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Community Centre

Energy Efficiency Training
and Information Project

Commercial Buildings

Kings
Langley
NSW

Research group

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

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Cover image:
Jim Southee Community Centre in Kings Langley, NSW.

Contents

1. Executive Summary

A complete renovation package ... will lead to energy savings of 65.9%

The 2006 Paris Agreement on climate change aims to hold the increase in global average temperatures to below 2°C above pre-industrial levels. In this context future Australian buildings may be expected to experience higher net average temperatures than they experience at present and will need to adapt to the upcoming climatic conditions. Almost 80% of 2050 buildings already exist today [1], and we must prioritise improving the efficiency of existing buildings. There are more than 1,000 community centres in Australia, and they have been operating in local communities, building capacity for inclusion and empowerment, community interaction, wellbeing, resilience and social cohesion [2].

This report tackles the operational energy consumption challenge for an existing community centre, using a real-life case study to visualise the impact of each energy optimisation strategy. A high-level framework prioritising different building enhancement methods is presented in this report.

Here, a typical community centre 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. This report summarises the findings of the performed analysis on the existing conditions and provides recommendations for the improvement of the energy performance of the Jim Southee Community Centre. It is a single-storey building with structural and energy performance features typical for community centres constructed in the early 1980s.

The analysis showed that the community centre hall has adequate daylight while the entrance has lower daylight availability than the recommended. The use of more efficient light sources and daylight linked controls in the building spaces would achieve a reduction of the total lighting load (kW) and the annual energy (kWh) ranging from 25 to 95%. The baseline scenario for determining feasible interventions addresses first the high energy consumption for heating and cooling. In particular, heating constitutes the largest fraction of site energy consumption. As a result, the primary focus is on lowering heating requirements. The main causes for those are:

- The uninsulated roof, which in such a low-rise building has a major impact on energy performance and the uninsulated walls.
- The HVAC system lags in efficiency, both for space heating and for DHW preparation. Replacing it will therefore have quite an impact on respective energy consumption.

Hot water production and the requirements for lighting and appliances are also significant. Based on these conclusions, the following recommendations are technically viable and relatively easy to implement:

- Refurbishment of the roof, fitting 120 mm of mineral wool under the existing roof, leading to a reduction of both heating and cooling loads.
- Refurbishment of the windows, with new aluminium framed, double glazed ones, of high energy efficiency, so as to reduce thermal losses in winter and achieve air-tightness throughout the year.
- Applying insulation on external walls. Insulation consists of 90 mm of mineral wool covered with plasterboard for brick walls and 8cm of mineral wool covered with plasterboard for timber stud walls, leading to reduction of both heating and cooling loads. ➔

- Improvement of the lighting systems.
- Replacement of old inefficient or non-functional ceiling fans to reduce cooling loads and to reduce the energy consumption of the fans.
- Installation of mechanical ventilation with heat recovery to reduce heating loads.
- Installation of an air-to-water heat pump (AWHP) or a ground source heat pump (GSHP) could lead to a drastic reduction of final energy consumption for space heating and domestic hot water (DHW).
- Finally, the installation of a 10 kWp net metering PV system on the northern roof to cover the electricity consumption of the building.

In conclusion, a complete renovation package is suggested that includes the drastic improvement of the building envelope's thermal protection by means of insulation of external walls and roof, and replacement of the windows and glazed surfaces, the upgrading of the lighting system, the installation of ceiling fans and mechanical ventilation with heat recovery, and eventually the use of a GSHP or, if this is not possible, of AWHP. Such a package will lead to energy savings of 65.9%, resulting in an energy consumption of 57.1 kWh/m²a, compared to the baseline of 167.2 kWh/m²a. The simulation results demonstrated that almost 45.4% of the cooling load in 2030 can be cut by completely retrofitting the building. This efficiency improvement can also reduce the total electricity demand of the building by 64.5%. ■

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 1982, representative of several other low-rise buildings constructed approximately in the same period. Clearly, one sample community centre building cannot completely fit all similar buildings, and each community centre has differences; however, even though the project-specific outcomes may differ, the logic and methodology presented here offer a high-quality framework to improve the energy efficiency in such buildings.

Assessing the energy performance of an old building is a complicated task. It starts with determining the building's constructional features, including the efficiency of the building envelope, lighting, HVAC equipment, etc. Considering the building's features, all calculations were based on the 'as-built' condition of the building elements (U-values, shading, air-permeability, etc.). The efficiency of the HVAC system (Coefficient of Performance (COP) and seasonal Energy Efficiency Rating (EER) were selected based on the provided information by their manufacturers, and installed lighting and plug loads were determined either by data provided by the building operators or in accordance with standards and regulations.

Additionally, two types of specific conditions that have a significant impact on the community centre building's performance must be considered:

(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.). ■

4. Jim Southee centre in Blacktown

4.1. Case study description

4.1.1. Climate

The case study community centre is located at 117 James Cook Dr, Kings Langley NSW, 2147 (33.744S, 150.924E). Blacktown is 30 km west of the Sydney central business district, and it is 70 m above sea level. In Köppen climate classification, Blacktown is categorised as Cfa, meaning that it is warm and temperate, with a humid subtropical climate [3]. 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 (Figure 1). ➔

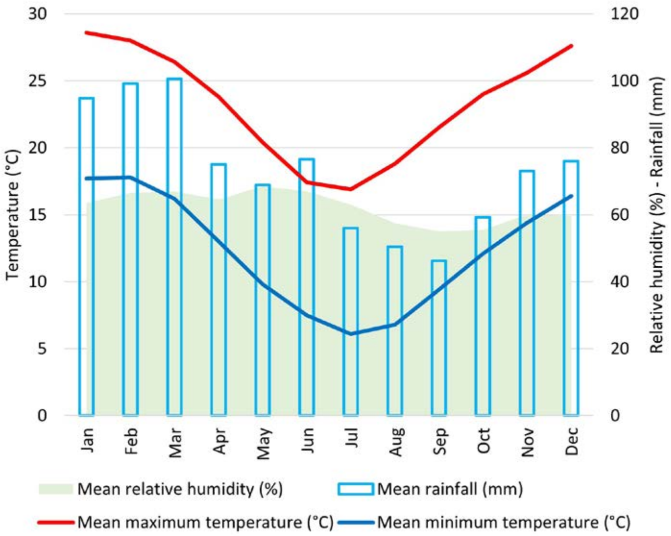


Figure 1. Climatic data for Blacktown [4].

