Office

Energy Efficiency Training
and Information Project

Commercial Buildings

Wagga Wagga
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

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Cover image:
43-45 Johnston Street Wagga Wagga, NSW

Contents

1. Executive Summary

A complete refurbishment package will lead to electricity savings of 24%

In this report, a typical office building is considered as a case study to explore opportunities to reduce the electricity consumption in office buildings. More in detail, the selected case is an office building in Wagga Wagga (NSW) built in the late 1950s, offering consistent opportunities for improving the energy performance.

The building was internally estimated NABERS Energy 3.5 star in October 2021, with 6% of energy supplied by green power, while going through renovations and HVAC&R commissioning. Due to the nature of this project, the energy consumption was fully investigated, while the on-site energy production (with renewable resources) was not evaluated.

A typical office building constructed in 1950s is considered as a case study to explore opportunities to reduce the electricity consumption (site energy). A dynamic thermal model of the building is simulated with TRNSys software, similar to the characteristics of the real building as much as possible.

The model is compared with the metered operational energy data, finding that the simulations offer a reliable representation of the energy profile of the building. It is to be noted that a calibrated simulation is beyond the scope of the project and would require extensive metering with indoor temperature measurements (among other quantities) beyond the comparison with the energy bills. Here, the comparison with metered electricity consumption serves the purpose of verification that the simulated scenario is reasonably close to the actual performance so that the identified retrofit options are representative and applicable.

A part of the collected data relates to a period affected by COVID-19 lockdowns, causing occupancy rates and energy consumption fluctuations. Therefore, input data from Australian and international standards are used to build a reliable model. Also, this report summarises the findings of the performed analysis on the existing lighting conditions. It provides recommendations for the improvement of the lighting conditions and the minimisation of the energy consumption for lighting.

The analysis showed that most of the continuously occupied spaces receive high natural lighting levels and are adequately shaded. Considering artificial lighting, which consists of fixtures with fluorescent tubes with on/off controls, some of the office spaces had lighting levels below the recommended values. In contrast, others had levels much above the recommended. The proposed measures enable a reduction of the energy consumption for lighting from 37 to 58% while restoring the lighting levels to the recommended by the appropriate Standards.

The baseline scenario for determining feasible interventions is based on the fact that energy consumption for cooling and heating are very significant issues to address, with a value of 66.6 and 38.4 kWh/m²a, respectively. →

Based on the results, the following recommendations are technically viable and relatively easy to implement:

- Refurbishment of the windows, with new aluminium framed, double glazed ones, of high energy efficiency to reduce thermal losses in winter, solar loads in summer and achieve airtightness throughout the year.

- Improvement of the lighting systems by installing LEDs and having controls on artificial lighting.

- Installation of ceiling fans to reduce cooling loads.

In conclusion, a complete renovation package is suggested that includes the drastic improvement of the building envelope's thermal protection by replacing the windows and glazed surfaces, upgrading the lighting system, and installing ceiling fans. The result indicates that by improving the case study office building condition, 24.0% of required electricity can be reduced, resulting in an energy consumption of 69.1 kWh/m^{2}a. compared to the baseline of 90.9 kWh/m^{2}a. Using NABERS Energy reversed calculator, if the building is fully retrofitted, the NABERS star rating can increase from 3.75 to 4.25 stars [16].

2. Regulations, Standards, and guidelines

The regulatory documents and Standards used for the analysis and the proposed energy retrofits are:

- National Construction Code of Australia 2019 Volume One.
- 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.
- 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: Non-residential 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

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 the improvement of the efficiency of the existing building stock.

The largest fraction of the energy consumption in an office building is related to energy uses for heating, ventilation, air conditioning and refrigeration (HVAC&R) applications, lighting, and appliances [2]. This report tackles the operational energy consumption challenge for existing offices, 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.

The office building selected as a case study is a typical office building built in Australia in the late 1950s. Hundreds of similar office buildings exist across the country. In fact, the aim of selecting 43-45 Johnston Street is the potential for methodology replication and findings expansion to similar buildings.

One sample office building cannot completely represent the whole stock, and each office has differences. However, even though the required procedure may differ, the logic and methodology presented here offer a high-level framework to improve the energy efficiency in office buildings.

Assessing the energy performance of a building is a complex task. It starts with the analysis of the building and its services, including the efficiency of the building envelope, lighting, HVAC&R systems, and other equipment. Considering the building's features, all calculations are based on the 'as-built' condition of the building elements (U-values, shading devices, air-permeability etc.), the HVAC&R systems (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 standards and regulations.

Furthermore, two types of specific conditions that have a significant impact on the 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, the existence of water surfaces, etc.).

4. Office Building in Wagga Wagga

4.1. Case study description

4.1.1. Climate

The case study building is located at 43-45 Johnston Street, Wagga Wagga NSW 2650 (-35.106S, 147.369E). Wagga Wagga is in the southern part of New South Wales and is 183 m above mean sea level. The climate is mild and generally warm and temperate. Wagga Wagga has an annual mean rainfall of 572 mm and median rainfall of 575 mm, distributed relatively equally over the entire year. Maximum temperatures in summer are warm averaging between 29 °C and 32 °C. Relative humidity, however, remains low in the summer months, with a 3 pm average of about 30%. The winters are cool to cold, with overnight minimums averaging 3°C and daily maximums climbing to only 12 °C to 14°C on average. Relative humidity is much higher in winter, with a 3 pm average of over 60% and a 9 pm average just below 90%. Frost and fog are a feature of Wagga Wagga in winter. Snow has been recorded in the area but is a very rare occurrence. The major climatic information of Wagga Wagga is illustrated in Figure 1. →

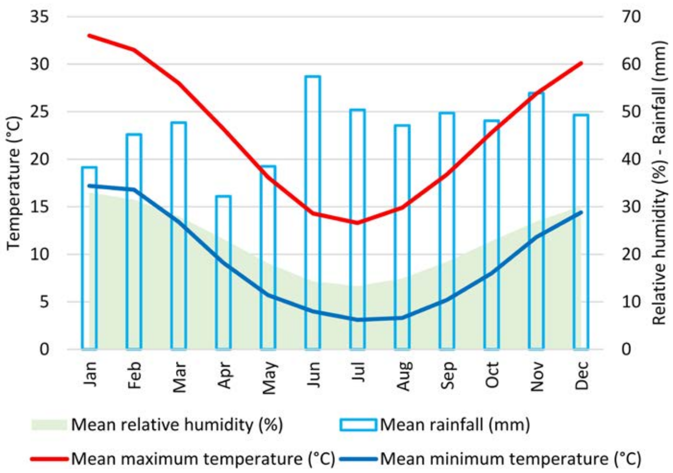

Figure 1. Climatic data of Wagga Wagga.

4.1.2. Building description

The building was constructed in 1959 (Figure 2) and is in Class 6 (office building used for professional or commercial purposes) following the classification of the Building Code of Australia [2].

Currently, three tenants occupy two levels of the building. NSW Fire and Rescue (Northern side) and NSW Education Standards Authority (Southern part) have leased level 1. Also, the NSW Department of Public Prosecutions occupies level 4. Figure 3 illustrates the treemap chart of the gross internal area of the case study building. The total gross floor area is 2717 m², and the net lettable area is 2178 m².

4.1.3. NABERS rating

The building was certified 3.5 star by NABERS Energy in October 2021. Based on the NABERS database, this building energy performance is categorised between 'Average' and 'Good'. Rooftop photovoltaic panels provide 6% of the site energy needs, and the building annual greenhouse gas emissions are equal to 170,258 kg CO_2 (183.9 kg CO_2/m^2). Also, the NABERS Water rating of this building is 3.5 [3].

