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Climate Adapted People Shelters: Field Assessment

Institute for Sustainable Futures

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Acknowledgement

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Executive Summary

The Climate Adapted People Shelters (CAPS) project was a collaborative, design-led approach to reimagining the place and function of bus shelters, specifically in response to conditions of increasing urban heat and extreme weather events in Western Sydney. CAPS was a collaboration between the University of Technology Sydney's (UTS) Institute for Sustainable Futures, U.lab and Centre for Management & Organisation Studies, the Adaptive Communities Node of the NSW Climate Adaptation Research Hub and the Institute for Culture and Society at Western Sydney University (WSU). The project was supported through the Building Resilience to Climate Change grants scheme, funded by the NSW Office of Environment and Heritage and the NSW Environmental Trust and administered by Local Government NSW.

Engagement with transport users through early stages of CAPS identified dissatisfaction with the protection afforded by bus shelter designs currently in use throughout western Sydney. In response, the CAPS project established an open innovation design competition to develop, in collaboration with a broad range of stakeholders, and design an improved prototype climate adapted people shelter. This winning design was subsequently installed adjacent to an existing bus shelter at a site within Penrith City Council's Local government area.

This report presents the results of an assessment of the CAPS prototype to determine:

- the thermal performance of the new shelter during heat wave conditions
- the social acceptance for users and the utility of the new design to transport operators

The report presents data on the ambient conditions (air temperature, humidity and wind speed) and temperatures of surfaces of selected design elements within the CAPS prototype and the existing bus shelter. Daily temperature profiles of each shelter were determined, and qualitative information was gathered on shelter acceptability through user surveys and observations of user behaviour. An online, 360^{o} video was prepared as a tool to broaden engagement with the community.

We make three conclusions:

1. Within the constraints imposed by a real world research setting and designs that relied on passive cooling of an open structure, it was possible, through incorporation of specific design elements, to influence radiation, temperature, and user thermal comfort within the shelters.
2. Users clearly adapted their behaviour to optimise their thermal comfort, and an outdoor thermal comfort assessment framework of Chen and Ng (2012) provides a useful guide to understanding user behaviour.
3. The elements of design most important to modification of temperature and user behaviour were provision of shade (mediated by roof size and aspect), and seating with respect to shade throughout the day.

Contents

Introduction

Bus shelters often fail to adequately protect users from adverse weather conditions because other design aspects are emphasised (Jacobs et al. in press), and this can present a significant barrier to public transport use that falls unequally on disadvantaged groups in the community (Hine and Mitchell 2001).

Over the past 100 years, heatwaves have caused more deaths in Australia than any other natural hazard (Steffen et al. 2014). By 2030, Western Sydney is projected to experience up to 7 additional days above 35°C per year placing exposed communities at heightened risk (AdaptNSW 2015), including Sydney's bus users (currently estimated at approximately 290 million trips per year). The NSW Government (2011) advises that bus shelters should provide a comfortable, convenient, reliable, and safe service that is accessible to all. They further advise that bus shelter designers keep in mind the requirements of the elderly; mobility, vision and hearing impaired; and people with young children, strollers and prams. These groups are often most heavily dependent on public transport and among the most vulnerable to the effects of urban heat. Incorporation of adaptation measures in bus shelters would likely have substantial co-benefits for human health and sustainability (Spencer et al 2017).

The Climate Adapted People Shelters project was an open innovation design competition, which used human-centred design, participation of multiple stakeholders and a research process to verify the effectiveness of project outcomes. The project was a collaborative process (Table 1) that involved transport users, local councils, planning and transport authorities, commercial users, and other interested parties in several high traffic locations in Western Sydney.

Table 1. Description of the activities included in each stage of the CAPS project.

Stage	Description
Plan	Project planning and preliminary stakeholder engagement with project partners. Media planning and engagement. Design and competition brief and production of web and other content.
Launch	Workshop/event for participating design teams to clarify design and competition criteria and a facilitated session with users and other stakeholders to share stories, experiences and needs.
Ideas	Open workshop where design teams present their concept ideas based on learnings from user research and collect feedback from users, experts and other stakeholders.
Prototypes	Public workshop and presentation of prototypes, anticipated user experience and models where further feedback is sought from users, experts and other stakeholders.
Reveal & Display	Public event where each team presented its final solution design as a model and a panel judged concepts and models according to design criteria. Announcement of competition winners and display of submissions.
Build	Winning design built to scale and installed at location in consultation with council.
Measure	New shelter effectiveness measured and documented to inform future urban planning and climate adaptation strategies.

This report is a companion document to two additional reports:

1. a review of the current and potential uses of smart infrastructure technologies within bus shelter designs with a view to informing ideas and strategies for future investment in urban heat mitigation activities in Western Sydney (Barnes et al 2017); and,
2. a detailed account of the design process (CAPS Plan to Reveal and Display stages), which is currently in press (Jacobs et al 2018).

The current document reports on the Build and Measure stages (Table 1) designed to assess the field performance of the shelter after installation at a field site.

Methodology

Location

The site selected for the installation of the CAPS prototype was Derby Street, Penrith (Figure 1).

Figure 1. (a) Location of the CAPS installation at Derby Street, Penrith; (b) an aerial view of the site showing Nepean Hospital (opposite); and, (c) street view prior to the CAPS installation of the existing shelter (BS) facing the direction of approaching buses, and adjacent medical centre-pharmacy complex. Source: Google Maps

The CAPS prototype was installed over night on 29 November 2017. The existing bus shelter was retained at the site to allow for a direct comparison of thermal performance with CAPS (Figure 2). The site was chosen as it was relatively busy during the day time and serviced transport users of a wide range of ages and with varying degrees of mobility given its proximity to Nepean Hospital.

Figure 2. Bus shelters installed at the monitoring site – the original bus shelter (BS, left) and the Climate Adapted People Shelter (CAPS, right).

Monitoring

The monitoring program was designed to provide data to assess:

- the thermal performance of the new shelter during heat wave conditions; and,
- the social acceptance for users and any difficulties observed for transport operators.

