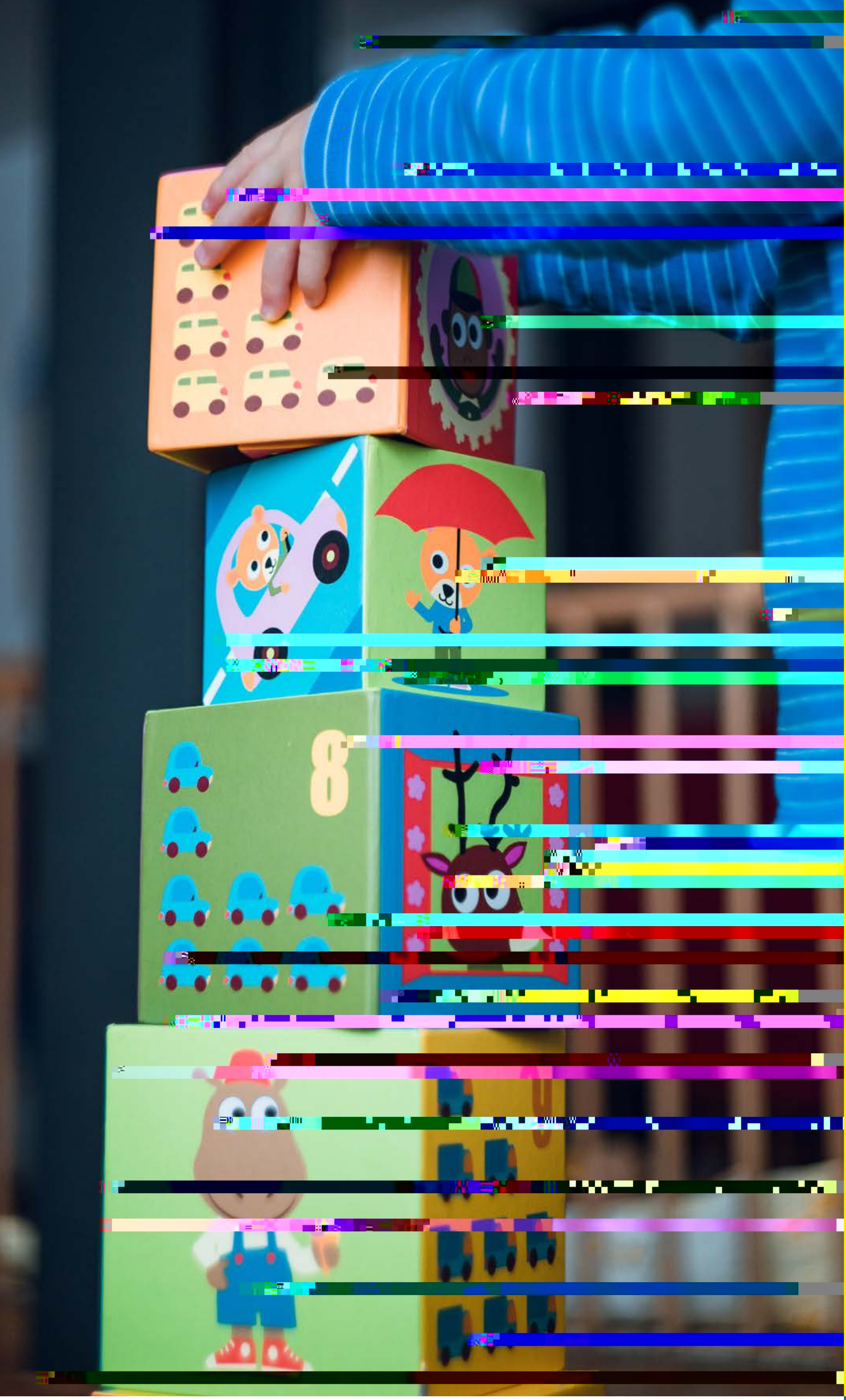

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C

1. E c S a

Global climate change is exposing existing buildings to conditions they were not designed to face, with a growing need for increased e f ciency, to reduce the operational cost and carbon dioxide emissions. To meet these goals, established buildings need energy retro f ts. Almost 80% of 2050 buildings already exist today [1], and we must prioritise improving the e f ciency 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 f uctuations 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 f ndings 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

- 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. R a , S a a , a

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.