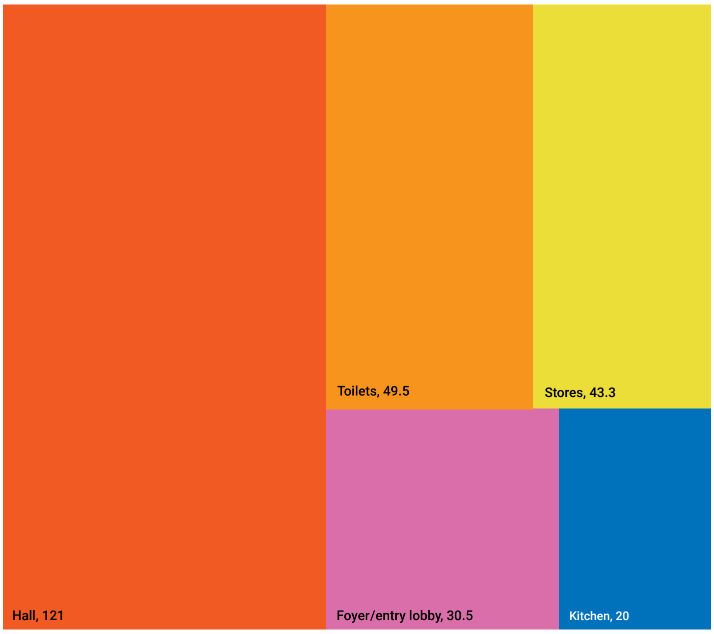


Figure 2. Gross floor divided area of case study building.

Figure 3. Northern view of Jim Southee centre.

4.1.2. Building description

This case study community centre is in a Greater Western Sydney suburb, and it was completed in 1982. In 1993, a storeroom was converted to a Kitchen in the western part of the building. According to the National Construction Code, the building classification is 'Class 9b: assembly buildings in which people may gather for social, theatrical, political, religious or civil purposes' [5]. The under-ceiling height for this single-storey building varies between 2.5-5 m. The total gross floor area is 264.3 m2. Figure 2 illustrates the treemap chart of the gross internal area of the case study building.

4.1.3. Energy consumption and sources

Improving energy efficiency is a practical way to reduce the building's operational cost. This building does not use any renewable resources generated on-site. Electricity is used for HVAC purposes, lighting, appliances, water heating and cooking in the Jim Southee centre. ➔

4.2. Building modelling input parameters

The modelling parameters are a combination of collected data from the building inspection and Australian and international standards. In this section, each modelling assumption will be briefly explained and referenced.

4.2.1. Occupancy

Currently, the Jim Southee centre has capacity for 60 people, and the occupancy schedule is selected based on the national code of construction (Table 9)[5].

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.

4.2.3. Building Components

A significant part of energy consumption is used to maintain comfort leaks through the building envelope. As a key step to assess the potential benefits of improving windows, walls, roofs and floors, the current thermal performance should be determined. Here, we assessed the thermal properties of the building envelope based on the age of construction. This information is used to model the building and develop a thermal model. In this section, the performance descriptors of external walls, roof, and windows are introduced.

4.2.3.1. External walls

The external wall of the case study building can be divided into two parts. There is a brickwork wall in the lower parts of the wall and timber studs in the upper part.

The brickwork wall includes three main layers: two layers of solid bricks with an air cavity in between. The R-value of the external wall is determined as 0.633 m^2.K/W. The solar reflectance is considered equal to 0.6. Also, using the average annual wind velocity in Blacktown (3.0 m/s) [4], the convective heat transfer coefficient is calculated as 17.6 W/(m^2.K) [6].

The timber stud wall includes three main layers: timber panels as the outer layer, an air cavity, and an interior layer of timber panels, with an R-value equal to 0.850 m^2.K/W. The solar reflectance coefficient is considered equal to 0.7. Also, using the average annual wind velocity in Blacktown (3.0 m/s) [4], the convective heat transfer coefficient is calculated as 17.6 W/(m^2.K) [6]. →

Table 1. Building geometric information.

Building	Air-conditioned area (m^2)	Unconditioned area (m^2)	Gross floor area (m^2)
Foyer/Entry lobby	30.5	0	30.5
Hall	121.0	0	121.0
Storerooms	0	43.3	43.3
Kitchen	20.0	0	20.0
Toilets	0	49.5	49.5
Total	171.5	92.8	264.3

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

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m^3)	Resistance (m^2.K/W)	Ref.	Section and page
Brick	110	0.78	0.8	1,950	-	[5]	Section J, page 389
Air space	50	-	-	-	0.18	[7]	Section 5.3, page 5
Brick	110	0.78	0.8	1,950	-	[5]	Section J, page 389

R-value: 0.633 m^2.K/W

Table 3. Building Components - Performance Descriptors – Construction – External Timber stud walls

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m^3)	Resistance m^2.K/W)	Ref.	Section and page
Timber panel	25	0.1	1.6	506	-	[5]	Section J, page 388
Air space	50	-	-	-	0.18	[7]	Section 5.3, page 5
Timber panel	25	0.1	1.6	506	-	[5]	Section J, page 388

Overall R-value: 0.850 m^2.K/W

4.2.3.2. Roof

The roof of the case study community centre consists of three layers. There are concrete tiles on the top layer, an air gap, and plasterboard inside, with an R-value equal to 0.545 m^2.K/W and a solar reflectance coefficient equal to 0.15. Also, using average annual wind velocity (3.0 m/s) [4], the convective heat transfer coefficient is calculated as 17.6 W/(m^2.K), respectively [6].

