Aged Care Centre

Energy Efficiency Training
and Information Project

Commercial Buildings

Canberra
ACT

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

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Cover image:
An aged care facility, Red Hill in Canberra, ACT.

Contents

1. Executive Summary

A complete ... retrofitting package will lead to total energy savings of 88.2%

Global climate change is exposing existing buildings to conditions they were not designed to face, with a growing need for increased efficiency, to reduce the operational cost and carbon dioxide emissions. To meet these goals, established buildings need energy retrofits.

Australia's aged care industry has been a growing business in recent years. The industry consists of over 900 companies that cater for nearly 190,000 residents [2]. Almost 85% of the energy consumed in aged care centres is used for heating, ventilation, cooling, lighting, and appliances [3]. This report tackles the operational energy consumption challenge for an existing aged care facility, 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.

A typical aged care facility centre is selected as a case study to explore opportunities to reduce energy consumption. A dynamic thermal model of the aged care centre buildings is simulated with the TRNSys software tool, reproducing the thermal features and building services in the real building.

This report summarises the findings of the performed analysis on the existing conditions and provides recommendations for the improvement of the aged care building complex and the minimisation of the energy consumption. The complex has eight buildings with structural and energy performance features that are representative of the typology and construction period (1990s).

The analysis showed that most rooms should have higher daylight levels, while some spaces, such as the lobby in building A and the corridors connecting buildings, should be shaded. The use of more efficient light sources and daylight linked controls in the common spaces may reduce the total lighting load (kW) and the annual energy (kWh) ranging from 20 to 90%.

The baseline scenario for determining feasible interventions is based on the fact that heating load (193 kWh/m^{2}a) is the most significant issue to address. Still, hot water production is crucial, and the other energy uses are not insignificant.

As a result, the primary focus is on lowering heating requirements. The main causes for those are:

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

Based on these conclusions, the following recommendations are feasible:

- Refurbishment of the roof, fitting 12 cm 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, solar loads in summer and achieve air-tightness throughout the year.
- Applying insulation on external walls. Insulation consists of 8cm of mineral wool covered with plasterboard, leading to a reduction in both heating and cooling loads.
- Improvement of the lighting systems.
- Installation of ceiling fans to reduce cooling loads.
- Finally, installing an air-to-water heat pump (AWHP) or a ground source heat pump (GSHP) could drastically reduce final energy consumption for space heating and DHW.

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, replacement of the windows and glazed surfaces, the upgrading of the lighting system, the installation of ceiling fans, and eventually the use of a GSHP or, if this is not possible, of AWHP. Such retrofitting package will lead to total energy savings of 88.2%, resulting in an energy consumption of 37.4 kWh/m^2a, compared to the baseline of 316.6 kWh/m^2a. ■

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 aged care centre built in Australia in the 1990s, representative of many other centres built in the same period. In fact, the aim of selecting this case study lies in the potential for methodology replication and findings expansion to other similar buildings.

Clearly, one sample aged care centre cannot completely fit all similar buildings, and each care facility has differences; however, even though the required procedure 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 aged care centre is a complicated task. It starts with determining the building's construction features, including the efficiency of the building envelope, the 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 following standards and regulations.

Additionally, two types of specific conditions that have a significant impact on such a centre'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. Aged Care Facility in Canberra

4.1. Case study description

4.1.1. Climate

The aged care facility centre is located in the central part of Canberra, at 622 m above sea level. In Köppen's climate classification, Canberra is categorised as Cfb, meaning that it has a temperate oceanic climate (mild summer and cold winters) [4], with moderate seasonal differences. Rainfall is fairly evenly spread throughout the year. The annual mean rainfall of 636 mm, and September has the highest amount of rainfall (65.2 mm). Due to its geographical location, the relative humidity is distributed unevenly throughout the year (62-85% in the morning and 35-60% in the afternoon). The winters are cold, with overnight minimums averaging 0.9°C and daily maximums climbing to 12.4°C. Moreover, summers are warm, and the average maximum temperature reaches 28.5°C in January. The primary climatic information for Canberra is illustrated in Figure 1. →

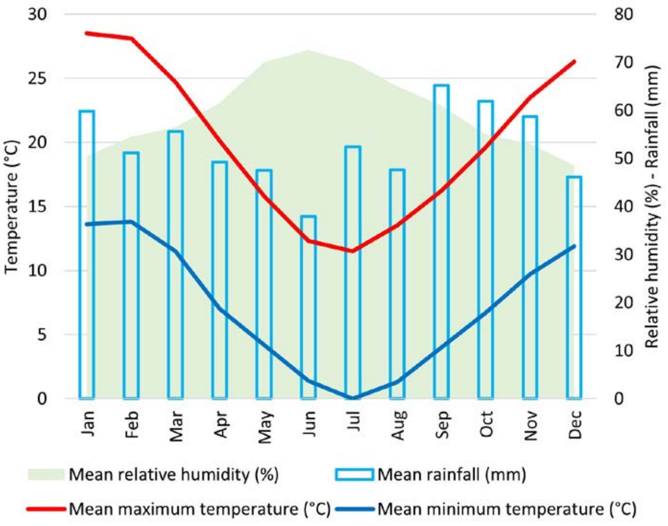

Figure 1. Climatic data for Canberra [5].

Figure 2. Northern view of buildings A and F of the complex.

4.1.2. Building complex description

The centre was constructed in 1995 (Figure 2). Its classification, according to the National Construction Code, is Class 9c: residential care buildings that may contain residents who have various care level needs, namely a place of residence where 10% or more of persons who reside there need physical assistance in conducting their daily activities and to evacuate the building during an emergency [6]. The centre has eight separate buildings (A-H) and provides care to 80 residents 24 hours a day. The under-ceiling height for the residential part of the aged care centre is 2.4 m. Figure 3 illustrates the treemap chart of the gross internal area of case study buildings. The total gross floor area is 4,507 m².

