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## **Thermal Resilience of Activity Patterns and Urban Greenery in Public Space: Three Case Studies in Adelaide, South Australia**

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## **Thermal Resilience of Activity Patterns and Urban Greenery in Public Space: Three Case Studies in Adelaide, South Australia**

**ABSTRACT:** *Australia has had seven extreme heatwaves since the beginning of the 20<sup>th</sup> century. During heatwaves, public spaces in cities are frequently warmer than is comfortable for humans. The regional warming projection of 2-5°C in Australia (by 2070) will be added to an existing 4-8°C extra heat in higher urban densities. This extra urban heat is because of urban structures, land cover, lifestyle and lack of landscape. Under question is how and to what extent contemporary public spaces can become more resilient to emerging higher temperatures in cities while maintaining their usability.*

*In this paper, we define thermal resilience in public space as the ability of the space to support its normal activities in higher temperatures. We also report on the correlations between activity patterns, thermal conditions and urban greenery in Hajek Plaza, Rundle Mall and Hindmarsh Square in Adelaide, South Australia. Case studies were monitored from February 2013 to April 2014 when experiencing temperatures between 20°C and 42°C.*

*Results indicate that both necessary and optional activities are highly sensitive to heat stress in public space and both start to decline after the Apparent Temperature (APT) reaches the threshold of 28-32°C. Activities in public spaces with more urban greenery show more resilience to excess heat, while shadowless and hard-landscaped public spaces lose their embodied activities in lower APTs. As such, urban greenery can facilitate more diverse and extended activities in public space especially in higher temperatures. Thus, an increase in the tree canopy and softer landscapes are suggested to achieve higher thermal resilience in public space.*

**Keywords:** *Thermal Resilience, Public Space, Public Life, Urban Heat Stress, Outdoor Activity Patterns*

### **Introduction**

Summer heatwaves are now more frequent and extended in Australian cities. Australia had seven extreme heat waves in 1908, 1939, 1960, 1973, 2004, 2009 and 2013 (Australian Bureau of Meteorology, 2008; Nairn & Fawcett, 2013). Although there are some differences in defining heat waves (Montero, Miron, Criado, Linares, & Díaz, 2013), there is no doubt about their significant damage on natural ecosystems and public health. During heat waves, public spaces in cities are frequently warmer than human thermal comfort levels (CSIRO, 2007; Australian Bureau of Meteorology, 2008; Williams et al., 2012). Extended heat stress in public space occurs partially because of urban structure, land cover, lifestyle and lack of landscape.

In response to the substantial temperature increase in public space (frequently between 4-8°C more than peri-urban surroundings) citizens move into air-conditioned buildings. However, air-conditioning create cooler microclimates with the cost of an ever-increasing outdoor

temperature (Ichinose, Matsumoto, & Kataoka, 2008). As a result of out-of-comfort outdoor space, citizens' transportation choices also shift towards more privatised modes in hotter urban climates. This demand for air-conditioning and transportation during higher temperatures is frequently accompanied by excess waste heat generation. As such, the consequent waste heat of air-conditioning and motorized transportation makes a feedback loop with heat stress in public spaces.

Anthropogenic (human made) waste heat in urban settings is cited as a key contributor to the artificial heat in higher densities, denoted as the Urban Heat Island effect (Oke, 2006; Gartland, 2008; Erell, Pearlmutter, & Williamson, 2011). Such artificial urban heat stress affect citizens' health, especially in regards to the elderly and children (Hu, Becker, McMichael, & Tong, 2007).

While climate change projections indicate a likely increase of 2-5°C in Australian surface temperature by 2070 (CSIRO, 2007; OECD, 2010), in several Australian cities, the combined effect of urbanisation and global warming have given an increase to urban heat island intensity, amplifying the risk to public life and health. Today, we have a better understanding of the relationship between urban form, orientation, materiality and green space in regard to their effect on the urban microclimate. Therefore, it's possible to develop urban prototypes of public spaces that respond not only to functional demands, but also to the specificities of local climate (Lehmann, 2014). These quality public spaces can enhance public health and public life in Australian cities.

## **Background**

Public life in contemporary cities is affected by mass urbanisation, both environmentally (Cliff Moughtin & Peter Shirley, 2005; Girardet, 2008; Lehmann, 2010; Crocker, 2012) and socially (Sennett, 1977, 1991; Gehl & Gemzoe, 2001; Louv, 2006). In the early 1930s, Le Corbusier claimed sun, sky, tree, steel and cement as the basic elements of urban design (Mumford, 1961; Corbusier, 1971). However, vast, neat and car-oriented streets and squares could not provide quality public spaces for modern cities (Gehl & Gemzoe, 2001; Madanipour, 2003). Indeed the allocation of steel and cement among basic elements of urban design has been criticized severely afterwards (Jacobs, 2004; Lang, 2005; Cliff Moughtin & P. Shirley, 2005).

Since the early 1960s, morphological analysis of successful streets and squares (as conventional public spaces) has established a number of physical quality indicators for public space. Cullen (1961) claims the contrast between existing and emerging vistas is a quality

indicator of public space, which promotes participants' mental connectedness to the space. Sense of place and sense of identity (sympathy with the surrounding environment) are the consequences of this mental mapping in public space. Krier (1979, 1993) highlights fine grain as a quality factor in public space, while Alexander (1977) focuses on distinguishable spatial patterns in successful public spaces. The common argument was that physical dimensions of public space have the most significant effect on its quality.

