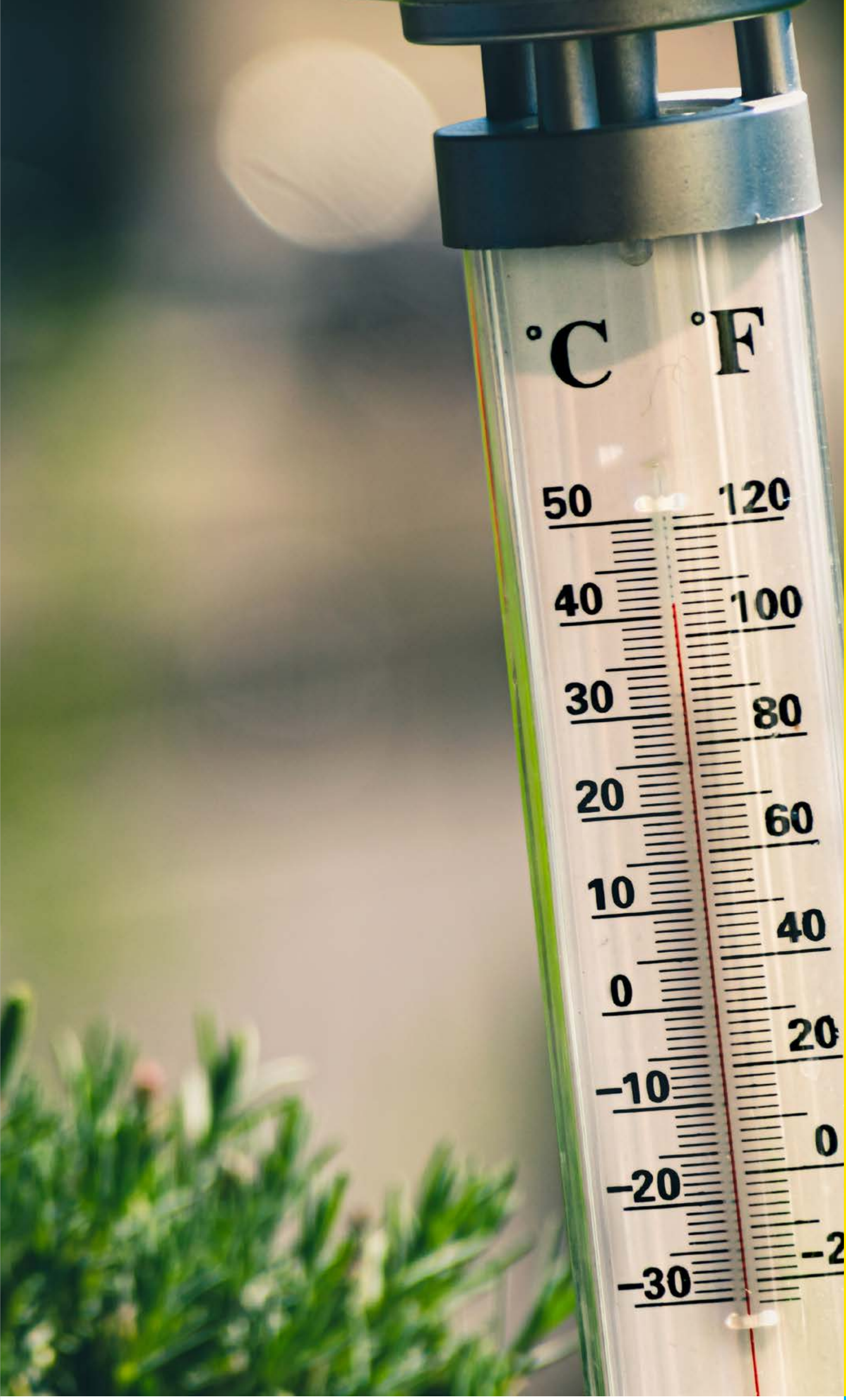

UNSW SYDNEY

Cool Centre

Energy Efficiency Training
and Information Project

Commercial Buildings

Tregear
NSW

Research group

High Performance Architecture research cluster, School of Built Environment, Faculty of Arts, Design and Architecture, UNSW

https://www.be.unsw.edu.au/research/research-clusters-and-groups/high-performance-architecture-research-cluster

Dr Riccardo Paolini
Soheil Roumi
Dr Konstantina Vasilakopoulou
Dr Shamila Haddad
Dr Jie Feng
Prof Deo Prasad
Prof Mattheos Santamouris

International contributors

Aristotle University of Thessaloniki (Greece), School of Mechanical Engineering, Process Equipment Design Laboratory.

Prof. A.M. Papadopoulos
Dr. E. Giama
Dr. G. Dermentzis
Mr. A. Manoloudis
Ms. M. Symeonidou
Mr. G. Chantzis

Project contact

Dr Riccardo Paolini – r.paolini@unsw.edu.au

Contract management contact

Paulina Muliuolyte
Client Relationship Consultant
Unisearch Expert Opinion Services
Level 2, South Wing, Rupert Myers Building
Gate 14, Barker Street
UNSW SYDNEY NSW 2052
p.muliuolyte@unsw.edu.au
+61 2 9385 1500

Acknowledgements

The research group thanks the Australian Department of Industry, Science, Energy and Resources for funding this project entitled “Energy Efficiency Training and Information”. The research group thankfully acknowledges Justine Teo | Coordinator Environmental Compliance Projects of Blacktown City Council for providing building documentation on Tregear Community Centre and granting access for inspection.

The legal entity for the contract is the University of New South Wales. ABN: 57 195 873 179. UNSW is a GST-registered organisation.

CRICOS Provider Code 00098G

Contents

1. Executive Summary

Extreme-heat events are a concern in Australian communities. Local governments are trying to increase the resilience to climate change and tackle the negative impacts of urban overheating with diverse approaches. In 2022, Blacktown City Council started a pilot operation of community centres as 'heat-safe' venues – or cool centres – during the heatwave season while retaining their use as community centres during the rest of the year. Here, we analyse the operational energy consumption of one of the first cool centres in Australia, namely the Tregear community centre. A high-level framework prioritising different building enhancement methods is presented in this report, showing opportunities for energy efficiency and improving indoor air temperature.

A typical community centre used as a 'heat-safe' venue is considered as a case study to explore opportunities to reduce site energy. A dynamic thermal model of this building is simulated with TRNSys software. The thermal-energy performance of the case study building is representative of the typology and construction period (1970s).

This report analyses the existing conditions and provides recommendations for the improvement of the centre conditions and the minimisation of the energy consumption in the Tregear community centre located at 108 Ellsworth Dr, Tregear NSW 2770.

The case study building energy performance was simulated in order to elaborate on the baseline conditions based on the building's construction and operational features and in accordance with the foresight of respective standards and regulations.

The unretrofitted building already displays a relatively low site energy consumption (total of ~70 kWh/m², of which 23.7 for cooling and 21.3 kWh/m² for lighting). This is due to the reduced number of hours of operation of the building, which, when used as a cool centre, is open to the public from 12 pm to 7 pm.

After consideration of multiple options, "low-hanging fruits" have been identified as opportunities for improving the energy efficiency and overall thermal performance of the building.

First, a replacement of the artificial lighting system with new LED fixtures with daylight control reduces the electricity use from 21.3 to 4.4 kWh/m², which also contributes to slightly reducing the cooling site energy because of reduced heat dissipation. Then, the next steps proposed for the retrofit consist of the minimisation of solar heat gains through the roof and walls with field-applied reflective coatings, which reduce the cooling site energy by approximately 10 kWh/m², or 44%. These interventions are relatively low-cost, rapid, and do not interrupt the use of the building.

Ceiling fans deliver cooling savings because they enable thermal comfort at higher temperatures. The only substantial intervention here advised is the replacement of the HVAC system, which currently is a set of three ductless split units. A new VRV system with the best-available efficiency on the market and an air handling unit would save energy and enable fresh-air supply. This is an absolute priority to minimise the risk of transmission of respiratory diseases (e.g., COVID-19, influenza, etc.) within an indoor environment operated with all windows and doors closed (thus without cross-ventilation) when used as a cool centre during a heatwave. ➔

Improving the shading of windows with exterior solar-control devices during the summer is also a priority, and this strategy can deliver further savings and comfort. The final electricity consumption for cooling after the retrofit is 4-5 kWh/m², with a total site energy consumption of 35 kWh/m², or 50% of the initial value (where 19 kWh/m² or 54% of the total are kitchen appliances).

The cool centre cannot operate without HVAC. The combined retrofit can reduce the peak indoor air temperature even by 4°C, but it cannot deliver thermal comfort without air conditioning and ceiling fans. Therefore, renewables on-site and a backup power generator are required to operate the centre in the event of major disruptions in the electrical grid.

This case study focuses on one of the few Australian buildings so far to be used specifically as cool centres, and future investigation of its performance will offer further insight.

2. Regulations, Standards, and guidelines

The regulatory documents and Standards used for the analysis and the proposals are:

- National Construction Code of Australia 2019 Volume One.
- ANSI/ASHRAE 62.1-2019 Ventilation for acceptable indoor air quality
- ANSI/ASHRAE 55-2020 Thermal environmental conditions for human occupancy
- ASHRAE Handbook Fundamentals 2017, Chapter 18: Nonresidential cooling and heating load calculation
- ISO 17772-1-2017 Energy performance of buildings - Indoor environmental quality, Part 1: Indoor environmental input parameters for the design and assessment of energy performance of buildings
- AS 1668.2-2012 The use of ventilation and air conditioning in buildings, Part 2: Mechanical ventilation in buildings
- AS/NZS 1680.1-2006: Interior and workplace lighting, Part 1 - General principals and recommendations.
- AS/NZS 1680.2.1-2008: Interior and workplace lighting, Part 1 - Specific applications. Circulation spaces and other general areas.
- AS/NZS 1680.2.2-2008: Interior and workplace lighting, Part 1 - Specific applications. Office and screen-based tasks. ■

3. Introduction

The selected case study building is a typical community centre built in Australia in 1972, representative of several other low-rise buildings constructed approximately in the same period. However, this is the first building to be used as a cool centre (or heatwave shelter) during hot periods in the Blacktown Local Government Area.