4.1.3. Energy consumption and sources

Natural gas is used for water heating and food preparation, while electricity is used for heating, ventilation, air conditioning, lighting and appliances. →

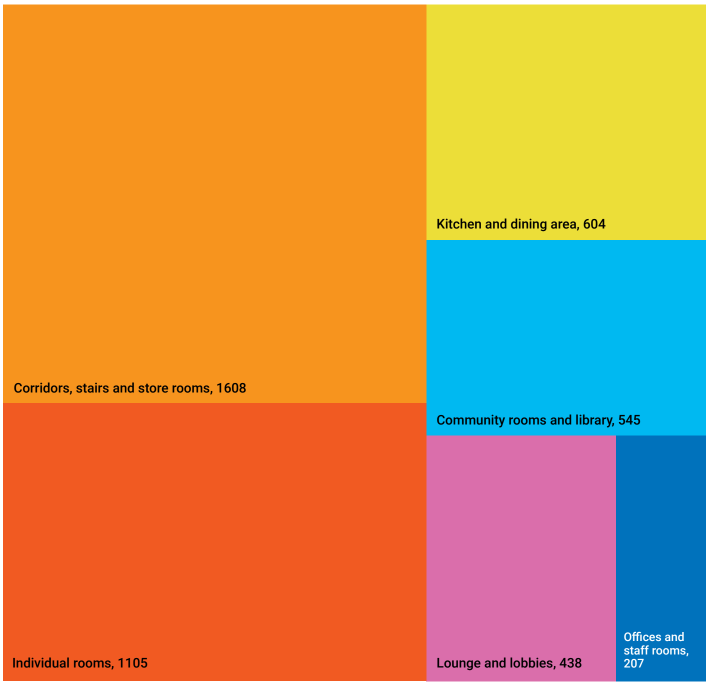

Figure 3. Gross floor divided area of case study building.

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

The aged care facility currently has 65 individual rooms and nine extra beds for residents needing extra care. The occupancy schedule is selected based on the national code of construction and provided information by the Facility Management [6].

4.2.2. Geometric data

As mentioned, the aged care centre includes eight buildings. Most of the buildings have only one floor except Building G, which is a 2-storey building. Table 1 shows the main purpose of each building and its location on site.

4.2.3. Building Components

A significant part of energy consumption is 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 aged care centre, we assessed the thermal properties of the building envelope based on construction features and age. This information is used to model the building and develop a thermal model. Here, 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 includes three main layers: solid brick on the exterior, air gap and again solid brick on the interior side. The R-value of the external walls is 0.633 m^2.K/W, while the solar reflectance coefficient is assumed equal to 0.4.
Also, using the average annual wind velocity in Canberra (2.4 m/s) [5], the convective heat transfer coefficient is calculated as 17.6 W/(m^2.K) [7]. ➔

Table 1. Building geometric information.

Building	Floor(s)	Main use	Orientation	Area (m^2)
A	1	Entrance and staff rooms	North-east	207.4
B	1	Residents suites	East	338.1
C	1	Residents suites, laundry	South-east	762.4
D	1	Kitchen and dining area	Central	604.2
E	1	Residents suites	Central	748.6
F	1	Residents suites	North	344.6
G	2	Ground floor – Residents suites Lower ground floor – Community centre	North	950.4
H	1		West	551.9

Table 2. Building Components - Performance Descriptors – Construction – External 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	-	[6]	Section J, page 389
Air space	50	-	-	-	0.18	[8]	Section 5.3, page 5
Brick	110	0.78	0.8	1,950	-	[6]	Section J, page 389

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

4.2.3.2. Roof

The roof is composed of 4 layers: concrete tiles as the top layer, an air gap, sarking, and plasterboard inside. The R-value of the roof is 0.645 m^2.K/W, and the solar reflectance is estimated equal to 0.4. Also, using average annual wind velocity (2.4 m/s) [5], the convective heat transfer coefficient is calculated as 17.6 W/(m^2.K) [7].

4.2.3.3. Windows

External windows in the case study buildings are single glazed with aluminium frame. The selected shading and glazing in the model are presented in Table 4.

4.2.4. Domestic hot water

The required hot water for the individual rooms is calculated based on Table 2m, NCC volume 1 page 355 [6]. Therefore, considering the need for a 50°C temperature increase and water heat capacity (4.19 KJ/kg.°C), 880 MJ of heating energy is required for daily heating of domestic water. ➔

Table 3. 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	-	[9]	Section 8.3, page 9
Roof planks & roof framing	30	0.16	1	677	-	[9]	Section 8.3, page 9
Air space & ceiling framing	100	-	-	-	0.23	[8]	Section 5.3, page 5
Plaster board	10	0.17	1	880	-	[9]	Section 8.3, page 9

R-value: 0.645 m^2.K/W

Table 4. Building Components - Performance Descriptors - Openings Shading.

Glazing	Value	Unit	Ref.
Thickness	14	mm	[10]
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 5. Domestic hot water.

Demand-side	Value	Unit Hot water demand	Daily hot water demand (lit)
	74 suites	50 lit/unit	3,700

4.2.5. Internal gains

The information regarding the setpoints for heating and cooling is provided by the facility manager. Lighting and personal heat gain assumptions in the model are based on Australian and international standards.

4.2.6. Ventilation and infiltration

The supplied fresh air flow rates and the infiltration rates are assumed based on international standards.

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 and natural gas. Natural gas is used for space and water heating and cooking. A slab heating system is installed throughout the facility. The coefficient of performance (COP) of the boiler used for heating purposes is considered equal to 0.90 based on the information provided by the facility management. Electricity is used for cooling, lighting, and appliances. Common areas are conditioned by split DX units in ducts along the corridors. Other spaces are conditioned by split systems. Based on the provided drawings and considering the age of the building, an energy efficiency ratio (EER) of 2.4 for the cooling units is considered. →

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

	Building	Value	Unit	Ref.	Section and page
Cooling setpoint temperature	All	24	°C	Facility Manag.	-
Heating setpoint temperature	All	20	°C	Facility Manag.	-
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 7. Ventilation and infiltration.