Jacobs (1961), however, criticizes lack of public life in modern cities, where public space users have been separated via functional zones. Therefore, she suggests mixed-use, fine-grain, diversity and density in urban design to support upholding, redundancy and vibrancy in public space. At the same time, Lynch (1960) emphasizes people's perception and memory of the place as a substantial factor in public space quality. He has argued that pedestrians' mental map is shaped by spatial information of paths, edges, districts, nodes and landmarks. Quality factors of 'legibility' and 'imageability' (way-finding) are Lynch's recommendations to improve identity in public space. Lynch's normative theory to explain urban space is focused on values of forms and functions instead of their physicality.

The majority of contemporary research on public space quality follows Jacobs and Lynch. Vitality of human activities in public space is the core concept of these studies (Lang, 1974; Whyte, 1980; Gehl, 1987; Lang, 1987, 2005; Gehl, 2010). Corresponding literature is focused on the interaction between the built environment and citizens' outdoor behavioural patterns. (Whyte, 1980; Gehl, 1987; Lang, 1987, 2005; Burton & Lynne, 2006; Dobbins, 2009; Gehl, 2010). The basic argument is that the built environment can significantly affect human outdoor activities, and also can be affected by people's social and behavioural activities (Lang, 1974; Christian Norberg-Schulz, 1980; C. Norberg-Schulz, 1984; Lang, 1987; Gehl, 2010). Therefore, public life is being affected by physical dimensions of public space, and takes part in defining the quality of public space simultaneously.

One of the physical dimensions of public space is its microclimate, which affects usability of the space. Outdoor comfort is a factor, affecting activity patterns in public space (Gehl, 1987; Bosselmann, Arens, Dunker, & Wright, 1995; Gehl, 2010). Excess heat in public space can cause huge discomfort, which can alter the frequency and patterns of outdoor activities in cities. Under question is how and to what extent contemporary public spaces can become more resilient to emerging hotter temperatures while maintaining their usability.

## **Theoretical Framework**

Like weather, public life is complex and hard to predict (Gehl & Svarre, 2013). As the main theoretical source for this research, the theory of 'public space and public life' argues that vibrant public life is the result of quality public spaces, as well as a significant contributor in shaping their quality (Gehl, 1987; Lillebye, 2001; Bosselmann, 2008; Gehl, 2010). The complex interaction between public space and public life shapes the core theoretical framework of the current research.

The effect of sun, wind, trees and water on people's attendance in public space has been a topic of research since the 1980s (Whyte, 1980; Givoni, 1998). Whyte's flagship study on public life in small urban spaces (in New York City) was a successful start, which has not been pursued thoroughly in further research. The majority of studies have looked at public space microclimates through absolute physical and quantitative lenses (Givoni, 1998; Oke, 2006; Gartland, 2008; Ichinose et al., 2008; Wong & Yu, 2008; Erell et al., 2011), whilst a few public space and public life monitoring investigations focus on pedestrian flow in ideal climate conditions. Existing studies on public space microclimates are focused on the physicality of the space (Shashua-Bar, Tzamir, & Hoffman, 2004; Johansson, 2006; Lin, Matzarakis, & Hwang, 2010; Correa, Ruiz, Canton, & Lesino, 2012), rather than discussing how these physical attributes can alter activities in outdoor space.

Defining the theory of public space and public life, Gehl (1987) classifies human activities in public space into three types of necessary, optional and social activities. This classification is based on the nature of activities and the number of participants. Necessary activities are related to unavoidable occasions in daily life that happen in almost all climate and time conditions. Traveling from home to school or work, everyday shopping and working in public space are clear examples of necessary activities, which are hardly affected by the physical environment including microclimates (according to the theory).

Optional activities take place only if the climate and time conditions are appropriate for humans to spend time outdoors. Sitting, standing, site seeing, laying down, individual eating, playing and sport are examples of optional activities. Optional activities are highly sensitive to the physical environment and only take place in ideal spatial conditions (Gehl & Svarre, 2013). Thus, microclimates can affect optional activities more than other activity patterns.

Social activities occur as the result of necessary and optional activities. Group playing, meeting and cultural events are examples of social activities. As such, social activities are affected by behavioural values, event management and sufficient population directly, and physical environment indirectly (Whyte, 1980; Gehl, 1987; Lillebye, 2001). For instance, an

outdoor music festival or football match is more sensitive to time and space management rather than the physical environment. Still supportive facilities and microclimates can affect social activities in some cases (e.g. Australian Open Tennis was continuing in 43°C temperature of Melbourne on 14 January 2014, while Federation Square had almost lost its normal activities).

Gehl (1987) argues that optional activities are the only ones which are influenced strongly by physical dimensions of public space. As such, he suggests that in order to make more active public spaces, specific focus should be on optional activities.

## **Materials and Methods**

Research on public space and public life in Sydney (2007), Melbourne (2004) and Adelaide (2002 and 2011) has been conducted by mapping pedestrian traffic and stationary activities in the three cities based on observational methods (Gehl, 2002, 2004, 2007, 2011). However, in existing public space and public life studies the focus is on pedestrian flow and stationary activities in ideal climates. This research aims to extend the scope of public space and public life research into higher temperatures (case study of Adelaide).

Recent Studies of outdoor thermal comfort are focusing on temperature, humidity, air-flow and radiation as physical factors of microclimate (Walton, Dravitzki, & Donn, 2007). Literature on outdoor thermal comfort reveals that the state of adaptation to outdoor climate and the natural air-conditioning are effective factors in human comfort in public space. People adapt themselves to climate conditions by selective activities such as clothing and sunlight expose-prevent actions (Brager & de Dear, 1998; Yao, Li, & Liu, 2009). Social interaction is also considered as a potential contributor (Yao et al., 2009). Public life in Australian cities involves a variety of users with different background environments (huge differences in general expectations from climate) and different cultural responses to combat the excess heat in public space (e.g. clothing and outdoor activity choices).