Cool centres, also known overseas as cooling centres or heatwave shelters, are buildings equipped with air conditioning that get opened to the public, offering shelter during extreme heat events. The purpose of these cool centres is to offer a thermally safe place during hot hours or days to vulnerable population, who would otherwise be exposed to extreme heat in their non-airconditioned dwellings and cannot stay for long hours or overnight in shopping malls (Figure 1). The vast literature on heat-related mortality and morbidity identifies elderly residents (65+) living alone, without air conditioning, and often on the top floor [ref], thus more exposed to indoor overheating.

In the United States, several cooling centres offer the possibility to sleep in and are operated by volunteers and supported by charities. Often, users of cooling centres in the United States include the homeless population. This is similar in concept to shelters that, during cold snaps, offer shelter to the homeless, who are the most exposed to extreme cold and poor weather.

Figure 1. An invitation to use the Cool Centre in Tregear.

In New South Wales, Blacktown City Council has started a trial of community-operated venues where people can find air conditioning during significant heatwave events. In this case, the venues part of the trial are community centres operated as cool centres following forecasts of heatwaves made by the Bureau of Meteorology (if rated 'severe' or extreme'). The venues part of the trial are Lethbridge Park Community Centre, Tregear Community Centre, Whalan Community Centre, and Oakhurst Neighbourhood Centre, which are Council-owned, with two more venues, Blacktown Workers Club and Bidwill Uniting Church, to be part of the network. Blacktown City Council plans on adding more cool centres to the network if the trial proves successful and there is a positive response in the community.

The network of Cool Centres is offering a service to citizens vulnerable to extreme heat, including people living with a disability or chronic illnesses and young children, in addition to the elderly. A not-for-profit organisation (i.e., Active Care Network) will transport less mobile residents in need to the venues. This does not include the most vulnerable citizens who cannot leave their homes even if assisted, but it alleviates the burden of crisis management, freeing resources to assist those who cannot reach a Cool Centre.

In this report, we present the methodology to analyse the possible improvements in the building envelope and energy performance of the selected case study and similar community centre buildings. First, the existing building's construction features, building services, and overall thermal-energy performance are analysed upon a survey. Based on that information, the retrofit scenarios are identified and assessed by means of numerical simulation.

4. Tregear cool centre/ community centre

4.1. Case study description

4.1.1. Climate

The case study building is at 108 Ellsworth Dr, Tregear NSW 2770 (33.744S, 150.795E). Tregear is within the local government area of Blacktown, 50 km west of Sydney's CBD and 70 m above mean sea level. In Köppen's climate classification, Blacktown is categorised as Cfa, meaning that it has a humid subtropical climate with mild to cool, short winters and warm, sometimes hot, prolonged summers.

The climate of Blacktown is warm and temperate. With a humid subtropical climate, the weather in Blacktown is warm, sometimes hot, in summer and cool during winter. Rainfall is fairly evenly spread throughout the year. Precipitation is slightly higher during the first half of the year, with an annual mean rainfall of 73 mm. March has the highest rainfall (100.6 mm). Due to its geographical location, the relative humidity is distributed evenly throughout the year (65-80% in the morning and 45-57% in the afternoon). The winters are cool, with overnight minimums averaging 7°C and daily maximums climbing to only 17°C. Moreover, summers are slightly warm, and the average maximum temperature reaches 28.6°C in January. The primary climatic information for Blacktown is illustrated in Figure 2.

The local climate in Tregear is similar to that in Mt Druitt, which is 3.5 km southeast of the community centre. The local climate in Mt Druitt has been monitored for over a year between 2020 and 2021 as part of the project "Evidence based interventions for urban cooling" funded by Local Government NSW ('Increasing Resilience to Climate Change')and carried out by Blacktown City Council and UNSW. The monitoring with five temperature sensors deployed in the built environment quantified that Mt Druitt, in peak conditions, is 1.2-1.7 °C hotter than Horsley Park, which is the closest station of the Bureau of Meteorology, approximately 10 km south of Mt Druitt, in a non-urban area at the same distance from the cost. Especially, the air temperature in Mt Druitt is even 2.5 °C hotter than in Horsley Park in the evening and night (Figure 3).

→

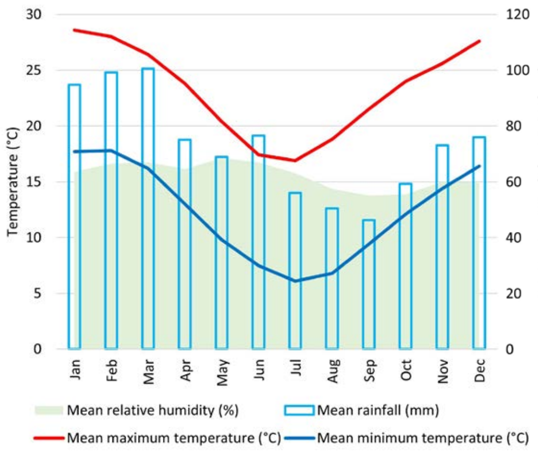

Figure 2. Climatic data for Tregear [4].

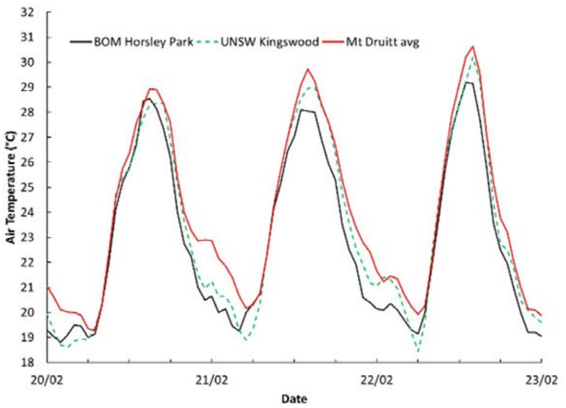

Figure 3. Ambient temperatures

in Mt Druitt (solid red line, average of five temperature stations within the urban area), Horsley Park (BOM, solid black line), and Kingswood (UNSW station, dashed green line) during a hot period in February 2021. Source: Blacktown City Council & UNSW report "Evidence-based interventions for urban cooling".

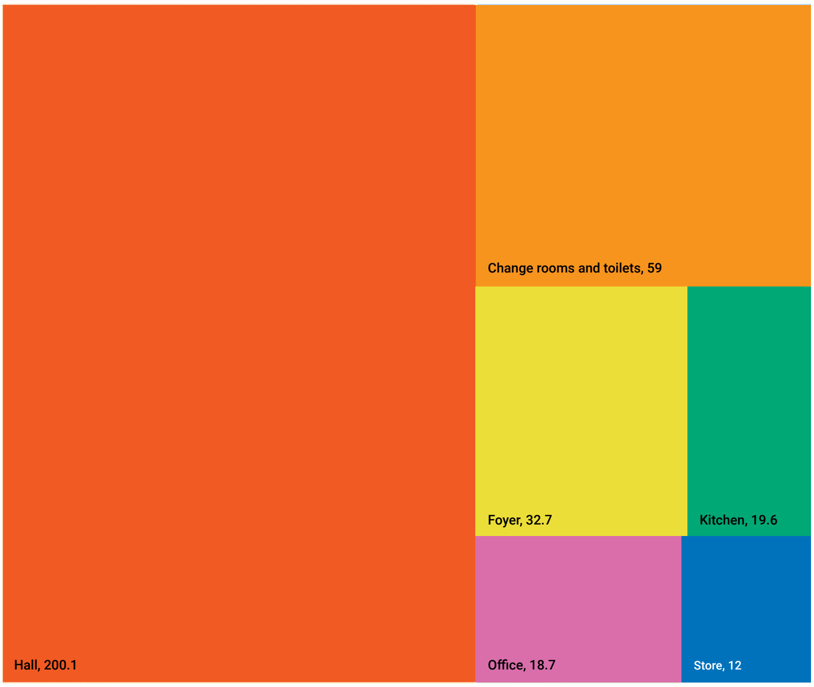

Figure 4. Treemap of the internal space distribution.

4.1.2. Building description

This case study building is within the local government area of Blacktown, in the Greater Sydney area, and it was completed in 1972. Following the building classification of the National Construction Code, the Tregear community centre belongs in Class 9b [5]. The Tregear community centre has a main hall with a capacity of 85 people, and this building has the capacity of 45 occupants while serving as a cool centre. The under-ceiling height of the mentioned community centre varies between 2.5-4.5 m. The total gross floor area is 342.1 m² (Figure 4).

4.1.3. Heat-safe venues in Blacktown

In Sydney, the overall average of extremely hot days is 10 days a year, where temperatures are above 35°C, while Western Sydney averages 10 to 20 days a year of temperatures above 35 degrees. It is predicted that extremely hot days by 2039 will rise to between 15 to 30 [6]. Heat-save shelters provide accommodation to vulnerable residents who seek shelter during heatwaves. Blacktown City runs the Australian-first trial idea of 'heat refuges'. Residents can go to these air-conditioned venues and be provided for during a significant heatwave event [6]

4.1.4. Energy consumption and sources

One of the best ways to decrease the operational cost of buildings is to improve energy efficiency. This building does not use any renewable resources. Electricity is used for HVAC purposes, lighting, appliances, and water heating of the Tregear community centre. ➔

.