4. C ca c Pa a a a

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. ➔

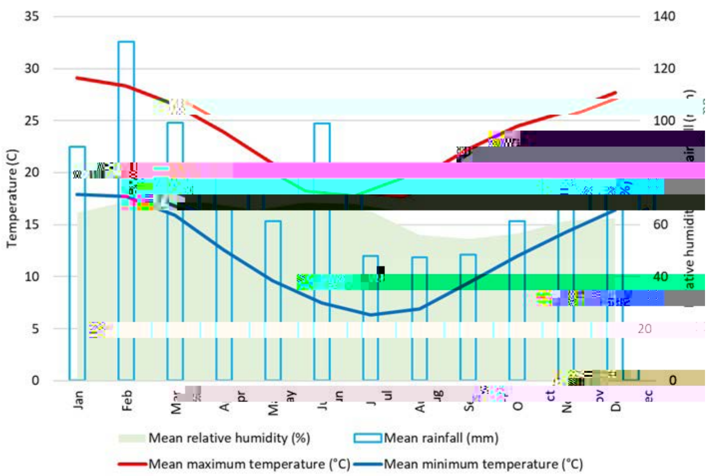

Figure 1. Climatic data for Parramatta.

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. ➔

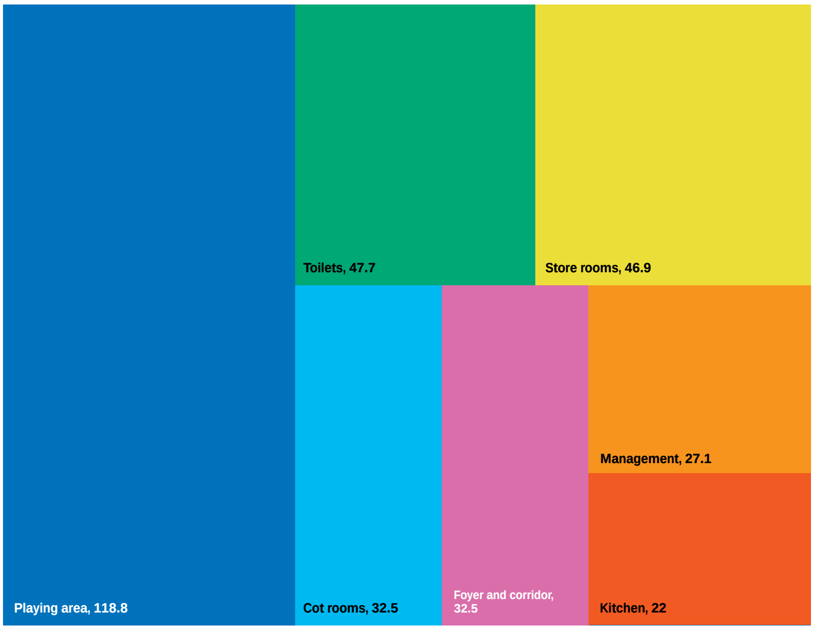

Figure 2. Gross floor divided area of case study building.

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

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 $m^2.K/W$. 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 $W/(m^2.K)$ [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 $m^2.K/W$. 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 $W/(m^2.K)$ [3]. ➔

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. ➔

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 coe f cient	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		

