Shopping Centre

Energy Efficiency Training and Information Project

Commercial Buildings

Underwood QLD

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

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Cover image: Officeworks store exterior

Contents

1. Executive Summary

A complete renovation package ... will lead to energy savings of 76.6%

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 buildings we already have.

According to Baker Consulting, 1,630 shopping centres in Australia exceed 1,000 square metres in gross lettable area [2]. In 2018, total retail sales made through Australian shopping centres were estimated to be $141 billion, equivalent to 7.4% of Australia's gross domestic product [2]. According to ICSC Research, the gross lettable area of Australian shopping centres (including homemaker, themed and factory outlet centres) is approximately 26.5 million square metres, about 46% of the total retail space in Australia [2]. This report tackles the operational energy consumption challenge for an existing shopping 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 s presented in this report.

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

This report summarises the findings of the performed analysis on the existing conditions. It provides recommendations for minimising the energy consumption in the Officeworks located at 183 Kingston Rd, Underwood, Qld 4119. The structural and energy performance features of the studied shopping centre are representative of the typology and construction period.

First, the optimisation of the artificial lighting system can lead to important energy savings. The addition of skylights or light pipes, combined with daylight linked controls, could decrease the lighting energy consumption by 90% compared to the base case scenario. The cost of such intervention is highly project-specific, and it should be assessed case by case, even for relatively similar buildings.

The baseline scenario for defining practical actions reveals that energy usage for cooling is the most significant, with a value of 92.8 kWh/m²a. Nonetheless, energy consumption for lighting and appliances remains critical.

As a result, the focus is mostly on reducing cooling requirements. The high solar absorbance of the roof, which has a significant impact on energy performance in such a low-rise building, is a focal target for reducing cooling loads. The HVAC&R system lags in efficiency. Replacing it with a state-of-the-art chiller will therefore have an impact on energy consumption. The building does not have a heating system installed. Based on these conclusions, the following interventions are recommended:

- Improvement of the energy efficiency of lighting systems.
- Coating of the roof using cool roof materials with low solar absorbance.
- Installation of ceiling fans and mechanical ventilation with heat recovery, and introduction of night ventilation patterns in the operation of the HVAC&R system, to reduce cooling loads.
- Installation of state-of-the-art Building Automation and Controls, together with a Building Management System, to interlock the use of HVAC&R and lighting systems with both the weather conditions and the operational requirements. →

- Installation of a more efficient air-cooled chiller or a ground source heat pump (GSHP) could drastically reduce final energy consumption for cooling due to its high efficiency.

In conclusion, a complete renovation package includes the installation of a cool roof solution, combined with an upgrading of the lighting system, the installation of ceiling fans and the use of night-time ventilation and mechanical ventilation with heat recovery, linked all with the implementation of a state-of-the-art BAC system, and eventually the use of a GSHP or, if this is not possible, of a more efficient air-cooled chiller. Such a package will lead to energy savings of 76.6%, resulting in an energy consumption of 41.2 kWh/m²a, compared to the baseline of 176.2 kWh/m²a. Moreover, such a building with a very big roof space would be ideal for the installation of rooftop PV.

The building cannot be rated NABERS for energy, as here only one portion of the shopping centre is considered.

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
- tANSI/ASHRAE 55-2020 Thermal environmental conditions for human occupancy
- ASHRAE Handbook Fundamentals 2017, Chapter 18: Nonresidential cooling and heating load calculation
- ISO 17772-1-2017 Energy performance of buildings -Indoor environmental quality, Part 1: Indoor environmental input parameters for the design and assessment of energy performance of buildings
- AS 1668.2-2012 The use of ventilation and air conditioning in buildings, Part 2: Mechanical ventilation in buildings
- AS/NZS 1680.1-2006: Interior and workplace lighting, Part 1- General principals and recommendations.
- AS/NZS 1680.2.1-2008: Interior and workplace lighting, Part 1- Specific applications. Circulation spaces and other general areas.
- AS/NZS 1680.2.2-2008: Interior and workplace lighting, Part 1- Specific applications. Office and screen-based tasks.

