Childcare centre

Energy Efficiency Training
and Information Project

Commercial Buildings

Parramatta
NSW

Research group

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

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

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

International contributors

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

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

Project contact

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

Contract management contact

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

Acknowledgements

The research group thanks the Australian Department of Industry, Science, Energy and Resources for funding this project entitled “Energy Efficiency Training and Information”. The research group thankfully acknowledges Nishan Adhikari | City Assets and Environment of City of Parramatta for providing building documentation and data on the case study analysed in this report.

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

CRICOS Provider Code 00098G

Contents

1. Executive Summary

A complete refurbishment package ... may lead to energy savings of 41.6%

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. Almost 80% of 2050 buildings already exist today [1], and we must prioritise improving the efficiency of established buildings. A high proportion of energy consumed in childcare centres is used for HVAC applications, lighting, and appliances. This report addresses the operational energy consumption challenge for an existing childcare 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.

A typical childcare building is considered as a case study to explore opportunities to reduce the site energy. Due to the nature of this project, the demanded energy consumption was fully investigated. A dynamic thermal model of the childcare building is simulated with TRNSys software, similar to the characteristics of the real building as much as possible. The COVID-19 pandemic caused fluctuations in the occupancy rates and energy consumption in the studied childcare centre. Hence, Australian and international standards are sourced to have a reliable model.

This report summarises the findings of the performed analysis on the existing conditions and provides recommendations for the improvement of the building conditions and the minimisation of the energy consumption in a childcare centre in the City of Parramatta's local government area (LGA), NSW. It is a comparatively small, low-rise building with structural and energy performance features typical for buildings of this type and age.

- The simulations proved that the natural lighting levels in the building are high. More specifically, approximately 95% of the childcare centre spaces receive at least 300 lux for at least 50% of the occupied hours. Moreover, the glazed areas are appropriately shaded externally, with hoods and overhangs, preventing glare and visual discomfort, and also the need for interior blinds used during sunny days (resulting in unnecessary lighting consumption).
- The artificial lighting system in the studied childcare centre was renovated in 2016 with LED lamps, and the established lighting power density is 3.5 W/m². Simulation of the effect of daylight linked controls in the playrooms showed that the energy consumption for lighting could be reduced by 85%. However, the switching on/off patterns should be carefully recorded before adopting such a strategy.
- Heating and cooling loads lead to similar overall energy consumption values over the year. This is due to the building's construction, the operational profile and the resulting internal loads in combination with the climate conditions.
- The building envelope's opaque elements are not insulated, but most of them have a very limited impact on the building's energy consumption. Exceptions are the uninsulated roof and floor, which cause high transmission losses both in the cooling and the heating season. There are two options for retrofitting the roof: 1) replacement of the roof tiles with solar reflective tiles or painting of the existing tiles with cool paint or 2) fitting 80 mm of mineral wool under the existing roof. The former option leads to a major reduction of the cooling loads (33%) but to an increase in the heating loads (19%). The latter reduces the cooling loads by 54% and slightly reduces the heating loads (0.4%). A decision can be made based on economics and the technical implications of implementing each option. →

- Despite the fact that the building has a high air permeability (infiltration) due to the poor airtightness of the openings, their contribution to energy losses is very low in comparison with the influence of the roof and the operating profile of the structure. As a result, replacing the windows for energy savings is not justified, as the total impact is minor and the cost of such an intervention is high.
- The building's HVAC system is old and inefficient. So the replacement of the old air-conditioning units with new ones, with a significantly increased energy performance should be considered.
- The installation of ceiling fans is recommended since it can lead to a drastic decrease in the cooling loads, enabling higher setpoint temperatures whilst retaining good levels of thermal comfort.

Overall, a complete refurbishment package should include refurbishing the roof with cool coating tiles or thermal insulation, installation of ceiling fans and replacement of the existing AC systems with new, highly efficient ones. This combined intervention may lead to energy savings of 41.6%, resulting in the energy consumption reduced to 50.5 kWh/m²a, compared to the baseline of 86.4 kWh/m²a. ■

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

3. Introduction

The selected case study building is a typical childcare centre built in Australia in the late 1990s, representative of many other centres built in the same period. In fact, the aim of selecting a childcare in the local government area of the City of Parramatta is the potential for methodology replication and findings expansion to other similar buildings.

Clearly, one sample childcare centre cannot completely fit all similar buildings, and each childcare 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 a childcare centre is a complicated task. It starts with determining the building's construction features, including the efficiency of the building envelope, the lighting, the HVAC equipment etc. Considering the building's features, all calculations are based on the 'as-built' condition of the building elements (U-values, shading, air-permeability, etc.). The efficiency of the HVAC system (Coefficient of Performance and Seasonal Energy Efficiency Rating) was 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 the childcare 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. Childcare centre in Parramatta

4.1. Case study description

4.1.1. Climate

The case study building is located in the local government area of the City of Parramatta, New South Wales, approximately 21 km west of the Sydney central business district, at 183 m above sea level. It has a humid subtropical climate with mild to cool, short winters and warm, sometimes hot, prolonged summers, and moderate rainfall spread throughout the year. Parramatta has an annual mean rainfall of 77 mm, and February has the highest rainfall (130 mm). Mean maximum temperatures in summer are warm averaging between 26°C and 29°C. Due to its geographical location, the relative humidity is distributed relatively throughout the year (64-79% in the morning and 45 -60% in the afternoon). The winters are cool, with overnight minimums averaging 7°C and daily maximums climbing to only 18°C to 20°C on average. The primary climatic information for the area of Parramatta is illustrated in Figure 1. ➔

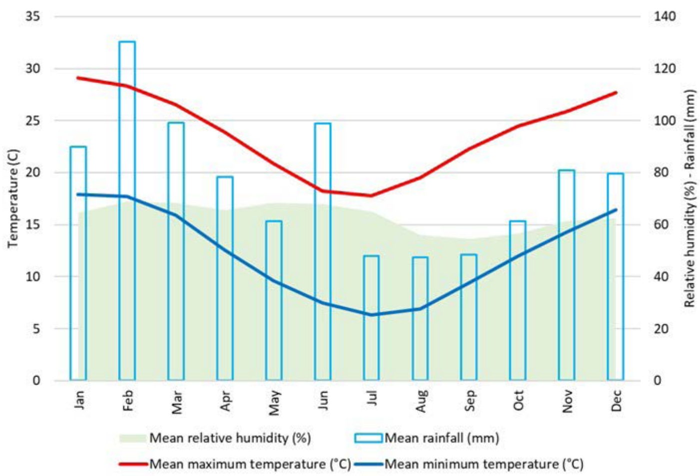

Figure 1. Climatic data for Parramatta.