	HVAC system	Value	Unit	Ref.	Section and page
Fresh air	On	10	L/s.person	[13]	Appendix A, Table A1
	Off	5	L/s.person		
Infiltration	On	1	ACH	[14]	Section 2.7
	Off	0.5	ACH		

Table 8. 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

4.2.9. Schedules

The schedules of occupancy, lighting and appliances of the guestrooms are selected based on page 348 of the Australian national construction code [6]. The occupancy, lighting and appliance schedules for common zones 1-8 (offices, entrance, meeting rooms, etc.) are considered based on pages 348-349 in NCC [6]. ➔

Table 9. Occupancy, lighting and appliances schedules

Time	Occupancy (Mon-Fri)	Occupancy (Sat-Sun & holidays)	Artificial lighting	Appliances and equipment
00:00-01:00	0.85	0.85	0.05	0.20
01:00-02:00	0.85	0.85	0.05	0.20
02:00-03:00	0.85	0.85	0.05	0.15
03:00-04:00	0.85	0.85	0.05	0.15
04:00-05:00	0.85	0.85	0.05	0.15
05:00-06:00	0.85	0.85	0.25	0.15
06:00-07:00	0.85	0.85	0.80	0.40
07:00-08:00	0.85	0.85	0.80	0.80
08:00-09:00	0.75	0.65	0.50	0.50
09:00-10:00	0.75	0.65	0.40	0.40
10:00-11:00	0.75	0.65	0.40	0.40
11:00-12:00	0.85	0.85	0.40	0.40
12:00-13:00	0.85	0.85	0.40	0.40
13:00-14:00	0.85	0.85	0.40	0.40
14:00-15:00	0.85	0.85	0.40	0.40
15:00-16:00	0.75	0.65	0.40	0.40
16:00-17:00	0.75	0.65	0.40	0.40
17:00-18:00	0.85	0.85	0.70	0.70
18:00-19:00	0.85	0.85	0.70	0.70
19:00-20:00	0.85	0.85	0.70	0.70
20:00-21:00	0.85	0.85	0.50	0.60
21:00-22:00	0.85	0.85	0.50	0.60
22:00-23:00	0.85	0.85	0.50	0.40
23:00-00:00	0.85	0.85	0.05	0.20

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 the aged care centre in Canberra. 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 data provided by facility management were: 1) The architectural drawings for the two levels of the complex, and 2) Drawings including the location of the lighting fixtures without information about their type or wattage. 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. The simulation results were then compared to the requirements and recommendations of the Australian NCC [6]. Based on the simulation findings, three scenarios were tested (Table 10). →

Table 10. Scenarios for reduced energy consumption for lighting.

Base-case scenario	Lighting power density calculated based on 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.
Scenario 1	As in the Base case scenario, with the fluorescent lamps replaced by LEDs.
Scenario 2	As for Scenario 1, with the addition of daylight controls.

4.3.2. Lighting analysis result

The results are analysed in two parts:

1) The assessment of the existing natural conditions; and

2) The calculation of the existing lighting power density (W/m²) and the proposal of scenarios for the reduction of the energy consumption for lighting.

4.3.2.1. Natural lighting

The building has many openings on all elevations. Most of the windows are partly shaded by the protruding roof and by the other buildings of the complex. The natural lighting conditions have been studied in all common spaces and in indicative rooms and bedrooms (Table 11).

The rooms have average Daylight Factors usually below 2% (1.3-2%), which is lower than the required by the NCC Daylight Factor (2%). Even though the rooms have large, glazed surfaces, the room depth affects the daylight availability. The daylight in the rooms could be increased with the use of skylights or light pipes placed towards the deepest and darker parts of the rooms. The lobby in Building A has a very high average Daylight Factor (11.5%) due to the skylight. If the skylight is not currently shaded, exterior shading or special glazing with shading elements should be considered.

Other spaces with very high daylight levels are the corridors between the Buildings (Wings) of the hostel, which appear to have glazing on both walls. If these corridors are not already shaded, they should be shaded using exterior elements (rollers, louvres, etc.) to avoid glare and overheating issues.

The rest of the spaces of the hostel are considered well lit, and interior shading devices, such as curtains, louvres and rollers, should provide comfortable visual conditions.

4.3.2.2. Artificial lighting

The facility management of the building complex provided the positions of the lighting fixtures in the building. The system has been updated to use LED lamps and is operated manually. However, the wattage of the light sources was not provided. Due to the minimum information on artificial lighting, no lighting level simulations were performed, as they would imply several assumptions producing inaccurate results. ■

Table 11. Average Daylight Factor of the spaces in the aged care centre.

	Building/Space	Average Daylight Factor (%)	Uniformity
Ground floor	A - Lobby	11.50	0.11
	A - B corridor	20.06	1.00
	A - F corridor	7.03	0.86
	A - Offices	2.70	0.20
	B - C corridor	10.72	0.76
	B - Lounge	2.31	0.40
	B - room east	1.82	0.43
	B - room west	1.81	0.36
	C room east	1.40	0.53
	C - Dining - Kitchen	2.39	0.50
	C - Lounge	5.85	0.37
	C - room South	1.30	0.45
	D	1.74	0.28
	E - F corridor	20.06	1.00
	E - Lounge	2.03	0.27
	E - Room east	1.56	0.40
	E - Room north	1.38	0.41
	E - Room west	1.55	0.39
	E - Salon	0.74	0.39
	E - Staff room	1.03	0.32
	F - room north	1.66	0.42
	F - Room south	2.03	0.36
	G - Office	2.67	0.34
	G - room east	1.82	0.39
	G- Room west	1.86	0.45
	H - Bed east	2.57	0.30
	H - Bed south	2.00	1.00
	H - Lobby - Dining	1.83	0.09
	H-Office	2.86	0.50
Basement	Community room	3.21	0.67
	Multi-purpose room 1	3.95	0.78
	Multi-purpose room 2	3.54	0.58
	Hairdresser	4.96	0.74
	Office	6.11	0.79