Monitoring was initially delayed awaiting forecast maximum temperatures of 30-40oC without rain from the Bureau of Meteorology for the Penrith area. On Tuesday and Wednesday 12-13 December conditions were suitable and UTS:ISF researchers attended the Derby Street site with representatives of Penrith City Council.

Monitoring of biophysical performance consisted of ‘spot’ readings of selected ambient environmental variables and surface temperature of shelter materials recorded at regular intervals over two consecutive days, and detailed temperature measurement at 10 minute intervals.

The assessment of user acceptability consisted of observation of user behaviour and surveys of bus stop users.

Temperature Loggers

Twenty ‘button’ data loggers (Thermocron General TC) were installed (10 in each shelter) to record at 10 minute intervals, the daily profile of temperature throughout the two days (Figure 3). Data loggers were attached at positions in each shelter not exposed to direct sunlight (generally on the underside of seats or structural beams).

Figure 3: Positions within each shelter of the thermal data loggers installed to monitor daily temperature changes.

Spot Readings

Spot readings of ambient temperature, relative humidity and wind speed were recorded from 0900–1700, at hourly, intervals over two days. Coincident with these measurements, surface temperature of shelter materials (horizontal seat surface, underside of the roof and concrete ground surface) were recorded on left and right sides of the shelters to ensure sun and shade readings were captured. Spot readings were measured using a Lutron LM-8000A 4-in-1 meter from Digital Instruments. Surface temperatures were measured with an infra-red thermometer (Repco RST195) with laser guided siting at a distance of between 10 and 30 cm.

Surveys

Bus stop users were surveyed in two ways:

1. on site throughout the monitoring period using a pre-tested survey instrument; and
2. in an online version of the same survey instrument hosted on the Penrith City Council website. The link to the survey was displayed on a poster within the CAPS prototype.

In addition, digital photographs of user behaviour were taken throughout the day to observe users' preferred locations for sitting or standing while waiting for buses within each of the shelters.

In accordance with human ethics approval, the researchers firstly informed people waiting at Derby Street bus stop about the about the installation of the CAPS prototype, and then requested their consent to participate in a short survey. The survey consisted of a mix between closed and open-ended questions (refer to Appendix A).

Recording

A 360 degree video and images were recorded (using a Garmin VIRB 360o video camera) during the monitoring period for promotion of the project. The resulting 360o images were integrated into the 360 web app Vizor (Vizor.io) with a series of infographics from this report to create a short interactive work to explore alternative ways to engage decision makers and the general public in the design of climate adapted infrastructure.

Findings

Ambient conditions

Air temperatures within each of the shelters were similar on both days (Figure 4a). On day 1 temperatures fluctuated throughout the day from a low of about 29ºC at 9:00 and 13:00 to maxima of just under 35º at 11:00 and 15:00 hours. This pattern most likely reflected the presence of scattered cloud and shade trees which caused variations in the radiation load on the local environment. On day 2, air temperatures rose throughout the day reaching a peak of about 40ºC at 15:00 hours.

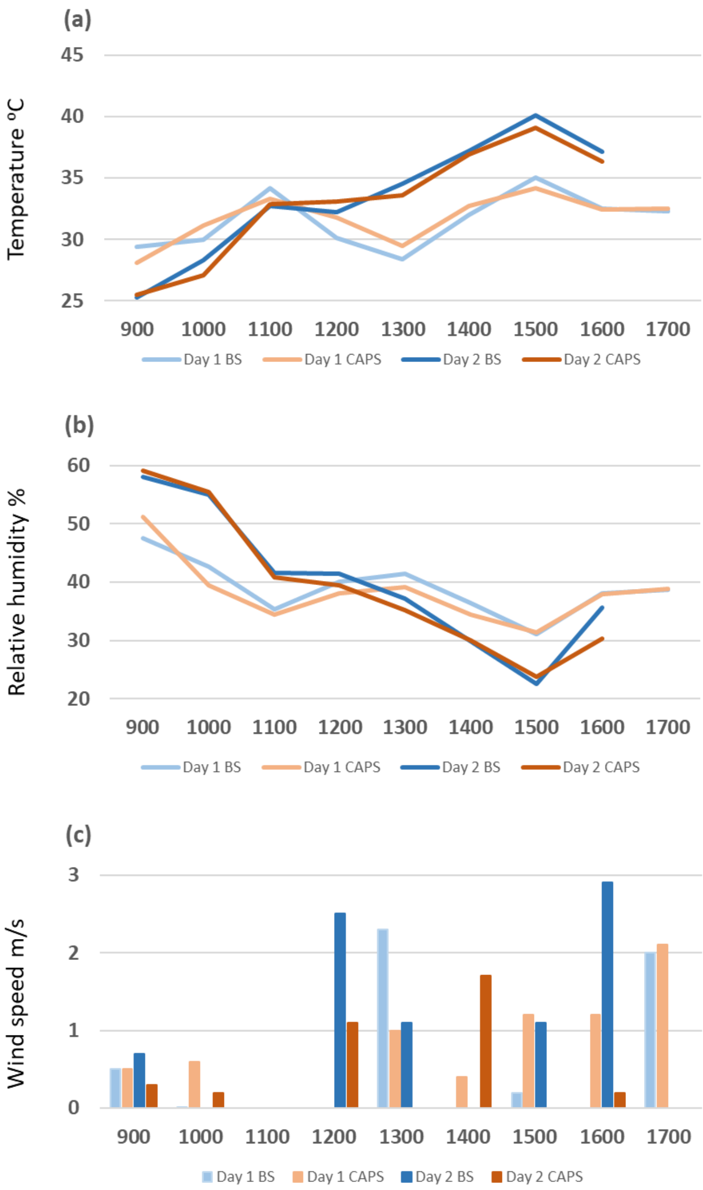

Figure 4. Changes in (a) air temperature (ºC), (b) relative humidity (%) and (c) wind speed in the two bus shelters (CAPS and BS) over two consecutive days.

Relative humidity (Figure 4b) generally fell throughout the day showing a typical inverse pattern of change when compared with temperature. Humidity was highest at 9:00 hours (approximately 50% and 59% respectively on days 1 and 2) and lowest at 15:00 hours (31 and 22% on days 1 and 2 respectively) with little difference between the shelters.