4.1.2. Building description

The building was constructed in 1995. The building class, according to the National Construction Code, is ‘9b: An assembly building including a trade workshop or laboratory in a primary or secondary school’ [2]. The building has only one floor with an under-ceiling height of 2.7 m. Figure 2 illustrates the treemap chart of the gross internal area of the case study building. The total gross floor area is 327 m², and the net lettable area is 270 m². ➔

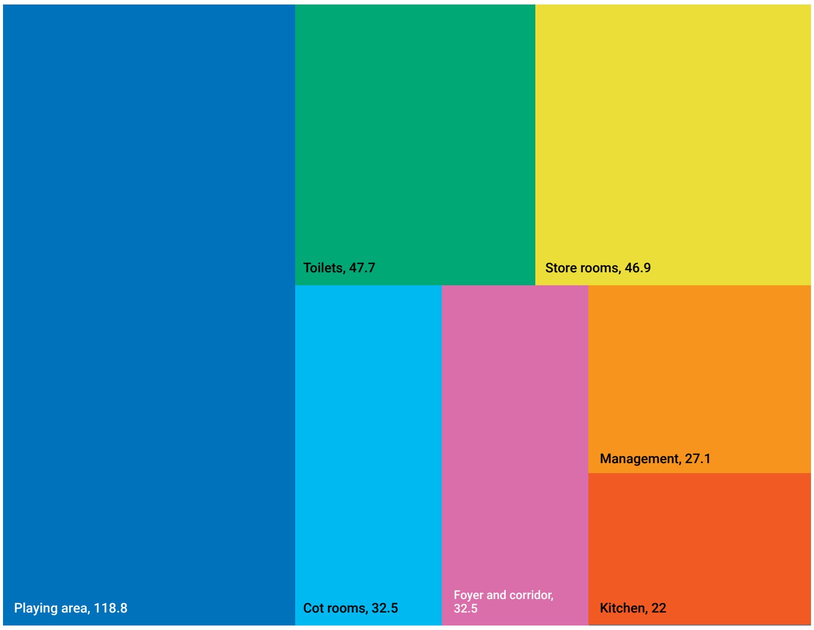

Figure 2. Gross floor divided area of case study building.

4.1.3. Energy consumption and sources

Improving energy efficiency is the best way to decrease the operational cost of buildings. The case study childcare centre uses energy as follows:

- For heating and cooling purposes, 5 indoor units (4 wall-hung and 1 cassette) are connected to 5 outdoor condensing units.
- Electricity is also used for lighting, appliances, etc.

Table 1 shows all the HVAC systems and zones which are supplied with them.

4.2. Building modelling input parameters

A combination of collected data from the building inspection, utility bills and Australian and global standards are used to define modelling parameters. In this section, each modelling assumption will be briefly explained, and the relative references will be presented. In order to have a better energy model for the studied childcare centre, the building is divided into two main zones. The first zone represents all the common areas in the building, including playrooms, offices, cot rooms, etc. The second zone represents the kitchen and laundry room which includes some appliances that produce a considerable amount of heat.

4.2.1. Occupancy

Currently, the studied childcare centre provides 39 long day childcare places for children between the ages of 6 weeks to 6 years. Including 6 staff, there are 45 people in this centre.

4.2.2. Geometric data

As mentioned earlier, the ceiling height is 2.7 m, and the childcare centre area is divided based on the need for air conditioning in the area (Table 2). →

Table 1. HVAC systems and supplied zones.

Type of asset	Location	Make	Capacity (kW)	Area
Cassette Condenser	Indoor Outdoor	Daikin	12.5	0-3 years room
Wall hung Condenser	Indoor Outdoor	Daikin	7.1	3-5 years room
Wall hung Condenser	Indoor Outdoor	Daikin	3.5	Cot room 1
Wall hung Condenser	Indoor Outdoor	Daikin	3.5	Cot room 2
Ducted wall hung Condenser	Indoor Outdoor	Mitsubishi	12.0	Offices and staff room

Table 2. Geometric data.

	Air-conditioned area (m^2)	Not air-conditioned area (m^2)	Gross floor area (m^2)
0-3 years room	71.6	0	71.6
3-5 years room	47.2	0	47.2
Cot room 1	16.2	0	16.2
Cot room 2	16.3	0	16.3
Management and staff room	27.1	0	27.1
Kitchen	22.0	0	22.0
Foyer and Corridor	32.5	0	32.5
Toilets and clean room	0	47.7	47.7
Store rooms	0	46.9	46.9
Total	**232.9**	**94.6**	**327.5**

4.2.3. Building Components

A significant part of the energy consumption to maintain thermal 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 childcare centre, we assessed the thermal properties of the building envelope based on the age of construction and drawings supplied by the facility management. 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 includes three main layers. There are solid bricks as the outer layer, an air cavity and a layer of bricks inside. The overall R-value of the external walls is equal to 0.63 m².K/W. The solar reflectance and thermal emittance are assumed equal to 0.4 and 0.9, respectively, based on the construction and visual inspection in comparison with data from the literature on clay bricks. Also, using the average annual wind velocity in Parramatta's area (2.7 m/s) [3], the convective heat transfer coefficient is calculated as equal to 17.6 W/(m².K) [4].

4.2.3.2. Roof

The roof of the case study childcare centre consists of four layers. There are tiles on the top layer, an air cavity and roofing felt, and then a gypsum plasterboard as an interior false ceiling. The R-value of the roof is 0.46 m².K/W. The solar reflectance and thermal emittance are assumed equal to 0.4 and 0.9, respectively, based on the construction and visual inspection in comparison with data from the literature on clay roofing tiles. Also, using the average annual wind velocity in the area (2.7 m/s) [1], the convective heat transfer coefficient is computed as equal to 17.6 W/(m².K) [3]. →

Table 3. Building Components - Performance Descriptors – Construction – External Walls.

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

R-value: 0.63 m².K/W

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

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m³)	Resistance (m².K/W)	Ref.	Section and page
Tiles (roofing Concrete)	13	1.5	1	2,100	-	[6]	Section 8.3, page 9
Air space	100	-	-	-	0.22	[5]	Section 5.3, page 5
Roof felt	4	0.23	1	1,100	0.02	[6]	Section 8.3, page 9
Plasterboard	10	0.20	1	800	0.05	[6]	Section 8.3, page 9

R-value: 0.46 m².K/W

4.2.3.3. Windows

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

4.2.4. Internal gains

The information regarding the thermal comfort in the case study childcare centre is provided by the facility management through the City Assets and Environment Unit (CAEU), City of Parramatta. Equipment and personal heat production loads assumptions in the model are based on Australian and international standards. Based on the information provided by CAEU, the internal gain of appliances in the childcare centre and their energy consumption rates are presented in Table 7. →

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

Shading type & material	External Shading is applied to the windows on the western and eastern sides of building			
Glazing	Value	Unit	Ref.	Section and page
Glazing U-value	5.69	W (m²/K)	[7]	Page 4
Glazing solar heat gain coefficient	0.82	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. General internal gains.