4.2.3.3. Windows

External windows in the case study community centre are single glazed with an aluminium frame. The selected shading and glazing in the model are presented in Table 5.

4.2.4. Domestic hot water

The needed hot water for the Jim Southee centre is calculated based on Table 2m, NCC volume 1 page 355 [5]. Therefore, considering the need for 50°C temperature increase and water heat capacity (4.19 KJ/kg.°C), and occupancy schedule of the community centre, 17.6 MJ heating energy is needed for daily heating domestic water (Table 6). →

Table 4. Building Components - Performance Descriptors – Construction – Roof

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m^3)	Resistance (m^2.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: 0.545 m^2.K/W

Table 5. Building Components - Performance Descriptors - Openings Shading.

Shading	External Shading is applied on the windows on the northern and western sides of building		
Glazing	**Value**	**Unit**	**Ref.**
Thickness	14	mm	[9]
Glazing U-value	5.44	(W/m^2.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 6. Domestic hot water.

Demand-side	Occupancy	Unit Hot water demand	Daily hot water demand (lit)
	60	2.8 lit/person	168

4.2.5. Internal gains

The information regarding the thermal comfort in the studied community centre is provided by the Blacktown City Council (BCC), as given in Table 7. Lighting and personal heat gain assumptions in the model are based on Australian and international standards. The assumed heat gain for kitchen appliances in Jim Southee centre is presented in Table 8. The heat rates are based on NCC volume 1 page 355 [5] and chapter 18.12 of ASHRAE Fundamental 2017 [10].

4.2.6. Ventilation and infiltration

The fresh air supplied to each space and the infiltration are assumed based on international standards (Table 9).

4.2.7. Thermal Comfort

The thermal comfort parameters have been considered as in Table 8, 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. The foyer, hall and kitchen are air-conditioned by split systems. Based on the information provided by BCC, COP and EER of the heating and cooling systems are considered as 2.8 and 2.4, respectively. →

Table 7. Temperature setpoints, lighting and personal heat gain.

	Building	Value	Unit	Ref.	Section and page
Cooling setpoint temperature	All	24	°C	BCAM	-
Heating setpoint temperature	All	20	°C	BCAM	-
Personal latent gain	8,9	55	W/person	[12]	Chapter 18.4
Personal sensible gain	All	75	W/person	[12]	Chapter 18.4
Appliances and equipment gain	All	160	W/room	[6]	Section J, page 355
Lighting heat gain	A	13.7	W/m^2	[6]	Section J, page 379
	D	8.8	W/m^2		
	B,C,E,F,G,H	8.6	W/m^2		

Table 8. Building appliances heat gains

Appliances	Electricity consumption (W)	Usage factor
Oven	1,174	0.25
Kitchen hood	330	0.5t
Fridge and Freezer	400	0.25
Microwave	1,450	1.39

Table 9. 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		

Table 10. Thermal comfort parameters

Factor	Value	Unit	Ref.	Section and page
Clothing Factor	Summer 0.6 – Winter 1	clo	[13]	Section 5, page 8
Metabolic rate	1.0	Met	[13]	Section 5, page 7
Relative air velocity	Less than 0.2	m/s	[13]	Section 5, page 11

4.2.9. Schedules

The schedules of occupancy, lighting and appliances of the Jim Southee Community Centre (Table 11) are selected based on pages 352-353 of the National Construction Code with some modifications due to provided documents by BCAM [5].

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 Jim Southee community centre. The steps taken in this regard are:

1. The analysis and simulations of the existing lighting conditions, based on information provided by the 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 while 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 data provided for the Jim Southee centre were the architectural drawings of the building. Photographs of the interior and exterior of the building were also provided, where some lighting fixtures and interior surfaces' properties were visible. Specific information about the building's lighting system was not available. Using the provided data, 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. The simulation results were then compared to the requirements and recommendations of the Australian NCC [5]. Based on the simulation findings, three scenarios were tested. These scenarios are described in Table 12.

→

Table 11. Occupancy, lighting and appliances schedules.

Time	Occupancy	Hall lighting and equipment	Kitchen lighting 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 12. Scenarios for reduced energy consumption for lighting

Base-case scenario	The lighting power density was considered equal to the maximum density permitted by the NCC for the specific type of space.
Scenario 1	The lighting power density was calculated using LEDs in all spaces instead of more conventional technologies, e.g., fluorescent tubes.
Scenario 2	Scenario 2 has the same lighting power density as Scenario 1. However, daylight controls are used at the building entrance and the hall.

4.3.2. Lighting analysis result

In this section, the calculation of the existing lighting power density (W/m²) is explained in detail, and scenarios for the reduction of the energy consumption for lighting are proposed.

4.3.2.1. Natural lighting

The studied spaces of the building have openings on the North and West elevations. The entrance to the community centre also has a north-facing skylight, while the hall has an east-facing skylight, both with vertical glazing. The windows are shaded by the protruding roof and by other structural elements. The natural lighting conditions have been studied in the entrance and the hall. The average Daylight Factor was calculated equal to 2.37% for the hall and 0.9% for the entrance of the building (Table 13). The daylight in the entrance is lower than the recommended by the Standards 2%. However, due to the use of the space and the fact that the entrance is not a continuously occupied space, there is no need to take measures to increase daylight availability.
The daylight entering the hall is considered adequate.

4.3.2.2. Artificial lighting

The community centre management provided photographs in which some lighting fixtures could be identified. The type of light source (lamp) used is not known. Due to the minimum information on artificial lighting, no lighting level simulations were performed, as they would require a great number of assumptions that would result in inaccurate results.