4.2. Building modelling input parameters

The modelling parameters are a combination of collected data from the building inspection, utility bills and Australian and global standards. In this section, each modelling assumption will be briefly explained, and relative references will be presented.

4.2.1. Occupancy

Currently, the Tregear community centre has a capacity for 85 people. The occupancy schedule is selected based on the National Construction Code for the period when the building is used as a community centre (i.e., out of the heatwave season) [5]. Instead, during the operation as Cool Centre, we considered the occupancy and opening hours as provided by Blacktown City Council.

4.2.2. Geometric data

The case study building has only one floor, and Table 1 shows the purpose of each part of the building. The building is located in a low-density area, next to a small shopping centre and Tregear Public School (Figure 5), with sparse vegetation and no shadows cast onto the building and immediate surroundings that reach high surface temperatures during extreme heat days, contributing to worsening the local microclimate (Figure 6). There is a playground and an outdoor barbeque facility within the community centre. →

Table 1. Building geometric information.

Building	Air-conditioned area (m²)	Not air-conditioned area (m²)	Gross floor area (m²)
Foyer	32.7	0	30.5
Hall	200.1	0	121.0
Office	18.7		
Storeroom	0	12.0	43.3
Kitchen	19.6	0	20.0
Change rooms and toilets	0	59.0	49.5
Total	271.1	71.0	342.1

Figure 5. Aerial view of the Tregear Community Centre (Source: Six Maps NSW).

4.2.3. Building Components

A significant part of energy consumption to maintain comfort leaks through the building envelope. As a key step in assessing the potential benefits of improving windows, walls, roofs and floors, the current thermal performance should be determined. Surveying the case study community centre, we assessed the thermal properties of the building envelope based on the age and construction. This information is used to model the building and develop a thermal model. This section introduces the performance descriptors of external walls, roof, and windows.

4.2.3.1. External walls

The building is characterised by fired brick walls, with a fascia in metal cladding, which is omitted in the simulations due to its limited surface (Figure 7). The external wall is an uninsulated cavity wall with an R-value of 0.633 m²․K/W (Table 2) and a solar absorbance estimated equal to 0.60. Also, using the average annual wind velocity in Tregear (3.0 m/s) [1], the convective heat transfer coefficient is calculated as 17.6 W/(m²․K) [4].

Table 2. Building Components - Performance Descriptors – Construction – External Walls.

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m³)	Resistance (m².K/W)	Ref.	Section and page
Brick	110	0.78	0.8	1,950	-	[2]	Section J, page 389
Air space	50	-	-	-	0.18	[5]	Section 5.3, page 5
Brick	110	0.78	0.8	1,950	-	[2]	Section J, page 389

R-value: 0.633 m².K/W

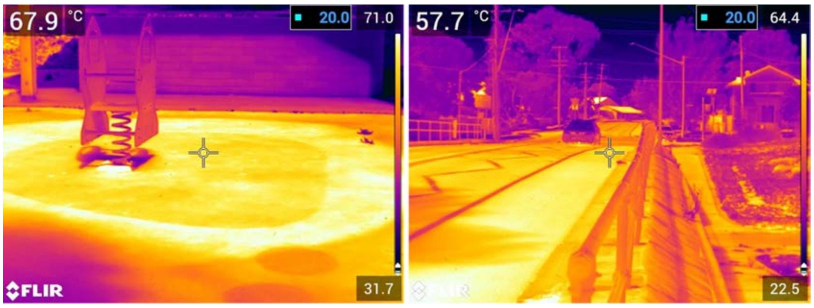

Figure 6. Infrared view of the playground and road in front of the Tregear Community Centre, reaching high surface temperatures during a summer afternoon, with a semi-hourly average outdoor air temperature of 35.3 °C measured on-site at 1.8 m height and relative humidity of 27% (images taken in February 2022).

Figure 7. Northern view of Tregear community centre building.

4.2.3.2. Roof

The roof of the case study community centre is composed of metal sheeting, with an anti-con blanket underneath and then an air gap and plasterboard making a false ceiling in all rooms (Figure 8). The R-value is computed as 0.698 m².K/W (Table 3), and the solar absorbance and thermal emittance of the roof are 0.75 and 0.50, respectively, based on measurements performed on similar roofing types in NSW. Also, using average annual wind velocity (3.0 m/s) [1], the convective heat transfer coefficient is calculated as 17.6 W/(m².K), respectively [4].

4.2.3.3. Windows

External windows in the case study buildings are single glazed with an aluminium frame, without shading, as presented in Table 4. Only the ground level windows have a metal grid positioned externally for security reasons (Figure 9). Although these have not been designed as shading devices, they perform as such. Metal mesh grids similar to those installed at the Tregear community centre have a solar transmittance of approximately 0.50 for near-normal incidence. However, the grids in front of the windows at Tregear have a coarser mesh. Therefore, we used an intermediate solar heat gain coefficient between that of clear glass (typically ~ 0.85) and that with the grids, which reemit part of the absorbed heat towards the windows. This is considered an acceptable approximation, while a more advanced simulation would require external raytracing calculation of the optical properties of the grids upon a detailed geometrical survey. ➔

Table 4. Building Components - Performance Descriptors - Openings Shading

Glazing	Value	Unit	Ref.
Thickness	14	mm	[11]
Glazing U-value	5.44	(W/m².K)	
Glazing solar heat gain coefficient	0.73	N/A	
Window frame material	Aluminium	N/A	
Window frame ratio or width	15	%	
Glazing layout – WWR	40	%	
Glazing type	Single glazed	N/A	

Table 3. Building Components - Performance Descriptors – Construction – Roof

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m³)	Resistance (m².K/W)	Ref.	Section and page
Tiles (roofing Concrete)	13	1.5	1	2,100	-	[8]	Section 8.3, page 9
Air space & ceiling framing	100	-	-	-	0.23	[7]	Section 5.3, page 5
Plaster board	10	0.17	1	880	-	[8]	Section 8.3, page 9

Overall R-value: 0.698 m².K/W

Figure 8. View of the ceiling with plasterboard panels in the main hall of the community centre. The windows on the perimeter are single-glazed without shading devices.

Figure 9. Security protections for ground-level windows.

4.2.4. Domestic hot water

The required hot water for the Tregear centre is calculated based on Table 2m, NCC volume 1 page 355 [5]. Therefore, considering the need for a 50°C temperature increase and water heat capacity (4.19 KJ/kg.°C), 20.5 MJ of heating energy is required for the daily heating of domestic water (Table 5).

4.2.5. Internal gains and HVAC setpoints

The information regarding the thermal comfort in the studied community centre is provided by Blacktown City Council (BCC), and presented in Table 6. Lighting and personal heat gain assumptions in the model are based on Australian and international standards. To account for the airflows between the hall and the foyer with a simplified approach, we considered a cooling setpoint of 30°C in the foyer, even though it is not airconditioned. The doors separating the foyer from the hall are unavoidably opened frequently, leading to an inflow of hot air from the foyer to the hall. Also, while the foyer is not air-conditioned at present, it is a reasonable assumption that it will be equipped with air conditioning in the future, as the Australian Red Cross and other volunteers welcome the users of the Cool Centre in the foyer.

Based on a survey on-site and on information provided by BCC, the internal gain of appliances in the kitchen and their energy consumption rates are presented in Table 7.

4.2.6. Ventilation and infiltration

The supplied fresh air flow rates and the infiltration rates are assumed based on international standards (Table 8). →

Table 5. Domestic hot water

Demand-side	Occupancy	Unit Hot water demand	Daily hot water demand (lit)
	85	2.8 lit/person	238

Table 6. Temperature setpoints, lighting, appliances and personal heat gain.

	Section	Value	Unit	Ref.	Section and page
Cooling setpoint temperature	Hall	25	°C	BCC	-
	Foyer	30	°C	BCC	-
Heating setpoint temperature	All	20	°C	BCC	-
	Foyer	16	°C	BCC	-
Personal latent gain	All	35	W/person	[12]	Chapter 18.4
Personal sensible gain	All	70	W/person	[12]	Chapter 18.4
Appliances and equipment gain	All	1030	W	[6]	Section J, page 355
Lighting heat gain	Foyer	9.0	W/m²	[2]	Section J, page 379
	Office	4.5	W/m²		
	Kitchen	4.0	W/m²		
	Hall	8.0			
	Changing rooms, store & toilets	3.0	W/m²		

Table 7. Appliances heat gain

Appliances	Electricity consumption (W)	Usage factor
Oven	1,174	0.25
Fridge and Freezer	400	0.25
Microwave	1,450	1.39

Table 8. Ventilation and infiltration

	Schedule	Value	Unit	Ref.	Section and page
Fresh air	Occupied period	10	L/s.person	[11]	Appendix A, Table A1
	Unoccupied period	5	L/s.person		
Infiltration	Occupied period	1	ACH	[12]	Section 2.7
	Unoccupied period	0.5	ACH		

4.2.7. Thermal Comfort

The thermal comfort parameters have been considered as in Table 9, using the PMV method, according to the National Construction Code.

4.2.8. Energy resources and HVAC systems

The total energy demand of this building is provided by electricity. Based on the information provided by BCC, the coefficient of performance (COP) and energy efficiency ratio (EER) of the heating and cooling systems are considered as 2.8 and 2.4, respectively. The community centre is equipped with three separate ductless split units. The internal units are located within the hall below the windows and along the wall between the kitchen and hall, and the external condensing units are below the rooftop level (Figure 10).

Table 9. Thermal comfort parameters

Factor	Value	Unit	Ref.	Section and page
Clothing Factor	Summer 0.6 – Winter 1	clo	[15]	Section 5, page 8
Metabolic rate	1.0	Met	[15]	Section 5, page 7
Relative air velocity	Less than 0.2	m/s	[15]	Section 5, page 11

Figure 10. Position of the split units (interior and exterior).