Wind speed (Figure 4c) showed little consistent pattern and was generally higher during the afternoon than the morning. The variation in wind speed indicates turbulent mixing of the air within the shelters with that of the external environment.

Temperature Loggers

The daily temperature profiles of the two shelters are shown in Figures 5 and 6. The profiles indicate that day 2 was up to 7°C hotter for brief periods than day 1 in some position within each shelter. Temperatures generally peaked at around 15:00 hours with some smaller peaks occurring at times between 12:00 and 15:00 hours.

The temperature profiles varied considerably with location of the sensor within the shelter. For example, in both shelters, sensors located at higher positions (Figures 5 and 6, 1-4) showed greater variation in temperature and reached higher maximum temperatures than at lower positions (Figures 5 and 6, 9-10).

Horizontal positioning also influenced the daily temperature profile because it determined the pattern of shade and therefore the radiation load on the shelters' surfaces throughout the day. For example, the seat located on the left-hand side of both shelters was exposed to direct solar radiation from 9:00 to about 10:30 hours each morning. Accordingly, the sensors at these positions (position 9 in Figures 5 and 6) recorded temperatures of up to 37oC, much hotter than the temperatures at other positions during this time.

The shelters had similar temperature profiles throughout the day with some variation. The major difference between the shelters was that the maximum temperature of the existing shelter (BS) was up to four degrees hotter at some positions than the CAPS prototype, particularly on day 2 when temperatures were between 35 and 45oC (for example, positions 4 and 8 in Figures 5 and 6).

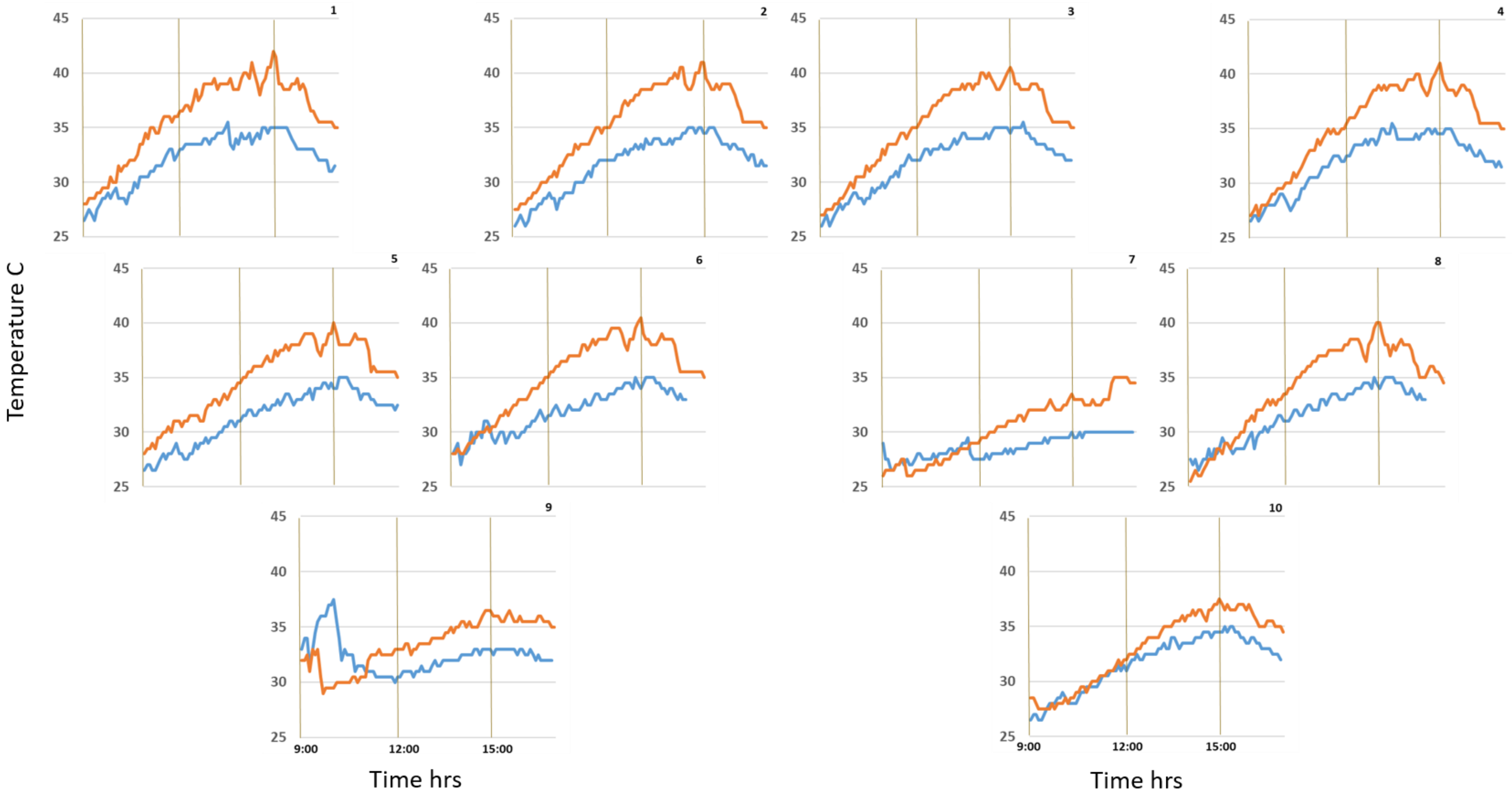

Figure 5. Daily temperature profile of the Climate Adapted People Shelter (CAPS). Temperatures were recorded on two consecutive days (Day 1 blue line; Day 2 orange line) at 10 positions within the shelter. Vertical lines are times 9:00, 12:00 and 15:00 hours.