Table 13. Mean Daylight Factor (%) of the occupied spaces of the Jim Southee centre

Space	Average Daylight Factor (%)	Uniformity
Entrance	0.9	0.35
Hall	2.37	0.34

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) (Figure 4).

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. [10].

After importing the aged care centre buildings 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 4. SketchUp model.

5.3. Retrofit approaches

Evaluating the energy performance of a building is a complicated task. It initiates 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 were based on the 'as-built' condition of the building elements (U-values, shading, air-permeability, etc.), the performance of the HVAC system (COP and EER as provided by manufacturers) Also, installed lighting and plug loads were determined either by data provided by the building operators or in accordance with 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.

This baseline condition cannot be straightforwardly derived from metered energy consumption since the latter is affected by the aforementioned building's specific operational and microclimate conditions and the weather conditions of the specific period. In that sense, while the metered consumption values are real, they do not necessarily represent a base for an objective assessment. Therefore, the building has to adopt standard reference conditions, as foreseen by national regulations and standards, which allow a good degree of replicability for the simulative calculations that allow a detailed breakdown of energy consumption by source and use and a reliable assessment of the improvements achieved by the interventions considered.

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 ASHRAE and ISO standards. Simulations are carried out with a 1-hour time step, whilst the thermal zoning is 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.

5.3.1. Lighting retrofit

This section aims to develop scenarios that would enable reduced energy consumption for lighting and provide an approximation of how much energy can be saved. Due to the lack of information about the installed lighting sources, the base-case scenario considers the maximum lighting power density permitted by the NCC for each type of space [5].

On the contrary, Scenarios 1 and 2 aimed to achieve minimum energy consumption. As a result, for Scenario 1, the illumination power density was decreased, assuming the conventional (fluorescent) light sources are replaced with LEDs. For Scenario 2, the power density of Scenario 1 was used and combined with continuous dimming of the light sources depending on daylight availability. The proposed scenarios resulted in a reduction of the total lighting load (kW) and the annual energy (kWh) ranging from 25 to 90% (Table 14). The hall and the entrance present higher energy savings, as these spaces receive daylight, and both energy-efficient light sources and controls can be used. →

Table 14. Illumination power density and energy consumption for the base case and the proposed scenarios

		Base case		Scenario 1		Scenario 2	Max. energy savings achieved (%)
Space	Area (m^2)	Max. illumination power density (W/m^2)	Energy consumption (kWh/year)	Max. illumination power density (W/m^2)	Energy consumption (kWh/year)	Energy consumption (kWh/year)	
Foyer/ Entry lobby	**30.5**	9.0	766.0	2.0	219.0	32.0	95.8
Hall	**121.0**	8.0	3554.0	2.3	1000.0	146.0	95.9
Stores	**43.3**	1.5	47.4	1	47.4	31.6	33.3
Kitchen	**20.0**	4.0	350.4	3.0	350.4	262.8	25.0
Toilets	**49.5**	3.0	650.4	2.0	650.4	433.6	33.3

5.3.2. Roof insulation

Insulation is a cost-effective way to save energy and improve the indoor environment. Roof insulation refers to the addition of a layer of Mineral wool (thickness of 120 mm) under the existing roof, leading to an average total thickness of 243 mm and an average R-value of 3.73 m^{2}K/W. The average installed cost is estimated at 52 AUD/m^2.

5.3.3. Windows retrofit and wall insulation

The current windows installed in the Jim Southee community centre are single glazed with aluminium frame, leading to substantial heat transmission losses. The proposed window has an aluminium thermally-broken frame, double glazing, and low-e external glass pane, with an average U-value of 1.53 W/m^{2}K, an SHGC value of 0.7 Air-tightness values of Class 3 with less than 2.5 L/s.m^2 at 100 Pa. The latter reduces the infiltration rate of the building to 0.30 1/h. The average cost for windows replacement is estimated at 600 AUD/m^2. Also, the application of 90 mm of mineral wool covered with plasterboard on external brick walls and 80 mm of mineral wool covered with plasterboard on external timber stud walls leading to an R-value of 2.94 m^{2}K/W.

5.3.4. Air-to-water heat pump (AWHP), ceiling fans and Mechanical Ventilation with Heat Recovery (MVHR)

The installation of an air-to-water heat pump with fan coils with a coefficient of performance COP=3.5 and energy-efficient rating EER=3.8, including distribution and terminal units losses. The heat pump is also used for DHW preparation with COP=2.6, including storage and distribution losses.

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 to be 3°C colder than the actual air temperature, thereby reducing the need for additional cooling. The existing ceiling fans should be replaced by higher efficiency ones. This replacement was modelled by increasing the cooling setpoint temperature to 26°C. The efficiency of the MVHR system is 80%.

5.3.5. Ground Source heat pump (GSHP), ceiling fans and MVHR

The GSHP cycle exchanges heat between two thermal reservoirs, one at a relatively high temperature and another at a lower one. Actually, the building and the underground temperatures are assumed to be high and low-temperature reservoirs during the hot season, respectively. In winter, the building is regarded as a high-temperature reservoir, and the underground is the low-temperature one. Each GSHP system consists of many components. The evaporator, compressor, condenser, and expansion valve are the main components of every GSHP system. Heat gained from the underground is released into the building by means of the condenser in cold seasons, while in summer, the evaporator extracts heat from the area, which should be cooled [15].

The GSHP here considered meets space heating, cooling and DHW demands. The GSHP with fan coils has an average COP=4.8 and EER=5 for HVAC applications, including losses of the distribution network and terminal units. The heat pump is also used for DHW preparation with COP=3.2, including storage and distribution losses. The replacement of ceiling fans and adding MVHR systems are similar to section 5.3.4.

5.3.6. Cool roof tiles

New coating tiles with albedo 0.75 solar absorbance 0.25 will be added in this retrofit scenario. Concerns either the installation of new white concrete tiles with an estimated average installed cost of 32 AUD/m^2 and expected life of 50 years, or the painting of the existing ones with an estimated average installed cost of 4.2 AUD/m^2 and expected life of 3-5 years.