4.2.5. Ventilation and infltration

4.2.8. Schedules

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

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., incor

5. S a a ac

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

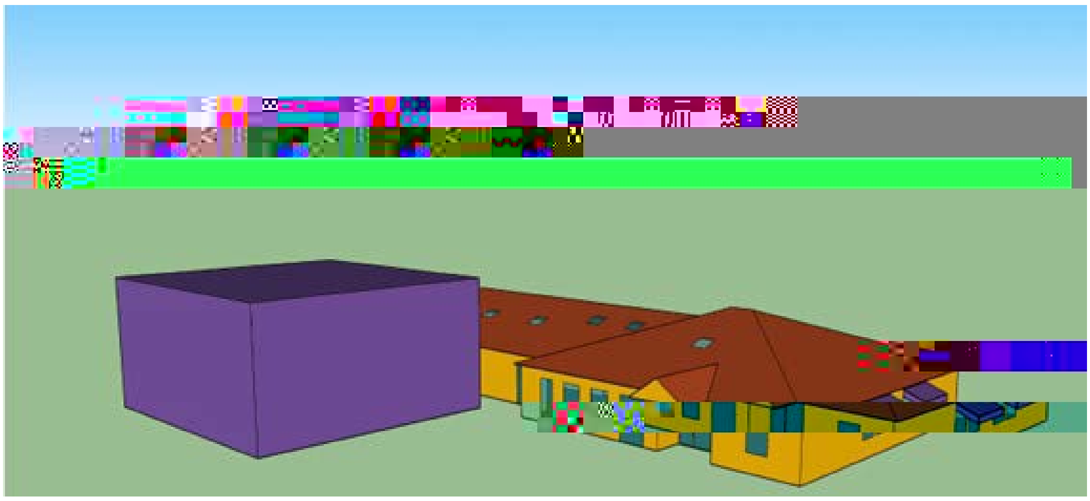

Figure 4. SketchUp model

5.3. Retrofit approaches

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 infltration 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. R

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. ➔

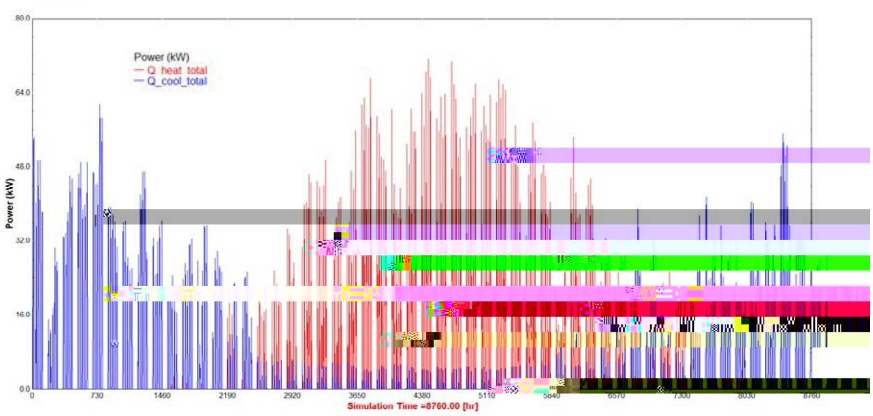

Figure 5. Hourly energy demand for HVAC purposes.

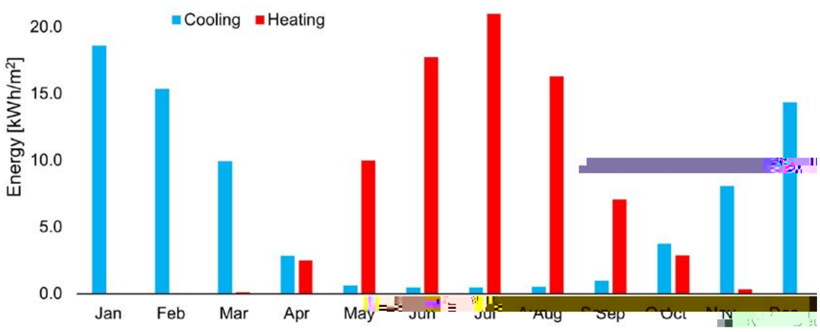

Figure 6. Monthly energy demand for HVAC purposes.

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

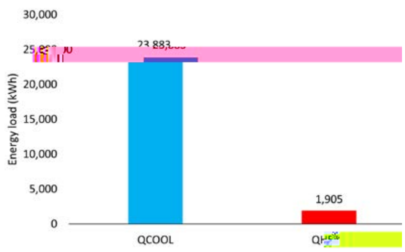

Figure 10. Whole building energy gain for heating and cooling load - cooling season

The monthly energy balance of the building and the infuence 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 bushfre), 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.