4.2.9. Schedules

The schedules of occupancy, lighting and appliances of the Tregear community centre are selected based on page 354 of the Australian national construction code with some modifications due to provided documents by BCC [2]. Also, the opening hours and thus schedule of occupancy during the operation as a Cool Centre (i.e., during heatwaves) is between 12 pm and 7 pm (Table 10).

4.3. Evaluating Lighting Condition

The aim of this section is to recommend appropriate solutions for the improvement of the natural and artificial lighting environment and for minimising the energy consumption for lighting of the interior spaces of Tregear Community Centre. The steps taken in this regard are:

1. The analysis and simulations of the existing lighting conditions, based on information from building management
2. The assessment of the compliance of the energy performance and the lighting conditions established with relevant regulations, standards, and guidelines; and
3. Research, simulation and presentation of appropriate techniques and methods to achieve minimum energy consumption for lighting and heating loads from artificial lighting, complying with the Australian building regulations.

4.3.1. Lighting evaluation method

Proposing strategies for improving lighting conditions or reducing energy use requires a detailed analysis of the existing natural and artificial lighting conditions. The material available for the specific building included the architectural drawings and some photographs of the building's interior and exterior.

Using the provided data and reasonable assumptions about the type of the lighting systems, the building was modelled in the software Rhinoceros, and the lighting conditions were simulated in the add-on tool Climate Studio. Climate Studio is an environmental performance analysis software with advanced lighting calculation capabilities. Due to the lack of information on the lighting system currently used in the community centre, an assumption was made on the lighting power density. This is that the maximum values permitted by the NCC are used, depending on the use of the space. Based on this assumption, three scenarios were tested (Table 11). →

Table 10. Occupancy, lighting, and appliances schedules

Time	Occupancy	Hall lights and equipment	Kitchen lights and equipment	Air-conditioning
00:00-01:00	0.00	0.15	0.05	Off
01:00-02:00	0.00	0.15	0.05	Off
02:00-03:00	0.00	0.15	0.05	Off
03:00-04:00	0.00	0.15	0.05	Off
04:00-05:00	0.00	0.15	0.05	Off
05:00-06:00	0.00	0.15	0.05	Off
06:00-07:00	0.05	0.25	0.10	On
07:00-08:00	0.10	0.45	0.15	On
08:00-09:00	0.20	0.45	0.15	On
09:00-10:00	0.20	0.45	0.15	On
10:00-11:00	0.25	0.60	0.40	On
11:00-12:00	0.30	0.60	0.40	On
12:00-13:00	0.30	0.60	0.10	On
13:00-14:00	0.35	0.60	0.10	On
14:00-15:00	0.30	0.45	0.10	On
15:00-16:00	0.30	0.60	0.10	On
16:00-17:00	0.35	0.60	0.40	On
17:00-18:00	0.25	0.60	0.10	On
18:00-19:00	0.20	0.60	0.05	On
19:00-20:00	0.15	0.25	0.05	On
20:00-21:00	0.10	0.25	0.05	On
21:00-22:00	0.10	0.25	0.05	On
22:00-23:00	0.10	0.25	0.05	On
23:00-00:00	0.05	0.25	0.05	Off

Table 11. Scenarios for reduced energy consumption for lighting

Base-case scenario	The existing power density for lighting is set to the maximum permitted by NCC. No daylight linked controls are used.
Scenario 1	The lighting power density is reduced with the use of efficient light sources. No daylight linked controls are used.
Scenario 2	Scenario 2 has the same lighting power density as Scenario 1. However, daylight controls are used in daylit spaces.

4.3.2. Lighting analysis result

The results are analysed in two parts:

1) the assessment of the existing natural conditions;

2) The calculation of the existing lighting power density (W/m^2), and the proposal of scenarios for the reduction of the energy consumption for lighting. Scenarios for improvement of the lighting conditions and minimising the energy consumption for lighting are also provided in the second part.

4.3.2.1. Natural lighting

The rooms with windows are the hall, the kitchen, the toilets, the foyer and one changing room. The office does not appear to have windows on the floor plan or in photographs of the building. The hall has windows on both the Southeast and Northwest sides, located high, and close to the roof. The foyer receives natural light from the entrance /glass doors.

The spaces of the community centre with windows have high Daylight factors, which are always above 2%. The Hall receives enough light for a wide range of activities that could be hosted by a Community Centre since it is in the range of 2 to 5%.

Spatial Daylight Autonomy (sDA) is the percentage of the regularly occupied floor area that is “daylit”. In this context, “daylit” locations are those meeting target illuminance levels (300 lux) using daylight alone for at least 50% of occupied hours. Such locations are said to be 50% daylight autonomous. sDA calculations are based on annual, climate-based simulations. The sDA of all the spaces is 100%, showing that the spaces will have sufficient light (above 300 lux) from the windows for at least 50% of the occupied hours. The only space receiving high amounts of sunlight is the kitchen, where some type of shading, preferably an exterior element, should be added (Table 12).

4.3.2.2. Artificial lighting

Due to the minimum information on artificial lighting, the lighting power densities of the various spaces have been set according to the NCC requirements, depending on the space use. ■

Table 12. Average Daylight Factors, Sunlight Exposure and Spatial Daylight Autonomy

Space	Area (m^2)	Average Daylight Factor (%)	Uniformity	sDA (%)
Foyer	20	3.32	0.66	100
Hall	111.9	3.49	0.44	100
Kitchen	12.3	9.16	0.68	100
Changing room	6.6	2.64	0.57	100
Toilets	10	2.54	0.62	100

5. Simulation approach

The simulation includes two main parts. First, the building was defined in SketchUp software and then energy modelling was conducted in TRNSys.

5.1. SketchUp

SketchUp is a 3D modelling computer program for a wide range of drawing applications such as architectural, interior design, landscape architecture, civil and mechanical engineering. The model was designed based on actual building dimensions, rotation, and shadings (adjacent building and external shadings). The case study building is defined in the SketchUp model because of the importance of load determination (Figure 11).

5.2. TRNSys

The TRNSys software tool is used to simulate the behaviour of transient systems. TRNSYS has an extensive library of components, which can help model the performance of all parts of the system. TRNBuild is the tool used to enter input data for multizone buildings. It allows specifying all the building structure details, as well as everything that is required to simulate the thermal behaviour of the building, such as windows optical properties, heating and cooling schedules, etc. [11].

After importing the building model into TRNSys, all building structural parameters (walls, windows, doors, etc.), schedules (occupancy, lighting, and appliances), internal loads, and HVAC systems (setpoint, ventilation, infiltration, and comfort) were defined in TRNBuild. By adding the proper climatic data (temperature, relative humidity, radiation, etc.) using the CSIRO weather database, the model was finalised. ➔

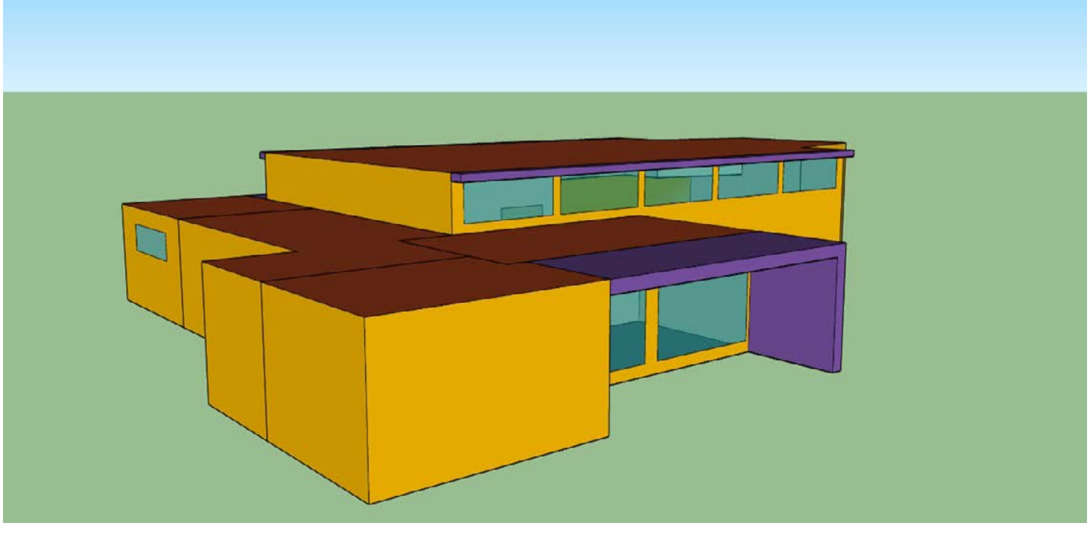

Figure 11. SketchUp model.

5.3. Weather data, simulation scenarios, and settings

The simulations have been performed considering three main climate scenarios:

- Heatwave year (2016-2017, May to April). This is a historical data series containing a frequent-hot year, including relevant heatwaves in January and February.
- Typical Meteorological year, present climate (CSIRO weather database). Typical Meteorological Years do not include extreme climate events, as they are made by a collection of months whose temperature, humidity and wind speed profile are closest to the profile with the highest probability of occurring (similar in concept to a median, although the statistical filter is different).
- Future typical meteorological year, considering the climate in 2030, RCP4.5 climate change trajectory (CSIRO projections database)

The simulations for the base case and all retrofitted scenarios for the heatwave year have been performed using:

- Non-urban data collected weather data for the weather station of the Bureau of Meteorology in Horsley Park (Horsley Park Equestrian Centre - station 067119, Lat: -33.851; Long: 150.8567), which is approximately 13 km southeast of Tregear. The solar radiation data are taken from Macquarie University, as it was the closest and only location with measured solar radiation, and compared with satellite estimates from the Bureau of Meteorology;
- Urban data obtained by correcting the weather dataset of Horsely Park with a correlation established with data from five temperature and humidity sensors that recorded data in Mt Druitt for 1 year as part of the project “Evidence-based interventions for urban cooling”. Urban data from Tregear were not available, and Tregear is 3.5 km northwest of Mt Druitt, with a similar urban texture.