5.3.7. PV system

Installation of a 10 kWp net metering PV system on the northern roof to cover the electricity consumption of the building. It can be a solution to make Jim Southee community centre a net positive energy building (i.e., producing more electricity than consumed, over the year). The required peak power was determined based on the residual site energy consumption after the retrofit and rooftop space availability. The use of batteries is not foreseen (PV is gridded), but the option of installing a solar diverter for DHW is advised, which can serve as thermal energy storage. ■

6. Results

6.1. Base building modelling

The result of the Jim Southee centre simulation in Blacktown is presented in this section. The hourly energy demand for heating and cooling (sensible and latent) is illustrated in Figure 5. Also, the monthly energy demand is presented in Figure 6. →

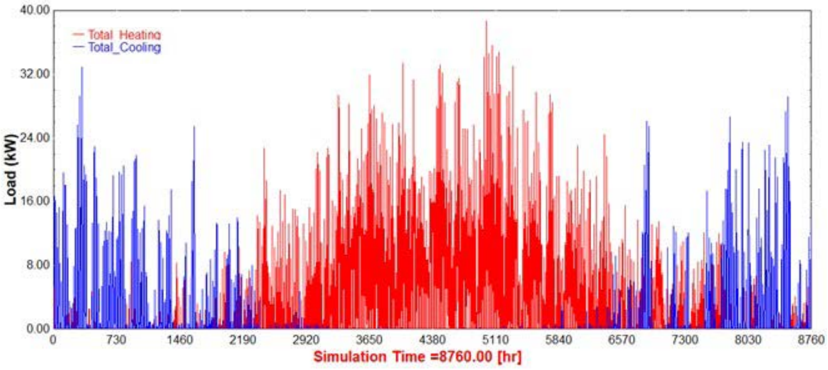


Figure 5. Hourly energy demand for HVAC purposes.

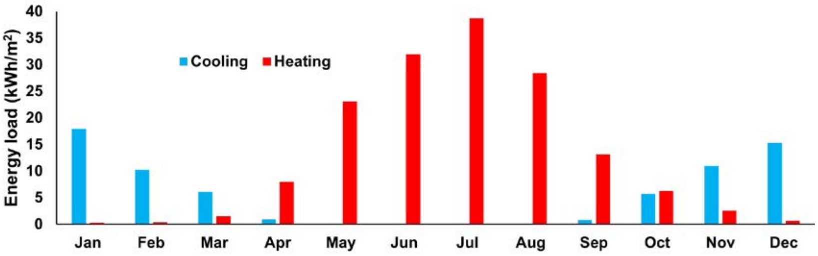


Figure 6. Monthly energy demand for HVAC purposes.

TRNSys calculates thermal loads through an energy balance that affects the air temperature inside the building:

$q_{BAL} = q_{DQAIRdt} + q_{HEAT} - q_{COOL} + q_{INF} + q_{VENT} + q_{TRANS} + q_{GINT} + q_{WGAIN} + q_{SOL}$

q_{BAL}: the energy balance for a zone and should always be close to 0;

$q_{DQAIRdt}$ is the change of internal energy of the zone (calculated using the combined capacitances of the building and the air within it);

q_{INF} is the gains by infiltration;

q_{VENT} is the gains by ventilation;

q_{TRANS} is transmission into the surface from an inner surface node;

qG_{INT} is internal gains by convection and radiation;

q_{WGAIN} represents gains by convection and radiation through walls, roof and floor;

q_{SOL} is absorbed solar gains on all inside surfaces;

q_{HEAT} is the power of ideal heating;

q_{COOL} is the power of ideal cooling.

Therefore, the ratio of each parameter in total energy gain can be decided for heating and cooling seasons (Figure 7 and Figure 9). Also, the amount of heating and cooling energy is illustrated in Figure 8 and Figure 10.

➔

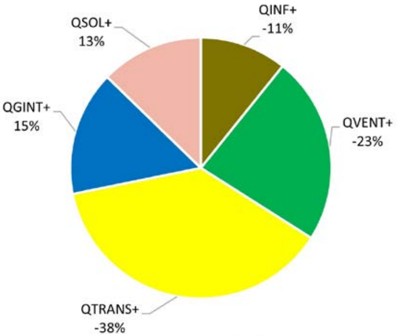


Figure 7. Whole building energy gain – heating season (May - September).

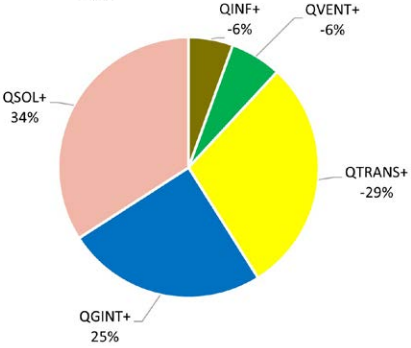


Figure 9. Whole building energy gain – cooling season (October - April).

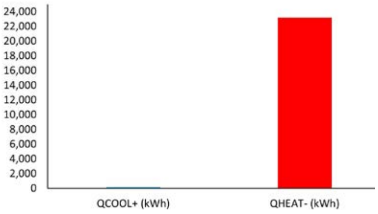


Figure 8. Whole building energy gain for heating and cooling load – heating season (May-September).

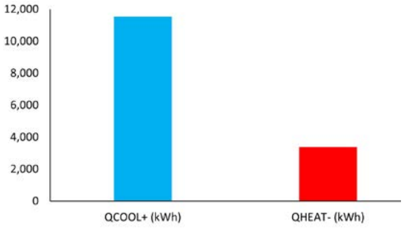


Figure 10. Whole building energy gain for heating and cooling load - cooling season (October-April).

The monthly energy gain of the community centre building and the influence of each factor in the total energy demand is presented in Figure 11.