3. Introduction

The selected case study building is a typical shopping centre built in Australia, exemplar of many other shopping centres constructed in the same period. In fact, the aim of selecting Underwood Officeworks is the potential for methodology replication and findings expansion to other similar buildings.

One sample shopping centre cannot wholly represent all similar buildings. Each retail centre 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 shopping centre is a complicated task. It starts with determining the building's construction features, including the efficiency of the building envelope, lighting, HVAC&R equipment etc. Considering the building's features, all calculations were based on the 'as-built' condition of the building elements (U-values, shading, air-permeability, etc.). The efficiency of the HVAC&R system (Coefficient of Performance (COP) and Seasonal Energy Efficiency Rating (EER) were selected based on the provided information by their manufacturers, and installed lighting and plug loads were determined either by data provided by the building operators or following standards and regulations.

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

(a) the operational parameters (hours of operation, set temperatures for heating and cooling, natural ventilation patterns, use of artificial lighting, etc.) andt

(b) the microclimate on the building's site (shading by natural obstructions and other buildings, albedo and thermal storage of surrounding areas, etc.).

4. Officeworks shopping centre in Underwood

4.1. Case study description

4.1.1. Climate

The case study building is located at 183 Kingston Rd, Underwood, QLD 4119 (27.617S, 153.114E). The building is a part of the Zone Underwood complex (20 km south of Brisbane) and has an elevation of 28 meters above mean sea level. In Köppen's climate classification, Underwood is categorised as Cfa, meaning that the weather is warm, sometimes hot, in summer and cool during winter [3]. Rainfall is more dominant between December to March. The annual mean rainfall is 879 mm, and January has the highest rainfall (159.6 mm). Due to its geographical location, the relative humidity is distributed evenly throughout the year (60-71% in the morning and 40-60% in the afternoon). The hottest month is January, with a mean maximum temperature of 29.4°C, and the coldest month in Brisbane is July, with a mean minimum temperature of 9.5°C (Figure 1). →

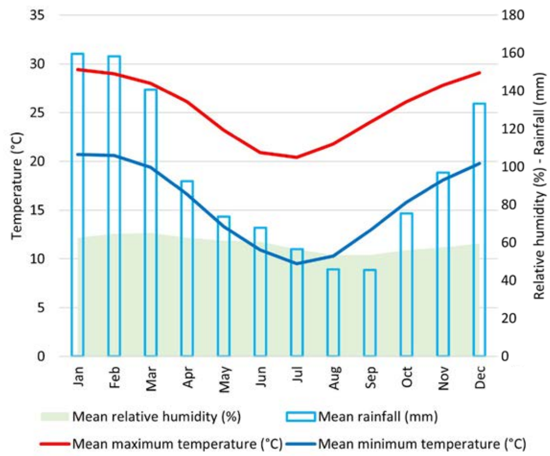

Figure 1. Climatic data for Underwood [4].

Figure 2. Eastern view of Officeworks shopping centre in Underwood.

4.1.2. Building description

This case study building is in a southern Brisbane suburb, and it was refurbished in 2009. The digital National Construction Code of Officeworks is Class 6: a shop or other building used for the sale of goods by retail or the supply of services direct to the public [5]. The shopping centre has a main retail area with a capacity of 150 people. The height of the mentioned building varies between 4.7-7 m. Figure 3 illustrates the treemap chart of the gross internal area of the case study building. The total gross floor area is 1815.4 m².

4.1.3. Energy consumption and sources

Electricity is used for HVAC&R purposes, lighting, appliances, and water heating of the case study building. ➔