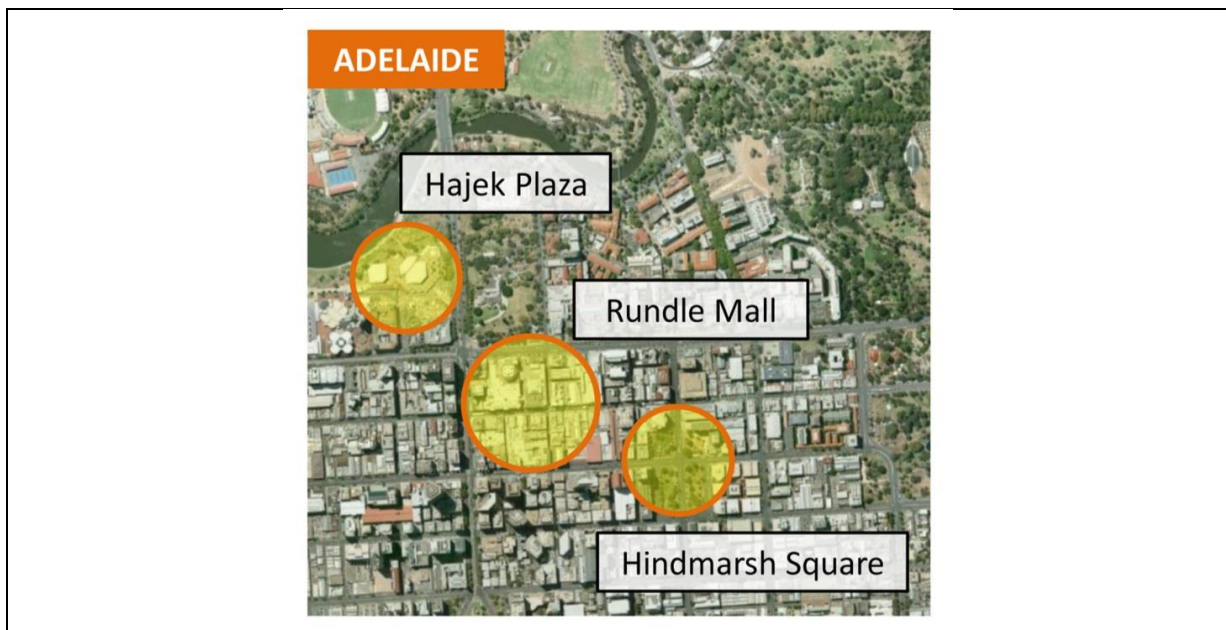
Direct observation and field measurement are used to identify the acceptable temperature thresholds for Thermal Resilience in public spaces of Adelaide. The current research will study three conventional public spaces in regards to their microclimates and embodied activity patterns. Selected public spaces were monitored from February 2103 to April 2014, concentrating on two stages:

- First, moderate climate condition during spring, autumn and summer (temperature between 19 and 28 degrees centigrade) as the benchmark point (during weekdays excluding public holidays)

- Second, hot climate of summer time (temperature between 28 and 42 degrees centigrade) to map the result of extra heat stress on outdoor activity patterns (during weekdays excluding public holidays)

The selected public spaces for this study are Rundle Mall as the pedestrian-oriented shopping street, Festival Centre and Hajek Plaza as hard-landscaped public spaces and Hindmarsh Square as soft-landscaped public space (see Figure 1). The selected public spaces are located within a kilometre distance from each other in the CBD of Adelaide.

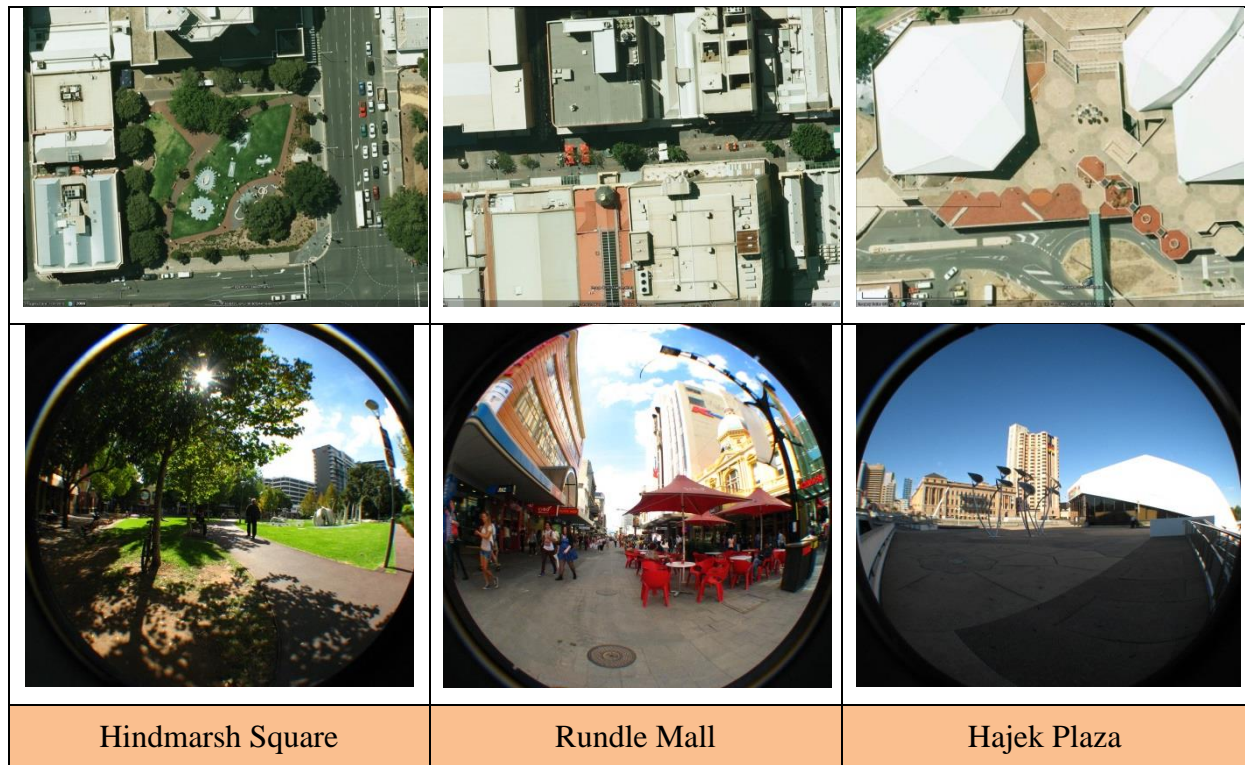
*Figure 1. Three selected public spaces in Adelaide are Rundle Mall, Hajek Plaza and Hindmarsh Square*