The building was retrofitted recently, with the replacement of the old HVAC&R systems with newer and more efficient ones. Here, the simulations are performed considering the new system with improved performance. →

Figure 2. South-western view of 43-45 Johnston Street.

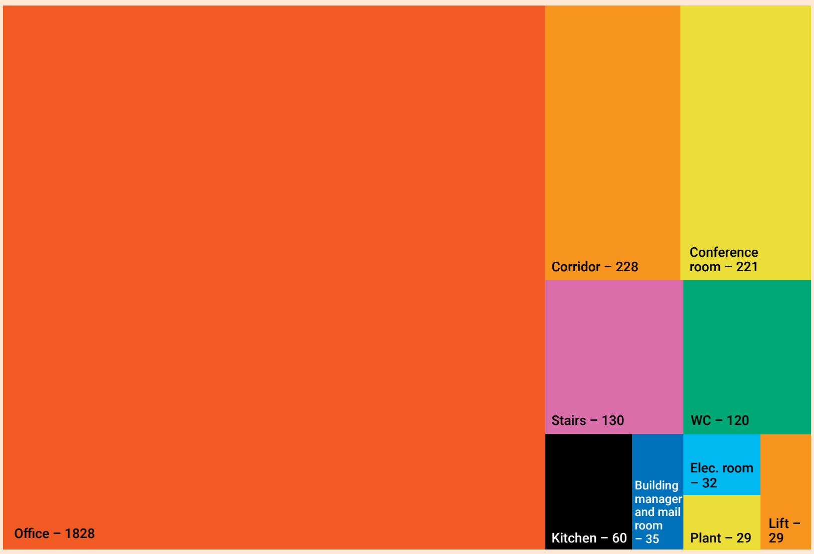

Figure 3. Gross floor divided area of case study building.

4.1.4. Energy consumption and sources

The best way to decrease the operational cost of buildings is to improve energy efficiency and shift from fossil fuel to renewable resources. The case study office building uses energy as follows:

- Heating, cooling, and air ventilation are provided using reverse cycle air-cooled DAIKIN systems (4 air handling units) connected to the outdoor units and 1 DAIKIN ONE TO ONE air conditioning unit. They consume electricity to perform, and their efficiency in providing heating and cooling is demonstrated using COP and EER, respectively.
- Electricity is also used for lighting, appliances, etc.

The building is divided into 5 vertical zones for HVAC&R purposes. 4 air-cooled reverse cycle 'DAIKIN VRV' AHU units supply the first 4 zones, and an air-cooled reverse cycle 'DAIKIN ONE TO ONE' AC unit supplies zone 5. Table 1 shows all the HVAC&R systems and zones which are serviced by them.

Table 1. HVAC&R systems and supplied zones.

Supplied zone	Outdoor DAIKIN model	Level 1	Level 2	Level 3	Level 4	COP	EER
Zone 1	RXYQ44AYMA	•	•	•	•	3.84	3.25
Zone 2	RXYQ44AYMA	•	•	•	•	3.83	3.11
Zone 3	RXYQ44AYMA	•	•	•	•	3.86	3.28
Zone 4	RXYQ44AYMA	•	•	•	•	4.04	3.62
Zone 5	FDYQN200/RZQ200		•			3.20	3.11

Table 2. Occupied zones.

Level 1	Zone 1	Level 4	Zone 1
	Zone 2		Zone 2
	Zone 3		Zone 3
	Zone 4		Zone 4

Table 3. Building area information.

	Level 1	Level 2	Level 3	Level 4	Total
Gross floor area (m²)	631.9	772.1	656.8	656.4	2717.2
Base Building Facilities (m²)	123.8	109.1	105.5	110.3	1448.6
Circulation Space (m²)	47.0	-	-	8.9	55.9
Floor space - Not Lettable (m²)	34.7	-	-	-	34.7
Lettable area (m²)	**426.4**	**663.0**	**551.4**	**537.2**	**2178**

4.2. Building modelling input parameters

The modelling parameters are a combination of collected data from the building inspection, utility bills and Australian and international standards (when no Australian Standard covers a specific topic). In this section, each modelling assumption is briefly explained, and relative references are presented.

4.2.1. Occupancy

Based on the provided data by DPIE (Department of Planning, Industry and Environment), the total occupancy can be considered as 40 people. Therefore, 5 people were considered in each occupant zone (Table 2).

4.2.2. Geometric data

Each level height is 3.5 m, and the ceiling height is 2.8 m, with a total lettable area of 2178 m² (Table 3). →

4.2.3. Building Components

A significant fraction of heat flows 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 office building, we assessed the thermal properties of the building envelope based on age and construction. This information is used to model the building and develop a thermal model. In this section, the performance descriptors of external walls, roof and windows are introduced.

4.2.3.1. External walls

The external wall is a double brick cavity wall with R-value equal to 0.63 m².K/W.

Table 4. Building Components - Performance Descriptors – Construction – External Walls.

Material	Thickness (mm)	Thermal Conductivity (W/m.K)	Thermal Capacity (kJ/kg.K)	Density (kg/m^3)	Thermal Resistance (m^2.K/W)	Ref.	Section and page
Brick	110	0.78	0.8	1950	0.14	[4]	Section J, page 389
Air space	50	-	-	-	0.18	[5]	Section 5.3, page 5
Brick	110	0.78	0.8	1950	0.14	[4]	Section J, page 389

R-value: 0.63 m².K/W

4.2.3.2. Roof

The roof has metal sheeting as the top layer, with waterproofing and air gap in the middle, and medium density concrete inside, delivering an R-value of 0.54 m².K/W. →

Table 5. Building Components - Performance Descriptors – Construction – Roof.

Material	Thickness (mm)	Thermal Conductivity (W/m.K)	Thermal Capacity (kJ/kg.K)	Density (kg/m^3)	Thermal Resistance (m^2.K/W)	Ref.	Section and page
Medium density Concrete	150	1.15	1000	1800	0.13	[6]	Section 8.3, page 9
Air space	50	-	-	-	0.22	[5]	Section 5.3, page 5
Water proofing	4	0.23	1000	1100	0.02	[6]	Section 8.3, page 9
Metal sheeting	1	50	450	7500	0.00	[6]	Section 8.3, page 9

R-value: 0.54 m².K/W

4.2.3.3. Windows

External windows in the case study office building are single glazed with an aluminium frame (Table 6).

Table 6. 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	4.3	W (m²/K)	[7]	Page 4
Glazing solar heat gain coefficient	0.63	N/A		
Window frame material	Aluminium	N/A		
Window frame ratio or width	15	%		
Glazing layout - WWR	40	%		
Glazing type	Single glazed	N/A		

4.2.4. Internal heat gains

The information regarding the thermal comfort and artificial lighting in the case study office building is provided by the building manager through the Department of Planning, Industry and Environment. Equipment and personal heat production loads assumptions in the model are based on Australian and international standards. ➔

Table 7. Internal heat gains.

	Value	Unit	Ref.	Section and page
Activities in the building	Office jobs -Mostly Sedentary	-	DPE	
Cooling setpoint temperature	24	°C	DPE	
Heating setpoint temperature	21	°C	DPE	
Equipment load	11	W/m²	[4]	Section J, page 355.
Ratio of equipment convection heat	90	%	[8]	Chapter 18, page 18.12
Elevator (occupied period)	3.71	kW	[9]	Page 5
Artificial lighting	6.4	W/m²	DPIE	
Ratio of lighting heat (convection + conduction)	42	%	[10]	Page 1
Personal latent gain	55	W	[8]	Chapter 18, page 18.4
Personal sensible gain	75	W	[8]	Chapter 18, page 18.4
Ratio of convection sensible heat	58	%	[8]	Chapter 18, page 18.4

4.2.5. Ventilation and infiltration

The building's HVAC&R systems have been upgraded recently. Therefore, fresh air supplied to each zone is based on AS1668.2 [10]. Also, depending on the activity of the air conditioning system, the infiltration rates vary.