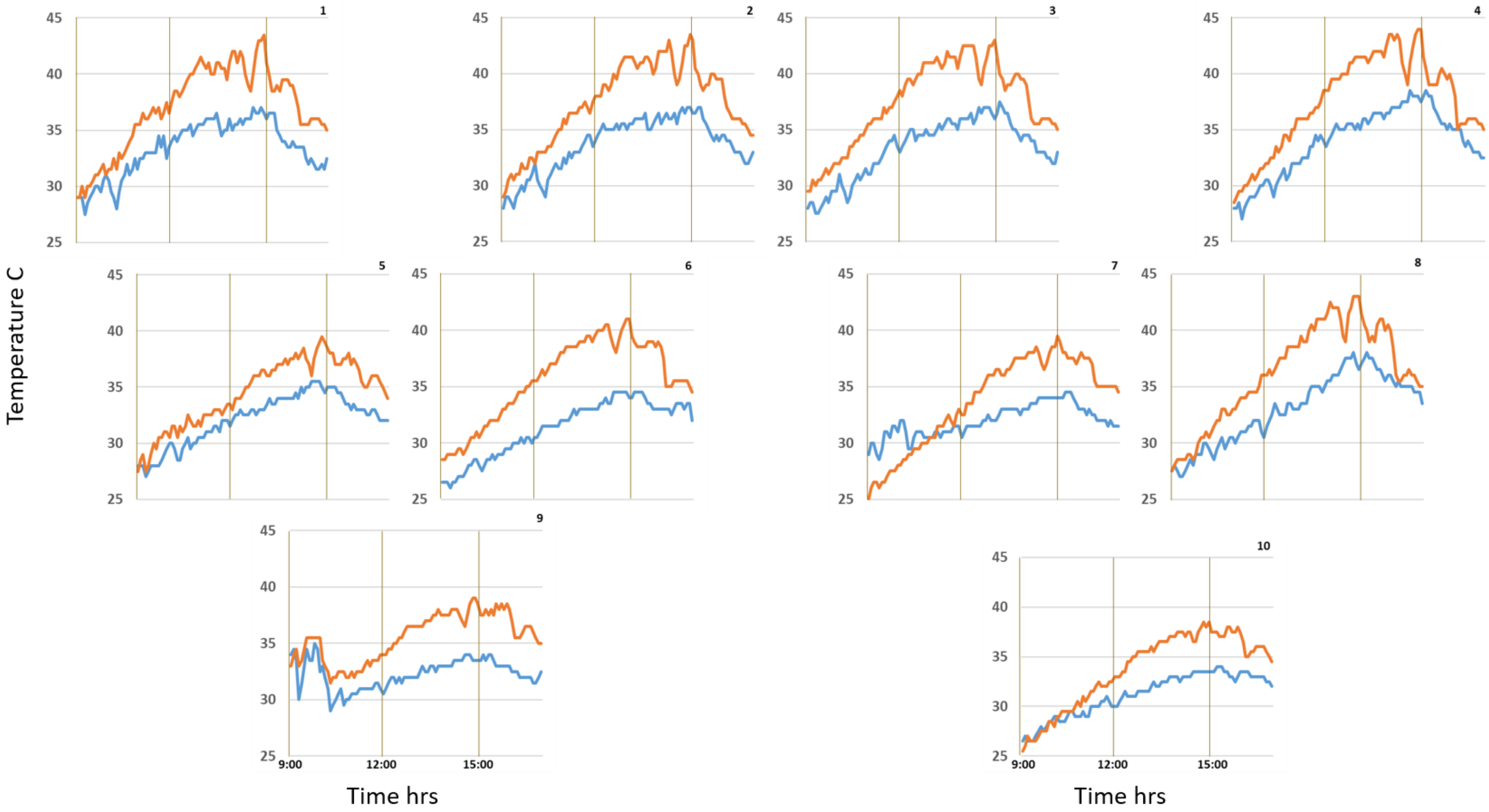

Figure 6. Daily temperature profile of the original Bus Shelter (BS). Temperatures were recorded on two consecutive days (Day 1 blue line; Day 2 orange line) at 10 positions within the shelter. Vertical lines are times 9:00, 12:00 and 15:00 hours.

Spot Readings of Surface Temperature

Surface temperatures change proportionally with incident solar radiation and through equilibration with the temperature of the surroundings. Under radiation load, surfaces increase in temperature as incident solar energy is converted to sensible heat driving changes in the thermal micro-environments within and around structures. People sense this heat where they come into close contact with surfaces (such as bus shelter seats) or the air in proximity to them (ground, walls or ceiling of a shelter) (Figure 8).

Figure 7 shows the changes in surface temperature of a section the ground (concrete slab) within each of the shelters. Ground surface temperatures were higher than air temperatures (Figure 4a) at all times of measurement. At 9:00 hours temperatures exceeded 36°C and rose steadily throughout the day to maxima of up to 61°C between 13:00 and 14:00, then declined with radiation load throughout the afternoon. Ground surface temperatures were hotter on day 2 than day 1 and reached slightly higher maximum values in the CAPS than BS.

Ground

	BS		CAPS	
	Day1	Day 2	Day 1	Day 2
900	37.7	37.2	36.3	37.8
1000	40.9	40.8	40.3	38.7
1100	43.6	36.2	43	48
1200	47.7	49.7	49	53.6
1300	54.4	58.7	55.5	61
1400	54.5	56.6	56.1	59.7
1500	50.1	42.3	51.2	37.4
1600	50.9	46	42.6	42.7
1700	48.5		39.9	

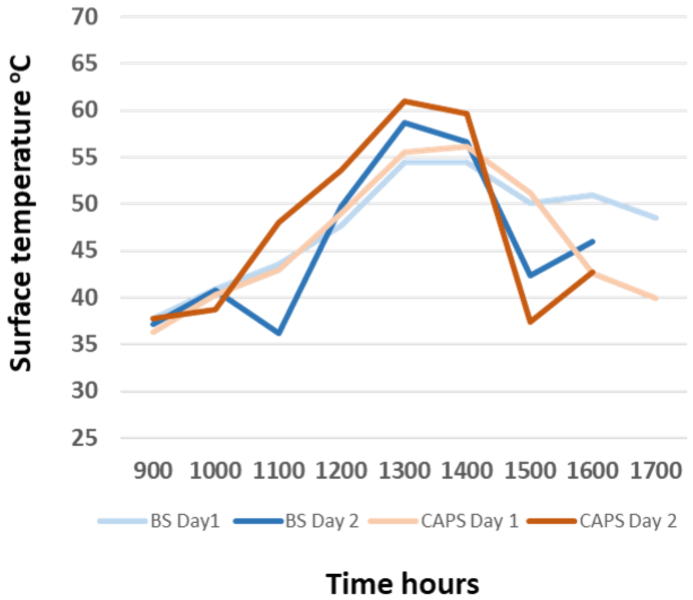

Figure 7. Surface temperature of the ground inside the two bus shelters (BS and CAPS) throughout two consecutive days.