	Value	Unit	Ref.	Section and page
Activities in the building	Kids early learning	-	CAEU	
Cooling setpoint temperature	23	°C	CAEU	
Heating setpoint temperature	22	°C	CAEU	
Equipment load	4.0	W/m²	[8]	Page 51
Ratio of equipment convection heat	90	%	[9]	Chapter 18, page 18.12
Personal latent gain	18.5	W	[8]	Page 50-51
Personal sensible gain	31.7	W	[8]	Page 50-51

Table 7. Appliances heat gains.

Appliances	Energy source		Electricity consumption	Usage factor
	Electricity	Gas		
Washing Machine- Electrolux WH6-6CP	√	–	4,700	0.12
Oven- Emelia – Di965ei2 gas & electric	√	√	35,169	0.25
CANOPY- ILVE X200 90 SS 1200M cube	√	–	330	0.5
Fisher & Paykel – Freezer E388LXFD	√	–	110	0.41
Fisher & Paykel – Fridge E450 LXFD	√	–	400	0.25
Blanco Microwave- MC 295X	√	–	1,450	1.39
Lamber L20 Pass through dishwasher	√	–	13,712	0.12

4.2.5. Ventilation and infiltration

The building's HVAC systems were upgraded recently. Therefore, the fresh air supplied to each zone is assumed based on Australian standards. Also, depending on the activity of the air-conditioning system, the infiltration rates vary. The ventilation for the kitchen is increased to 145 L/s when the oven is running based on the information provided by CAEU.

4.2.6. Thermal Comfort

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

4.2.7. Energy resources and HVAC systems

The efficiency of HVAC systems is determined by COP and EER provided by the manufacturer. The information regarding the air-cooled split air conditioning systems is presented in Table 10. These HVAC systems have been performing for a couple of years, and their COP and EER have decreased considerably. Therefore, the average actual COP and EER are considered as 2.6 and 2.4, respectively. ➔

Table 8. Ventilation and infiltration.

	Zone	Schedule	Value	Unit	Ref.	Section and page
Fresh air	Common area	Occupied period	12	L/s.person	[10]	Appendix A, page 64
	Kitchen	Occupied period	12.5	L/s	[10]	Appendix A, page 64
Infiltration	All zones	Occupied period	1	ACH	[11]	Section 2.7
		Unoccupied period	0.5	ACH	[11]	Section 2.7

Table 9. Thermal comfort parameters.

Factor	Value	Unit	Ref.	Section and page
Clothing Factor	Summer 0.6 – Winter 1	clo	[12]	Section 5, page 8
Metabolic rate	1.0	Met	[12]	Section 5, page 7
Relative air velocity	Less than 0.2	m/s	[12]	Section 5, page 11

Table 10. HVAC systems.

Manufacturer	Outdoor model	Capacity (kW)	COP	EER	Ref.
Daikin	RQ125LV1A	12.5	3.35	2.99	[13]
Daikin	FTXS71LVMA	7.1	3.67	3.41	[14]
Daikin	FTXS35LVMA	3.5	4.55	3.85	[15]
Mitsubishi	MXZ-6C120VA	12.0	3.88	3.21	[16]

4.2.8. Schedules

The schedules of occupancy, lighting and appliances are selected based on the information provided on page 51 of ISO 17772-1:2017 [8]. Also, the Kitchen and laundry room appliances schedule is presented in Table 12. →

Table 11. Schedules

Time	Occupancy, lighting and appliances
12 AM - 07 AM	0.0
07 AM - 08 AM	0.4
08 AM - 09 AM	0.8
09 AM - 10 AM	0.8
10 AM - 11 AM	0.3
11 AM - 12 PM	0.3
12 PM - 1 PM	0.8
1 PM - 2 PM	0.1
2 PM - 3 PM	0.1
3 PM - 4 PM	0.4
4 PM - 5 PM	0.3
5 PM - 6 PM	0.3
6 PM - 7 PM	0.3
7 PM - 12 AM	0.0

Table 12. Active hours of kitchen and laundry room appliances

	Washing machine		Dishwasher		Oven		Canopy		Microwave		Fridge and Freezer	
	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
12 - 9 AM												
10 AM												
:15												
:30												
:45												
11 AM												
:15												
:30												
:45												
12 PM												
:15												
:30												
:45												
1 PM												
:15												
:30												
:45												
2 PM												
:15												
:30												
:45												
3 PM-12 AM												

4.3. Evaluating Lighting Condition

The aim of this section is to investigate the potential solutions for the improvement of the natural and artificial lighting environment and for minimising the energy consumption for lighting of the used interior spaces of the studied childcare 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 studied childcare centre were the architectural drawings and the type of lighting fixtures installed. The original, mainly fluorescent lighting, was replaced with LED lighting fixtures in 2016.

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 compare to the requirements and recommendations of the Australian NCC [2].

4.3.2. Lighting analysis result

The results are analysed in two parts:

1. the assessment of the existing natural conditions and
2. the artificial lighting conditions and energy consumption for lighting.

4.3.2.1. Natural lighting

The building has numerous openings on all elevations and on the roof. The north elevation has a great number of windows and glazed doors, as it provides access to the Centre's courtyard. All glazed elements of the north elevation are shaded by the protruding roof (width=2.70m), which forms a veranda for exterior activities. The east and west-facing windows are partly shadowed by tile-covered hoods. Skylights are located above the Older Playrooms and the corridor of the Centre.

The glazed area of the windows is more than 10% of the gross area of the centre (approximately 44 m² of glazing for 327 m² of continuously occupied gross space), which is compliant with the requirements of the NCC ([2], Part F4.2). Most of the continuously occupied spaces of the studied childcare centre receive high levels of natural lighting, which are adequate for the mixed tasks carried out for at least half of the working hours during the whole year. More specifically, the Spatial Daylight Autonomy (sDA), i.e., the percentage of space receiving at least 300 lux for at least 50% of the occupied hours, is approximately 95% (Figure 3).

The mean Daylight Factor (%) of the Centre's occupied spaces ranges from 0.2 to 2%. The lower levels are recorded in the rooms where children sleep or relax (Table 13). Overall, the natural lighting levels in the Centre are considered adequate, and further increase or decrease of the glazed elements is not advised. →

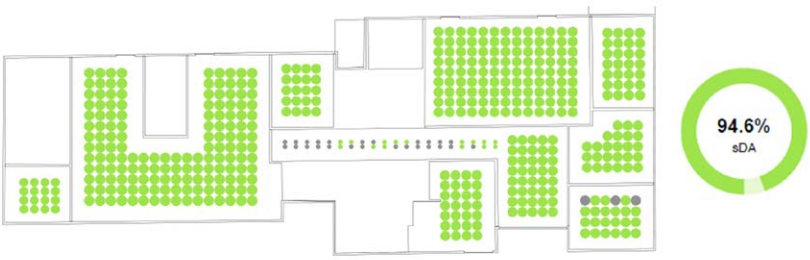

Figure 3. Spatial Daylight Autonomy (sDA) distribution in the studied childcare centre.