In all cases, the Tregear community centre was considered in operation:

- As a cool centre (heatwave shelter) from 16th November to 15th February, open from 12 pm to 7 pm, as operated by volunteers in collaboration with Blacktown City Council. The heatwave season is considered to be starting in mid-November and ending in mid-February, based on historical data;
- As a normal community centre from 16th February to 15th November.

The operation of the building as a Cool Centre for the entire period when heatwaves are probable is a simplification used in this project since the operation of the heat-safe venue is being trialled in 2022, triggered by heatwave forecasts of the Bureau of Meteorology. Therefore, applying retrospectively the operation as Cool Centre only to historical heatwave days would not be correct, as only forecasts and not measured data would be available to decide on the operation mode. Accurate modelling would imply the use of historical modelling uncertainty in forecast and decision making. In fact, a readiness threshold has not been defined yet, and the operation dynamics are part of the trial. Future research will thus need to separate the simulation of cool centre operation and normal community centre operation based on such more realistic patterns.

In all scenarios and situations, simulations have been performed with the HVAC in operation according to the heating/cooling setpoints and schedule given in the previous sections. Finally, no metered data are available for the building in Cool Centre operation mode since it is the first year that the building is used as such.

Only for the heatwave year simulated in Tregear, we also considered free-floating conditions, which means that the air conditioning is not in operation. These simulation settings mimic the worst-case scenario of a prolonged blackout in the area and assess the thermal energy performance without mechanical ventilation and cooling and without a power generator which the community centre is not currently provided with. ➔

As the building is used as a heatwave shelter, it is important to ensure that retrofit scenarios deliver thermally safe conditions even in the event of significant power outages during extreme climate events, as possible with climate change and already observed overseas (e.g., in Texas in 2021). The operation for the entire heatwave season in free-floating conditions might appear to be an extreme choice, but it considers the unfavourable conditions of long hot periods with heat accumulation in the building and the extreme scenarios of significant failure of the HVAC requiring maintenance or replacement or a complete failure of the power grid, with the need for black-starting generating stations (i.e., recovering from a total shutdown), which might involve time-consuming testing of generators.

5.4. Retrofit approaches

Evaluating the energy performance of a building begins with determining the building's constructional characteristics, including the efficiency of the building envelope, lighting, HVAC equipment, etc. Considering the building's features, all calculations are based on the 'as-built' condition of the building elements (U-values, shading, air-permeability etc.), of the HVAC system (Coefficient of Performance and Seasonal Energy Efficiency Rating as provided by manufacturers or (for older systems) by regulations), whilst installed lighting and plug loads were determined either by data from management or following standards and regulations.

Additionally, other specific conditions that have a significant impact on the building's performance are:

(a) the operational parameters (hours of operation, set temperatures for heating and cooling, natural ventilation patterns, use of artificial lighting, etc.) and

(b) the microclimate on the building's site (shading by natural obstructions and other buildings, albedo and thermal storage of surrounding areas, etc.). Finally, a baseline or reference condition should be determined, against which the effectiveness of interventions can be evaluated.

The building has to adopt standard reference conditions, as foreseen by national regulations and standards, which allow a good degree of replicability, independent of the specificity of the operation during a particular period. In this line of approach, all operational parameters for the baseline scenario were considered in accordance with national standards, regulations and recommendations or in accordance with NCC, ASHRAE and ISO standards. Simulations were carried out on an hourly basis, hence resulting in a high temporal analysis, whilst the thermal zoning was based on the differentiation of thermal conditions. This approach not only allows a reliable and cohesive assessment for the specific building but enables using the outcomes as a pilot for further similar projects.

In this case, the identification of retrofit scenarios focused on the performance of the building as a cool centre, thus targeting the minimisation of cooling energy needs and indoor temperatures primarily during summer. The summary of retrofit scenarios, presented in detail in the subsequent sections, is the following:

- Base case – the building as it is, unretrofitted
- Case A – Lighting retrofit 1
- Case B – Lighting retrofit 2
- Case C – As Case B + installation of a standard cool roof
- Case D – As Case B + installation of a supercool roof, i.e., a daytime radiative cooler
- Case E – As Case D + cool walls
- Case F – As Case E + ceiling fans
- Case G – As Case F + HVAC replacement
- Case H – As Case G + windows shading
- Case I – As Case H + night ventilation

➔

5.4.1. Case A and B – Lighting retrofit

The aim of the next step of the study was to develop scenarios that would enable reduced energy consumption for lighting and would provide an approximation of how much energy can be saved. Due to the lack of information, the lighting power densities of the various spaces have been set according to the NCC requirements, depending on the space use. Scenario 1 includes the reduction of the power density with the use of efficient LED lighting fixtures. Scenario 2 includes the addition of daylight linked controls to the daylit spaces resulting in a reduction in the energy consumed for artificial lighting in the range of 30 to 85% (Table 13).

5.4.2. Case C and D – cool roof and supercool roof

The building currently has a roof with uncoated metal sheeting with high solar absorbance (0.75) and intermediate thermal emittance (0.50), resulting in high surface temperatures. Since the roof is uninsulated (only an anti-con blanket is considered), the solar radiation absorbed by the roof sheeting and converted into heat is transmitted by conduction to the interior, leading to high ceiling temperatures.

Therefore, reducing the solar absorbance of the roof is an effective strategy to minimise indoor overheating. This can be achieved by applying on the existing roof a solar-reflective coating with solar absorbance of 0.20 and thermal emittance of 0.90, which is a standard cool roof product (Case C). Even if the thermal emittance of the metal sheeting is low, the coating is sufficiently thick to increase the infrared emissivity.

A second option is the installation of a supercool roof (Case D) that is a daytime radiative cooler with enhanced solar reflectance and thermal emittance, which by means of radiative cooling can achieve surface temperatures lower than the ambient temperature. This is simulated by setting the solar absorbance equal to 0.05 and the thermal emittance to 0.95. These parameters take into consideration some performance loss due to soiling, while a newly installed daytime radiative cooler would display higher performance. →

Table 13. Illumination power density and energy consumption for the base case and the proposed scenarios

Space	Area (m²)	Base case		Scenario 1		Scenario 2	Max. energy savings achieved (%)
		Max. illumination power density (W/m²)	Energy consumption (kWh/year)	Max. illumination power density (W/m²)	Energy consumption (kWh/year)	Energy consumption (kWh/year)	
Hall	**8.0**	7894.0	3.5	3414.0	1.2	1175.0	85.1
Foyer	**9.0**	1573.0	5.0	874.0	1.8	326.0	79.3
Office	**4.5**	249.0	3.0	165.9	3.0	165.8	33.4
Kitchen	**4.0**	264.0	3.0	198.0	1.1	73.0	72.4
Toilets	**3.0**	715.0	3.0	715.0	1.5	355.0	50.4
Changing rooms	**3.0**	180.0	3.0	180.0	1.1	64.0	64.4

5.4.3. Case E – Cool walls

As the building has large uninsulated opaque walls with high solar absorbance, solar heat gains by the walls can be reduced by increasing the solar reflectance. This can be achieved by applying a reflective coating having solar absorbance of 0.30 and a thermal emittance of 0.90.

5.4.4. Case F – Ceiling fans

Ceiling fans are a simple and cost-effective method to enhance the indoor air quality in summer and also to receive points in energy rating stars. They provide additional air movement by increasing the relative air velocity resulting in the apparent temperature felt on exposed skin being 3° C colder than the actual air temperature, thereby reducing the need for additional cooling. The proposed scenario will be modelled by increasing the cooling setpoint temperature to 26°C.

5.4.5. Case G – HVAC replacement

The three ductless mono-split units are replaced with a ducted VRV with an air handling unit. This also provides fresh air supply to the hall of the cool centre. While this is not a “low-hanging fruit”, it is an essential feature to be considered, as, without fresh-air supply, the use of airconditioning with all windows closed and 45 people in the building would lead to poor indoor air quality (high CO_2 concentration) and increased risk of transmission of communicable respiratory diseases (e.g., COVID-19, influenza, etc.). The new VRV would be of the best available technology, with COP = 4.3 and EER = 4.8.

5.4.6. Case H – Windows shading

The existing building has no shading for the windows in the hall. Improved shading is implemented and simulated by considering a solar heat gain coefficient of 0.25 in summer and 0.60 in winter (i.e., shading is almost removed).

5.4.7. Case I – Night ventilation

As heatwaves in Australian cities display peak temperatures during the daytime and low temperatures during the night with a significant thermal excursion, there is the opportunity of cooling the building with increased airflow during the night when the outdoor air temperature is lower than the cooling setpoint. This is done by setting the air changes per hour to 5 between 12 am and 6 am. ■

6. Results and discussion

6.1. Base building modelling

The result of the simulation of the Tregear community centre (as a Cool Centre during the summer and community centre during the rest of the year) is presented in this section. The hourly energy needs (i.e., loads) for heating and cooling (sensible and latent) are illustrated in Figure 12. Also, the monthly energy demand is presented in Figure 13. In addition to cooling energy uses, also lighting and appliances constitute a relevant fraction of the yearly consumption (Figure 14), while during the period when heatwaves are probably – namely from mid-November to mid-February – the cooling site energy is preponderant (Figure 14). The appliances are mostly the kitchen equipment and refrigerators, which are not considered as part of the retrofit options since they are not part of the building and thus beyond the scope of the study.