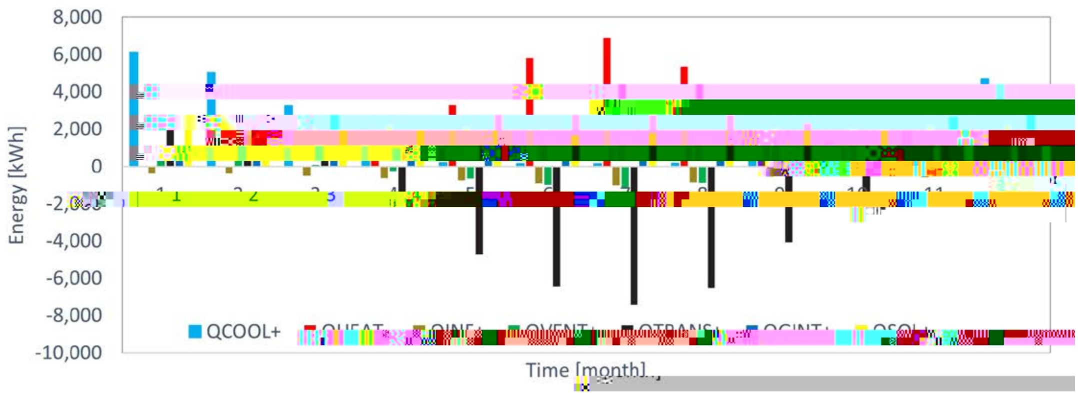

Figure 11. Monthly building energy balance.

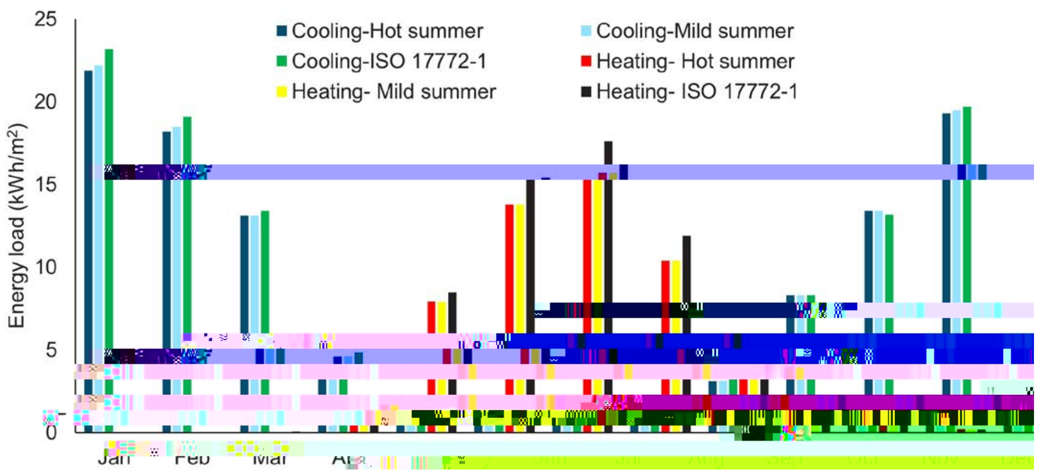

Figure 12. Sensitivity analysis result.

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).

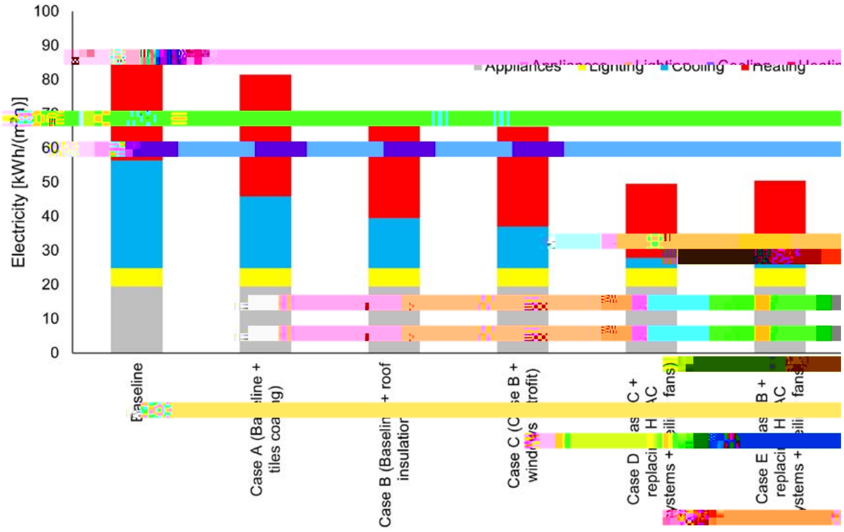

Figure 13. Site energy of the retrofit scenarios.