4.2.6. Thermal comfort

The thermal comfort parameters are offered in Table 9. The thermal comfort metric used in this assessment is the PMV, in compliance with the National Construction Code.

4.2.7 Energy resources

The total energy demand of this building is provided by electricity. Based on the latest NABERS rating certificate for the case study building, 6% of the delivered energy is generated by 11 kWp rooftop PV (Figure 4) [3].

4.2.8 Schedules

The schedules of occupancy, lighting and appliances are selected based on those provided in the National Construction Code [4].

Table 8. Ventilation and infiltration.

	Schedule	Zone	Value	Unit	Ref.	Section and page
Fresh air	Occupied period	Ventilated zones	10	L/s.person	[11]	Appendix A, page 64
Infiltration	Occupied period	Ventilated zones	0.5	ACH	[12]	Section 2.6, page 385
	Unoccupied period	Ventilated zones	1	ACH	[12]	Section 2.6, page 385
	All hours	Non-ventilated zones	1	ACH	[12]	Section 2.6, page 385

Table 9. Thermal comfort parameters.

Factor	Value	Unit	Ref.	Section and page
Clothing Factor	Summer 0.6 – Winter 1	clo	[13]	Section 5, page 8
Metabolic rate	1.2	Met	[13]	Section 5, page 11
Relative air velocity	0.1	m/s	[13]	Section 5, page 11

Figure 4. Installed solar photovoltaic panels.

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 software 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 5).

5.2. TRNSys

TRNSys software is used to simulate the behaviour of transient systems. TRNSYS has an extensive library of components, which can help to model the performance of all parts of the system.

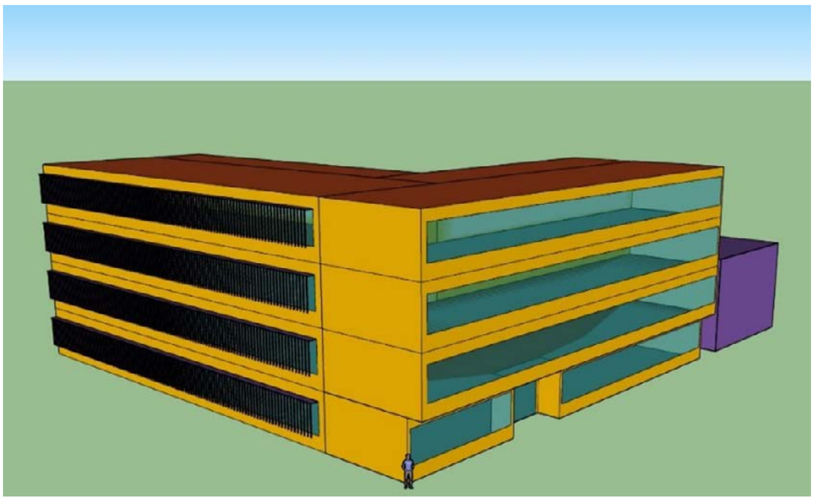

Figure 5. SketchUp model

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. [14].

After importing the building model into TRNSys, all building structural parameters (walls, windows, doors, etc.), schedules (occupancy, lighting, and appliances), internal loads, and HVAC&R systems (setpoint, ventilation, infiltration, and comfort) were defined in TRNBuild. By adding the proper climatic data (temperature, relative humidity, radiation, etc.) using the EnergyPlus weather database [15] the building 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&R systems, etc. Considering the building's features, all calculations are based on the 'as-built' condition of the building elements (R-values, shading, air-permeability etc.), HVAC&R systems (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, existence of water surfaces, 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 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 must 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 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.

The retrofitting options are explained separately, and then their combined impact will be investigated.

5.3.1. Lighting retrofit

Proposing strategies for improving lighting conditions or reducing energy use requires a detailed analysis of the existing natural and artificial lighting conditions. The assistance of the building management was crucial in acquiring the necessary information on the quality and quantity of the light sources in the used spaces and photographs showing the distribution of the lighting fixtures and the interior shading elements.

Using the provided data, the first and 4th levels of the building were modelled and simulated with the lighting software Relux. Relux is a software that performs accurate artificial lighting simulations using manufacturers' data. It also performs natural lighting simulations and provides the basic indices for assessing the natural lighting availability in interior spaces. The simulation results were then compared to the requirements and recommendations of the Australian NCC and lighting Standards. Based on this comparison, areas with poor lighting conditions or installed power exceeding the required were identified.

As described in the following table, three scenarios are considered. The base-case scenario represents the status quo. The retrofit scenarios are investigated based on the findings of the assessment. In the lighting retrofit scenario 1, the existing artificial lighting level is provided with more efficient luminaires. In the lighting retrofit scenario 2, the recommended lighting levels by NCC Australia are provided with efficient lights. →

Table 10. Scenario for reduced energy consumption for lighting

Base-case scenario	Light sources were selected and distributed in the spaces according to information provided by the building management.
Scenario 1	Achieve the existing artificial lighting levels with more efficient lighting sources
Scenario 2	Achieve the artificial lighting levels recommended by the Standards with more efficient lighting sources

The results are analysed in two parts: 1. the assessment of the existing natural conditions and the artificial lighting conditions and energy consumption for lighting, and 2. The proposed retrofit scenario aims at improving the lighting conditions and minimising the energy consumption for lighting.

5.3.1.1. Assessment of the existing lighting conditions and energy consumption for lighting

Natural lighting: The building has large openings in the south, east, and west facades. The glazed area of the windows is approximately 10% of the gross area of each level, which is compliant with the requirements set in the NCC (NCC, Part F4.2). Most of the continuously occupied spaces of both the levels studied receive high levels of natural lighting, which should be adequate for the office tasks carried out. However, the photographs provided show that the users prefer the interior shading elements covering the windows, even though exterior shading is present on the first-floor openings and the west openings of Level 4 while the artificial lighting is on. It is assumed that the first level users prefer to have the interior shading on for privacy, while the rest of the users probably need to avoid glare.

Even though large openings ensure ample natural light, their performance in shared spaces is often eliminated by the users to exclude the unwanted properties and establish comfortable visual conditions for the most sensitive users. While the latter consideration might or might not apply to the specific case study, it is taken into account as a general approach. Thus, further increase or decrease of the natural lighting levels is not advisable.

Artificial lighting: The artificial lighting equipment, i.e., the number of lighting fixtures for each space, the type and wattage of each fixture, was provided by the building management. The artificial lighting conditions in the occupied floors were simulated using similar lights that actually installed, to assess the resulting lighting levels. It was found that most of the offices located on the first floor were underlit, with artificial lighting levels below the recommended values for office spaces in Australia. On the contrary, there were many spaces on the 4th level with artificial lighting levels much above the recommended. The simulated Illuminance values, the total artificial lighting load and the recommended lighting levels are presented in Attachment 2.

5.3.1.2. Calculation of the illumination power density and energy

The aim of the next step of the study is to develop a scenario that would enable reduced energy consumption for lighting. Even though no information about special lighting requirements, such as the need for lighting levels higher than the recommended, was provided, lighting retrofit scenario 1 was defined to significantly reduce installed power and energy consumption without changing the existing lighting levels. On the other hand, the retrofit scenario was designed to achieve minimum energy consumption and provide the recommended lighting levels (lx), uniformity and maximum illumination power density (W/m^2). As a result, the illumination power density was decreased in many spaces but needed to be increased elsewhere.