In free-floating conditions, i.e., without air conditioning because of a power outage or HVAC malfunction, with data from Horsley Park, the indoor air temperature in the hall is as high as the outdoor air temperature (Figure 15). Using urban data from Mt Druitt, the indoor air temperatures reach even higher values without air conditioning (Figure 16). The occupants would still be sheltered from the solar radiation and thus in more comfortable thermal conditions, but still subject to extreme heat conditions in case of a critical situation with the HVAC system not in operation. ➔

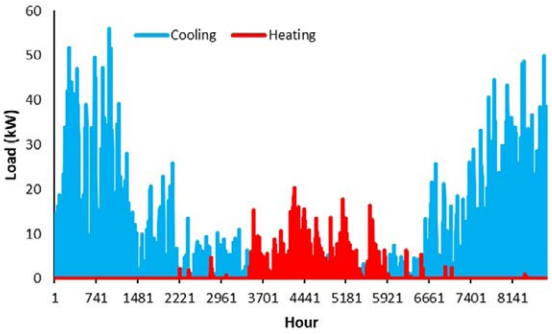

Figure 12. Hourly energy demand for HVAC purposes.

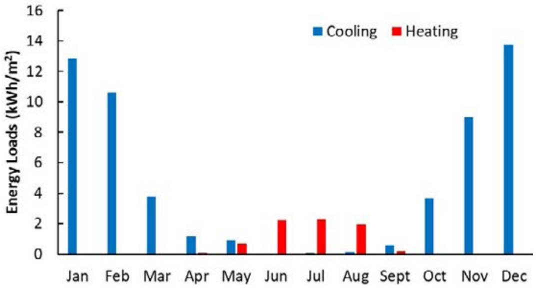

Figure 13. Monthly energy demand for HVAC purposes.

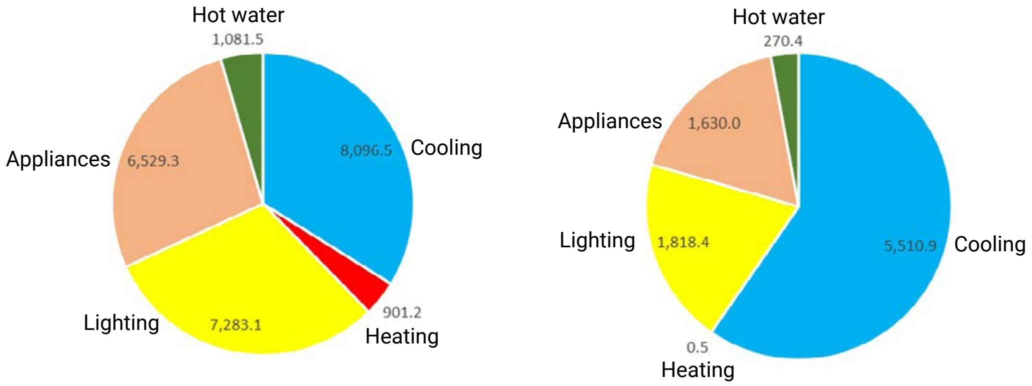

Figure 14. Yearly site energy (electricity) per use for the Tregear Community Centre (left) and site energy during the heatwave period (16th Nov – 15th Feb) for the Tregear Community Centre (right).

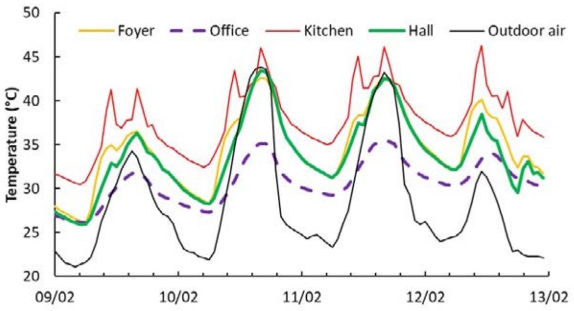

Figure 15. Indoor air temperatures in **non-urban setting**, computed during a historical heatwave event (February 2017) in the foyer, hall, kitchen and office. The black solid line displays the outdoor air temperature as measured at the closest station of the Bureau of Meteorology (Horsley Park).

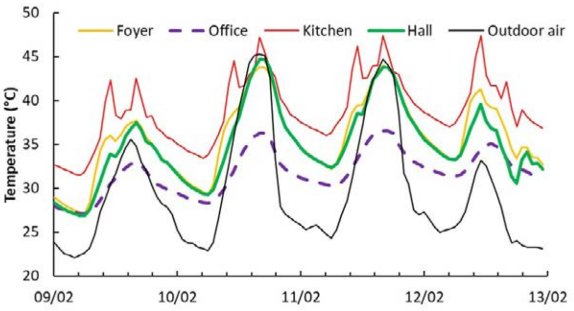

Figure 16. Indoor air temperatures in an **urban setting** computed during a historical heatwave event (February 2017) in the foyer, hall, kitchen and office. The black solid line displays the outdoor air temperature as obtained for Mt Druitt (3.5 km from Horsley Park) with a regression on a 1-year measurement campaign.

6.2. Retrofit scenarios

The investigated retrofit cases in this report are presented in Table 14. The retrofit options are progressively implemented after case B. Some options such as replacing windows with double glazing were not considered in this case, prioritising instead "light" retrofits that could deliver the maximum savings with quick interventions with a contained cost.

All retrofit scenarios have been considered with the HVAC in operation, while the scenarios focussing on the retrofit of the artificial lighting system (Cases A and B) and on HVAC replacement (Case G) have not been analysed in free-floating conditions because that analysis focuses only on the thermal conditions and consider the HVAC not in operation. While the increased efficiency in artificial lighting reduces heat dissipation and thus the cooling load, this variation is moderate and not likely to produce a notable variation in the indoor air temperature. ➔

Table 14. Retrofit cases.

Cases	Description
Baseline	The lighting power density was calculated using the lighting drawings provided by the building management and on assumptions about the wattage of the fixtures. The light sources used are fluorescent tubes or compact fluorescent lamps. Heating and cooling setpoint and setback temperatures are set according to the NCC and industry standards.
Case A	**Baseline + lighting scenario 1:** The number of lighting fixtures is the same as in the Base case scenario, but the fluorescent lamps are replaced with LEDs.
Case B	**Baseline + lighting scenario 2:** The power density of lighting scenario 1 was used and combined with continuous dimming of the light sources depending on daylight availability.
Case C	**Case B + standard cool roof:** A field-applied coating is sprayed onto the metal sheeting, increasing the reflectivity and emissivity of the roof. The solar absorbance is reduced to 0.20 (from the initial 0.75) and the thermal emittance is increased to 0.90 (from the initial 0.50).
Case D	**Case B + super-cool roof (daytime radiative cooler):** The roof coating is a daytime radiative cooler, which by means of radiative cooling, can achieve surface temperatures lower than the ambient temperature. This is simulated by setting the solar absorbance equal to 0.05 and the thermal emittance to 0.95.
Case E	**Case D + Cool walls:** The walls are coated with a paint, increasing the solar reflectance. The new solar absorbance is 0.30 and the thermal emittance 0.90.
Case F	**Case E + ceiling fans:** Ceiling fans are modelled by increasing the cooling setpoint temperature to 26°C, because air movement can increase thermal comfort.
Case G	**Case F + HVAC replacement:** Installation of a new HVAC system with a VRV and an air handling unit, providing fresh air. The efficiency parameters of the new HVAC are COP = 4.3 and EER = 4.8.
Case H	**Case G + increased window shading:** Improved window shading is implemented and simulated by considering a solar heat gain coefficient of 0.25 in summer and 0.60 in winter.
Case I	**Case H + night cross ventilation:** Air changes per hour set to 5 between 12 am and 6 am.

6.3. Results with HVAC in operation

6.3.1. Energy uses in the present climate context

The energy savings after the implementation of the different retrofit options are detailed in Table 15 for what concerns the loads and in Table 16 for site energy (i.e., electricity) in the current climate in Horsley Park during a hot year (2016-2017). The improved efficiency in artificial lighting delivers already a small reduction in the cooling load (~2.6%) and a small increase in the heating load (4.2%) because it reduces the heat dissipation from the lighting apparatuses. ➔

Table 15. Simulation results – Heating and cooling loads.

	Heating loads	Cooling loads	Heating + Cooling	Heating loads	Cooling loads	Heating + Cooling
Unit	kWh/(m^{2}a)			difference (%)		
Baseline	7.4	56.8	64.2	-	-	-
Case A (Baseline + Lighting 1)	7.8	55.4	63.2	5.4	-2.5	-1.6
Case B (Baseline + Lighting 2)	8.1	54.4	62.5	9.5	-4.2	-2.6
Case C (Case B + Cool roof)	12.3	36.2	48.5	66.2	-36.3	-24.5
Case D (Case B + Daytime radiative cooling)	13.5	32.6	46.1	82.4	-42.6	-28.2
Case E (Case D + Cool walls)	13.7	32.2	45.9	85.1	-43.3	-28.5
Case F (Case E + Ceiling fans)	13.7	25.7	39.4	85.1	-54.8	-38.6
Case G (Case F + HVAC replacement)	13.7	25.7	39.4	85.1	-54.8	-38.6
Case H (Case G + Improved windows shading)	18.2	20.1	38.3	145.9	-64.6	-40.3
Case I (Case H + night ventilation)	18.7	18.8	37.5	152.7	-66.9	-41.6

Table 16. Simulation results - Site energy.