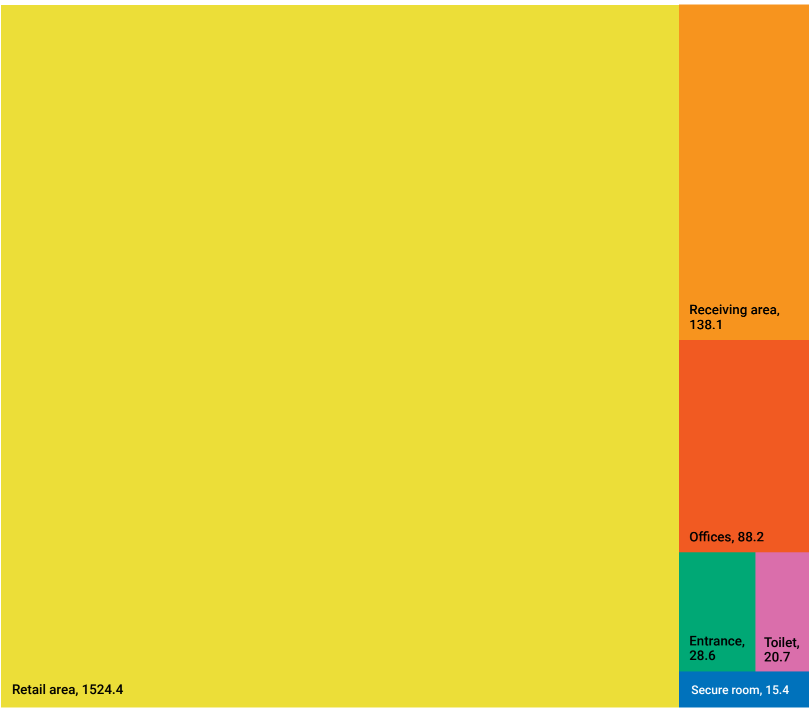

Figure 3. Gross floor divided area of case study building.

4.2. Building modelling input parameters

The modelling parameters are a combination of collected data from the building inspection, utility bills and Australian and global standards. In this section, each modelling assumption will be briefly explained, and relative references will be presented.

4.2.1. Occupancy

Currently, the case study building has a capacity of 150 people, and the occupancy schedule is selected based on the national code of construction [5].

4.2.2. Geometric data

The case study building has one floor. Table 1 shows the main purpose of each part of the shopping centre.

4.2.3. Building Components

A significant part of energy consumption is maintaining comfort leaks through the building envelope. The current thermal performance should be determined as a key step in assessing the potential benefits of improving windows, walls, roofs, and floors. Surveying the shopping centre, the thermal properties of the building envelope are assessed based on construction features and age. This information is used to model the building and develop a thermal model. Here, the performance descriptors of external walls, roof and windows are introduced.

4.2.3.1. External walls

The case study shopping centre has concrete walls. The R-value of the external walls is 0.343 m².K/W, and the solar absorbance coefficient is assumed equal to 0.60. Also, using the average annual wind velocity in Underwood (2.8 m/s) [4], the convective heat transfer coefficient is calculated as 17.6 W/(m².K) [6].

4.2.3.2. Roof

The roof of the case study shopping centre consists of 2 layers: metal sheeting and structure on top of an anti-con blanket. The R-value of the roof is 0.422 m².K/W, and the solar absorbance coefficient is considered equal to 0.70, with a thermal emittance of 0.50 for sandblasted metal sheeting. Also, using average annual wind velocity (2.8 m/s) [4], the convective heat transfer coefficient is calculated as 17.6 W/(m².K) [6]. ➔

Table 1. Building geometric information.

	Air-conditioned area (m²)	Not air-conditioned area (m²)	Gross floor area (m²)
Entrance	28.6	0	28.6
Secure room	15.4	0	15.4
Retail area	1524.0	0	1524.0
Offices	88.2	0	88.2
Receiving area	138.1	0	138.1
Toilets	0	20.7	20.7
Total	**1794.7**	**20.7**	**1815.4**

Table 2. 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
Concrete block	200	0.85	1	1250	-	[5]	Section J, page 388

R-value: 0.343 m².K/W

Table 3. 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
Metal sheeting & structure	1	220	1	7500	-	[5]	Section J, page 388
Anti-con blanket	20	-	1	30	0.25	[7]	Page 1

R-value: 0.422 m².K/W

4.2.4. Domestic hot water

The required hot water for the case study shopping centre is calculated based on Table 2m, NCC volume 1 page 355 [5]. Considering the need for a 50°C temperature increase and water heat capacity (4.19 KJ/kg.°C) and the occupancy schedule of the case study shopping centre, 37.6 MJ of heating energy is required for daily heating domestic water uses.