The lighting retrofit scenario 1 is valuable to show by only changing the luminaires, a great amount of electricity can be saved. However, the lighting is insufficient in some parts of the building. On the other hand, the proposed retrofit scenario resulted in a reduction of the total lighting load (kW) and the annual energy (kWh) ranging from 37.50-55.33%, while providing sufficient lighting in all spaces in the building. Therefore, the retrofit scenario will be investigated further with other building retrofitting options in section 6.2. ➔

Table 11. Total load for artificial lighting and the annual energy for the base case and the proposed scenarios.

		Base-case scenario	Scenario 1		Scenario 2	
		Electricity consumption	Electricity consumption	Reduction compared to base case (%)	Electricity consumption	Reduction compared to base case (%)
Level 1	Total Load (kW)	2.48	1.30	47.6	1.55	37.5
	Annual Energy (kWh)	6,438	3,383		4,023	
Level 4	Total Load (kW)	4.88	2.60	46.7	2.18	55.3
	Annual Energy (kWh)	12,698	6,757		5,671	

5.3.2. Windows retrofit

The current windows installed in the Wagga Wagga office building are single glazed with aluminium frames and cause high 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 for the Wagga Wagga office building has an aluminium framed, with thermal break, double glazed, with Low-E external glass pane. Therefore, the average U-value and SHGC will be 2.58 W/m²K, and 0.42, respectively. In this case, the airtightness will improve (Class 3 with less than 9 m³/h.m² at 100 Pa), and the infiltration rate of the building can be reduced to 0.30 ACH.

5.3.3. Auto night ventilation, heat recovery and ceiling fans

Intensive ventilation through windows during the night is a cost-saving and energy-efficient method of cooling buildings in summer. It uses the natural pressure differences between at least two openings (e.g., windows, doors) of a building to the outside for air exchange. Such a pressure gradient already exists in weak winds. To enable automated night natural ventilation, the windows replaced with the retrofit would need to be either motorised and equipped with sensors or integrate a window ventilator (which is commercially available).

Also, ceiling fans are a simple and cost-effective method to enhance the indoor air quality in summer and receive points in energy rating stars. They supply 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 auto night ventilation between 20:00 and 7:30 with the same airflow as during office hours and is activated only when the difference between indoor and outdoor temperature is greater than 4°C. The efficiency of the heat recovery ventilation is 80%. Also, ceiling fans are modelled by increasing the cooling setpoint temperature to 27°C.

5.3.4. Inverted roof insulation

An inverted roof is a type of roof construction where the waterproofing layer lies beneath the insulation instead of above it. Inverted roofs can keep complete roof construction (including roof covering) warm during the winter months and at moderate temperatures during the summer months.

The proposed inverted roof solution consists of extruded polystyrene boards (thickness of 80 mm) covered by gravel (thickness 50 mm), leading to an R-value of 2.86 m²K/W, which is less than the Deemed to Satisfy Provisions given in the NCC but still allows some heat dissipation during the cooling season, thus pursuing a performance solution.

6. Results

The simulation result is based on the modelled building. A brief comparison with the provided energy bills for 2020 is presented in Attachment 3. After the results for the base building and retrofit scenarios, a comparison between existing weather databases is presented, future prediction weather models will be discussed, and the impact of retrofitting scenarios will be investigated.

6.1. Base building modelling

The energy demand for heating and cooling (sensible and latent) is illustrated in Figure 6, while the monthly energy balance is presented in Figure 7. →

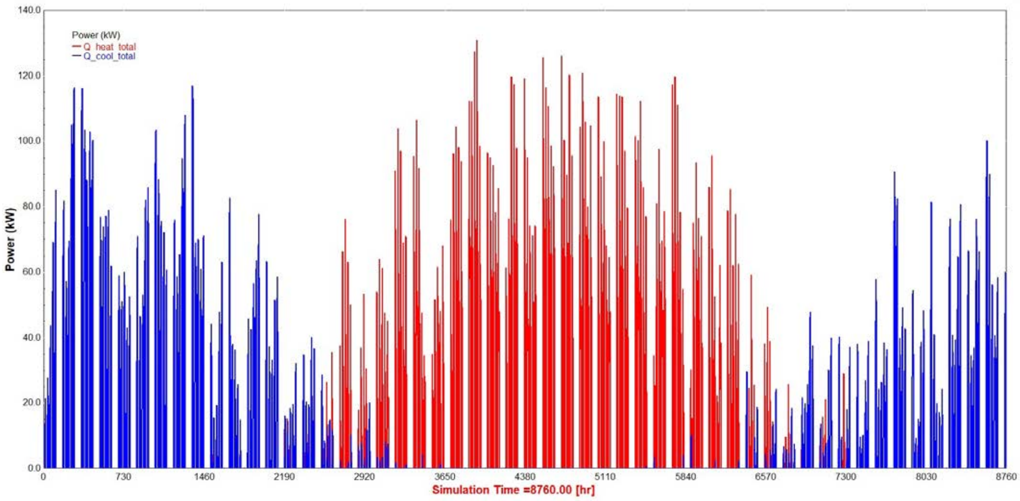

Figure 6. Hourly energy demand for HVAC&R purposes.

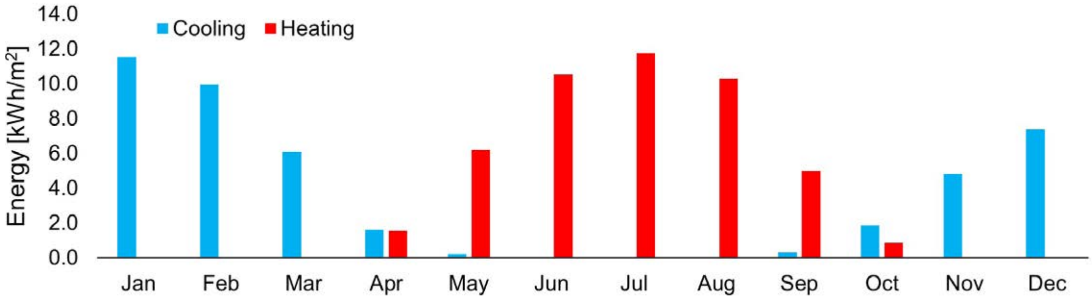

Figure 7. Monthly energy demand for HVAC&R purposes.

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 8 and Figure 10). Also, the amount of heating and cooling energy balance is illustrated in Figure 9 and Figure 11. →

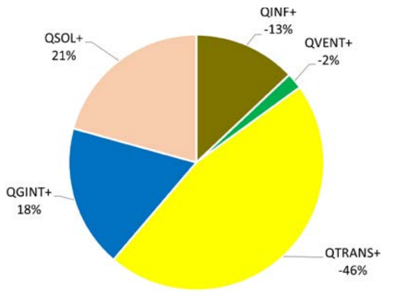

Figure 8. Whole building energy gain – heating season (May-September).

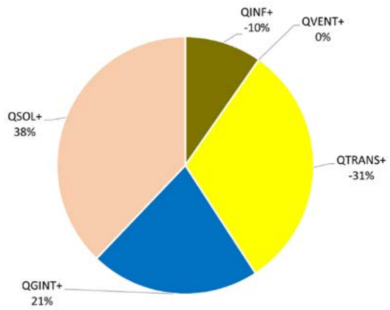

Figure 10. Whole building energy gain – cooling season (October-April).

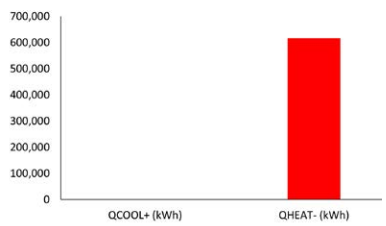

Figure 9. Whole building energy gain for heating and cooling load – heating season (May-September).