	Heating	Cooling	Lighting	DHW	Appliances	Total	Total difference
Unit	kWh/(m^{2}a)						%
Baseline	2.6	23.7	21.3	3.2	19.1	69.9	-
Case A (Baseline + Lighting 1)	2.8	23.1	11.1	3.2	19.1	59.3	-15.2
Case B (Baseline + Lighting 2)	2.9	22.7	4.4	3.2	19.1	52.3	-25.2
Case C (Case B + Cool roof)	4.4	15.1	4.4	3.2	19.1	46.2	-33.9
Case D (Case B + Daytime radiative cooler)	4.8	13.6	4.4	3.2	19.1	45.1	-35.5
Case E (Case D + Cool walls)	4.9	13.4	4.4	3.2	19.1	45	-35.6
Case F (Case E + Ceiling fans)	4.9	10.7	4.4	3.2	19.1	42.3	-39.5
Case G (Case F + HVAC replacement)	2.9	6.0	4.4	3.2	19.1	35.5	-49.2
Case H (Case G + Improved windows shading)	3.8	4.7	4.4	3.2	19.1	35.2	-49.6
Case I (Case H + night ventilation)	3.9	4.4	4.4	3.2	19.1	35	-49.9

Overall, the implemented solutions deliver some increases in the heating loads (from 7.4 to ~18 kWh/m^2.a), with more consistent savings in cooling loads. However, increases in electricity use for heating are contained, thanks to the efficiency of the system.

The most significant relative reduction in cooling loads with a single retrofit option is achieved with the application of a cool roof or daytime radiative cooler (Case D or E, from ~ 57 to 36 or 32 kWh/m^2.a). The ceiling fans achieve an important reduction in the cooling loads simply by allowing a higher cooling setpoint temperature while retaining thermal comfort conditions (because with air movement, convective cooling of the human body is increased). Further significant savings are achieved with the replacement of the HVAC and then with efficient window shading.

Night ventilation delivers some further savings in cooling site energy, although it can be further optimised with a building management system, exploiting learning and predictive algorithms, as it depends on the outdoor air temperature. After all proposed interventions have been implemented, the electricity used by appliances constitutes almost 55% of the total site energy consumption. Therefore, further savings can be achieved with a replacement with more efficient appliances and additional interventions on the building envelope, which would entail a more substantial investment, such as an improvement in thermal insulation, and replacing windows or ground source heat pumps. These retrofit options represent the "low hanging fruits".

Furthermore, we computed the performance of the building in the base case and the last retrofitted scenario (case I) using urban weather data obtained for Mt Druitt, which is 3.5 km southeast of Tregear (Table 17). →

Table 17. Simulation results – Heating and cooling loads in non-urban (Horsley Park) and urban contexts (Mt Druitt).

Case	Location	Heating loads	Cooling loads	Heating+ Cooling	Heating loads	Cooling loads	Heating+ Cooling
		(kWh/m^2)			Difference urban-rural (%)		
Baseline	Non-urban	7.4	56.8	64.2	-	-	-
	Urban data	5.2	68.0	73.2	-29.7	19.7	14.0
Case I (Case H + night ventilation)	Non-urban	18.7	18.8	37.5			
	Urban data	18.7	23.9	42.7	0	27.1	13.9

Table 18. Simulation results - Site energy.

Case	Location	Heating	Cooling	Lighting	DHW	Appliances	Total	Difference urban-rural
		(kWh/m^2)						%
Baseline	Non-urban	2.6	23.7	21.3	3.2	19.1	69.9	-
	Urban	1.8	28.3	21.3	3.2	19.1	73.7	5.5
Case I (Case H + night ventilation)	Non-urban	3.9	4.4	4.4	3.2	19.1	35	
	Urban	2.0	5.6	4.4	3.2	19.1	34.2	-2.2

6.3.2. Energy uses in other cities and future climate

Here, the case study community centre building is simulated in 8 representative cities in Australia. CSIRO has current and future weather models. Therefore, this database is selected to investigate the impact of geographical locations and climate change on the case study building energy demand. Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases are called Representative Concentration Pathways (RCPs) [16]. The word representative indicates that each RCP provides one of many possible scenarios that would lead to a specific radiative forcing characteristic. The term pathway denotes that not only the long-term concentration levels are of interest, but also the path taken over time to reach that outcome is important. RCP4.5 is selected as the future pathway to compare different cities. RCP4.5 is an intermediate condition in which radiative forcing is stabilised at approximately 4.5 W/m^2 after 2100.

Table 19 presents the site energy needs of the Tregear community centre in 8 representative cities, where the cooling site energy will increase by 7-22% by 2030. Melbourne is the city with the highest relative variation in cooling demand (increased by ~22%), while the increase in cooling site energy due to climate change effects is expected to be less pronounced in hot and humid climates such as Darwin (~7%). Only in Hobart the heating energy reduction outweighs the increase in cooling energy resulting in overall savings over time. In all other cities, the unretrofitted building is exposed to an increase in total site energy. →

Table 19. Current and future energy demand of the case study building based on CSIRO weather database.

		Site energy (kWh/m^2)						Relative variation (%)		
Location	**Period**	**Water heating**	**Heating**	**Cooling**	**Lighting**	**Appliances**	**Total**	**Cooling**	**Heating**	**Total**
Adelaide	Present	3.3	5.1	24.0	21.3	19.1	72.8	-	-	-
	2030	3.3	3.7	27.9	21.3	19.1	75.3	16.3	-27.5	3.4%
Brisbane	Present	3.3	0.3	34.7	21.3	19.1	78.7	-	-	-
	2030	3.3	0.1	39.5	21.3	19.1	83.3	13.8	-66.7	5.8%
Canberra	Present	3.3	13.7	17.9	21.3	19.1	75.3	-	-	-
	2030	3.3	11.2	20.5	21.3	19.1	75.4	14.5	-18.2	0.1%
Darwin	Present	3.3	0.0	88.0	21.3	19.1	131.7	-	-	-
	2030	3.3	0.0	94.0	21.3	19.1	137.7	6.8	-	4.6%
Melbourne	Present	3.3	11.9	13.0	21.3	19.1	68.6	-	-	-
	2030	3.3	9.4	15.9	21.3	19.1	69	22.3	-21.0	0.6%
Perth	Present	3.3	1.9	35.1	21.3	19.1	80.7	-	-	-
	2030	3.3	1.1	39.9	21.3	19.1	84.7	13.7	-42.1	5.0%
Sydney	Present	3.3	1.9	20.6	21.3	19.1	66.2	-	-	-
	2030	3.3	1.2	23.6	21.3	19.1	68.5	14.6	-36.8	3.5%
Hobart	Present	3.3	16.8	5.2	21.3	19.1	65.7	-	-	-
	2030	3.3	14.9	6.3	21.3	19.1	64.9	21.2	-11.3	-1.2%

To evaluate the impact of retrofitting the case study community centre, the base case and highly retrofitted scenario (Case I) were simulated in Blacktown. As it is presented in Table 20, the total base case site energy will increase in 2030 compared with the current consumption, principally due to the cooling energy needs. The retrofitted scenario will see also an increase, but it will be of only 1.4 kWh/m² due to the increased overall efficiency.

6.3.3. Energy uses in other cities – hot year

In addition to the simulations performed with the weather data from CSIRO for the present climate and 2030, we also used data directly sourced from the Bureau of Meteorology for a hot year (2016-2017). In this case, we used the same year for all cities, aiming to perform a comparison (Table 21). In some cities, such as Sydney, the site energy in 2016-2017 (23.8 kWh/m²) is greater than for the typical weather year (20.6 kWh/m²) and even for the 2030 weather file (23.6 kWh/m²), showing that a hot year can be more challenging in terms of cooling energy consumption and peak power demand than the typical weather file with the addition of climate change. In other cities, the selected year is cooler than the typical weather year. These results highlight the importance of the definition of a heatwave year or design summer year that is city-specific and can be used to design the cooling performance of building across Australia.

6.4. Free-floating performance

Finally, the building was simulated during the heatwave year in Horsley Park (out of the urban area) and within the urban area (using data from Mt Druitt) without HVAC or ceiling fans to quantify indoor overheating in case of a prolonged blackout or failure of the HVAC system (Table 22). The analysis has been performed considering only the hours of operation as a cool centre, namely from 12 pm to 7 pm and during the period when heatwaves are probable (from 16th November to 15th February). During this period, the building without air conditioning and before retrofits presents extreme indoor air temperatures, above 30°C for more than 70% of the time the cool centre is open to the public, with indoor air temperatures exceeding 40°C for 5% of the time, and peak temperatures exceeding 43°C (Tables 22 and 23). Within the urban area, the indoor

→

Table 20. Current and future energy demand of the case study building based on CSIRO weather database

		Site energy (kWh/m²)						Relative variation (%)		
Location	Period	Water heating	Heating	Cooling	Lighting	Appliances	Total	Cooling	Heating	Total
Blacktown Base case	Present	1.1	147.3	61.4	21.1	4.6	93.4	-	-	-
	2030	1.1	164.9	68.7	21.1	4.6	99.4	-23.1%	11.9%	6.5%
Blacktown retrofitted	Present	0.3	31.3	4.4	4.5	4.6	14.6	-	-	-
	2030	0.3	40.0	5.6	4.5	4.6	15.5	-25.0%	27.3%	6.2%

Table 21. Site energy consumption of the case study building simulated with weather data for a hot year (2016-2017) from the Bureau of Meteorology.

		Site energy (kWh/m²)					
Location	Period	Water heating	Heating	Cooling	Lighting	Appliances	Total
Adelaide	2016-2017	3.2	5.9	16.9	21.3	19.1	66.3
Brisbane	2016-2017	3.2	0.2	32.6	21.3	19.1	76.3
Darwin	2016-2017	3.2	0.0	82.9	21.3	19.1	126.5
Melbourne	2016-2017	3.2	12.1	13.1	21.3	19.1	68.7
Perth	2016-2017	3.2	2.9	27.4	21.3	19.1	73.8
Sydney	2016-2017	3.2	1.7	23.8	21.3	19.1	69.1

Table 22. Risk of indoor overheating in free-floating conditions in the different retrofit scenarios: number of hours and percentage of time during the hours of operation as cool centre (12 pm – 7 pm) during the heatwave period (16th Nov – 15th Feb).