Due to various functions of the selected public spaces, it is not practical to compare the number of users and activity patterns in each space to the others. Each public space is being monitored and compared to its own benchmark (average) situation. Thermal Resilience of each space is based on a comparison between its normal and heat stress conditions. Then the normalised results can be compared to each other to study which space has the higher Thermal Resilience and Performance.

APT and activity patterns in each public space are observed and mapped in 10 minutes intervals during hourly periods. Observation is limited to working hours between 10am to 5pm during weekdays to insure the consistency of the collected data. Weekends and public holidays are not included in the final data, because activity patterns and users of the public spaces change significantly during these periods, and they do not represent daily life of the public space in these cases (they can still inform some aspects of the public life, but are out of the scope of this study).

*Figure 2. Three selected public spaces has diverse physical and activity characteristics*



Activity patterns are coded 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). Based on the literature, direct observation is considered as an effective method to investigate people activities in the natural settings of the built environment (Sanoff, 1991; Sirkin, 1999; Bryman, 2008; Kllet, 2011; Gehl & Svarre, 2013). Patterns and frequency of each activity are recorded, utilising direct observation mapping sheets. Observed data is analysed via scattered graphs, correlational and linear regression analysis to investigate the effect of APT on outdoor activity patterns in public spaces of Adelaide.

Urban greenery is mapped via desktop extraction of urban canopy coverage (i.e. surfaces up to the canopy of trees in public space) from Google Earth images. The proportion of tree, concrete, paving, asphalt, surface water, grass, sand and bark chips in each public space is calculated with iTree Canopy tool. In each public space 100 sample points are selected randomly (by the software) for the evaluation of this canopy features. Due to the land cover feature limitation of iTree Canopy (maximum six layers), public space features with similar thermal characteristics are grouped (see Figure 7). Thermal Resilience of activities in each

space is compared to the urban greenery ratio and typology for further analysis of any potential correlations.

Apparent Temperature (APT) is used as the reference for the human-perceived equivalent temperature in the space. As Steadman (1979) defines APT can be calculated based on dry-bulb temperature (what thermometers show) and relative humidity. APT is also known as Heat Index, real feel temperature and humidex in the literature.