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). As discussed previously, eight buildings were defined in SketchUp because of the importance of load determination (Figure 4). ➔

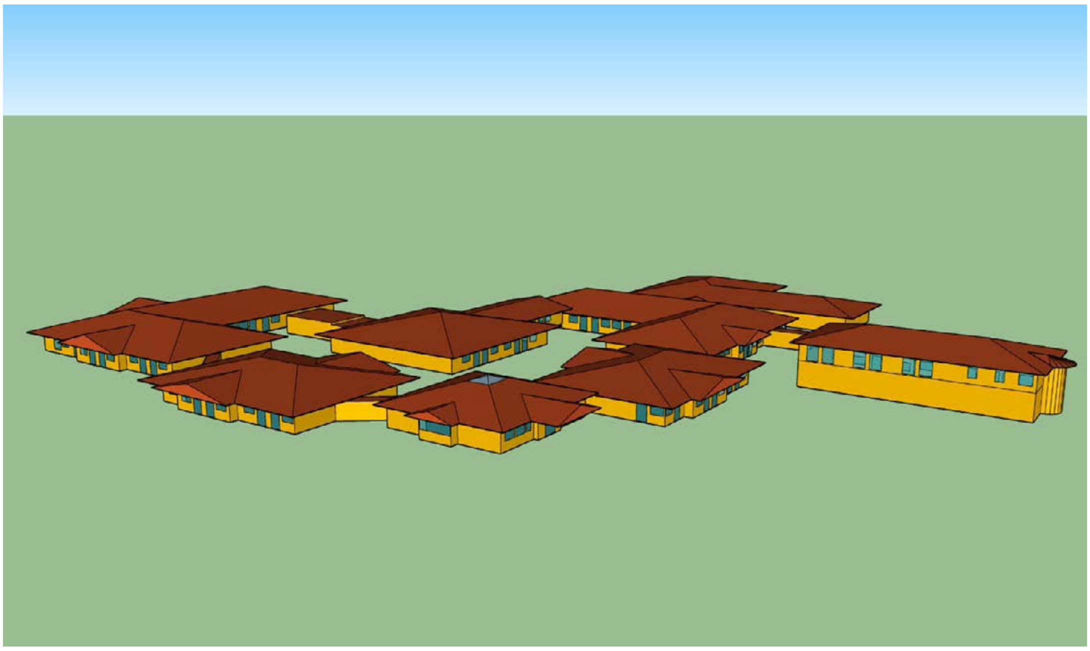

Figure 4. SketchUp model.

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.

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.), 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.

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, as well as by 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 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. →

5.3.1. 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 about the installed lighting sources, the base-case scenario has the provided number of lighting fixtures and considers that they host fluorescent lamps (Table 12).

Scenarios 1 and 2 aim to achieve minimum energy consumption. For Scenario 1, the illumination power density was decreased, assuming the fluorescent light sources had been 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 23 to 92% (Table 12). The residents' rooms present the smallest opportunity for energy savings for lighting, as controls are not used for these spaces. The schedules used are presented in Table 9. Also, the area used for the lighting calculations is limited in the vicinity of the windows.

5.3.2. Windows retrofit and wall insulation

The windows now installed are single glazed with aluminium frame. The thermal break (insulation within a window) is a constant barrier between the inside and outside window frames that avoid conductive thermal energy loss. This barrier securely bonds the interior and exterior metal frames of the window. This thermal break creates thermal energy loss resistance and, combined with double-pane glazing, keeps the interior space of the window at a more comfortable temperature. The proposed window is thermally-broken aluminium framed, double glazed, with Low-E external glass pane, with an average U-value of 1.4 W/m^{2}K, an SHGC value of 0.7 and 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. Adding wall insulation includes the application of 80 mm of mineral wool covered with plasterboard on external walls. Such thermal resistance improvement will lead to a total R-value of 2.747 m^{2}K/W. →

Table 12. Illumination power density and energy consumption for the base case and the proposed scenarios.

	Base case		Scenario 1		Scenario 2	Maximum energy savings achieved (%)
Space	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)	
Lobbies	7.8	3002	2	770	216	92.80
Lounges	17.3	12408	5.3	3802	2921	76.46
Offices & Staff rooms	17.4	10923	5.8	3641	1278	88.30
Kitchen & Dining areas	8.8	13333	3	4546	1848	86.14
Glazed corridors	9	3362	2.5	933	601	82.12
Corridors	7	16908	3.5	8455	8455	49.99
Resident bedrooms (x 65)	6	409	4.6	314	314	23.23
Additional bedrooms (x9)	6	490	4.6	376	376	23.27
Retail	9	2936	3	979	540.00	81.61
Kitchen	17	6078	6	2145	2145	64.71
Basement (spaces with windows)	16	12314	6	4618	939	92.37

5.3.3. 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 12 cm) between the ceiling and the external roof, leading to an average R-value of 3.70 m^2K/W.

5.3.4. 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.

5.3.5. Air-to-water heat pump (AWHP)

Improving the HVAC system by adding one air-to-water heat pump for each building can prevent a large amount of energy loss. Such an HVAC system will have COP=3.5 and EER=3.8. Also, it can be used for DHW preparation with COP=2.6 (including storage and distribution losses).

5.3.6. Ground Source heat pump (GSHP)

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 the winter period, 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 [16].