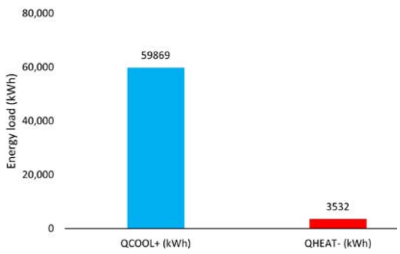

Figure 11. Whole building energy gain for heating and cooling load – cooling season (October-April).

The monthly energy balance of the building and the influence of each factor on the total energy balance is presented in Figure 12.

6.2. Retrofit scenarios and results

The investigated retrofit cases in this report are presented in Table 12.

Table 13 shows the influence of different retrofitting cases on heating and cooling loads energy. Also, Table 14 demonstrates the impact of different retrofit scenarios on electricity consumption in the case study building. The result indicates that by improving the building condition, 24.0% of the needed electricity can be reduced. A more detailed illustration of the retrofitting impact is presented in Figures 13-15. Using NABERS Energy reversed calculator, if the building is fully retrofitted, the NABERS star rating can increase to 4.5 stars [16]. →

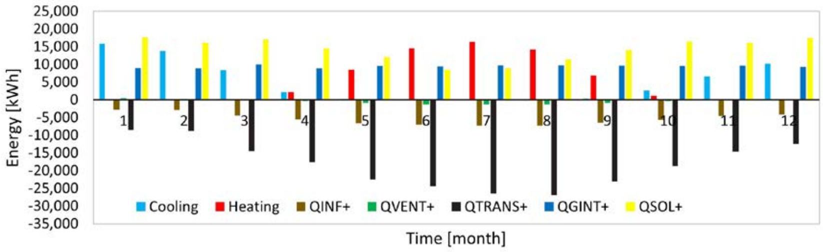

Figure 12. Monthly building energy balance.

Table 12. Retrofit cases.

Scenario	Retrofit
Baseline	ASHRAE temperature setpoints (heating setpoint 21°C, cooling setpoint 24°C) + base case lighting. No setback temperature during building vacancy based on NCC Vol.1 [4]
Case A	Baseline + lighting retrofit scenario 2.
Case B	Case A + windows retrofit.
Case C	Case B + auto night ventilation + heat recovery + ceiling fans.
Case D	Case C + inverted roof insulation.

Table 13. Simulation results – heating and cooling loads.

	Heating loads	Cooling loads	Heating + Cooling	Heating loads	Cooling loads	Heating + Cooling
	kWh/(m²a)			difference (%)		
Baseline	38.4	66.6	105.0	-	-	-
Case A (Baseline+ lighting improvement)	40.6	63.9	104.5	5.6%	-4.0%	-0.5%
Case B (Case A + windows retrofit)	32.3	55.1	87.4	-16.0%	-17.3%	-16.8%
Case C (Case B + auto night ventilation + heat recovery + ceiling fans)	29.1	33.9	63.1	-24.2%	-49.1%	-40.0%
Case D (Case C + inverted roof insulation)	19.2	40.0	59.2	-50.1%	-40.0%	-43.7%

Table 14. Simulation results - Site energy (electricity).

	Heating	Cooling	Lighting	Appliances	Total	Total difference
	kWh/(m²a)					%
Baseline	9.2	18.6	20.0	43.1	90.9	-
Case A (Baseline+ lighting improvement)	9.7	17.9	10.3	43.1	81.0	-10.9%
Case B (Case A + windows retrofit)	7.7	15.4	10.3	43.1	76.5	-15.8%
Case C (Case B + auto night ventilation + heat recovery + ceiling fans)	7.00	9.5	10.3	43.1	69.9	-23.1%
Case D (Case C + inverted roof insulation)	4.6	11.2	10.3	43.1	69.1	-24.0%

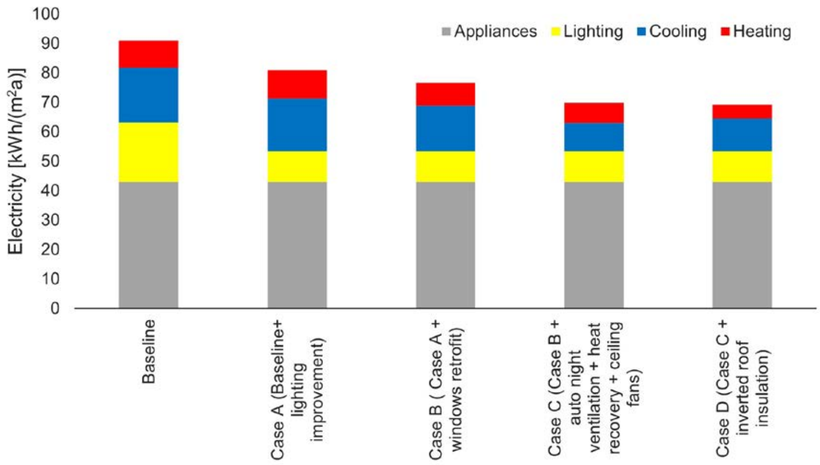

Figure 13. Site energy of the retrofit scenarios.

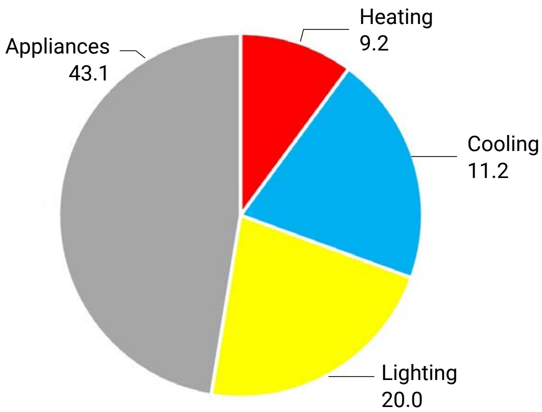

Figure 14. Share of Site energy for the baseline – before retrofit (kWh/m²a).

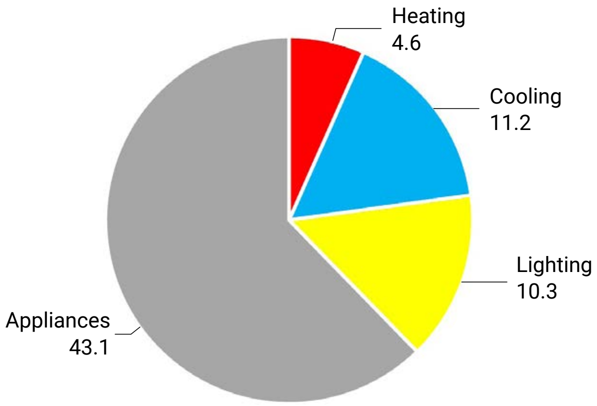

Figure 15. Share of Site energy for retrofit scenario – case D (kWh/m²a).

6.3. Interventions proposed

Depending on the building typology, function and condition, there is a plethora of possible interventions which can be considered. Choosing the suitable ones is a challenging problem since they must be technically applicable, efficient, and cost-effective.