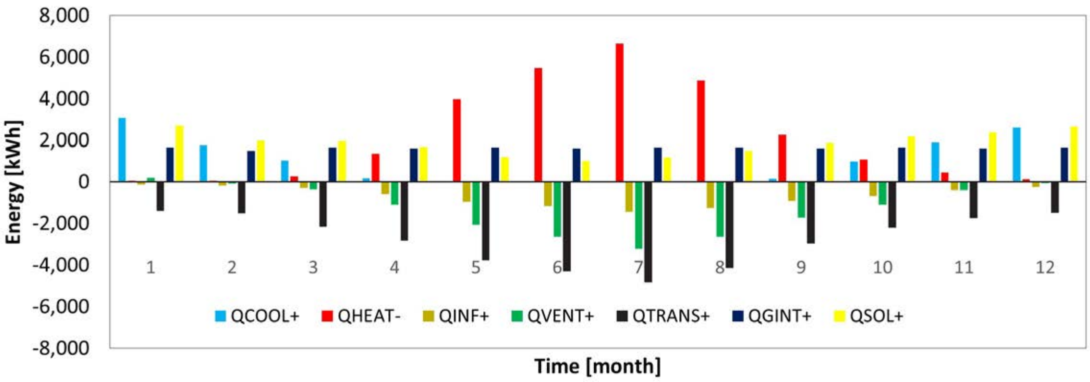


Figure 11. Monthly building energy gain.

6.2. Retrofit scenarios

The investigated retrofit cases in this report are presented in Table 13. →

Table 15. Retrofit cases.

Cases	Description
Baseline	The base-case scenario considers the maximum lighting power density permitted by the NCC for each type of space. For the cases where a range of power densities is allowed by NCC, the maximum value is considered. Heating and cooling setpoint and setback temperatures are set according to the NCC.
Case A	**Baseline + lighting scenario 1:** Illumination power density decreased in many spaces, either using the information for the actual lighting systems of the building or by adopting the minimum power density as required by the NCC.
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 + roof insulation:** Refurbishment of the roof, fitting 12cm of mineral wool under the existing roof, leading to a total R-value of 3.73 W/m²K.
Case D	**Case C + windows retrofit + wall insulation:** Application of 9cm of mineral wool covered with plasterboard on external brick walls and 8cm of mineral wool covered with plasterboard on external timber stud walls, leading to a total R-value of 2.94 m²K/W. New windows are aluminium framed, with a thermal break in the frame, double glazed, with an average U-value of 1.53 W/m²K, an SHGC value of 0.7.
Case E	**Case D + Installation of AWHP, replacing ceiling fans and MVHR:** Installation of one Air-to-water heat pump with fan coils with a coefficient of performance COP=3.5 and energy-efficient rating EER=3.8, including distribution and terminal units losses. The heat pump is also used for DHW preparation with COP=2.6, including storage and distribution losses. The efficiency of the MVHR system is 80%. Replaced ceiling fans are modelled by increasing the cooling setpoint temperature to 26°C.
Case F	**Case D + Installation of GSHP, replacing ceiling fans and MVHR:** Installation of one ground source heat pump with fan coils, with a coefficient of performance COP=4.8 and energy-efficient rating EER=5, including distribution and terminal units losses. The heat pump is also used for DHW preparation with COP=3.2, including storage and distribution losses. The efficiency of the MVHR system is 80%. Replaced ceiling fans are modelled by increasing the cooling setpoint temperature to 26°C.
Case G	**Case F + cool roof tiles:** New coating tiles with albedo 0.75 (i.e., solar absorbance 0.25). It can be achieved either with the installation of new white concrete tiles or the painting of the existing ones with a solar reflective coating.
*	**PV system.:** Installation of a 10 kWp net metering PV system on the northern roof to cover the electricity consumption of the building.

Between the presented scenarios, Case G has the most retrofitting steps. Table 16 shows the influence of different retrofitting cases on heating and cooling loads. Also, Table 17 demonstrates the impact of different retrofit scenarios on electricity consumption in the case study community centre. The result indicates that 65.9% of the needed electricity can be reduced by improving the building condition. A more detailed illustration of the retrofitting impact is presented in Figures 12-14. ➔

Table 16. 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	154.9	68.1	223.0	-	-	-
Case A (Baseline + lighting scenario 1)	160.8	64.8	225.6	4%	-5%	1%
Case B (Baseline + lighting scenario 2)	162.7	63.8	226.5	5%	-6%	2%
Case C (Case B + Roof insulation)	124.7	55.2	179.9	-20%	-19%	-19%
Case D (Case C + Windows retrofit + Wall insulation)	70.3	49.7	120.0	-55%	-27%	-46%
Case E (Case D + AWHP + Ceiling fans + MVHR)	12.7	42.1	54.8	-92%	-38%	-75%
Case F (Case D + GSHP + Ceiling fans + MVHR)	12.7	42.1	54.8	-92%	-38%	-75%
Case G (Case F + Cool roof tiles)	13.7	38.5	52.2	-91%	-43%	-77%

Table 17. Simulation results - Site energy.

	Heating	Cooling	Lighting	DHW	Appliances	Total	Total difference	Total difference
Unit	kWh/(m^{2}a)							%
Baseline	55.3	26.2	30.1	20.8	34.7	167.2	0.0	0%
Case A (Baseline + lighting scenario 1)	57.4	24.9	10.9	20.8	34.7	148.8	-18.4	-11.0%
Case B (Baseline + lighting scenario 2)	58.1	24.5	5.3	20.8	34.7	143.5	-23.7	-14.2%
Case C (Case B + Roof insulation)	44.5	21.2	5.3	20.8	34.7	126.6	-40.6	-24.3%
Case D (Case C + Windows retrofit + Wall insulation)	25.1	19.1	5.3	20.8	34.7	105.0	-62.2	-37.2%
Case E (Case D + AWHP + Ceiling fans + MVHR)	3.6	11.1	5.3	8.0	34.7	62.7	-104.5	-62.5%
Case F (Case D + GSHP + Ceiling fans + MVHR)	2.6	8.4	5.3	6.5	34.7	57.6	-109.6	-65.6%
Case G (Case F + Cool roof tiles)	2.8	7.7	5.3	6.5	34.7	57.1	-110.1	-65.9%