4.3.2.2. Artificial lighting

The artificial lighting system of the childcare centre was upgraded in 2016, and the sources installed are the following:

- 5 Pierlite 40 watt DBLED/4
- 12 Pierlite 36 watt ECOPL12-3
- 1 Sunny Lighting Australia 35 watt SL9721
- 32 Phillips 7 watt MLED7W274K60
- 2 LED floodlights
- 8 Sunny Lighting 18 watt or 36 watt (SO3700/30LCW or SO3700/40LCW)
- 12 Sunny Lighting of 5, 7 or 9 watt

Moreover, motion sensors are installed in storerooms and in the staff toilets. Unfortunately, the location of each lighting source in the centre is not known. The illumination power density for the whole centre is 3.5 W/m², approximately, excluding the floodlights, which most likely light the exterior space. According to the NCC, most of the spaces in the centre could have higher Illumination Power Density (e.g., offices: 4.5W/m², learning areas and tutorial rooms: 4.5 W/m², entrance: 9 W/m², corridors, toilets and staff rooms: 3W/m²) [2]. This fact, as well as the existence of motion sensors, makes the replacement of the existing light sources with new ones – more energy and light efficient than those in place – a costly and inefficient procedure. However, interviewing the staff about the adequacy of the artificial lighting levels is advised in order to identify if and where the lighting levels should be increased.

Using more sophisticated controls, i.e., incorporating continuous dimming of the artificial light sources depending on the daylight availability, would reduce the energy consumption for lighting compared to a scenario where all the lights are switched on during the working hours of all days. However, the activities that children and staff carry out in childcare centres in Australia mainly take place outdoors, except during very cold or wet days. For centres with high natural lighting levels, like the studied childcare centre, the artificial lighting could be manually turned on for a short period each day, and the addition of automation might increase the energy consumption.

Table 2. Geometric data.

Space ID	Area (m²)	Mean DF (%)	Uniformity
Corridor	14.15	0.9	0.68
Cot Room 1	11.28	0.20	0.42
Cot Room 2	10.42	0.18	0.32
Director	9.69	1.31	0.39
Entrance	14.64	2.07	0.62
Kitchen	8.06	0.73	0.51
Nursery	42.37	0.72	0.49
Older playrooms	60.03	1.41	0.56
Quiet room	6.12	1.77	0.41
Staff room	10.79	2.1	0.31

To compare the difference between a scenario in which all light sources are switched on in 100% output for all working days and hours per day and an optimised scenario in which light sources are continuously dimmed based on the daylight availability during the working days and hours, Older Playrooms 1 and 2 and the toilet inside this space were modelled and the lighting conditions were simulated. With a lighting power density equal to 3.5W/m², the energy consumed for lighting for the first scenario is 818 kWh per year. The energy consumed for lighting when the sources are continuously dimmed is 123 kWh per year. This constitutes an 85% reduction in the energy used, which is significant and is due to the high daylight availability of the space. However, an approximately equal reduction could already be achieved with the manual on/off switches in the playrooms of the centre. Thus, no changes are recommended to the artificial lighting of the centre.

5. Simulation approach

The simulation includes two main parts. First, the building geometry was modelled in the SketchUp software environment, 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 venetian blinds) (Figure 4).

5.2. TRNSys

TRNSys software 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 needed to simulate the thermal behaviour of the building, such as windows optical properties, heating and cooling schedules, etc. [17].

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

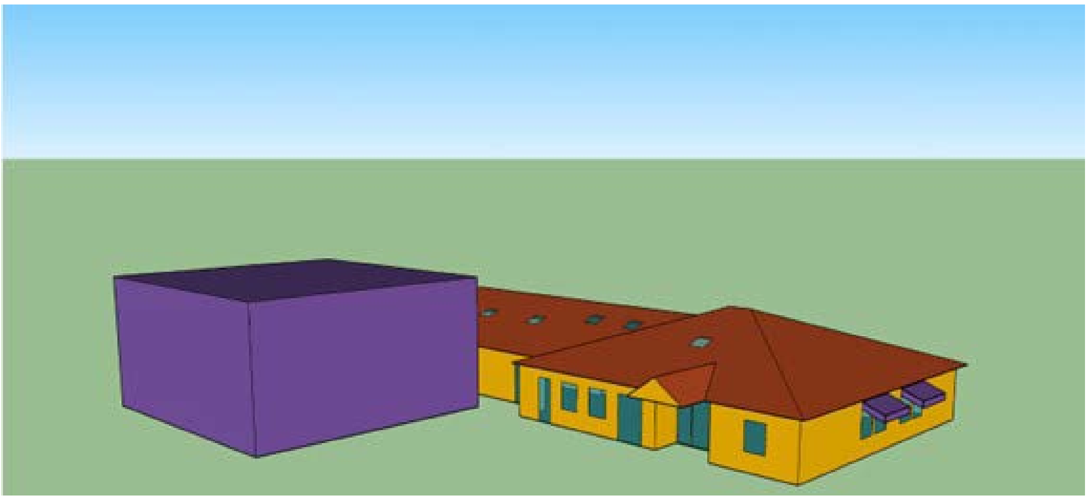

Figure 4. SketchUp model

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 are based on the 'as-built' condition of the building elements (U-values, shading, air-permeability etc.), of the HVAC system (Coefficient of Performance and Seasonal Energy Efficiency Rating as provided by manufacturers or (for older systems) by regulations), whilst installed lighting and plug loads were determined either by data provided by the building operators or in accordance with standard 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 ASHRAE and ISO standards. Simulations were carried out on an hourly base, 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.

As mentioned previously in section 4.3.2, the artificial lighting system in the childcare centre was renovated in 2016 with LED lamps, and the established lighting power density is 3.5 W/m². The simulations proved that the natural lighting levels in this centre are high, and approximately 95% of the building spaces receive at least 300 lux for at least 50% of the occupied hours. Moreover, the glazed areas are appropriately shaded externally, with hoods and overhangs. Therefore, no changes are recommended to the artificial lighting of the Centre. The other retrofitting options are explained separately, and then their combined impact will be investigated in the next chapter. ➔

5.3.1. Roof tiles

Improving the roof tiles is the first retrofit approach. Two possible options are the installation of new white concrete tiles with an estimated average installed cost of 30 AUD/m² (expected life of 50 years) or the painting of the existing ones with an estimated average installed cost of 3.9 AUD/m² (expected life of 3-5 years). Either way, the tiles can reach albedo 0.7 and solar absorbance of 0.3, which can prevent absorbing a great amount of solar radiation.

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 8 cm) between the ceiling and the external roof, leading to an average total thickness of 0.11 m and an average R-value of 2.74 m²K/W. The average installed cost is estimated at 52 AUD/m².