4.2.5. Internal gains

The information regarding the thermal comfort in the studied shopping centre is provided by the Clarence property facility management (CPFM). Lighting and personal heat gain assumptions in the model are based on Australian and international standards.

4.2.6. Ventilation and infiltration

The thermal comfort parameters have been considered as in Table 7, using the PMV method, according to the National Construction Code.

4.2.7. Thermal Comfort

The thermal comfort parameters have been considered as in Table 7, using the PMV method, according to the National Construction Code. →

Table 4. Domestic hot water.

Demand-side	Occupancy	Unit Hot water demand	Daily hot water demand (lit)
	150	4 lit/person	600

Table 5. Temperature setpoints, lighting and personal heat gain.

	Section	Value	Unit	Ref.	Section and page
Cooling setpoint temperature	All	22	°C	[8]	Page 1396
Heating setpoint temperature	All	16	°C	CP FM	-
Personal latent gain	All	55	W/person	[9]	Chapter 18.4
Personal sensible gain	All	75	W/person	[9]	Chapter 18.4
Appliances and equipment gain		5	W/m²	[5]	
Lighting heat gain	Entrance	9	W/m²	[5]	Section J, page 355
	Retail area	14	W/m²		
	Offices	4.5	W/m²		
	Secure room	4.5	W/m²		
	Receiving area	4.0	W/m²		
	Toilets	3.0	W/m²		

Table 6. Ventilation and infiltration.

	HVAC&R	Value	Unit	Ref.	Section and page
Fresh air	On	10	L/s.person	[10]	Appendix A, Table A1
	Off	5	L/s.person		
Infiltration	On	1	ACH	[11]	Section 2.7
	Off	0.5	ACH		

Table 7. 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

4.2.8. Energy resources and HVAC&R systems

The total energy demand of this building is provided by electricity. Based on the information provided by CPFM, there are three air-cooled chillers in service in the Officeworks shopping centre. The energy efficiency ratio (EER) of the cooling systems is considered equal to 2.0.

4.2.9. Schedules

The schedules of occupancy, lighting and appliances of the Officeworks shopping centre are selected based on page 350 of the Australian national construction code with some modifications due to provided documents by CPFM [5]. →

Table 8. Occupancy, lighting and appliances schedules.

Time	Occupancy	Lighting	Equipment	Air-conditioning
00:00-01:00	0.00	0.25	0.25	Off
01:00-02:00	0.00	0.25	0.25	Off
02:00-03:00	0.00	0.25	0.25	Off
03:00-04:00	0.00	0.25	0.25	Off
04:00-05:00	0.00	0.25	0.25	Off
05:00-06:00	0.00	0.25	0.25	Off
06:00-07:00	0.00	0.25	0.25	Off
07:00-08:00	0.10	1.00	0.70	On
08:00-09:00	0.20	1.00	0.70	On
09:00-10:00	0.20	1.00	0.70	On
10:00-11:00	0.15	1.00	0.70	On
11:00-12:00	0.25	1.00	0.70	On
12:00-13:00	0.25	1.00	0.70	On
13:00-14:00	0.15	1.00	0.70	On
14:00-15:00	0.15	1.00	0.70	On
15:00-16:00	0.15	1.00	0.70	On
16:00-17:00	0.15	1.00	0.70	On
17:00-18:00	0.15	1.00	0.70	On
18:00-19:00	0.15	1.00	0.70	Off
19:00-20:00	0.05	0.10	0.10	Off
20:00-21:00	0.05	0.10	0.10	Off
21:00-22:00	0.00	0.10	0.10	Off
22:00-23:00	0.00	0.10	0.10	Off
23:00-00:00	0.00	0.10	0.10	Off

4.3. Evaluating Lighting Condition

This section aims to recommend appropriate solutions for improving the natural and artificial lighting environment and minimising the energy consumption for artificial lighting of the Officeworks retail shop in Underwood. The steps taken in this regard are:

1. The analysis and simulations of the existing lighting conditions, based on information from building management;
2. The assessment of the compliance of the energy performance and the lighting conditions established with relevant regulations, standards and guidelines; and
3. Research, simulation and presentation of appropriate techniques and methods to achieve minimum energy consumption for lighting and heating loads from artificial lighting, complying with the Australian building regulations.