The GSHP considered in retrofitting the aged care centre meets the space heating, cooling and DHW demands of each building, and it has an average COP = 4.8 and EER = 5.0. Also, it can be used for DHW preparation with COP = 3.2 (including storage and distribution losses).

5.3.6. Domestic hot water intervention

Installation of water-efficient faucets and drain water heat recovery are efficient ways to decrease energy consumption. A drain water heat recovery (DWHR) unit can capture almost 60% of that heat and return it to the shower water or the hot-water tank. Such units can also triple the heat recovery rate of a water heater by making hot water available much faster. The efficiency of the heat recovery ventilation is 80%..

5.3.7. Ground Source heat pump (GSHP)

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 the winter period, 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 [18].

The GSHP considered in retrofitting of Fraser Suites Perth meets space heating, cooling and DHW demands, and it has an average COP=3 and EER=2.8, including losses of the distribution network and terminal units. ■

6. Results

6.1. Base building modelling

The result of the building simulations in Canberra is presented in this section. Hourly energy demand for heating and cooling (sensible and latent) is illustrated in Figure 5. The monthly energy demand is presented in Figure 6. ➔

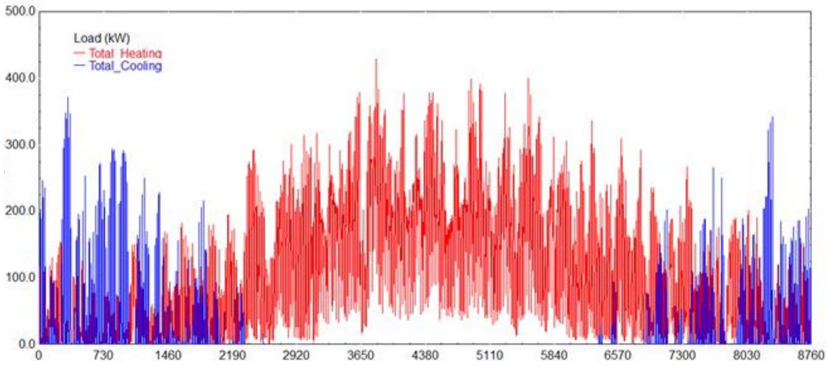

Figure 5. Hourly energy demand for HVAC purposes.

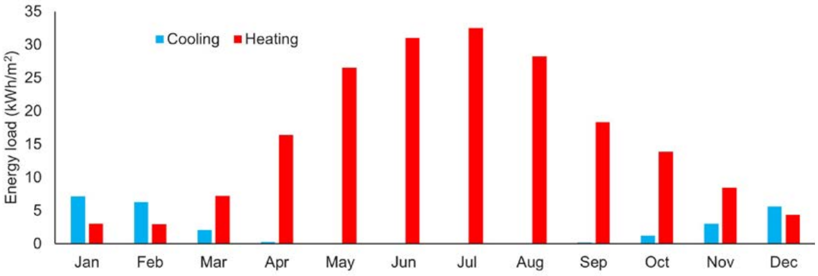

Figure 6. Monthly energy demand for HVAC purposes.

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 Figures 8 and 10. ➔

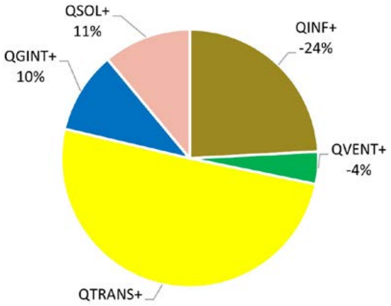

Figure 7. Whole building energy gain – heating season (May - September).

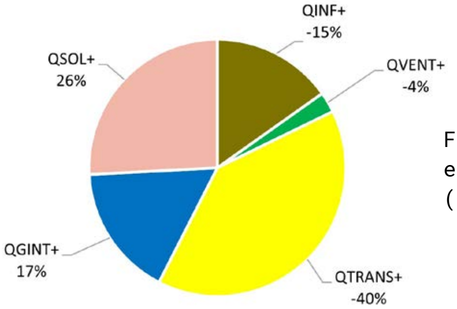

Figure 9. Whole building energy gain – cooling season (October - April).

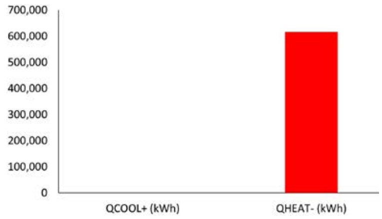

Figure 8. Whole building energy gain for heating and cooling load – heating season (May-September).

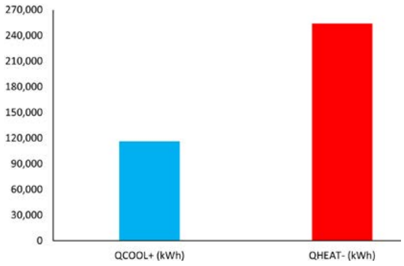

Figure 10. Whole building energy gain for heating and cooling load - cooling season (October-April).

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

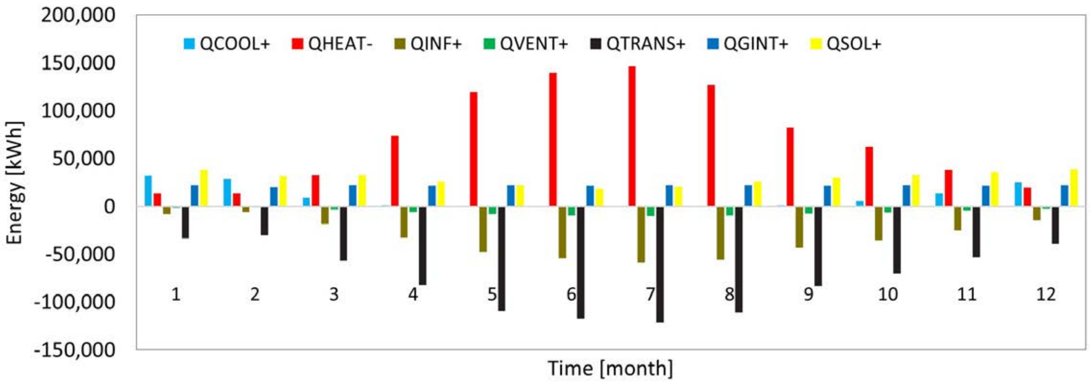

Figure 11. Monthly building energy gain.