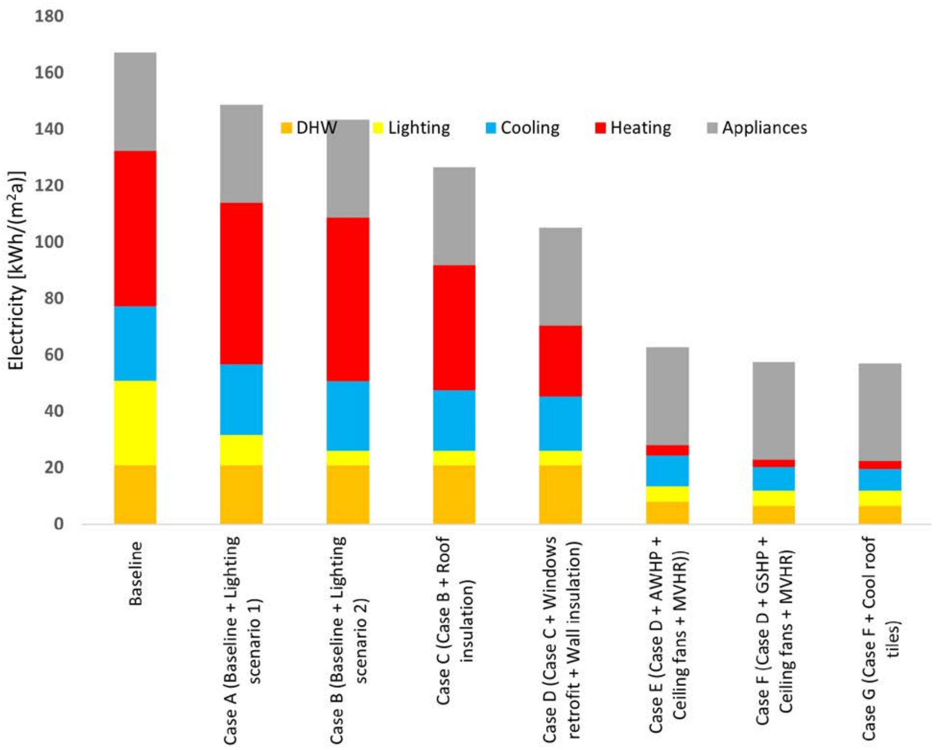
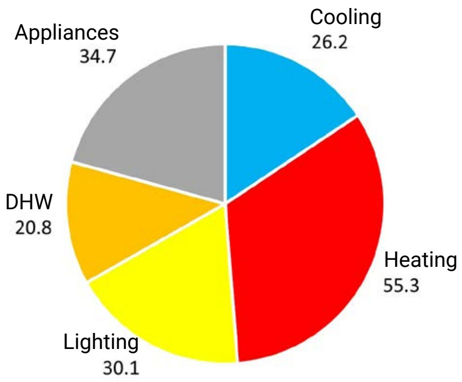


Figure 12. Site energy of the retrofit scenarios.



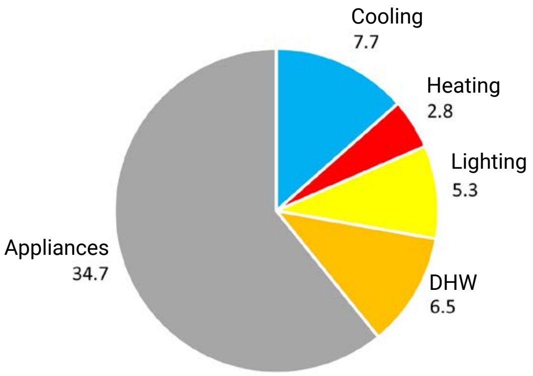


Figure 13. Share of site energy for the baseline (kWh/m²a).

Figure 14. Share of Site energy for retrofit scenario – case F (kWh/m²a).

6.3. Future climate simulation

In this section, 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/m² after 2100.

Table 18 presents the energy load and final energy demand by the community centre building in 8 representative cities, where the cooling site energy will rise between 10.9-31.3% until 2030. Melbourne is the city with the highest rise in cooling demand (31.3%). However, due to the reduction in the energy demand for heating, the total electricity needed in the modelled building would decrease by 4.8%.

To evaluate the impact of retrofitting the case study community centre, the base case and highly retrofitted scenario (Case G) were simulated in Blacktown. As it is presented in Table 19, the total base case site energy

→

Table 16. Current and future energy demand of the case study aged care centre based on CSIRO weather database

Location	Period	Water heating	Heating site energy	Space cooling	Cooling site energy	Lighting site energy	Appliances site energy	Total site electricity demand	Increase in total cooling site energy	Increase in total heating site energy	Increase in total electricity site energy
		(kWh/m²)							%		
Adelaide	Present	20.8	58.1	75.8	31.6	30.1	34.7	175.3	-	-	-
	2030	20.8	48.5	91.7	38.2	30.1	34.7	172.3	20.9	-16.5	-1.7
Brisbane	Present	20.8	17.6	109.2	45.5	30.1	34.7	148.7	-	-	-
	2030	20.8	13.4	129.4	53.9	30.1	34.7	152.9	18.5	-23.9	2.8
Canberra	Present	20.8	114.0	40.3	16.8	30.1	34.7	216.4	-	-	-
	2030	20.8	102.0	50.2	20.9	30.1	34.7	208.5	24.4	-10.5	-3.7
Darwin	Present	20.8	0.0	402.2	167.6	30.1	34.7	253.2	-	-	-
	2030	20.8	0.0	445.9	185.8	30.1	34.7	271.4	10.9	-	7.2
Melbourne	Present	20.8	94.3	32.2	13.4	30.1	34.7	193.3	-	-	-
	2030	20.8	80.9	42.2	17.6	30.1	34.7	184.1	31.3	-14.2	-4.8
Perth	Present	20.8	41.8	112.1	46.7	30.1	34.7	174.1	-	-	-
	2030	20.8	33.4	134.9	56.2	30.1	34.7	175.2	20.3	-20.1	0.6
Sydney	Present	20.8	33.4	49.7	20.7	30.1	34.7	139.7	-	-	-
	2030	20.8	26.9	63.6	26.5	30.1	34.7	139.0	28.0	-19.5	-0.5
Hobart	Present	20.8	117.3	6.0	2.5	30.1	34.7	205.4	-	-	-
	2030	20.8	107.6	7.8	3.3	30.1	34.7	196.5	29.4	-8.3	-4.4