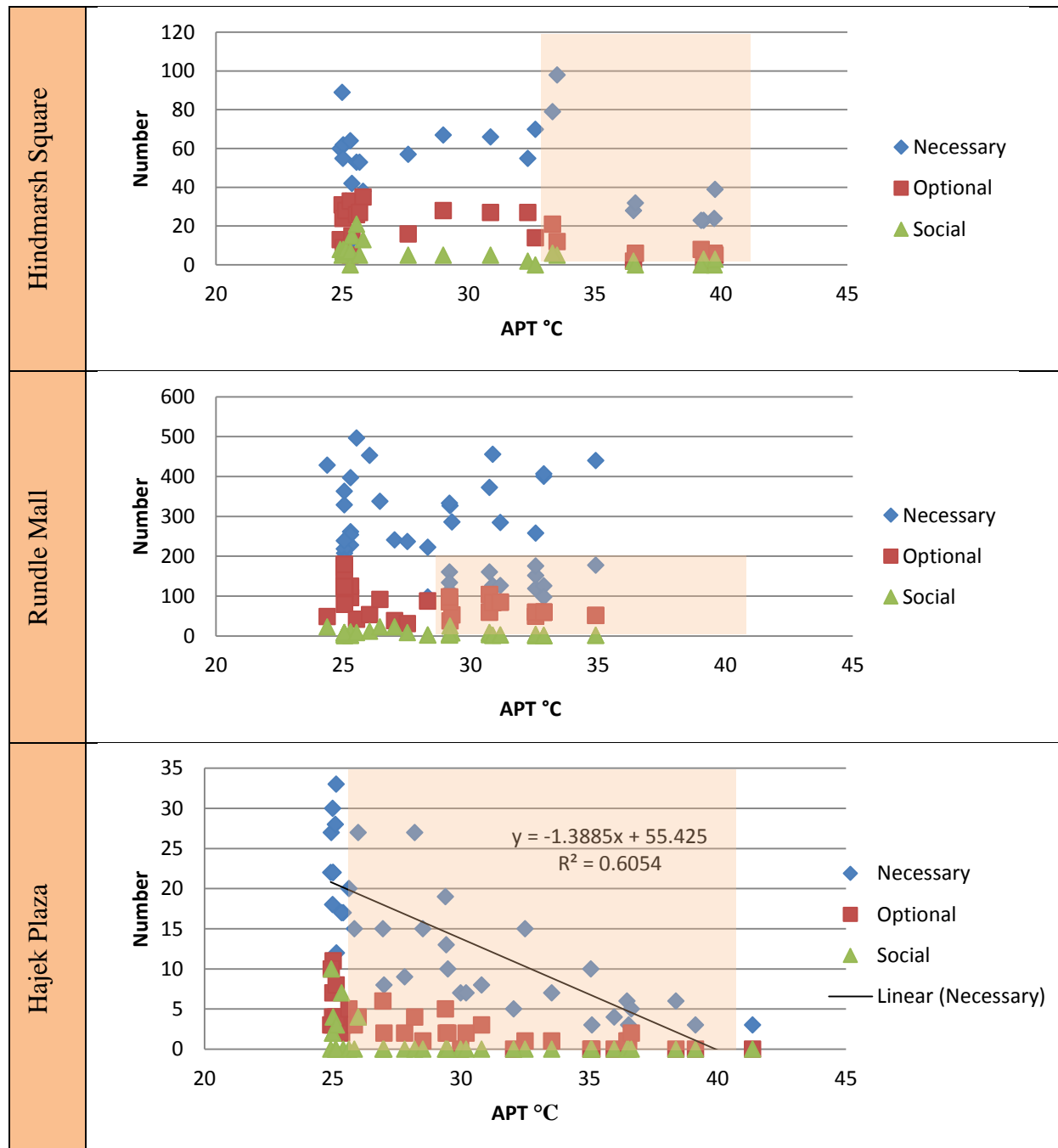
## **Results**

Activity patterns in Hindmarsh Square, Rundle Mall and Hajek Plaza have been monitored, coded and mapped from February 2013 to April 2014 to ensure that seasonal changes in activity patterns do not blur research results. Frequency and location of walking, working, sitting, standing, lying down, meeting, eating, playing, sport, music playing and socio-cultural activities were recorded in observation sheets, and then transferred to data sheets. Although activity patterns have more in-detail codes, for data analysis activity patterns are 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).

Activity patterns in the three spaces are reflected in Figure 2. A primary comparison of the results shows the relatively significant amount of necessary activities in Rundle Mall compared to the other two public spaces. This significant rate of walking activities is related to daily pedestrian travels to the city through the pedestrian mall and shopping activities. On the other side of the range is Hajek Plaza, which is located near the riverbank, far from everyday necessary travel.

Rundle Mall also shows lower maximum temperature compared to Hajek Plaza and Hindmarsh Square (max APT of 35°C compared to 42°C in Hajek Plaza and 39°C in Hindmarsh Square). Considering the similar timeframe of observations; this cooler microclimate may be because of the air-conditioning of numerous shops, projecting to outdoor space through the open doors (based on the field measurement in this study the 24°C indoor air is moderating the hotter temperature of outdoors via air flow in micro scale).

Figure 3. Necessary, optional and social activities in Hindmarsh Square, Rundle Mall and Hajek Plaza between February 2013 and April 2014



#### The Effect of APT on Necessary Activities

According to Figure 3 necessary activities in Rundle Mall, are spread randomly in the thermal spectrum. In other words, necessary activities are not dependent on APT in the Mall.

However, the pattern of walking in Rundle Mall is shifting towards shadowed areas for the temperatures above 28°C.

*Figure 4. Walking activities shift towards shadowed areas in hotter temperatures in Rundle Mall*



On the other side of the range, a drop in necessary activities in Hajek Plaza is very significant (see Figure 3). Starting at 25°C with an average 30 people walking through the space, Hajek Plaza loses 0.7% (1.38 people per degree) of its necessary activities for each 1°C increase of APT. This drop of necessary activities has the correlation coefficient (R) value of -0.77 to APT. It means that this constant decrease in Hajek Plaza has a strong dependency on an increase in APT (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 Apparent Temperature, the P value (significant f) is less than 0.001 (P values less than 0.05 in regression analysis indicate that is less than 5% chance that the two variables are not related, and this is considered as a reliable model for prediction future scenarios). Thus, based on the observed data and the regression model Hajek Plaza will have no necessary activities in APTs over 40°C (the prediction matches the observed data).

Necessary activities have a significant drop in Hindmarsh Square for APTs above 32°C. It means that citizens meaningfully avoid walking through Hindmarsh Square in over 32°C APTs. Background research in Japan (Ichinose et al., 2008) reveals that a larger proportion of people stay indoors in air-conditioned shopping areas or walk through buildings to reach their destinations in such hotter microclimates. Necessary activities in Hindmarsh Square have the correlation coefficient (R) value of -0.88 to APTs above 32°C. It shows strong negative (downhill) dependency of necessary activities to APT for hotter microclimates. In the regression model P value (significant f) is 0.002, which shows that the model in Figure 4 can