6.2. Retrofit scenarios

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

Table 13. 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. Natural gas boiler for space heating and domestic hot water is assumed.
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 A + roof insulation:** Refurbishment of the roof, fitting 120 mm of mineral wool under the existing roof, leading to a total R-value of 3.7 m²K/W. The average cost of roof insulation is expected to be around 40 $/m².
Case D	**Case B + windows retrofit + wall insulation:** Application of 80 mm of mineral wool covered with plasterboard on external walls, leading to a total thickness of 0.31 m and a total R-value of 2.74 m²K/W. New windows are aluminium framed (thermally-broken), double glazed, with an average U value of 1.4 W/m²K, an SHGC value of 0.7 and Air-tightness values of Class 3 with less than 9 m³/h.m² at 100 Pa. The latter reduces the infiltration rate of the building to 0.30 1/h. The average cost of roof insulation is expected to be around 38 $/m² and of new windows around 250 $/m², respectively.
Case E	**Case D + Installation of Air-to-water heat pump (AWHP) and ceiling fans:** Installation of one Air-to-water heat pump per building with fan coils with a coefficient of performance COP=3.5 and energy-efficient rating EER=3.8, including distribution and terminal unit losses. The heat pump is also used for DHW preparation with COP=2.6, including storage and distribution losses. Ceiling fans are modelled by increasing the cooling setpoint temperature to 26°C (depending on the existence of suspending ceiling).
Case F	**Case D + Installation of a ground source heat pump (GSHP) and ceiling fans:** Installation of one ground source heat pump per building with fan coils, exploiting one common borehole field, 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. Ceiling fans are modelled by increasing the cooling setpoint temperature to 26°C (depending on the existence of suspending ceiling).

Between the presented scenarios, Case F has the most retrofitting steps. Table 14 shows the influence of different retrofitting cases on heating and cooling loads. Also, Table 15 demonstrates the impact of different retrofit scenarios on electricity and natural gas consumption in the case study aged care centre. The result shows that by improving the building condition, 55.1% and 53.2% of the needed natural gas and electricity can be reduced, respectively. A more detailed illustration of the retrofitting impact is presented in Figures 12-14. →

Table 14. 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	193.0	26.0	219.0	-	-	-
Case A (Baseline + lighting scenario 1)	200.8	23.9	224.7	4%	-8%	3%
Case B (Baseline + lighting scenario 2)	202.2	23.5	225.8	5%	-9%	3%
Case C (Case B + roof insulation)	128.9	16.2	145.1	-33%	-38%	-30%
Case D (Case C + windows retrofit + wall insulation)	39.1	20.0	59.1	-80%	-23%	-70%
Case E (Case D + AWHP + ceiling fans)	37.7	12.3	49.9	-80%	-53%	-74%
Case F (Case D + GSHP + ceiling fans)	37.7	12.3	49.9	-80%	-53%	-74%

Table 15. Simulation results – Site energy.

	Heating	Cooling	Lighting	DHW	Appliances	Total	Total difference	Total difference	Total gas	Total electricity
Unit	kWh/(m^{2}a)							%	kWh/(m^{2}a)	
Baseline	9.0	39.8	16.3	10.9	9.1	103.8	0.0	0%	10.9	92.9
Case A (Baseline + lighting scenario 1)	9.5	22.6	16.3	10.9	9.1	83.7	-20.1	-19.3%	10.9	72.9
Case B (Baseline + lighting scenario 2)	6.5	15.3	16.3	10.9	9.1	71.4	-32.4	-31.3%	10.9	60.5
Case C (Case B + roof insulation)	6.5	8.1	16.3	10.9	9.1	62.6	-41.2	-39.7%	10.9	51.8
Case D (Case C + windows retrofit + wall insulation)	6.5	8.1	16.3	8.1	9.1	59.7	-44.1	-42.5%	8.1	51.6
Case E (Case D + AWHP + ceiling fans)	4.5	5.8	16.3	2.1	9.1	48.1	-55.7	-53.7%	0.0	48.1
Case F (Case D + GSHP + ceiling fans)	4.7	5.5	12.5	2.1	9.1	44.1	-59.7	-57.5%	0.0	44.1
Case G (Case E + Lighting scenario 2)	4.8	5.4	10.1	2.1	9.1	41.6	-62.2	-59.9%	0.0	41.6