5.3.3. Windows retrofit

The current windows installed in the studied childcare centre are single glazed with aluminium frame and cause a high amount of energy loss. Insulation within a window is called "thermal break". The thermal break 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 has an aluminium thermally-broken frame, double glazing, with Low-E external glass pane, with an average U-value of 2.58 W/m²K, an SHGC value of 0.42 and Airtightness values of Class 3 with less than 2.5 L/s.m² at 100 Pa. The latter reduces the infiltration rate of the building to 0.30 1/h. The average installed cost is estimated at 600 AUD/m².

5.3.4. Replacement of HVAC systems and ceiling fans

The current split units in the studied childcare centre are fairly old with low COP and EER. It can cause a high amount of energy waste for HVAC purposes. New high-performance split units (COP=3.5, EER=3.8) and ceiling fans are proposed for the HVAC retrofitting. Ceiling fans are modelled by increasing the cooling setpoint temperature to 26°C.

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. The total HVAC retrofitting cost is estimated at 9,500 AUD.

6. Results

The simulation result is based on the modelled building. The provided energy bills only cover 9 months (Oct 2020-Jun 2021). In the next section, different occupancy schedules due to the climatic conditions will be compared, and the impact of retrofitting scenarios will be investigated.

6.1. Base building modelling

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

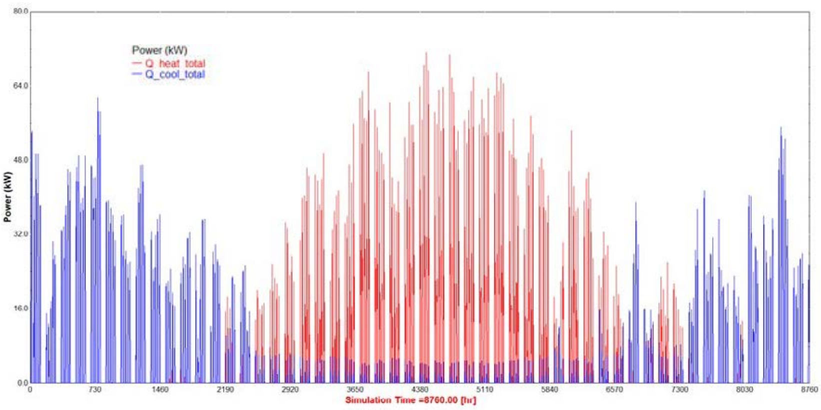

Figure 5. Hourly energy demand for HVAC purposes.

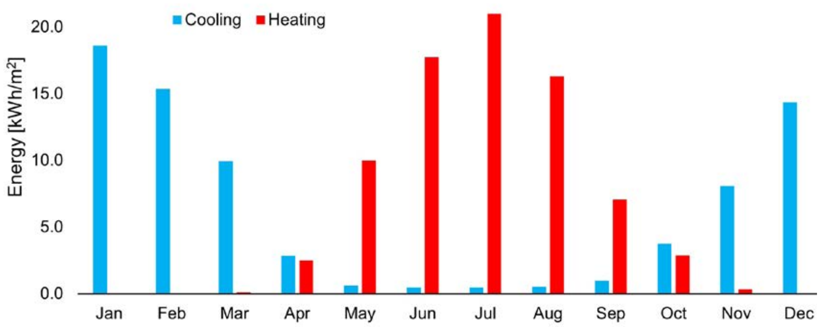

Figure 6. Monthly energy demand for HVAC purposes.

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 balance is illustrated in Figures 8 and 10. ➔

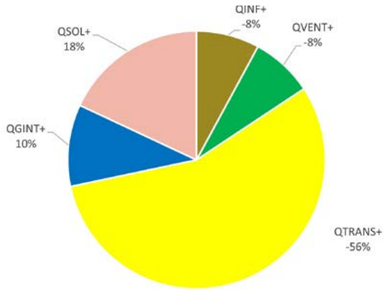

Figure 7. Whole building energy gain – heating season (May - September).

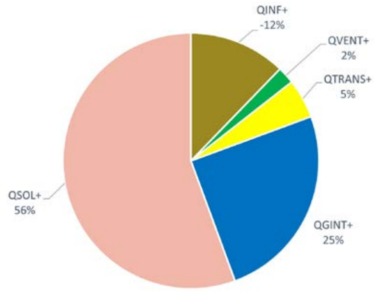

Figure 9. Whole building energy gain – cooling season (October - April).

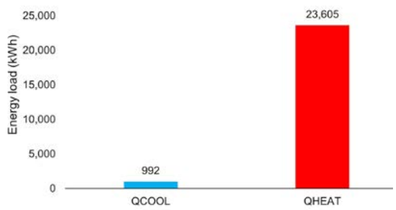

Figure 8. Whole building energy gain for heating and cooling load – heating season (May-September).

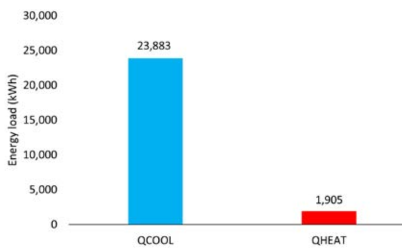

Figure 10. Whole building energy gain for heating and cooling load - cooling season (October-April).

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

6.2. Sensitivity analysis of occupancy schedule

As mentioned in section 4.2.8, ISO 17772-1 is considered as the base schedule for modelling the studied childcare centre. In this section, the other possible schedules based on the Australian weather are compared with the ISO 17772-1 as an international standard. Three evaluated schedules are:

- A hot summer (heatwave or bushfire), so children only play outside in transition seasons, and they are mostly inside in summer and winter.
- A mild summer, children play outside in spring, summer and autumn, and they are inside in winter
- Based on ISO 17772-1 standard without any adjustments.

The results of the sensitivity analysis scenarios are presented in Figure 12. As illustrated, the only considerable difference is the heating season, when based on ISO 17772-1 standard, kids go out to play outside. The difference caused 10.7% more heating load in ISO standard in comparison with Mild summer. Similarly, because of the children playing outside in summer based on the ISO standard, the cooling load in summer is 2.9% more in this scenario in comparison with the hot summer scenario. ➔

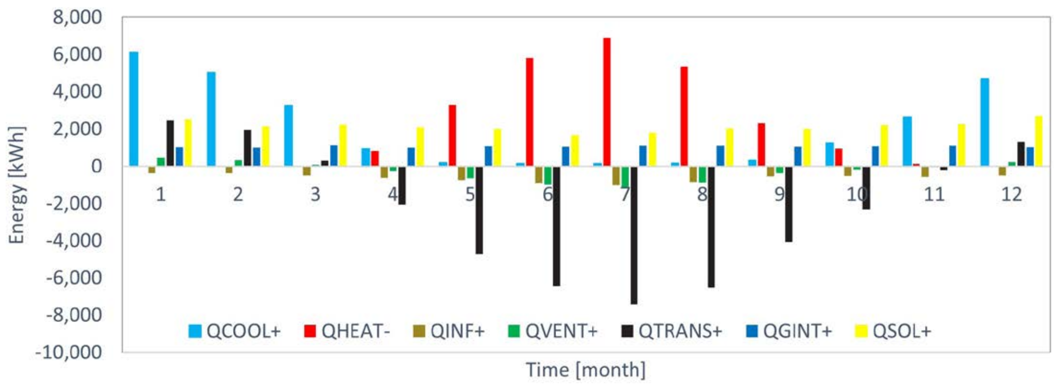

Figure 11. Monthly building energy balance.