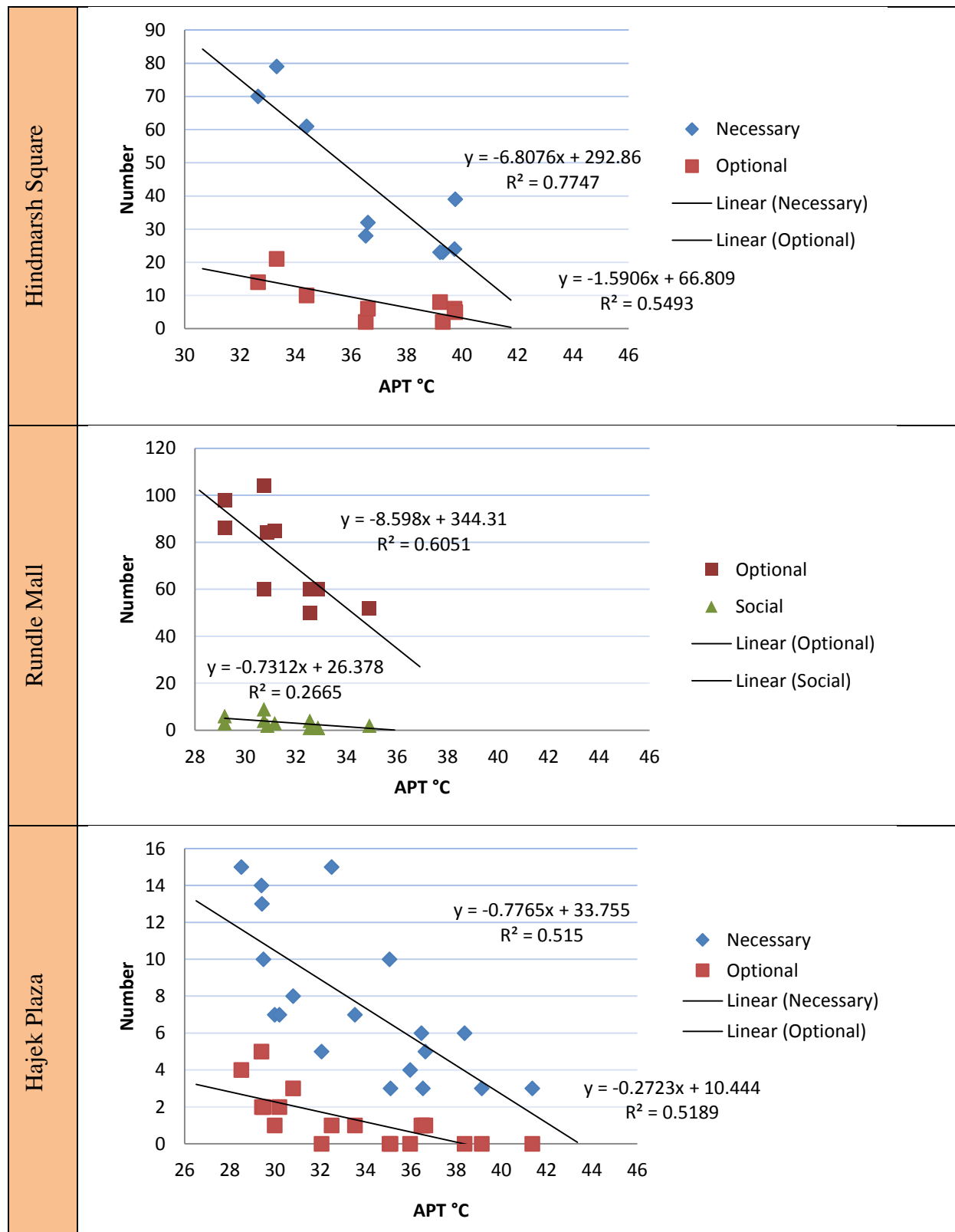
be used to predict necessary activities in Hindmarsh Square for APTs above 32°C. As such, starting from the average of 73 necessary activities at 32°C, Hindmarsh Square is losing 6.8 people for every 1°C increase in APT. The regression model also reveals that at APT=43°C, Hindmarsh Square will not have any necessary activities (because of cooler materials, good shadow coverage and tree canopy, APT in Hindmarsh Square was 39.3°C when Adelaide CBD was experiencing 43°C on 16 January 2014). This conclusion depends on the assumption that the form of relationship is maintained in higher temperatures.

### *The Effect of APT on Optional Activities*

According to the theory of public space and public life, optional activities are the most vulnerable activities to the microclimate of the space. Although the maximum vibrancy of optional activities is happening around 25°C in all the three public spaces, a random distribution of optional activities is identifiable until the APT reaches a specific threshold in each public space (see pink shades in Figure 4). This Critical Thermal Threshold (CTT) is 32°C in Hindmarsh Square, 29°C in Rundle Mall and 27°C in Hajek Plaza. After this CTT, a consistent decline in optional activities begins (see Figure 5). The decline of optional activities in Hindmarsh Square has the correlation coefficient (R) value of -0.74 to APTs above 32°C (significant negative dependency). The R value of optional activities is -0.77 (significant negative dependency) to APTs above 29°C in Rundle Mall, and -0.72 (significant negative dependency) to APTs above 27°C in Hajek Plaza.

A linear regression model of optional activities and APT in the three public spaces indicates that Hindmarsh Square will lose all its optional activities at 42°C (see Figure 5 and Table 1). This critical zero-activity condition will happen 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 APTs over 38°C many times with no optional activities within 10 minutes of observation time (see Figure 5). It means that Hajek Plaza is already experiencing its critical thermal conditions, whereas Hindmarsh Square and Rundle Mall have a few degrees left to reach its critical thermal conditions. This difference is being facilitated by the projected cool air from the indoor air-conditioning systems in Rundle Mall, and the envisaged critical zero-activity condition depends on the assumption that the form of relationship is maintained in higher temperatures.