Considering the specific buildings, the following points must be underlined:

- The simulations proved that the natural lighting levels in the studied floors are high and the glazed areas are appropriately shaded. The artificial lighting analysis showed that some of the office spaces are lit to lower and some to higher lighting levels, compared to the recommended. The retrofitting scenario showed that by using the LED lighting fixtures and adjusting the lighting levels to match the recommended, a reduction of energy consumption between 37.5 and 55.3% can be achieved.
- The building envelope's opaque elements are not insulated but have a very limited impact on the building's energy consumption. One exception is the roof, which could be retrofitted with insulation to reduce heating and cooling loads and to improve thermal comfort conditions.
- The building suffers from very high air-permeability (infiltration) due to the poor airtightness of the openings. Replacing the windows with state-of-the-art ones with improved glazing and low air-permeability is a high priority. This will enable controlled ventilation, and hence reduced heating and cooling energy consumption, improved thermal comfort conditions and, it will enable the implementation of more effective setpoint temperatures and ventilation schemes.
- The building's HVAC&R systems are new and efficient. No interventions on the hardware are necessary. However, the system could benefit from a more efficient set of operational temperatures both during office hours and off-hours.
- The use of ceiling fans can contribute significantly to the reduction of energy consumption for cooling, enabling higher setpoint temperatures whilst retaining good levels of thermal comfort.
- The use of controls for artificial lighting is also highly recommended: occupancy and illuminance sensors can significantly contribute to reducing consumption whilst maintaining and, in some cases, improving visual comfort.
- In the medium-term, consideration should be given to upgrading office equipment to more energy-efficient models. This will be beneficial not only for reducing the plug loads but also for further reducing cooling loads. ➔

6.4. Weather database investigation

The climatic data provided by TRNSys is limited (only 33 cities in Australia). To compare the external weather databases (CSIRO and EnergyPlus), modelled the building was simulated in three cities representing different climatic conditions in Australia. Table 15 compares the heating and cooling load in 3 different cities and two weather databases. Also, Figure 16 illustrates the result of site energy demand in different sectors.

The comparison shows an acceptable difference between weather databases. The CSIRO database is selected for further modelling based on the following reasons:

- Public availability and ease of access
- Recently released
- Developed multiple future weather prediction models

➔

Table 15. Weather database comparison in different climates.

#	Location	Source	Load (kWh/m².a)		Site Energy (kWh/m².a)				
			Heating	Cooling	Heating	Cooling	Lighting	Appliances	Total
1	Sydney	E+	12.4	44.7	3.2	13.7	23.7	43.1	83.7
2	Darwin	E+	0	153.1	0	46.7	23.7	43.1	113.6
3	Melbourne	E+	44.8	17.8	11.5	4.5	23.7	43.1	83.8
4	Sydney	CSIRO	13.2	54.7	3.4	16.8	23.7	43.1	87.0
5	Darwin	CSIRO	0	183.3	0	56.0	23.7	43.1	122.8
6	Melbourne	CSIRO	29.0	32.3	7.5	9.9	23.7	43.1	84.2

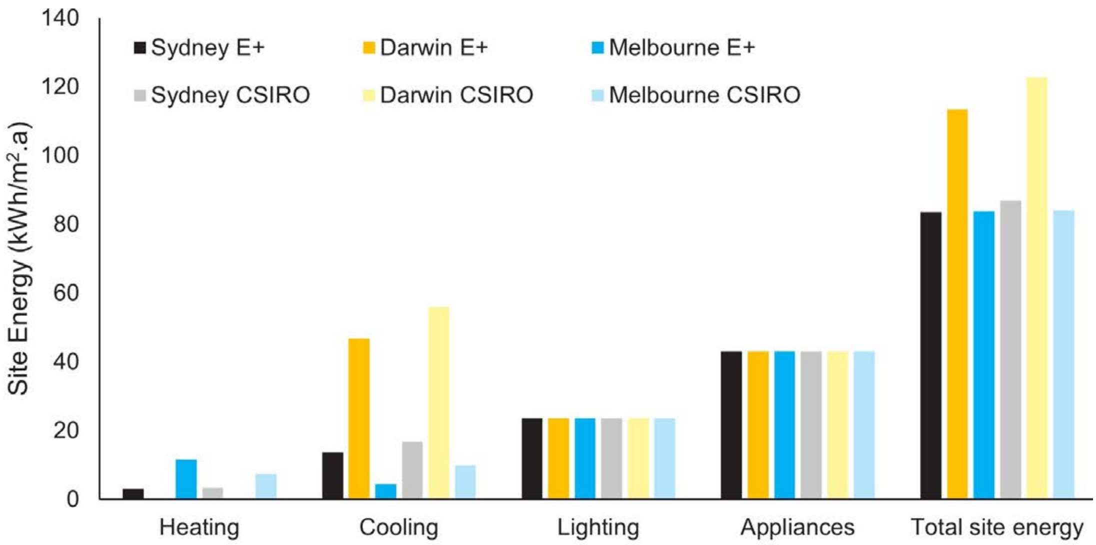

Figure 16. Site energy demand in different cities.

6.5. Future climate simulation

In this section, the modelled building is simulated with future weather data developed by CSIRO with climate change prediction models. 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 demonstrates the result of modelling the case study building with future CSIRO weather prediction models. The result indicates that in all RCP models, the cooling site energy will rise between 6.0%-23.5% by 2030. →

Table 16. Future CSIRO weather prediction model results.

Location	Period	Heating site energy (kWh/m²)	Cooling site energy (kWh/m²)	Lighting site energy (kWh/m²)	Appliances site energy (kWh/m²)	Total site electricity demand (kWh/m²)	Increase in total cooling site energy (%)	Increase in total heating site energy (%)	Increase in total electricity site energy (%)
Adelaide	Present	5.4	15.2	20.0	43.1	83.7	-	-	-
	2030	4.4	17.6	20.0	43.1	85.1	15.8	-18.5	1.7
Brisbane	Present	1.2	26.5	20.0	43.1	90.8	-	-	-
	2030	0.8	29.2	20.0	43.1	93.1	10.2	-33.3	2.5
Canberra	Present	9.5	18.8	20.0	43.1	91.4	-	-	-
	2030	7.9	21.3	20.0	43.1	92.4	13.3	1.1	-16.8
Darwin	Present	0.0	55.2	20.0	43.1	118.3	-	-	-
	2030	0.0	58.5	20.0	43.1	121.6	6.0	0.0	2.8
Melbourne	Present	9.7	8.1	20.0	43.1	80.9	-	-	-
	2030	8.2	10.0	20.0	43.1	81.3	23.5	-15.5	0.5
Perth	Present	3.7	21.5	20.0	43.1	88.3	-	-	-
	2030	2.8	24.4	20.0	43.1	90.3	13.5	-24.3	2.3
Sydney	Present	2.8	17.5	20.0	43.1	83.4	-	-	-
	2030	2.1	19.6	20.0	43.1	84.8	12.0	-25.0	1.7
Hobart	Present	12.4	4.5	20.0	43.1	80.0	-	-	-
	2030	11.2	5.5	20.0	43.1	79.8	22.2	-9.7	-0.3

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

Location	Period	Space heating (kWh/m²)	Space cooling (kWh/m²)	Lighting site energy (kWh/m²)	Appliances site energy (kWh/m²)	Total site electricity demand (kWh/m²)	Increase in total cooling site energy (%)	Increase in total heating site energy (%)	Increase in total electricity site energy (%)
Canberra Base case	Present	9.5	18.8	20.0	43.1	91.4	-	-	-
	2030	7.9	21.3	20.0	43.1	92.4	13.3	1.1	-16.8
Canberra retrofitted	Present	4.7	11.3	10.3	43.1	69.4	-	-	-
	2030	3.8	12.9	10.3	43.1	70.1	14.2	1.0	-19.1

6.6. Concluding remarks

Here, the energy performance of an office building built in Wagga Wagga at the end of the 1950s was investigated. The building currently has performance equivalent to 3.5-star NABERS for energy (internal assessment); thus, there is a considerable margin for improvement. With the replacement of new high-efficiency HVAC&R systems, the building has already reduced its energy consumption. A series of retrofit options have been considered: use of efficient lighting, windows retrofit, auto night ventilation with heat recovery and ceiling fans, and then insulation of the inverted roof. Being an office building, its energy profile is cooling-dominated, meaning that it needs more energy for cooling than for heating, already with the current climate profile.