Indicator	Base case	Base case (urban data)	Case C Cool roof	Case D Daytime rad cooler	Case E Cool walls	Case H window shading	Case I Natural ventilation	Case I Nat. ventilation (urban data)
Hours T ≥ 30°C	461	522	333	312	308	259	305	376
Hours T ≥ 27°C	603	631	542	505	501	440	561	605
Hours T ≥ 25°C	640	643	627	616	614	587	627	643
%time T ≥ 30°C	71.6%	81.1%	51.7%	48.4%	47.8%	40.2%	47.4%	58.4%
%time T ≥ 27°C	93.6%	98.0%	84.2%	78.4%	77.8%	68.3%	87.1%	93.9%
%time T ≥ 25°C	99.4%	99.8%	97.4%	95.7%	95.3%	91.1%	97.4%	99.8%

air temperatures exceed 30°C for more than 80% of the time the centre is open to the public if air conditioning is not in operation.

The local urban climate conditions lead to significantly higher indoor air temperatures, and Case I with natural night ventilation shows a greater risk of indoor overheating than Case C (standard cool roof) outside of the urban environment. This is not surprising as during hot periods, and especially within an overheated built environment, night ventilation is less effective since the outdoor air temperature is not low enough to cool the building and dissipate heat stored during the day (Figure 17).

For the same reason, Case H is more effective than Case I at reducing the risk of indoor overheating. Thus, night ventilation should be implemented only with a more advanced system with temperature control and a building management system to operate windows.

Further, even with retrofit options aimed at reducing solar heat gains (cool roof or daytime radiative cooler, cool walls, and window shading) and increasing heat dissipation (night cross-ventilation), the building displays rapid indoor air temperature increases due to low thermal mass. Therefore, while the retrofits are effective in reducing the indoor overheating by even 4°C (from base case to Case H), the indoor air temperatures are still high and, in most cases, above 37°C, which is often assumed as a threshold for concern as the conventional core body temperature of the human body.

Hence, a cool centre should be equipped with on-site renewable energy systems (e.g., rooftop PV) and a small backup power generator to prevent the exposure of occupants to extreme heat. In brief, a cool centre should be equipped with redundancy, so it can be in operation even during compound crises (e.g., prolonged heatwaves during bushfires with power outages).

Future research will concern the risk of indoor overheating with power outages of different lengths and additional optimisation of night ventilation. Also, future weather data collection in the area will enable more robust simulations with urban data not derived from a correlation but using directly collected data. ➔

Table 23. Statistics of the indoor air temperature in free-floating conditions in the different retrofit scenarios during the hours of operation as a cool centre (12 pm – 7 pm) during the heatwave period (16th Nov – 15th Feb).

Statistic	Base case	Base case (urban data)	Case C Cool roof	Case D Daytime rad cooler	Case E Cool walls	Case H window shading	Case I Natural ventilation	Case I Nat. ventilation (urban data)
Max	43.4	44.7	41.0	40.5	40.5	39.4	41.0	42.3
95th percentile	40.0	41.2	37.6	37.1	37.0	36.2	36.8	38.0
90th percentile	38.4	39.7	36.2	35.7	35.7	34.8	35.1	36.3
Median	32.6	33.7	30.2	29.8	29.7	28.8	29.8	30.8
Min	23.7	24.6	22.7	22.6	22.5	22.1	23.3	24.2

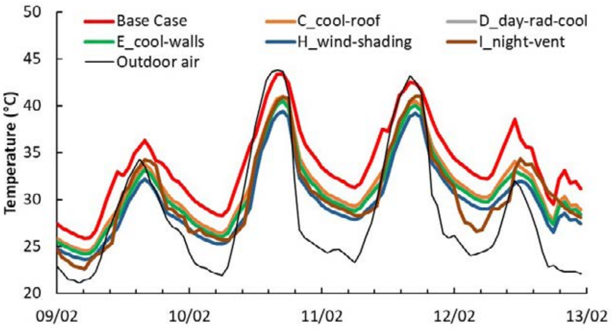

Figure 17. Indoor air temperatures in the hall, in the unretrofitted (base case) and retrofitted scenarios, computed during a historical heatwave event (February 2017). The solid black line displays the outdoor air temperature as measured at Horsley Park.

6.5. Conclusions and recommendations

The use of community centres as ‘heat-safe’ venues or cool centres has been first trialled by Blacktown City Council in 2022, and more information concerning the operation of the centres may reduce the uncertainty concerning the input parameters. The case study building energy performance was simulated to elaborate the baseline conditions based on the building’s construction and operational features and in accordance with the foresight of respective standards and regulations.

Several retrofit options have been investigated, aiming at minimising the solar heat gains (i.e., solar reflective roof and walls and window shading), improving indoor thermal comfort (i.e., use of ceiling fans) and dissipating heat with night ventilation. Further interventions concerned the reduction of the electricity demand for lighting and using a more efficient ducted HVAC system.

To minimise electricity consumption in the building, the following recommendations are offered:

- The centre uses old artificial lighting systems, which can be replaced with daylight linked controls and LED with substantial savings (from 21.3 to 4.4 kWh/m²), also reducing heat dissipation from the light fixtures.
- Simple interventions reducing the solar absorption of the opaque building envelope, consisting of field-applied reflective coatings on the roof and walls, reduce the cooling site energy by more than 43%.
- The installation of efficient ceiling fans can reduce the cooling site energy by enabling thermal comfort at higher temperatures, thanks to air movement.
- The replacement of the HVAC with a new ducted system (now three separate ductless split units are in use) would achieve greater efficiency and deliver fresh air, thus reducing the risk of respiratory diseases transmission when the cool centre is in operation without natural cross ventilation (i.e., air conditioning on, and windows and doors closed), as it expected during a heatwave.
- Efficient window shading and night cross-ventilation can achieve further savings, reducing the cooling site energy to 4-5 kWh/m², which can be covered with on-site renewables.

All identified retrofit options are relatively “low-hanging fruits”, which have been considered as they are easy to implement and do not entail major interventions on the building envelope (such as reroofing or removing the false ceiling to include more thermal insulation). Also, they can be implemented rapidly by councils managing community centres to be used as cool centres (i.e., ‘heat-safe’ venues) across Australia. The only proposed intervention that is more substantial is the replacement of the HVAC, which is motivated by the need to reduce the risk of transmission of respiratory diseases in an indoor environment, currently without ventilation, as it is common in many community centres.

We also considered the same building in operation without air conditioning or ceiling fans to simulate the extreme scenario of prolonged power outages during an extreme heat season, which might occur after a major grid failure. This analysis has shown that the building is at significant risk of indoor overheating without air conditioning or ceiling fans. The retrofit options can reduce the peak indoor air temperatures even by 4°C, which would still be very high, and frequently above 35-37C° during the heatwave season.

Therefore, a cool centre would need energy provided by renewables on-site and backup power generation to manage extended blackouts, even in case of a major failure of the electrical grid due to a compound crisis. Further, the optimisation of the operation of night ventilation managed by a building management system could deliver additional savings.

References

1. UK Green Building Council, *Climate Change*, in https://www.ukgbc.org/climate-change/ [accessed 7 August 2021].
2. Rooney, D., *Mapping Australia's neighbourhood centres* 2011.
3. Peel, M.C., B.L. Finlayson, and T.A. McMahon, *Updated world map of the Köppen-Geiger climate classification*. Hydrol. Earth Syst. Sci., 2007. 11(5): p. 1633-1644.
4. Bureau of Meteorology. *Climate statistics for Australian locations*, http://www.bom.gov.au/ [Accessed 8 August 2021].
5. Australian Building Codes Board, *National Construction Code Volume One, Amendment 1*,. 2019.
6. Walls, M. *Refuges provide shelter in heatwaves*. 2021.
7. Mirsadeghi, M., et al., *Review of external convective heat transfer coefficient models in building energy simulation programs: Implementation and uncertainty*. Applied Thermal Engineering, 2013. 56(1): p. 134-151.
8. International Organization for Standardization, *ISO 6946:2007, in Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*. 2007.
9. British standard, BS EN ISO 10456:2007, in *Building materials and products — Hygrothermal properties –Tabulated design values and procedures for determining declared and design thermal values*. 2007.
10. CSR Bradford. *Acoustic & thermal insulation for residential metal roof*. 2013.
11. TRNSYS, *A transient systems simulation program*. 2017, https://sel.me.wisc.edu/trnsys/index.html.
12. ASHRAE, *Fundamentals Handbook*. 2017.
13. Standards Australia, *AS 1668.2, Amendment 1, The use of ventilation and airconditioning in buildings-Mechanical ventilation in buildings, in Mechanical ventilation in buildings*. 2012.
14. Daly, D., P. Cooper, and Z. Ma, *Understanding the risks and uncertainties introduced by common assumptions in energy simulations for Australian commercial buildings*. Energy and Buildings, 2014. 75: p. 382-393.
15. ASHRAE, *ANSI/ASHRAE Standard 55, in Thermal Environmental Conditions for Human Occupancy*. 2020: https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy.
16. Yousefi, H., et al., *Feasibility study and economical evaluations of geothermal heat pumps in Iran*. Geothermics, 2018. 72: p. 64-73.
17. Moss, R.H., N. Nakicenovic, and B.C. O'Neill, *Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies*, ed. IPCC EXPERT MEETING REPORT. 2008, IPCC.

Attachment 1

The following figures show daylight factor distribution in Tregear centre.

Fig. A1. Distribution of Average Daylight Factor in daylit spaces.