Table 17. The comparison between the base case and fully retrofitted scenario

Location	Period	Water heating	Space heating	Space cooling	Cooling site energy	Lighting site energy	Appliances site energy	Total site electricity demand	Cooling site energy increase	Heating site energy increase	Total site electricity increase
		(kWh/m²)							%		
Blacktown Base case	Present	20.8	55.3	68.1	26.2	30.1	34.7	167.2	-	-	-
	2030	20.8	44.8	82.0	31.5	30.1	34.7	162.0	-13.8	20.2	-3.1
Blacktown retrofitted	Present	6.5	2.8	38.5	7.7	5.3	34.7	57.1	-	-	-
	2030	6.5	2.1	44.7	8.9	5.3	34.7	57.5	-7.5	16.1	0.7

will rise sharply by 2030. This is because of the climate change impact, which causes a considerable increase in the cooling demand. The simulation results demonstrated that almost 45.4% of the cooling load in 2030 can be cut by completely retrofitting the building. This efficiency improvement can also reduce the total electricity demand of the building by 64.5%.

6.4. Discussion and recommendations

The Jim Southee community centre building energy performance was simulated to elaborate the baseline conditions based on the building's construction and operational features and according to the foresight of respective standards and regulations. The results show a relatively high heating and cooling energy consumption. Furthermore, the electricity consumption of appliances, DHW system, and lighting are significant, too. The following efficiency measures are suggested:

- The simulations proved that, while the natural lighting level in the community centre hall is high, the Entrance to the building has lower daylight availability, as the vertical glazing is heavily shaded.
- The artificial lighting analysis showed that replacing inefficient light sources and using daylight linked controls can reduce the total lighting load (kW) and the annual energy (kWh) ranging from 25 to 95%.
- Refurbishment of the windows, with new aluminium framed, double glazed ones, of high energy efficiency to reduce thermal losses in winter, solar loads in summer, and achieve air-tightness throughout the year.
- Thermal insulation of the roof and external walls, reducing both heating and cooling loads.
- Install ceiling fans or replace the old ones to reduce the cooling energy demand.
- Installation of mechanical ventilation with heat recovery to reduce mainly heating loads.
- Install an air-to-water heat pump (AWHP) or a ground source heat pump (GSHP) to meet the space heating, space cooling, and DHW demands to reduce the final energy consumption.

In conclusion, a complete renovation package is suggested that includes the drastic improvement of the building envelope's thermal protection by means of thermal insulation of external walls and roof, and replacement of the windows and glazed surfaces, the upgrading of the lighting system, the installation of ceiling fans and mechanical ventilation with heat recovery, and eventually the use of a GSHP or, if this is not possible, of AWHP. Such a package will lead to energy savings of 65.9 %, resulting in an energy consumption of 57.1 kWh/m^{2}a, compared to the baseline of 167.2 kWh/m^{2}a.

The specific building features a roof that is ideally suited for installing PVs. Given the fact that the appliances loads are a major contributor to the building's energy demand which cannot be further reduced, the installation of the proposed PV system, which in typical Blacktown weather conditions produces 14 MWhel/a (81.6 kWh/m^{2}a), is a highly effective intervention that will lead to a positive energy building and also reduce energy expenses.

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Attachment 1

The following figures show daylight factor distribution in Jim Southee hall and interior views.

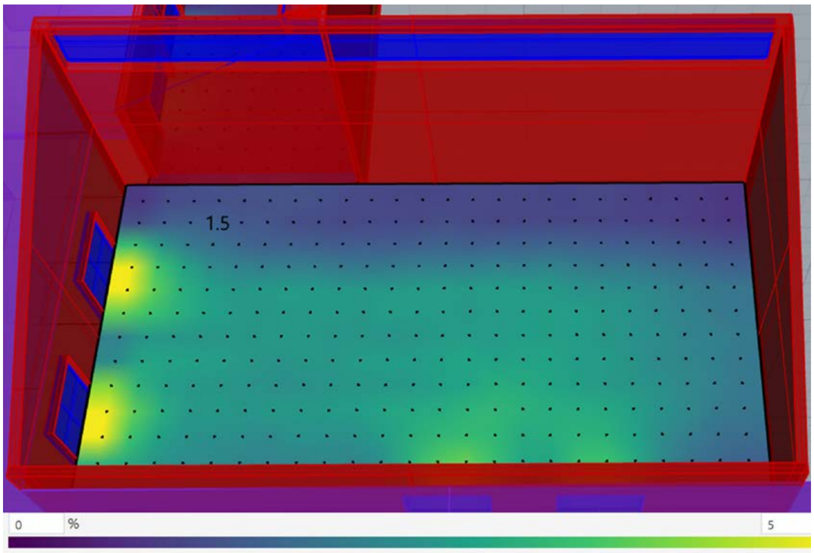

Fig. A1. Exterior view of the building.

Attachment 2

Fig. A2. Interior view.

Fig. A3. Interior view.

Fig. A4. Kitchen - appliances.

Fig. A5. Kitchen – appliances and hood.