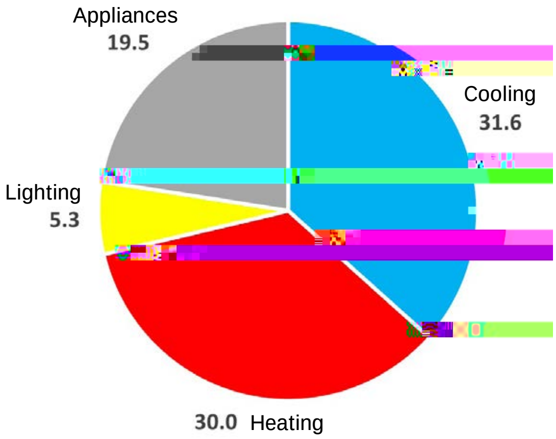

Figure 14. Share of site energy for the baseline – before retrofit.

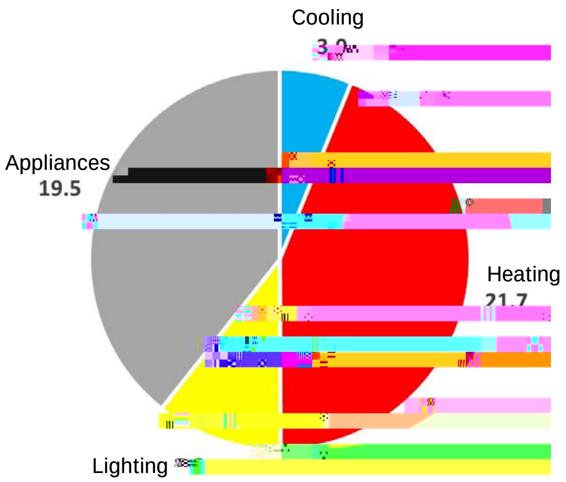

Figure 15. Share of Site energy for retrofit scenario – case D (all retrofit scenarios applied).

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

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 cth γ ӟ m]

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

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A ac 1

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

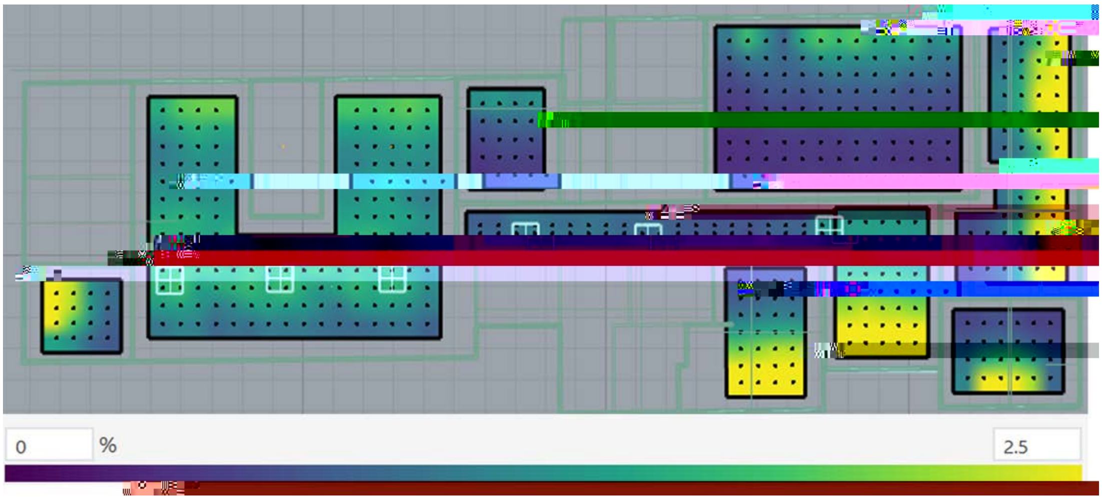

Figure A1. Distribution of Average Daylight Factor in continuously occupied spaces