Figure 8: Side view of the two shelters (BS, left; CAPS, right) illustrating the differences in seat and roof construction and areas of shade.

The upper surface of the shelter roof is exposed to extreme levels of incident solar radiation. However, people standing within the shelters would sense, at head height, heat that is transmitted through the roofing material and radiated into the shelter from the lower surface.

Figure 9 shows the changes in surface temperature of the underside of the roof of each of the shelters. Roof surface temperature peaked between 13:00 and 14:00 hours on both days. In contrast to ground surface temperature, the differences between the shelters was quite marked. The existing shelter (BS) had higher roof temperatures throughout most of the day, and peak temperatures up to 15ºC higher than CAPS at 14:00 hours.

The sharp decline in roof temperature after 14:00 (Figure 9b) may have been at least partly attributable to shadows cast on the shelters late in the day from nearby buildings and vegetation growing at the right hand end of CAPS (visible in Figure 8).

(a) Roof Left

	BS		CAPS	
	Day1	Day 2	Day 1	Day 2
900	49.3	44.8	38.8	39.8
1000	48.6	47.3	40.8	41.7
1100	46.6	59	42.4	47
1200	56	56.7	45.6	49.3
1300	56.3	60.5	48.9	54.4
1400	56.1	63.8	45.9	52.1
1500	50.7	31.8	39.6	35.1
1600	32.2	38.7	37.8	39.4
1700	38.3		36	

(b) Roof Right

	BS		CAPS	
	Day1	Day 2	Day 1	Day 2
900	49.3	43.3	37.4	37.9
1000	49.4	49.9	37.8	38
1100	49.6	59.3	40.3	45.5
1200	55.4	58	43.7	47.8
1300	57.7	63	47.1	53.2
1400	57.9	65.2	44.8	51
1500	32.4	31.1	36.9	32.7
1600	46.6	39.89	36.7	39.4
1700	44.6		34.8	

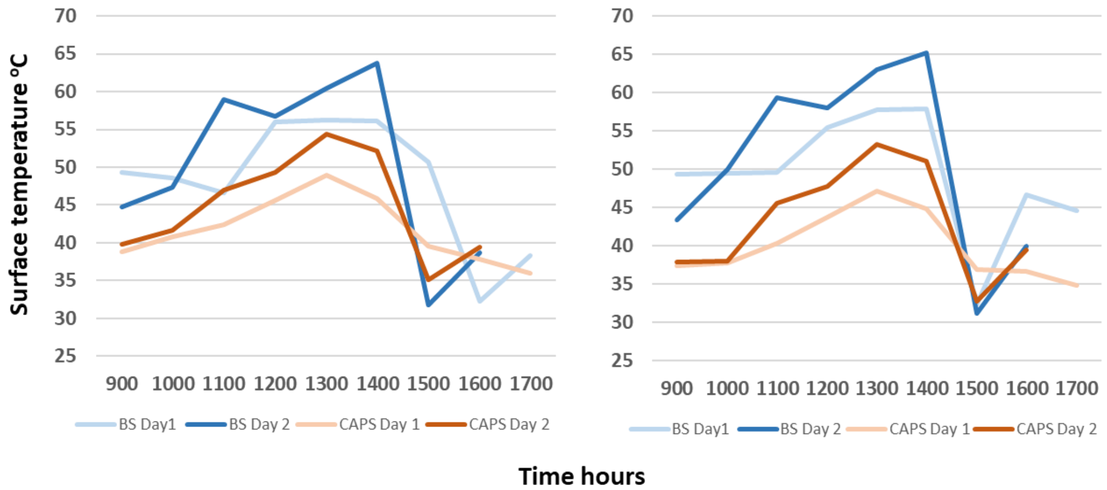

Figure 9. Surface temperature of the underside of the roof of the two bus shelters (BS and CAPS) at two positions (left and right) within each shelter. Shading of cells within tables indicates the relative heat of the surfaces.

Bus shelter users experience heat most intimately through the temperature of the seats. Seats of both shelters remained cooler than the ground surface and underside of the roof for most of the day, except for a short period at 10:00 hours when the CAPS seats were exposed to direct solar radiation (Figure 10). Seats in both shelters were exposed to the sun at various times during the day depending on the shade profile of the shelter roof. Under direct exposure seat temperatures rose peaking at around 42°C. The Temperature of CAPS seats tended to be up to 2°C hotter and warmed faster than BS. However, the CAPS seats also cooled at a faster rate than those installed in BS.

(a) Seat left

	BS Day1	BS Day 2	CAPS Day 1	CAPS Day 2
900	35.8	38.7	33.5	47.3
1000	40.6	37.9	51.4	51.3
1100	38.2	40.8	43.1	48.4
1200	34.5	36	33	37.6
1300	36.1	41	37.3	43.4
1400	36.2	39.4	36.6	41.3
1500	36.4	32	31.5	27.3
1600	33.2	36.6	34	37.9
1700	32.1		34	

(b) Seat right

	BS Day1	BS Day 2	CAPS Day 1	CAPS Day 2
900	33.5	30.6	34.5	34.3
1000	30.3	31.3	36.4	30.6
1100	31.6	31.9	30.4	34.5
1200	32.1	32	32.6	35.9
1300	35.2	41.2	37.3	43.4
1400	35.6	37.2	36.6	41.6
1500	30.6	27.2	31.1	28.5
1600	38.8	35.1	34.8	37.9
1700	37.8		34.1	