The use of efficient lighting directly reduces the electricity need, and it reduces the heat released by the lighting fittings into the indoor environment, thus reducing the cooling load. Then, the night ventilation allows for heat dissipation during the night by exploiting the thermal mass in the building and reducing the number of hours required for cooling. Then, the improvement of the roof insulation offers further savings.

The total savings account for 21.8 kWh/m² per annum or 24% of electricity consumption. The replacement can deliver further savings of appliances – which represent 62% of the site energy in the most comprehensive retrofitted scenario – with more efficient ones, thus reducing the plug loads. This is not considered in this study as it is not part of the building but of its use. Therefore, the on-site renewable energy production with rooftop PV can cover a larger fraction of the building's electricity consumption since the energy needs would be greatly reduced.

In future climates, the building electricity consumption for heating will be further reduced, becoming almost negligible, with an increasing cooling energy need, which then becomes the priority.

Using NABERS Energy reversed calculator, if the building is fully retrofitted, the NABERS star rating can increase from 3.75 to 4.25 stars [16].

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Attachment 1: Site photos

Fig. A1. Exterior Facade – South-East

Fig. A2. Exterior Facade — South-West

Fig. A3. Exterior Facade – West

Fig. A4. Main Entrance - South

Fig. A5. Side Entrance — East.

Fig. A6. Parking entrance

Fig. A7. Side Entrance – Parking space

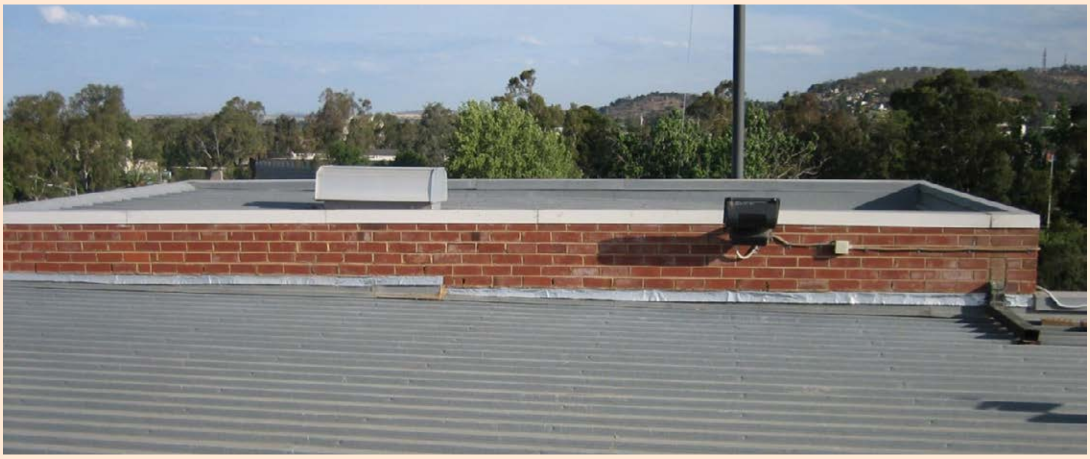

Fig. A8. Rooftop view

Attachment 2

The following tables include analytic results of the simulated and recommended lighting levels, lighting uniformity and Illumination power density.

Notes

- The Illumination power density (W/m²) for the storerooms and the toilets has been set equal to the recommended by the NCC values.
- The range of the recommended Illumination power density (W/m²) is according to the NCC provision J6.2 Artificial lighting.
- The number of the scenarios for each space depend on its use and characteristics, e.g., availability of natural lighting, width of space, etc.
- The proposed scenarios do not include the recommended Illuminance levels (lx) for the corridors and the entrance of the building, as these spaces are adaptation spaces (spaces between the bright exterior or interior spaces with high natural lighting levels and darker interior spaces, or spaces without openings linking two bright spaces). →

Level	Occupant	Space	Scenario	Total circuit	Illuminance (lx)	Uniformity	Illumination power density (W/m^2)	Recommended Uniformity (AS 1680.1 2006)	Required maximum Illumination power density (W/m^2) (NCC)	Total
1st floor	Fire	Storeroom north	Base case	176	240	0.20	4.67	80	-	1.5
			1	57	-	-	1.5			
		Office (East enclosed space)	Base case	176	156	0.5	2.8	320	0.5	4.5-6.6
			1	77	153	0.33	1.2			
			2	176	293	0.52	2.8			
			3	148.5	-	-	-			
		Office – 1.04	Base case	704	439	0.55	8.76	320	0.5	4.5-6.1
			1	480	455	0.50	5.97			
			2	297	405	0.62	3.70			
			3	247.5	-	-	-			
		Corridor	Base case	120	180	0.62	6.5	40	0.3	5
			1	55	160	0.59	3			
		Office – 1.03	Base case	176	141	0.06	2.4	320	0.5	4.5-6.3
			1	132	204	0.05	1.8			
			2	231	316	0.4	3.15			
			3	193	-	-	-			
		Office – 1.05	Base case	176	258	0.41	5.25	320	0.5	4.5-6.9
			1	88	281	0.49	2.63			
			2	110	359	0.48	3.28			
	Common	Entrance Area	Base case	308	229	0.36	6.8	160	0.3	9
			1	132	250	0.43	2.9			
	NSW Education	Open office	Base case	396	136	0.04	2.8	320	0.5	4.5-5.5
			1	187	138	0.3	1.31			
			2	473	333	0.42	3.31			
			3	385	-	-	-			
	Common	Toilets – Men's & Women's	Base case	200	-	-	5	80	-	3
			1	117	-	-	2.9			
4th floor	DPP	South Office – Office S1	Base case	396	450	0.68	10.95	320	0.5	4.5-6.7
			1	220	515	0.65	5.35			
			2	176	401	0.66	4.3			
		South Office – Office S2	Base case	176	440	0.56	11.5	320	0.5	4.5-7.5
			1	88	482	0.66	5.75			
			2	66	373	0.6	4.3			
		South Office – Office S3	Base case	176	425	0.7	12	320	0.5	4.5-7.5
			1	66	389	0.61	4.5			
		South Office – Office S4	Base case	88	246	0.56	6	320	0.5	4.5-7.5
			1	44	269	0.64	3			
		Office 1	Base case	176	300	0.51	9.7	320	0.5	4.5-7.5
			1	88	326	0.5	4.9			
		Office 2	Base case	44	180	0.77	4.7	320	0.5	4.5-7.76
			1	22	189	0.76	2.3			
			2	44	342	0.74	4.7			
		Lunchroom	Base case	176	332	0.52	7.96	160	0.3	4.5-6.5
			1	99	378	0.6	4.5			
		Offices 3 & 7	Base case	88	309	0.73	9.1	320	0.5	4.5-7.76
			1	44	330	0.74	4.5			
		Offices 4-6	Base case	132	440	0.7	12.6	320	0.5	4.5-7.5
			1	66	447	0.74	6.3			
			2	44	310	0.74	4.2			
		Offices 8-13	Base case	132	420	0.7	12	320	0.5	4.5-7.5
			1	66	425	0.7	6			
			2	44	308	0.66	4			
		Office 14	Base case	88	340	0.76	10.1	320	0.5	4.5-7.8
			1	33	262	0.83	3.8			
			2	44	364	0.84	5			
		Central area 1	Base case	264	225	-	6.2	160-320 (unknown use)	0.3-0.5 (unknown use)	4.5-5 (unknown use)
			1	132	240	-	3.1			
		Central area 2	Base case	264	230	-	6.2			
			1	154	285	-	3.6			
		Central area 3	Base case	132	155	-	7.2	40	0.3	5
			1	88	230	-	4.8			