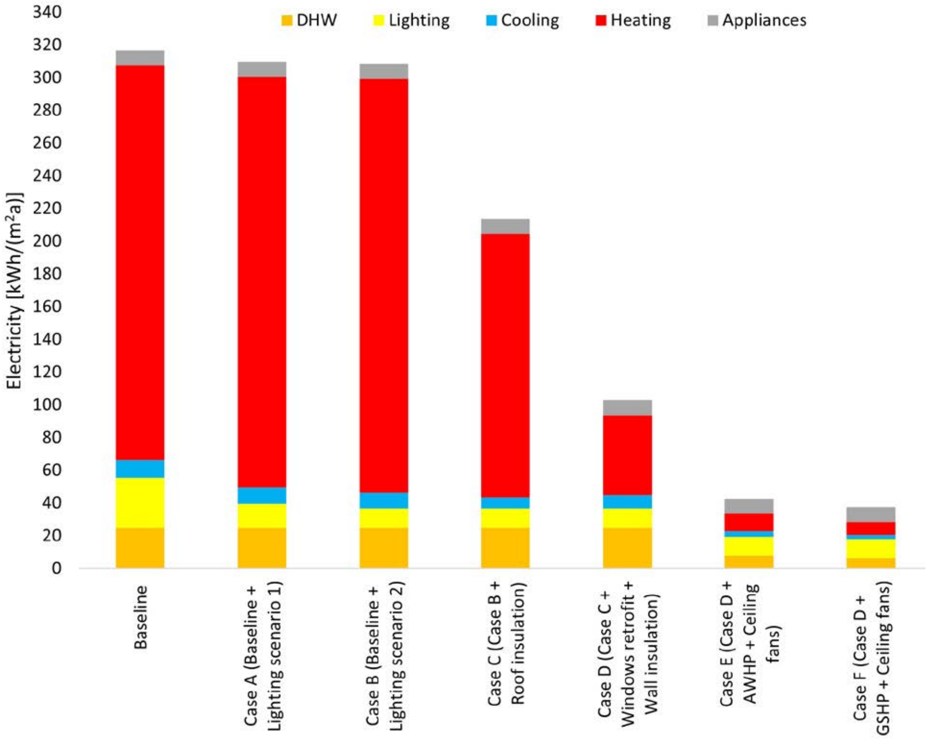

Figure 12. Site energy of the retrofit scenarios.

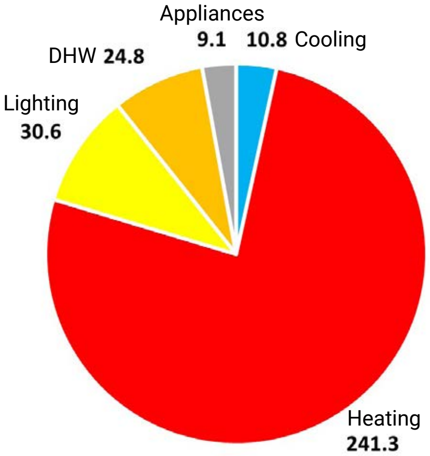

Figure 13. Share of site energy for the baseline (kWh/m²a).

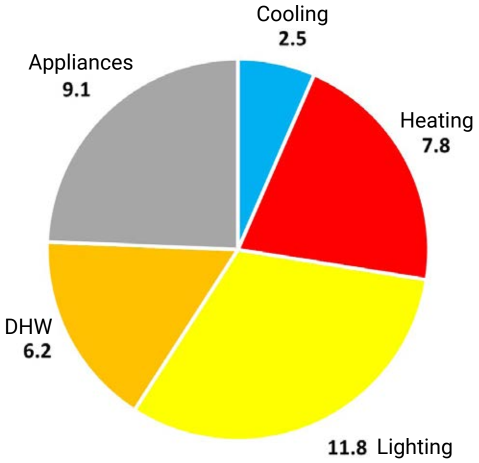

Figure 14. Share of Site energy for retrofit scenario – case F (kWh/m²a).

6.3. Future climate simulation

In this section, the case study aged care centre 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) [17]. 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 16 presents the energy load and final energy demand by the aged care centre in 8 representative cities. The results indicate that in all representative cities, the cooling site energy will rise between 10.3%-26.9% by 2030. This considerable amount of energy demand for cooling would cause a 1.7%-7.0% rise in the total electricity demand in representative cities by 2030.

To evaluate the impact of retrofitting case study aged care centre, the base case and highly retrofitted scenario (Case F) were simulated in Canberra. As it is presented in Table 17, the total base case site energy will rise sharply until 2030. This is because of the climate change impact, which causes a considerable increase in the cooling demand. The simulation results demonstrated that the unretrofitted aged care centre's total electricity demand would rise by 3.8%, while the natural gas needs will decrease by 8.8% since heating

→

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

Location	Period	Water heating	Space heating site energy	Space cooling	Cooling site energy	Lighting site energy	Appliances site energy	Total site electricity demand	Natural gas demand	Increase in total cooling site energy	Increase in total heating site energy	Increase in total electricity site energy
		(kWh/m²)								%		
Adelaide	Present	24.8	130.2	43.4	18.1	30.6	9.1	57.8	155.0	-	-	-
	2030	24.8	111.6	51.8	21.6	30.6	9.1	61.3	136.4	19.3	-12.0	6.1
Brisbane	Present	24.8	51.4	61.2	25.5	30.6	9.1	65.2	76.2	-	-	-
	2030	24.8	42.0	71.5	29.8	30.6	9.1	69.5	66.8	16.9	-12.3	6.6
Canberra	Present	24.8	241.3	26.0	10.8	30.6	9.1	50.5	266.1	-	-	-
	2030	24.8	217.8	30.4	12.7	30.6	9.1	52.4	242.6	17.6	-8.8	3.8
Darwin	Present	24.8	0.0	205.4	85.6	30.6	9.1	125.3	24.8	-	-	-
	2030	24.8	0.0	226.6	94.4	30.6	9.1	134.1	24.8	10.3	0.0	7.0
Melbourne	Present	24.8	201.1	20.6	8.6	30.6	9.1	48.3	225.9	-	-	-
	2030	24.8	176.1	26.2	10.9	30.6	9.1	50.6	200.9	26.7	-11.1	4.8
Perth	Present	24.8	99.1	61.4	25.6	30.6	9.1	65.3	123.9	-	-	-
	2030	24.8	82.6	72.2	30.1	30.6	9.1	69.8	107.4	17.6	-13.3	6.9
Sydney	Present	24.8	78.9	31.9	13.3	30.6	9.1	53.0	103.7	-	-	-
	2030	24.8	66.0	38.2	15.9	30.6	9.1	55.6	90.8	19.5	-12.4	4.9
Hobart	Present	24.8	246.7	6.2	2.6	30.6	9.1	42.3	271.5	-	-	-
	2030	24.8	228.8	7.9	3.3	30.6	9.1	43.0	253.6	26.9	-6.6	1.7