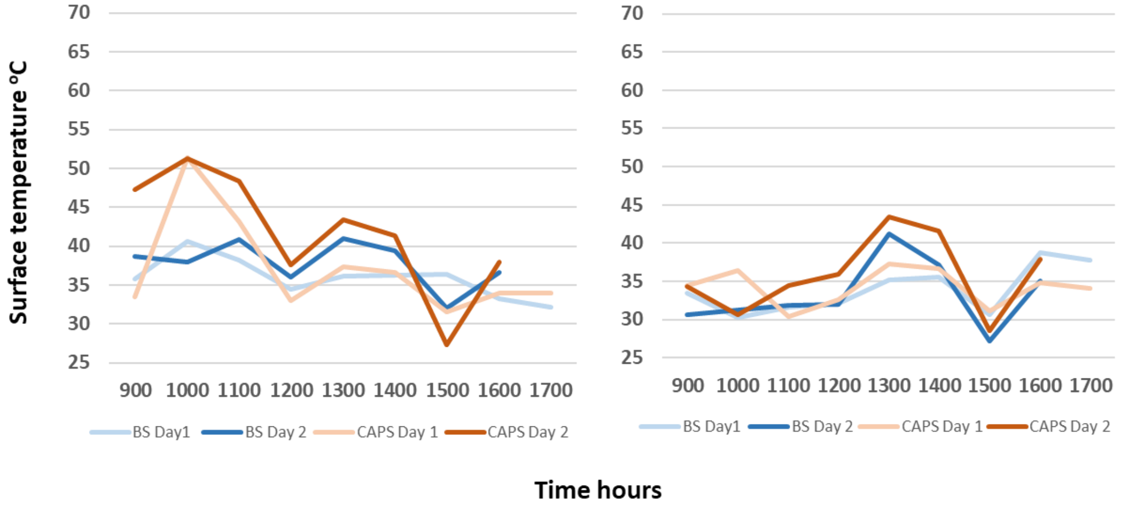

Figure 10. Surface temperature of the upper surface of the seats of the two bus shelters (BS and CAPS) at two positions (left and right) within each shelter. Shading of cells within tables indicates the relative heat of the surfaces.

Surveys

User Behaviour

An overwhelming majority of the people using the Derby Street bus stop stood or sat in one of the shelters. Residence time of passengers at the stop was relatively brief, owing to the frequency of the bus service. Just over half 57% (29 of 51) said their average wait time at the Derby Street bus stop was 10 minutes or less. Only 22% (20 of 51) reported that their wait times were longer than 10 minutes. Almost twice as many people used BS than CAPS; over the 2 days of observation, 109 individuals used BS and 56 used CAPS. However, these figures are not a true reflection of user preference as the results are skewed by the position of the shelter in relation to the direction of approach of the bus; the positioning of the bus time table; the proximity to the pedestrian crossing from Nepean Hospital; and, the position of the stationary bus during embarkation and disembarkation of passengers, all of which favoured BS. Although many participants initially sat in the traditional bus shelter, when invited to try CAPS they stated a preference for the new shelter.

Table 2. Bus shelter usage

Number of users (no count between 1200-1300)				
	BS	CAPS	Parents with prams	Neither shelter
Day 1	69	27	5	3
Day 2	40	29	0	3

Irrespective of which shelter people used, their preference for waiting under shade was clear (Figure 11). Shelter users invariably sat on shaded seats. Many passengers at the Derby Street stop had visited Nepean Hospital, many as patients, and required seating that was comfortable and accessible.

Figure 11. Users generally seek shaded areas of the shelters while waiting for buses.

User satisfaction

In total, 59 people were surveyed, 24 males and 35 females. Overall, the response to the CAPS prototype shelter was overwhelmingly positive. The majority of users mentioned the visual amenity, the perception of cooler ambient temperatures and improved thermal comfort of CAPS. For example, one respondent remarked that the CAPS prototype was "a hell of a lot cooler".

Respondents liked the aesthetics of the CAPS remarking that the design was "clean, fresh, modern and attractive". Others liked the laser cut motif on the rear of the shelter and noted that it increased ventilation and passive cooling for bus patrons. A number of users commented the CAPS roof profile, in particular, how the "longer roof provides safety for people from the elements such as sun and rain". The CAPS roof is wider and provides a great area of shade in front of the shelter's seating than the existing shelter (Figure 8), which resulted in reduction of direct sun exposure for users and improvement in human comfort. The researchers observed that in the middle of the day users sitting in the BS had their knees exposed to the sun and mothers with prams had little choice but to park their prams in the sun. Users' comments supported these observations, with some respondents noting that "more shade was better for people with prams".

There were varied responses regarding the seating design. A few users commented that the CAPS seats were harder than the style of seating in the BS (although both shelter's seats were metal fabrication), while others felt they were "more comfortable" and were "more suitable for human beings" (presumably reference to the seating shape). Several elderly and people living with a disability reported that it was easier to use the CAPS seats as the handles that made it easier to transition between sitting and standing. For example, one woman noted “my husband is blind so the chair handles are better for him to hold onto”.

Suggestions for improvements

Despite the positive feedback of the users surveyed, there were a small number suggestions for improvements to CAPS. These included:

- the installation of a drinking fountain for people to access water on a hot day to avoid dehydration;
- to move the disability strip for blind people to alert them to the presence of the new bus shelter; and
- the possibility of installing CCTV given the close proximity to a mental health unit; to improve safety especially at night and minimise vandalism and graffiti.

Important bus stop features

The researchers also asked users about one feature that every bus stop should have. The most frequently cited responses included cover from rain or sun; seats; a bus timetable and a light at night for safety. (Note: The CAPS shelter does have solar lighting strips within the shelter, however the transistor for the solar panels was not yet fully functional at the time of monitoring. Furthermore, the CAPS monitoring took place during daylight hours.)

Usage of local bus shelters

The majority of survey respondents (77 per cent % or 40 of 52) indicated that they used bus shelters frequently, either on a daily (42 %) or on weekly (35 %) basis. Frequency of use of the Derby Street bus stop varied among respondents with 13 % indicating they used it on a daily basis (6 of 47); 21% used the bus stop weekly (10 of 45); 9% fortnightly (4 of 47) and 28% used it on a monthly basis (13 of 47). A further 30% of respondents indicated that they had not previously used the stop (14 of 47).