Figure 5. Necessary and optional activities in Hindmarsh Square, Rundle Mall and Hajek Plaza in hotter temperatures



### *The Effect of APT on Social Activities*

As Figures 4 and 5 and Table 1 show, the distribution of social activities does not have any meaningful correlation to normal APT ranges. In higher temperatures, when the space reaches its CTT, this lack of correlation continues to occur in Hindmarsh Square and Hajek Plaza. However, this correlation shows moderate dependency in Rundle Mall (R value = -0.51), and it gives us the ability to predict (P value = 0.01). The model reveals that Rundle Mall will lose its social activities for  $APT > 36^{\circ}\text{C}$ , which is not a confident statement. In reality, Rundle Mall does keep its social activities in almost a constant minimum level after its CTT of  $30^{\circ}\text{C}$ . 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 (see Figure 6).

*Table 1. Statistical significance (P value) and correlational coefficient (R value) of activities to Apparent Temperature after the Critical Thermal Threshold (CTT)*

| R value<br>(correlational analysis)                    | Necessary Activities above<br>Critical Thermal Threshold<br>(CTT) | Optional Activities<br>above Critical Thermal<br>Threshold (CTT) | Social Activities<br>above Critical Thermal<br>Threshold (CTT) |
|--|---|--|--|
| P value<br>(regression analysis)                       |   |  |  |
| APT in Hindmarsh<br>Square, CTT = $32^{\circ}\text{C}$ | R = -0.88<br>P = 0.002  | R = -0.74<br>P = 0.02  | R = -0.17<br>P = 0.66  |
| APT in Rundle Mall,<br>CTT = $30^{\circ}\text{C}$      | R = 0.22<br>P = 0.31  | R = -0.77<br>P < 0.001   | R = -0.51<br>P = 0.01  |
| APT in Hajek Plaza,<br>CTT = $28^{\circ}\text{C}$      | R = -0.71<br>P < 0.001  | R = -0.72<br>P < 0.001   | R = N/A (div/0)<br>P = N/A                                     |

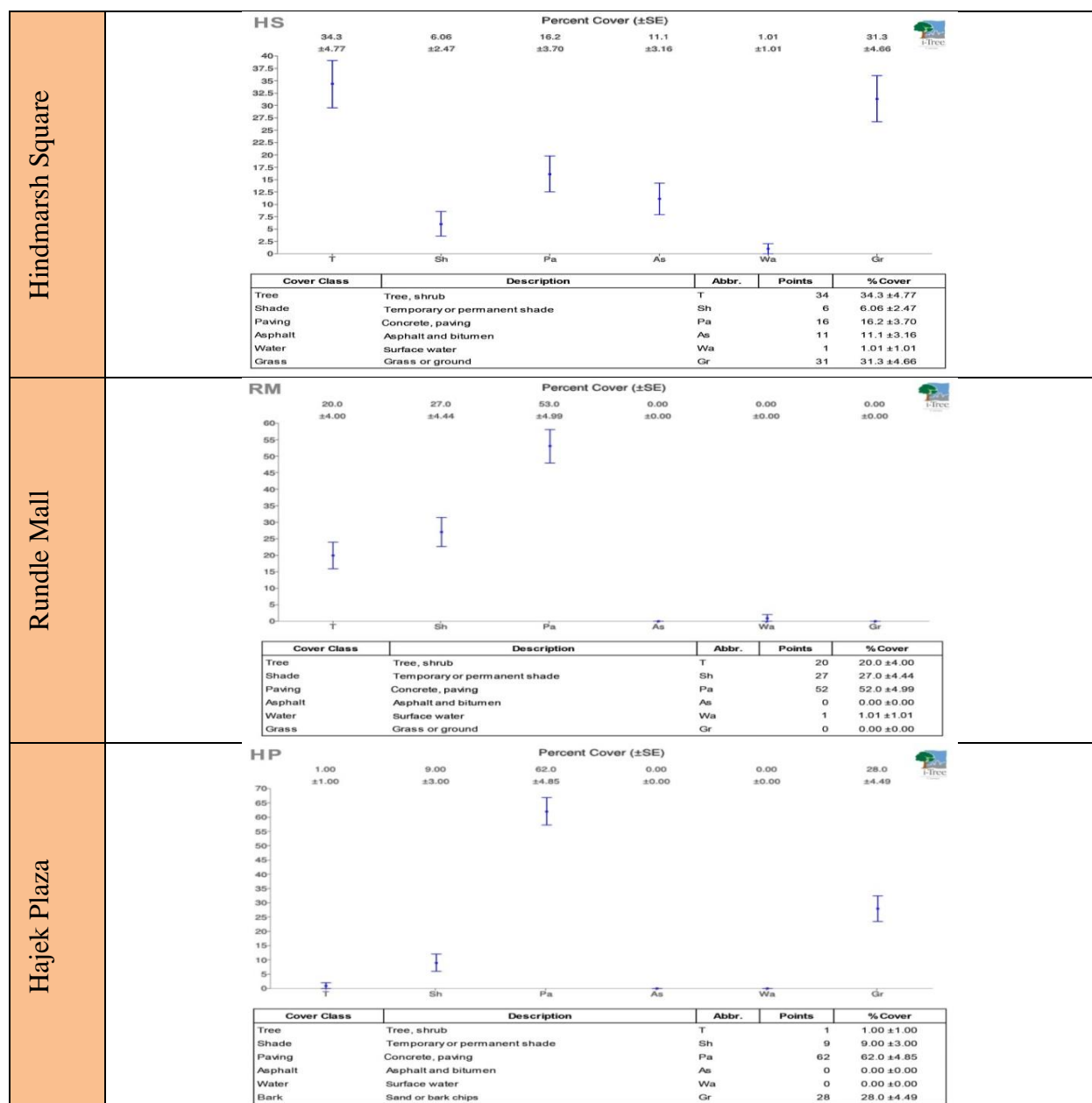
*Figure 6. Rundle Mall keeps its minimum level of social activities, after its CTT of  $30^{\circ}\text{C}$  with the aid of shadow patterns, mechanical support and event management during Fringe Festival, February 2014*