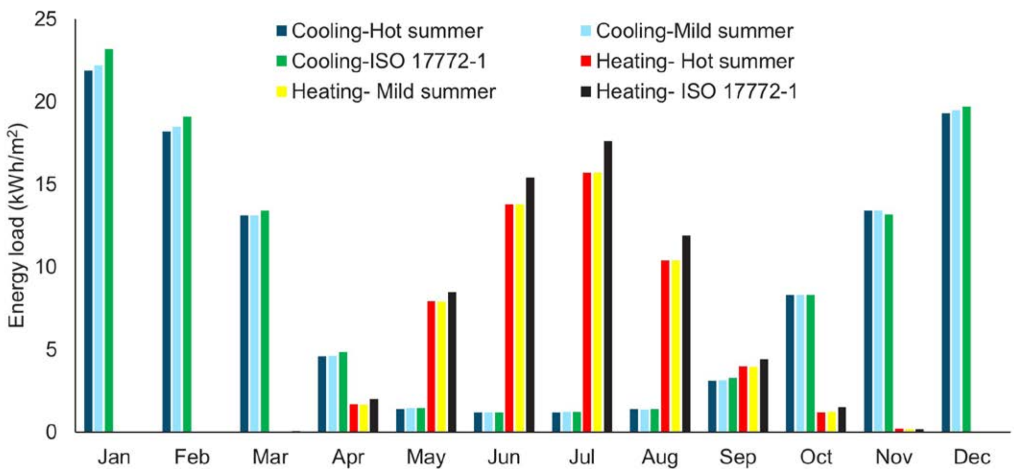

Figure 12. Sensitivity analysis result.

6.3. Retrofit scenarios

The investigated retrofit cases in this report are presented in Table 14.

Between the presented scenarios, Case D has the most retrofitting steps. Also, to evaluate the impact of windows retrofit, Case E is developed and compared with Case D. Table 15 shows the influence of different retrofitting cases on heating and cooling loads. Also, Table 16 demonstrates the impact of different retrofit scenarios on electricity consumption in the case study childcare centre. The result indicates that by improving the building condition, 41.9% of the needed electricity can be reduced. Comparison between Case D and Case E demonstrated that when applying other retrofit choices, changing windows does not have a major impact, considering its high cost. A more detailed illustration of the retrofitting impact is presented in Figures 13-15. →

Table 14. Retrofit cases

Scenario	Retrofit
Baseline	Based on CAEU provided data Heating setpoint 22°C, cooling setpoint 23°C + base case lighting + HVAC systems are only supplying while occupants are present. Cooling setback is set to 26° C for the kitchen to avoid cooling during the cooking period
Case A	Baseline + tiles coating
Case B	Baseline + roof insulation
Case C	Case B + windows retrofit
Case D	Case C + replacing HVAC systems + ceiling fans
Case E	Case B + replacing HVAC systems + ceiling fans

Table 15. Simulation results – heating and cooling loads.

	Heating loads	Cooling loads	Heating + Cooling	Heating loads	Cooling loads	Heating + Cooling
	kWh/(m²a)			difference (%)		
Baseline	77.9	76.0	153.8	-	-	-
Case A (Baseline + tiles coating)	92.5	50.7	143.2	19	-33	-7
Case B (Baseline + roof insulation)	77.6	35.1	112.7	0	-54	-27
Case C (Case B + windows retrofit)	75.9	29.5	105.4	-3	-61	-32
Case D (Case C + replacing HVAC systems + ceiling fans)	75.9	11.5	87.4	-3	-85	-43
Case E (Case B + replacing HVAC systems + ceiling fans)	77.5	13.4	91.0	0	-82	-41

Table 16. Simulation results - Site energy (electricity).

	Heating	Cooling	Lighting	Appliances	Total	Total difference
	kWh/(m²a)					%
Baseline	30.0	31.6	5.3	19.5	86.4	-
Case A (Baseline + tiles coating)	35.6	21.1	5.3	19.5	81.5	-5.7
Case B (Baseline + roof insulation)	29.8	14.6	5.3	19.5	69.3	-19.8
Case C (Case B + windows retrofit)	29.2	12.3	5.3	19.5	66.3	-23.3
Case D (Case C + replacing HVAC systems + ceiling fans)	21.7	3.0	5.3	19.5	49.5	-42.7
Case E (Case B + replacing HVAC systems + ceiling fans)	22.2	3.5	5.3	19.5	50.5	-41.6

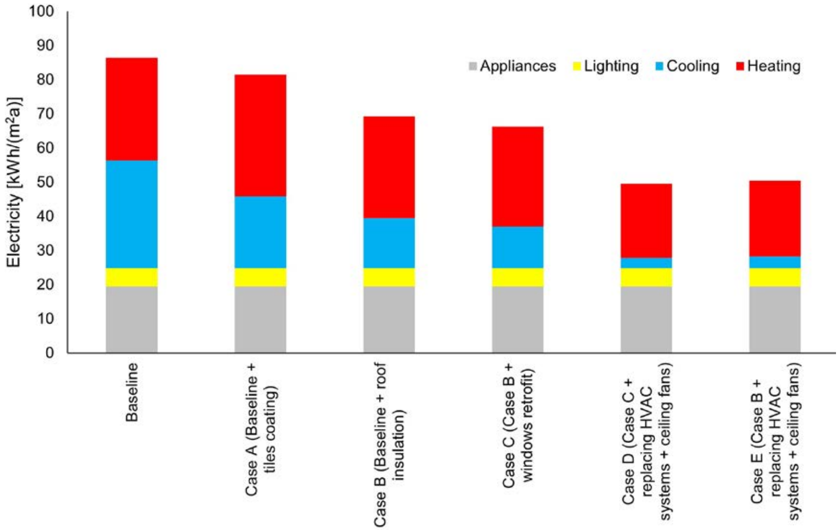

Figure 13. Site energy of the retrofit scenarios.