The majority of respondents (61 % or 35 of 57) used the Derby street bus stop to travel to or from the Nepean Hospital. These were people attending appointments at the hospital or visiting patients. One respondent noted “I think CAPS is a great idea, good for people with chronic illnesses such as diabetes”. While a further 12% (7 of 57) used the bus stop as a transit point to catch a bus or transfer between busses.

Recording - 360º tour

An interactive 360º tour of both the traditional bus shelter and CAPS prototype is available at https://vizor.io/rcunningham/caps

The output can be viewed in Virtual Reality (e.g., Samsung VR headset), on desktop computer (PC/Mac), tablet or phone using the URL (best browsers Google Chrome or Safari). This immersive web app features 360º imagery and data overlays of the shelters design features and some of the thermal performance data. This is a dynamic and experimental work that will have independent user feedback. As such we anticipate additional information will be added to the current version over time (URL will remain as above).

Discussion and Conclusions

In-service testing of prototypes of small-scale infrastructure in a 'real world' environment is inherently difficult and involves the need for pragmatic approaches to monitoring. The research community has responded to this need through the establishment of 'living labs' to assess, in partnership with users, innovations in health services and, in particular, information technology products (Schumacher and Feurstein 2007), although not without some criticism (Yazdizadeh and Tavasoli 2016). The CAPS project adopted some of the 'living labs' approach. However, assessment of in-service performance of the CAPS prototype presented both advantages and disadvantages. For example, among the advantages was:

- the retention of the existing older style shelter at the Derby Street site, which allowed us to make a direct comparison with CAPS.
- The location of the site in a health care precinct of Penrith City LGA, which ensured that members of the community known to be vulnerable to extreme heat (the elderly, disabled and chronically ill) were well represented among the shelter users in surveys.
- The ability to observe unconscious behaviours of shelter users, in addition to the qualitative information collected through surveys, which would be problematical in a controlled research setting.

However, field testing also presented some difficulties:

- Shelter thermal performance was influenced by the surrounding environment with the placement of trees and buildings variably effecting solar radiation load (through shadows) and air movement throughout the day.
- The aspect of the shelters with respect to the movement of the sun throughout the day was fixed by the existing streetscape. Positioning within the streetscape was also constrained by the need to comply with the safety requirements of transport operators (clearance, visibility etc.). A change in aspect would undoubtedly alter the thermal dynamics of the shelters and user behaviour.
- The positioning of the prototype with respect to the existing shelter (furthest from the direction of approach of pedestrians and buses) favoured the latter.
- We had limited control over the gender balance or age profile of survey participants, and no control over the residence time of users in the shelter with periods of user observation frequently disrupted by the arrival of a bus.

Notwithstanding the shortcomings of the research setting, we were able to gather information on thermal performance and user acceptance of shelters that can provide some guidance to decision makers and infrastructure designers.

Both the CAPS prototype and the existing shelter rely on passive approaches to modification of the thermal environment in a structure that is open to the surroundings, rather than actively conditioning the air in a closed structure (as in bus shelters installed in other 'hot' countries such as United Arab Emirates). This means that there is limited scope for dramatic reductions in temperature, as the inside of the shelter is closely coupled to the external environment. Despite this, subtle differences in performance of the two shelters were observed and resulted from variations in shade profile, surface properties, roof construction, and seat design. Both the size of the roof and its orientation with respect to the position of the sun throughout the day, which determine the area of shade within the shelter, appeared to be critical to modifying the temperature and convection of heat from the ground surface. Although not part of shelter design, modification of the surface properties of the concrete slab on which both shelters were constructed, through the use of porous materials, might further limit heating of the ground surface (e.g. Kevern et al 2012).

The construction of the roof had an effect on the transmission of heat into the interior through the shelter ceiling. The underside of single-sheet, corrugated metal roof of the existing shelter reached higher temperatures than the multi-layer construction of CAPS. In addition, the CAPS roof was fitted with a photovoltaic panel to capture solar energy for LED lighting (Figure 12). This panel effectively intercepted about 20% of the radiation incident on the CAPS roof, further reducing heat transmission through the ceiling.

Figure 12. Solar panel installed on the roof of the CAPS prototype.

As with roof construction, the construction of the seats affected temperature but in a more complex way. CAPS seats were constructed from a single layer of light grey coloured, powder-coated metal. The existing shelter's seats were fabricated from shiny, polished metal 'planks' that appeared to be largely hollow. These differences in albedo (surface reflectance) and seat structure influenced thermal capacity. CAPS seats were quicker to heat up under exposure to solar radiation, reached a slightly higher temperature but cooled faster once shaded. Clearly there is a trade-off that should be considered between the maximum temperature reached and the rate of cooling of the material when designing a shelter's seating.

Many of the general observations of user behaviour can be explained in terms of thermal comfort. A review of thermal comfort in outdoor spaces (Chen and Ng 2012) revealed that perception of outdoor thermal comfort by open space users was determined by a combination of physical, physiological, psychological and social/behavioural attributes (Figure 13). Of the physical factors, temperature, wind speed and solar radiation were the most important determinants. However, up to 50% of the variation in perceived thermal comfort in some studies (e.g. Nikolopoulou and Steemers 2003) was explained by psychological factors, which Chen and Ng (2012) suggest should be a consideration for open space designers. The behaviour observed among the users of the Derby Street shelters can be interpreted as an attempt to maximise thermal comfort. Using the model in Figure 2 as a guide:

- Shelter users clearly responded to the physical environment of the streetscape by seeking shaded areas within the shelter.
- Physiological factors influencing thermal comfort relate to an individual's ability to thermoregulate under heat stress. In our study, residence time of users in a shelter was generally short; however, because of the proximity to medical services (particularly Nepean Hospital) many users may have been suffering physical disability, chronic illness or mental stress. Little is known about the physiological effects of transient exposure to extreme heat on such people, but Chen and Ng (2012, p119-120) suggest that 'assessment of unsteady outdoor thermal comfort conditions remains an active area of thermal comfort research, and constant efforts are being made for model development and field study'.