### Land Cover Materials and APT

Canopy cover materials evaluation via iTree canopy shows that 65% of Hindmarsh Square canopy is covered by grass and tree feature layers, while this percentage is 20% of Rundle Mall and only 1% for Hajek Plaza. Hard surfaces (including asphalt, concrete and paving; 6% under shadow in average) cover 33% of Hindmarsh Square canopy, while this percentage is 79% in Rundle Mall (27% under shadow in average), and 71% in Hajek Plaza (9% under shadow in average). Surface water covers less than 1% in Hindmarsh Square and Rundle Mall and does not exist in Hajek Plaza (see Figure 7).

Figure 7. Canopy cover materials in Hindmarsh Square, Rundle Mall and Hijek Plaza in 2013



### **Further Discussion:**

Based on the results of this research, we define thermal resilience as the ability of the space to maintain its normal activity patterns during out of comfort temperature ranges. As such, thermal resilience deals with two aspects of outdoor activities: typology and frequency of activities. Distribution of necessary, optional and social activities over the public space and the number of participants in certain timeframe can be proper indicators for thermal resilience in public space.

#### *Thermal Resilience of different Activity Patterns*

According to this definition, Table 1 and Figures 5 and 7, thermal resilience of necessary activities is higher in Rundle Mall with a higher rate of supporting land uses, shadow coverage and medium rate of urban greenery, followed by Hindmarsh Square. Necessary activities in Rundle Mall are not be affected by the Apparent Temperature (APT), and in Hindmarsh Square has a high Critical Thermal Threshold (CTT) of 32°C. However, necessary activities in Hajek Plaza with very low supporting land uses, shadow coverage and urban greenery has the least resilience to heat stress with 4°C lower Critical Thermal Threshold.

Thermal resilience of optional activities, however, is higher in Hindmarsh Square with higher CTT of 32°C, and lower rate of activity fade in higher temperatures (see Figure 5 and Table 1), followed by Rundle Mall (CTT = 30°C and activity higher rate of optional activity fade). However, optional activities in Hajek Plaza have the least CTT of 28°C, and start to disappear (with zero values) from the public space right after 32°C (reach a statistical mean zero value at 38°C).

#### *Urban greenery and Thermal Resilience of activities*

As optional activities are the subject of concentration in the theory of public space and public life, we argue that Hindmarsh Square has the best performance in average resilience rate of activity patterns to higher APTs. According to the current study results of urban greenery and Figure 7, Hindmarsh Square has the highest rate of urban greenery including tree canopy and grass cover among the studies public spaces.

Tree canopy covers 34% of Hindmarsh Square; while in Rundle Mall covers 20% and in Hajek Plaza only 1%. Furthermore, 31% of Hindmarsh Square canopy is covered by grass, while the grass cover is almost zero in Rundle Mall and Hajek Plaza. Although, this primary result cannot be generalized due to the limited number of observed public spaces, it opens a

new logic towards supporting the vitality of increase in urban greenery for quality public space and public life.

### *Boundaries of Necessary and Optional Activities in Higher Temperatures*

A comparison between the behaviour of necessary and optional activities for APTs above the Critical Thermal Thresholds in Figures 5 and 6 show that necessary activities in Hindmarsh Square and Hajek Plaza behave similar to optional activities in higher temperatures (even with higher R value). It shows that the boundaries between necessary and optional activities can shift based on the functions of the space. It means that walking, which is a necessary activity in Rundle Mall, looks more optional activity in Hajek Plaza and Hindmarsh Square. It becomes more reasonable when we consider that necessary activities become optional in the places where other options are available (i.e. there are other routes to work, home or school or they can work more safe somewhere else). This shifting activity effect in higher temperatures reflects that activities in spaces with less supportive activities and shadow coverage are far more sensitive to excess heat.

### **Conclusions**

Physical dimensions of public space including metric dimensions and microclimates can affect public life duration and frequency in public space. 'Public life changes constantly in the course of the day, week, month and over a year' (Gehl & Svarre, 2013, p 12). In the physical context, public space is less flexible because of its fixed elements. However, the complex interaction between public space and public life can define the public space in a broader context, which is more diverse, flexible and adaptable to changes. In reality, each public space provides thermal comfort in some proportion of the day. Based on the empirical data, the current research indicates that:

- There are Critical Thermal Thresholds for heat-sensitivity in public spaces. These CTTs vary from 28°C to 32°C in different public spaces.
- Optional activities (sitting, standing, eating, playing and sport) are highly sensitive to heat stress in public space and start to fade after the public space reached its thermal threshold.
- Necessary activities (walking between home and work or for daily shopping) have more resilience to heat stress and have a higher thermal sensitivity threshold than optional activities in public spaces with a diversity of supportive land uses

- Necessary and optional activity patterns are shifting towards shadowed places in higher temperatures.
- Social activities (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 and are more resilient to heat stress.

Urban greenery and shadow coverage can facilitate more diverse and extended activities in public space especially in higher temperatures. Thus, an increase in the tree canopy, softer landscapes and shadow coverage are suggested to achieve higher thermal resilience in public space.

### **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 Australian cities are subject of further analysis via similar method as people responses to urban microclimate are highly contextual.

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