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

Location	Period	Water heating	Space heating site energy	Space cooling	Cooling site energy	Lighting site energy	Appliances site energy	Total site electricity demand	Natural gas demand	Increase in total cooling site energy	Increase in total heating site energy	Increase in total electricity site energy
		(kWh/m²)								%		
Canberra Base case	Present	24.8	241.3	26.0	10.8	30.6	9.1	50.5	266.1	-	-	-
	2030	24.8	217.8	30.4	12.7	30.6	9.1	52.4	242.6	11.3	3.8	-8.0
Canberra retrofitted	Present	6.2	7.8	12.3	2.5	11.8	9.1	37.4	0.0	-	-	-
	2030	6.2	6.9	14.1	2.8	11.8	9.1	36.8	0.0	20.4	1.0	-13.0

requirements are expected to drop. Also, the results show that the cooling load in 2030 can be reduced by 53.6% in the case of a complete refurbishment of the aged care centre. The resulting reduction in the total electricity demand of the building is 29.8%.

6.4. Discussion and recommendations

The energy performance of the aged care centre was simulated in order 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. The findings suggest that, in particular, heating but also cooling energy usage are relatively high. Electricity usage of appliances, lights and the energy required for hot water generation are also significant. The following suggestions are made to reduce energy consumption:

- The simulations proved that the natural lighting levels in the bedrooms are lower than they should be. Also, spaces with skylights or large glazed areas should be shaded to prevent excessive heat from entering the building.
- The artificial lighting analysis showed that the replacement of inefficient light sources and the use of daylight linked controls may result in a reduction of the total lighting load (kW) and the annual energy (kWh) ranging from 20 to 90%.
- Thermal insulation of the roof and external walls, 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, solar loads in summer and achieve air-tightness throughout the year.
- Installation of ceiling fans to reduce cooling demands.
- Installation of an air-to-water heat pump (AWHP) or a ground source heat pump (GSHP) to meet the space heating, space cooling and DHW demand so as to reduce the final energy requirement.

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, replacement of the windows and glazed surfaces, the upgrading of the lighting system, the installation of ceiling fans, and eventually the use of a GSHP or, if this is not possible, of AWHP. Such a package will lead to energy savings of 88.2%, resulting in an energy consumption of 37.4 kWh/m^{2}a, compared to the baseline of 316.6 kWh/m^{2}a.

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Attachment 1

The following figures show daylight factor distribution in the aged care centre.

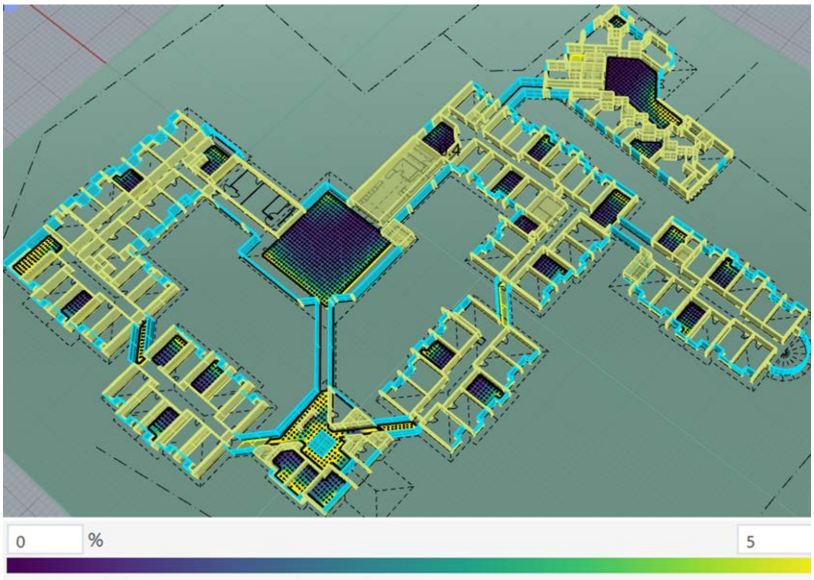

Fig. A1. Exterior view of the building.

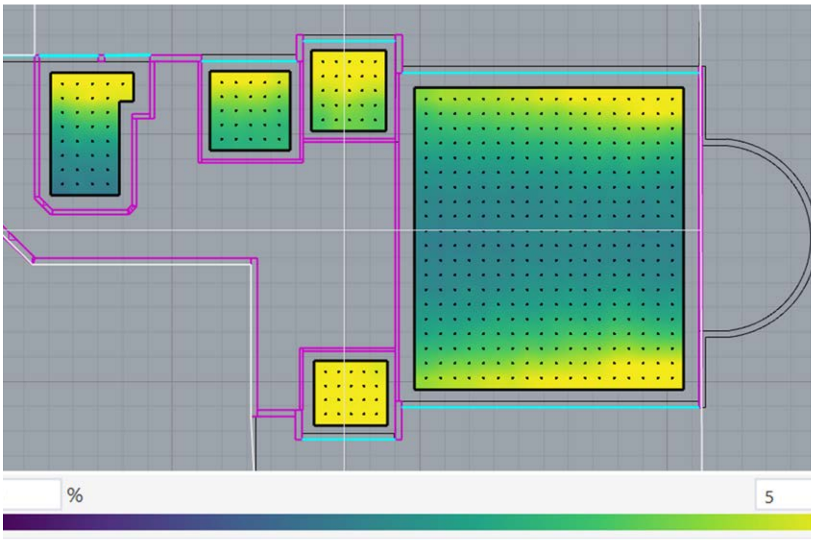

Fig. A2. Exterior view of the building.

Attachment 2

Fig. A3. Exterior view of the complex.

Fig. A4. Exterior view of the complex.

Fig. A5. Exterior view of the centre.