field Study of Thermal Comfort in Outdoor and Semi-outdoor Environments in Subtropical Sydney Australia." *Building and Environment* 38(5): 721-738.

Stathopoulos, T., H. Wu and J. Zacharias 2004. "Outdoor Human Comfort in an Urban Climate." *Building and Environment* 39(3): 297-305.

Steadman, R. G. 1979. "The Assessment of Sultriness. Part I: A Temperature-Humidity Index Based on Human Physiology and Clothing Science." *Climate and Applied Meteorology* 18(7): 861-873.

Steadman, R. G. 1984. "A Universal Scale of Apparent Temperature." *Climate and Applied Meteorology* 12(23): 1674-1687.

Steadman, R. G. 1994. "Norms od Apparent Temperature in Australia." *Australian Meteorological Magazine* 43(1): 1-16.

Steffen, W., L. Hughes and S. Perkins 2014. Heatwaves: Hotter, Longer, More Often, Climate Council of Australian.

Szokolay, S. 2008. *Introduction to Architectural Science: The Basis of Sustainable Design*. Philadelphia, Taylor & Francis Group.

Thom, E. C. 1959. "The Discomfort Index." *Weatherwise* 12(2): 57-61.

Tseliou, A., I. X. Tsiros, S. Lykoudis and M. Nikolopoulou 2010. "An Evaluation of Three Biometeorological Indices for Human Thermal Comfort in Urban Outdoor Areas Under Real Climatic Conditions." *Building and Environment* 45(5): 1346-1352.

Van Dillen, S. M. E., S. de Vries, P. P. Groenewegen and P. Spreeuwenberg 2012. "Greenspace in urban Neighbourhoods and Residents' Health: Adding Quality to Quantity." *Journal of Epidemiology and Community Health* 66(6): e8.

van Hoof, J. and J. L. M. Hensen 2007. "Quantifying the Relevance of Adaptive Thermal Comfort Models in Moderate Thermal Climate Zones." *Building and Environment* 42(1): 156-170.

Walton, D., V. Dravitzki and M. Donn 2007. "The Relative Influence of Wind, Sunlight and Temperature on User Comfort in Urban Outdoor Spaces." *Building and Environment* 42(9): 3166-3175.

Wang, Z., L. Zhang, J. Zhao and Y. He 2010. "Thermal Comfort for Naturally Ventilated Residential Buildings in Harbin." *Energy and Buildings* 42(12): 2406-2415.

Wendt, D., L. J. C. Van Loon and W. D. V. M. Lichtenbelt 2007. "Thermoregulation during Exercise in the Heat: Strategies for Maintaining Health and Performance." *Sports Medicine* 37(8): 669.

Whyte, W. H. 1980. *The Social Life of Small Urban Spaces*. Washington, D.C, Conservation Foundation.

Williams, S., M. Nitschke, T. Sullivan, G. R. Tucker, P. Weinstein, D. L. Pisaniello, K. A. Parton and P. Bi 2012. "Heat and health in Adelaide, South Australia: Assessment of Heat Thresholds and Temperature Relationships." *Science of The Total Environment* 414: 126-133.

Williams, S., M. Nitschke, P. Weinstein, D. L. Pisaniello, K. A. Parton and P. Bi 2012. "The Impact of Summer Temperatures and Heatwaves on Mortality and Morbidity in Perth, Australia 1994–2008." *Environment International* 40(Journal Article): 33-38.

Zacharias, J., T. Stathopoulos and H. Wu 2001. "Microclimate and Downtown Open Space Activity." *Environment & Behavior* 33(2): 296-315.