Details of the artificial lighting system of the first floor and simulated illuminance

Level	Occupant	Space	Qty	Luminaire	Total luminaires watts	Total circuit	Simulated Illuminance (lx)
1st floor	Fire	Storeroom North	4	1/36W RT MAG REF	44	176	240
		Office	4	1/36W RT MAG REF	44	176	156
		Office	16	1/36W RT mag	44	704	439
		Corridor	4	1/28W T5	30	120	180
		Office 1	4	1/36W RT mag	44	176	141
		Office 2	4	1/36W RT mag	44	176	258
	Common	Entrance Area	7	1/36W RT MAG REF	44	308	229
	NSW Education	Open office	9	1/36W RT MAG REF	44	396	136
		Men's Toilets	1	2/40 SM MAG	100	100	-
	Common	Women's Toilets	1	2/40 SM MAG	100	100	-

Details of the artificial lighting system of fourth floor and simulated illuminance

Level	Occupant	Space	Qty	Luminaire	Total luminaires watts	Total circuit	Simulated Illuminance (lx)
4th floor	DPP	South Office – Office S1	9	1/36W RT MAG REF	44	396	450
		South Office – Office S2	4	1/36W RT MAG REF	44	176	440
		South Office – Office S3	4	1/36W RT MAG REF	44	176	425
		South Office – Office S4	4	1/36W RT MAG REF	44	176	425
		South Office – Office S5	4	1/36W RT MAG REF	44	176	425
		South Office – Office S6	4	1/36W RT MAG REF	44	176	425
		South Office – Office S7	2	1/36W RT MAG REF	44	88	246
		Office 1	4	1/36W RT MAG REF	44	176	300
		Offices 2	1	1/36W RT MAG REF	44	44	180
		Lunchroom	4	1/36W RT MAG REF	44	176	332
		Office 3 & 7	2	1/36W RT MAG REF	44	88	309
		Office 4	3	1/36W RT MAG REF	44	132	440
		Office 5	3	1/36W RT MAG REF	44	132	440
		Office 6	3	1/36W RT MAG REF	44	132	440
		Office 8-13	3	1/36W RT MAG REF	44	132	420
		Office 14	2	1/36W RT MAG REF	44	88	340
		Central Area 1	6	1/36W RT MAG REF	44	264	225
		Central Area 2	6	1/36W RT MAG REF	44	264	230
		Central Area 3	3	1/36W RT MAG REF	44	132	155
		Toilet Men's	2	1/18 SM	22	44	-
		Toilet Men's	1	1/36W SM	44	44	-
		Toilet Women's	2	1/18 SM	22	44	-
		Toilet Women's	1	1/36W RT MAG REF	44	44	-

The properties of the LED lighting fixture used for the proposed scenarios

Product name: Jilly square Recessed luminaires

Mounting place: Ceiling

Mounting type: Recessed

LiTG class: A60

CIE flux codes: 86 100 100 100 100

Absolute Photometry

System power: 11 W

Luminaire output: 123.6 lm/W

System Light flux: 1360 lm

Protection class: Protection class II

Lamp type: 1 x LED

ZVEI / ILCOS:LED 8,4W Neutralweiß /LED

Lamp power: 8.4 W

Colour temperature: 4000

Colour rendering: 82

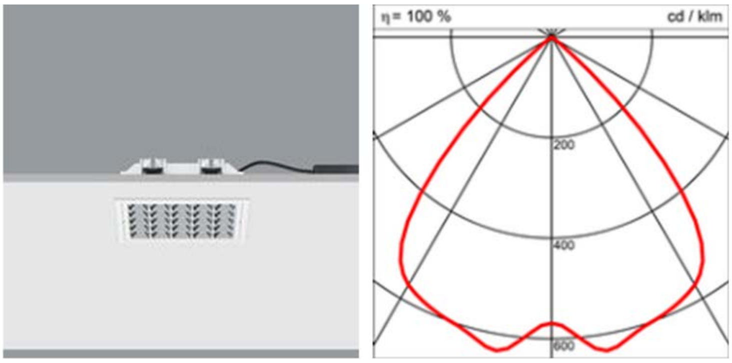

Fig. A9. Fixture position and light efficiency solid.

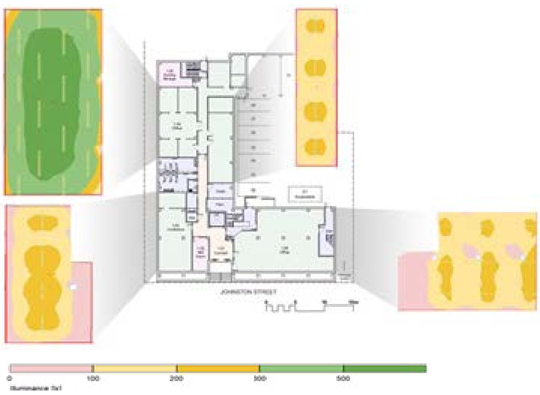

Fig. A10. Illuminance (lx) distributions in representative spaces of first floor

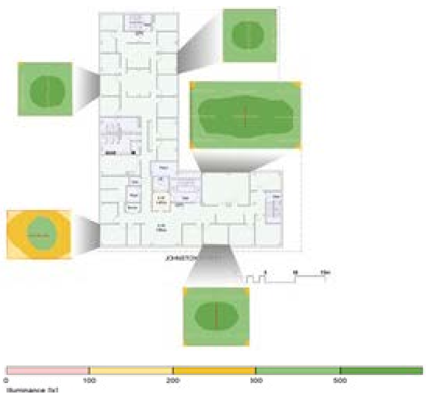

Fig. A11. Illuminance (lx) distributions in representative spaces of 4th floor

Attachment 3

While the verification of energy consumption in the case study office building is out of the scope of this report, a brief comparison between the actual electricity consumption in the case study office building (based on the monthly energy bills) and simulation result is provided in the below graph.

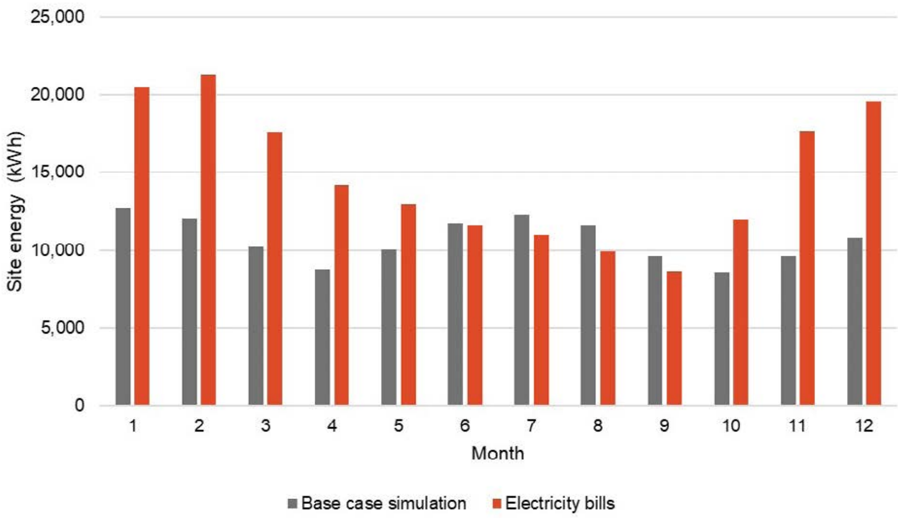

Fig. A12. Comparison between simulation and electricity bills.

The annual energy consumption result of the simulation is 19% less than the bills data. The reason behind this difference is the HVAC&R systems retrofit of the building in the past year.