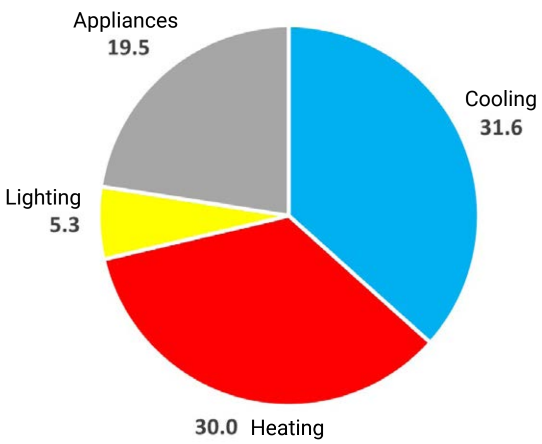

Figure 14. Share of site energy for the baseline – before retrofit.

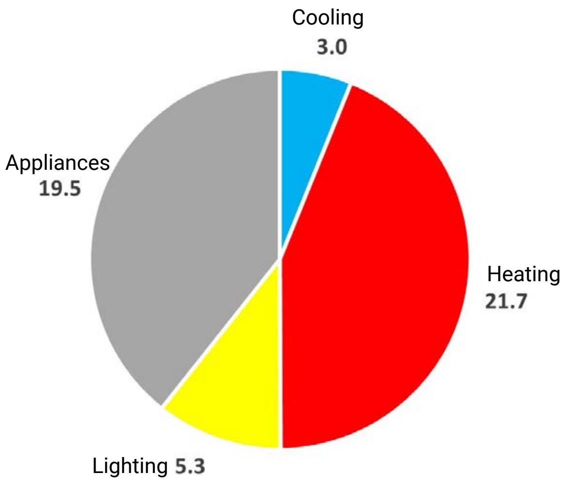

Figure 15. Share of Site energy for retrofit scenario – case D (all retrofit scenarios applied).

6.4. Sensitivity analysis of geographical location and retrofit impact

In this section, the case study childcare 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 global warming on the case study building energy demand. Scenarios that include time series of emissions and concentrations of the full suite of green-house gases (GHGs) and aerosols and chemically active gases are called Representative Concentration Pathways (RCPs) [18]. 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. The results indicate that in all representative cities, the cooling site energy will rise between 6.7%-14.4% by 2030 (Table 17).

The base case and highly retrofitted scenario (Case D) are simulated in the closest representative city (Sydney) to evaluate the impact of retrofitting childcare centre. As presented in Table 18, the total site energy is not different in the base case scenario for the present and future climate. This is because while global warming causes an increase in the cooling demand, the heating load will decrease. On the other hand, almost 85% of the cooling load can be decreased by childcare building enhancement. This efficiency improvement can reduce the total electricity demand of the building by 35.6%. ➔

Table 17. Current and future energy demand of the childcare centre based on CSIRO weather database. The increase in cooling and total site energy is in comparison with the present climate.

Location	Period	Heating load	Cooling load	Heating site energy	Cooling site energy	Lighting site energy	Appliances site energy	Total site energy	Cooling site energy increase	Total site energy increase
		(kWh/m²)							%	
Adelaide	Present	88.9	82.1	34.2	34.2	5.3	19.5	93.2		
	2030	78.8	91.7	30.3	38.2	5.3	19.5	93.3	11.7%	0.1%
Brisbane	Present	33.3	133.9	12.8	55.8	5.3	19.5	93.4		
	2030	28.1	145.2	10.8	60.5	5.3	19.5	96.1	8.4%	2.9%
Canberra	Present	137.5	64.8	52.9	27.0	5.3	19.5	104.7		
	2030	126.1	71.0	48.5	29.6	5.3	19.5	102.9	9.6%	-1.7%
Darwin	Present	1.6	247.4	0.6	103.1	5.3	19.5	128.5		
	2030	1.0	264.0	0.4	110.0	5.3	19.5	135.2	6.7%	5.2%
Melbourne	Present	127.4	51.6	49.0	21.5	5.3	19.5	95.3		
	2030	114.1	59.0	43.9	24.6	5.3	19.5	93.3	14.4%	-2.1%
Perth	Present	69.2	115.0	26.6	47.9	5.3	19.5	99.3		
	2030	60.1	127.4	23.1	53.1	5.3	19.5	101.0	10.9%	1.7%
Sydney	Present	60.8	85.9	23.4	35.8	5.3	19.5	84.0		
	2030	53.3	94.1	20.5	39.2	5.3	19.5	84.5	9.5%	0.6%
Hobart	Present	148.7	31.0	57.2	12.9	5.3	19.5	94.9		
	2030	140.1	35.0	53.9	14.6	5.3	19.5	93.3	13.2%	-1.7%

Table 18. The comparison between the base case and fully retrofitted scenario

	Period	Heating load	Cooling load	Heating site Energy	Cooling site energy	Lighting site energy	Appliances site energy	Total site energy	Cooling site energy increase	Total site energy increase
		(kWh/m²)							%	
Base case	Present	60.8	85.9	23.4	35.8	5.3	19.5	84.0		
Sydney	2030	53.3	94.1	20.5	39.2	5.3	19.5	84.5	9.5%	0.6%
Retrofitted	Present	62.4	12.72	24	5.3	5.3	19.5	54.1		
Sydney	2030	56.42	14.64	21.7	6.1	5.3	19.5	52.6	15.1%	-2.8%

6.5. Discussion and recommendations

The Childcare Centre's energy performance 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 simulations proved that the natural lighting levels in the Centre are high. More specifically, approximately 95% of the childcare centre spaces receive at least 300 lux for at least 50% of the occupied hours. Moreover, the glazed areas are appropriately shaded externally, with hoods and overhangs.
- The artificial lighting system in the studied childcare centre in the City of Parramatta LGA was renovated in 2016 with LED lamps, and the established lighting power density is 3.5 W/m^2. Simulation of the effect of daylight linked controls in the playrooms showed that the energy consumption for lighting could be reduced by up to 85%. However, the switching on/off patterns should be carefully recorded before adopting such a strategy. It is highly probable that the lights are mostly off during almost all days, as the majority of the activities take place externally in day-care centres in Australia.
- Heating and cooling loads lead to similar overall energy consumption values over the year. This is due to the building's construction, the operational profile and the resulting internal loads in combination with the climate conditions.
- The building envelope's opaque elements are not insulated but have a very limited impact on the building's energy consumption. There is, therefore, no reason to intervene. Exceptions are the uninsulated roof and floor, which cause high transmission losses both in the cooling and the heating season. The impact of the roof is expected in such a low rise building. Thus, since the roof has a major impact on energy performance, it can be retrofitted with insulation to reduce heating and cooling loads and to improve thermal comfort conditions, or by replacement of the roof tiles with cool coating tiles, which leads to a drastic reduction of the cooling loads but to an increase in the heating loads. However, this heating penalty is decreasing with climate change.
- Despite the fact that the building has a high air permeability (infiltration) due to the poor airtightness of the openings, considering the influence of the roof and the operating profile of the structure, their contribution to energy losses is very low. As a result, replacing the windows for energy savings is not justified, as the total impact is minor and the cost of such an intervention is high. Such an intervention could only be considered in order to improve thermal comfort conditions.
- The building's HVAC system is old enough and inefficient, given the development in HVAC systems over the last 10 years and the impact of operating hours and maintenance levels on its performance. So the replacement of the old air-conditioning units with new ones, with a significantly increased energy performance should be considered.
- The installation of ceiling fans is recommended since it can lead to a drastic decrease in cooling loads, enabling higher setpoint temperatures whilst retaining good levels of thermal comfort. →

Based on the modelling results, the following recommendations are offered:

- Refurbishment of the roof. There are two options with comparable overall efficiency
  - Op.1 replacement of the roof tiles with solar reflective tiles or application of a cool coating on the existing roof
  - Op.2 fitting 8cm of mineral wool under the existing roof.