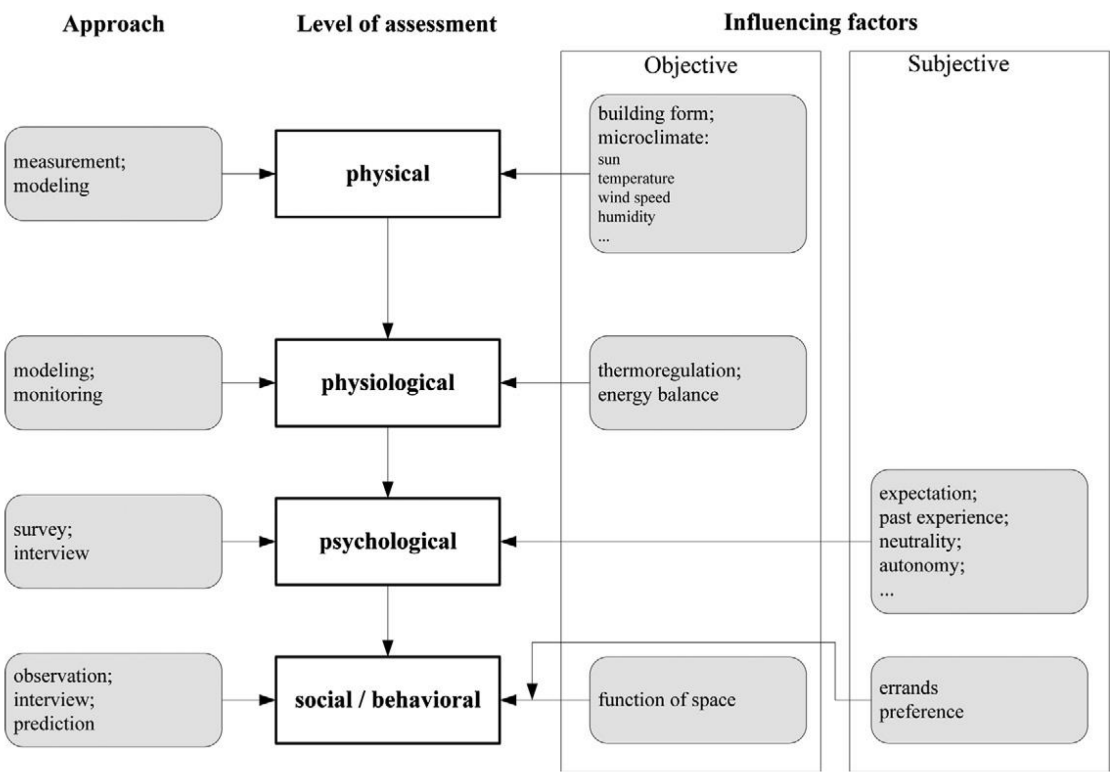

Figure 13. Cheng and Ng's general framework for outdoor thermal comfort assessment based on behavioural aspects (Chen and Ng 2012).

- Our on-site user interviews examined behavioural/social factors mainly through assessment of the functional aspects of the shelters and their interaction with the preferences of users. Users clearly expressed their views on the functional requirements of shelters in general (provision of shade especially for prams, comfortable seating, visibility, security, installation of a drinking fountain etc.) and some of combinations of these likely influenced selection of a seat within the shelter. For example, people selected seats to closer to the door of the bus that were also in shade, or stood in shade that allowed a view of an approaching bus. The views expressed on functionality were consistent with the information obtained through user engagement in the earlier phases of the CAPS project (Table 1) (Jacobs et al. 2018).

- Psychological factors contained in the model were not the focus of our user surveys. However, the influence of users' familiarity with the frequency of bus service, their expectation that shade and seating were available at the Derby Street bus stop, and their previous experience of extreme heat in the Penrith area are likely to play role in determining some aspects of shelter use (such as the time of day of travel). However, the degree of autonomy users can exert over their travel will likely be constrained by the timing of medical appointments and hospital visiting hours, which are largely outside of their control and highly specific this site.

Finally, the contribution of aesthetic aspects of the shelters to the street scape should not be overlooked. Users generally commented favourably on the design of the shelters, in particular, the incorporation of art work (laser cut back panel), and the seats (shape and arm rests).

We hope that through the availability of the on-line 360^{o} video engagement with a broader range of stakeholders will be possible.

In conclusion:

1. Within the constraints imposed by a real world research setting and designs that relied on passive cooling of an open structure, it was possible through incorporation of specific design elements to influence radiation, temperature, and user thermal comfort.
2. Users clearly adapt their behaviour to optimise their thermal comfort, and the outdoor thermal comfort assessment framework of Chen and Ng (2012) provides a useful guide to understanding user behaviour.
3. The elements of design most important to modification of temperature and user behaviour were provision of shade (mediated by roof size and aspect) and seating with respect to shade throughout the day.

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Appendix A – CAPS User Survey

1. What is the post code where you live?

2. What is your gender?

   Female
   Male
   Would prefer not to say

3. What is your age?

   Under 18 years
   18 to 24 years
   25 to 34 years
   35 to 44 years
   45 to 54 years
   55 to 64 years
   Age 65 or older

4. How did you hear about the Climate Adapted People Shelter (CAPS) project?

   Never heard of it
   Through the media (newspapers, radio, internet)
   Poster displayed in the CAPS shelter
   Attendance at a CAPS workshop/event
   Other

5. Approximately how often do you use bus shelters?

   Never
   Daily
   Weekly
   Fortnightly
   Monthly

6. Approximately how often do you use the shelter at ……….?

   Never
   Daily
   Weekly
   Fortnightly
   Monthly

7. Approximately how long do you spend at this bus stop?

I don’t use this bus stop
Don’t know - I rarely catch a bus from this stop
About 5 minutes
About 10 minutes
Longer than 10 minutes

8. What was the main reason you visited this bus stop?

To wait for a bus
To get off a bus
Walking on the street
Visiting the hospital
Visiting nearby shops / businesses
Other

9. Of the two shelters available at this stop, which one did you use?

Neither
The old style shelter
The new CAPS shelter
I tried them both

10. What features do you most like about the CAPS prototype shelter?

11. What is one feature you think every bus stop should have?