4.3.1. Lighting evaluation method

Proposing strategies for improving lighting conditions or reducing energy use requires a detailed analysis of the existing natural and artificial lighting conditions. The material available for the specific building included the architectural drawings and images supplied by the facility manager.

Using the provided data and reasonable assumptions about the type of the lighting systems, the building was modelled in the software Rhinoceros, and the lighting conditions were simulated in the add-on tool Climate Studio. Climate Studio is an environmental performance analysis software with advanced lighting calculation capabilities. Due to the lack of information on the lighting system currently used in the retail space, an assumption was made on the lighting power density. This is that the maximum values permitted by the NCC are used, depending on the use of the space. Based on this assumption, two scenarios were tested (Table 9).

4.3.2. Lighting analysis result

Since there are no windows in the studied building, only the results of the artificial lighting conditions and the energy consumption for lighting are analysed and presented. Towards the end of the report, the addition of skylights and the resulting energy savings are discussed.

Table 9. Scenarios for reduced energy consumption for lighting.

Base-case scenario	The existing power density for lighting is set to the maximum permitted by NCC. No daylight linked controls are used.
Scenario 1	The lighting power density is reduced with the use of efficient light sources. No daylight linked controls are used.
Scenario 2	Scenario 2 has the same lighting power density as Scenario 1. However, daylight controls are used in the retail space. Since the building does not have windows, skylights were considered.

5. Simulation approach

The simulation includes two main parts. First, the building was defined in SketchUp software and then energy modelling was conducted in TRNSys.

5.1. SketchUp

SketchUp is a 3D modelling computer program for a wide range of drawing applications such as architectural, interior design, landscape architecture, and civil and mechanical engineering. The model was designed based on actual building dimensions, rotation, and shadings (adjacent building and external shadings). The case study building is defined in the SketchUp model because of the importance of load determination (Figure 4). →

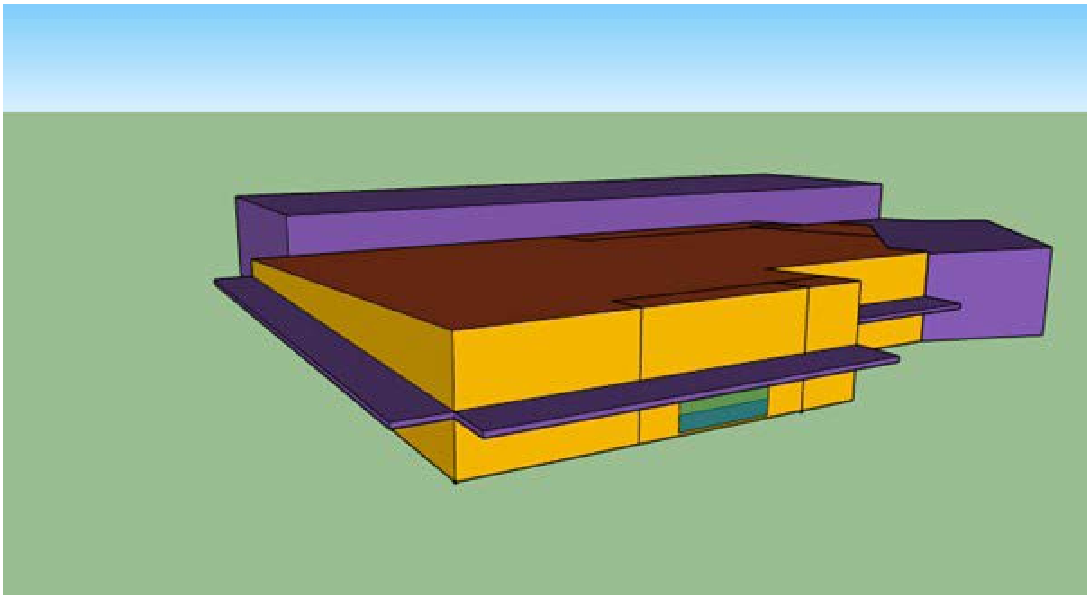

Figure 4. SketchUp model.