The former option leads to a major reduction of the cooling loads but to an increase in the heating loads. The latter reduces the cooling loads drastically and reduces the heating loads slightly. A decision can be made based on economics and on the technical implications of implementing each option. Also, the use of cool roofing provides other benefits, such as contributing to urban overheating mitigation.

- Replacement of the old air-conditioning units with new ones, with a significantly increased energy performance and installation of ceiling fans
- The installation of ceiling fans is recommended since it can lead to a drastic decrease in cooling loads.
- Replacing the windows is not justified for reasons of energy savings since the overall impact is negligible and the cost of such an intervention is high. It could only be considered in order to improve thermal comfort conditions.
- Education of staff on the energy benefits of turning off lighting to the centre's playrooms when not in use

Overall, a complete refurbishment package should include refurbishing the roof with cool coating tiles or thermal insulation, installation of ceiling fans and replacement of the existing AC systems with new, highly efficient ones.

References

1. UK Green Building Council, *Climate Change*, in https://www.ukgbc.org/climate-change/ *[accessed 7 August 2021]*.
2. Australian Building Codes Board, *National Construction Code Volume One, Amendment 1*,. 2019.
3. Bureau of Meteorology. *Climate statistics for Australian locations*, http://www.bom.gov.au/ [Accessed 8 August 2021].
4. Mirsadeghi, M., et al., *Review of external convective heat transfer coefficient models in building energy simulation programs: Implementation and uncertainty*. Applied Thermal Engineering, 2013. 56(1): p. 134-151.
5. International Organization for Standardization, ISO 6946:2007, in *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*. 2007.
6. British standard, *BS EN ISO 10456:2007*, in *Building materials and products — Hygrothermal properties - Tabulated design values and procedures for determining declared and design thermal values*. 2007.
7. Dowell, *Technical & Size Supplement*, in http://www.dowell.com.au/media/dowellimages/brochures/Technical_And_Sizes_Brochure_d.pdf. 2017.
8. ISO 17772-1, *Energy performance of buildings — Indoor environmental quality, in Part 1: Indoor environmental input parameters for the design and assessment of energy performance of buildings*. 2017.
9. ASHRAE, *Fundamentals Handbook*. 2017.
10. Standards Australia, *AS 1668.2, Amendment 1, The use of ventilation and air-conditioning in buildings-Mechanical ventilation in buildings, in Mechanical ventilation in buildings*. 2012.
11. Daly, D., P. Cooper, and Z. Ma, *Understanding the risks and uncertainties introduced by common assumptions in energy simulations for Australian commercial buildings*. Energy and Buildings, 2014. 75: p. 382-393.
12. ASHRAE, ANSI/ASHRAE Standard 55, in *Thermal Environmental Conditions for Human Occupancy*. 2020: https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy.
13. DAIKIN, DAIKIN *Skyair – Air Conditioning Systems FCQN-KVEA + RQ-LV1A*. [Accessed: 8 August 2021]: http://assets.jaicrest.com.au/downloads/brochures/daikin/Daikin%20SKY%20AIR%20Brochure.pdf.
14. DAIKIN, DAIKIN *L-SERIES - RXS71LVMA*. [Accessed: 8 August 2021]: https://hewitttradeservices.com.au/products/daikin-l-series-ftxs71lvma/.
15. DAIKIN, DAIKIN *L-SERIES - FTXS35LVMA*. [Accessed: 8 August 2021]: https://hewitttradeservices.com.au/products/daikin-l-series-ftxs35lvma/.
16. Mitsubishi, *MXZ-6C120VA - 6 head/12 kW*. [Accessed: 8 August 2021]: https://www.mitsubishielectric.com.au/Mitsubishi_MXZ-6C120VA-12kW_multi_split_system.htm.
17. TRNSYS, *A transient systems simulation program*. 2017, https://sel.me.wisc.edu/trnsys/index.html.
18. Moss, R.H., N. Nakicenovic, and B.C. O'Neill, *Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies*, ed. IPCC EXPERT MEETING REPORT. 2008, IPCC.

Attachment 1

The following figure shows the potential of natural lighting in studied childcare centre building.

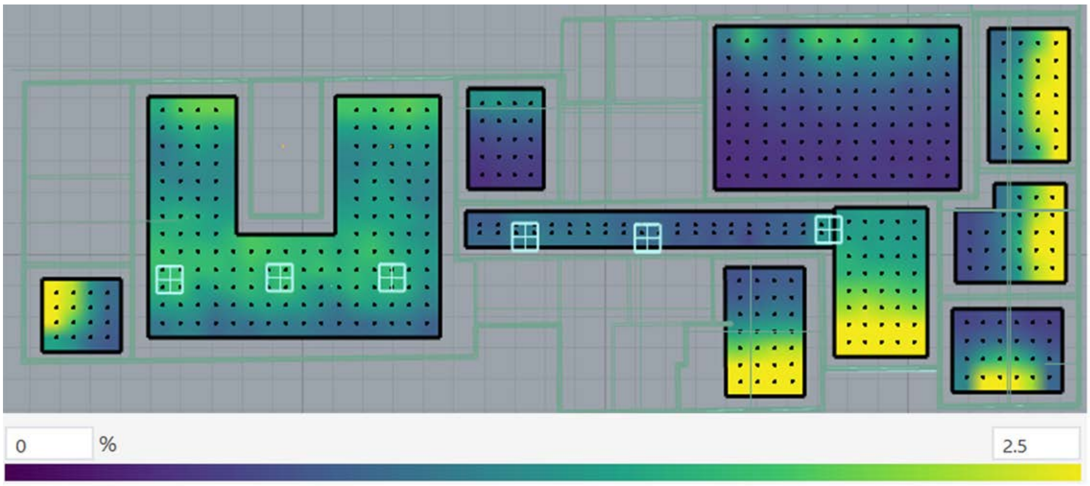

Figure A1. Distribution of Average Daylight Factor in continuously occupied spaces