5.2. TRNSys

The TRNSys software tool is used to simulate the behaviour of transient systems. TRNSYS has an extensive library of components, which can help model the performance of all parts of the system. TRNBuild is the tool used to enter input data for multizone buildings. It allows specifying all the building structure details and everything required to simulate the thermal behaviour of the building, such as windows' optical properties, heating and cooling schedules, etc. [13]. After importing the case study shopping centre 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 CSIRO weather database, the model was finalised.

5.3. Retrofit approaches

Evaluating the energy performance of a building is a complicated task. It initiates with determining the building's constructional characteristics, including the efficiency of the building envelope, lighting, HVAC&R 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&R system (Coefficient of Performance and Seasonal Energy Efficiency Rating as provided by manufacturers or (for older systems) by regulations), whilst installed lighting and plug loads were determined either by data from management or following standards and regulations.

Additionally, other specific conditions that have a significant impact on the building's performance are:

(a) the operational parameters (hours of operation, set temperatures for heating and cooling, natural ventilation patterns, use of artificial lighting, etc.) and

(b) the microclimate on the building's site (shading by natural obstructions and other buildings, albedo and thermal storage of surrounding areas, etc.).

Finally, a baseline or reference condition should be determined, against which the effectiveness of interventions can be evaluated.

This baseline condition cannot be straightforwardly derived from metered energy consumption since the latter is affected by the aforementioned building's specific operational and microclimate conditions and the weather conditions of the specific period. 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 following national standards, regulations and recommendations or following NCC, ASHRAE and ISO standards. Simulations were carried out on an hourly basis, hence resulting in a high temporal analysis, whilst the thermal zoning was based on the differentiation of thermal conditions. This approach not only allows a reliable and cohesive assessment for the specific building but enables using the outcomes as a pilot for further similar projects. ➔

5.3.1. Lighting retrofit

The aim of the next step of the study was to develop scenarios that would enable reduced energy consumption for lighting and would provide an approximation of how much energy can be saved. The lighting power densities of the various spaces have been set according to the NCC requirements, depending on the space use. Scenario 1 includes the reduction of the power density with the use of efficient LED lighting fixtures, resulting in a reduction in energy consumed for artificial lighting in the range of 17 to 62.50%.

Scenario 2 includes the addition of skylights on the roof above the main retail space. 150.60m² of skylights were considered, with the glazing of 50% transparency and a U-value of 1.36 W/m²K. The skylights would significantly contribute to the decrease of the energy consumption for artificial lighting, which for the main retail space would be over 90%, compared to the base case scenario (Table 12).

5.3.2. Cool roof solution

A new roof coating with albedo 0.80 (i.e., solar absorbance 0.20) and thermal emittance 0.90, consists of the spraying of a field-applied solar-reflective coating on the metal sheeting, which also improves the resistance to corrosion.

5.3.3. Ceiling fans

Ceiling fans are a simple and cost-effective method to enhance the indoor air quality in summer and improve the energy efficiency. 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 25°C, considering the size of the building and the efficacy of air movement. ➔

Table 10. Illumination power density and energy consumption for the base case and the proposed scenarios.

	Base Case		Scenario 1		Scenario 2		
Space	Max. illumination power density (W/m²)	Energy consumption (kWh/year)	Max. illumination power density (W/m²)	Energy consumption (kWh/year)	Max. illumination power density (W/m²)	Energy consumption (kWh/year)	Percentage of maximum energy savings achieved (%)
Entrance	9.00	1,177.0	5.0	654.0	5.0	654.0	44.4
Main retail space	14.0	88,590.0	6.0	37,967.0	1.3	7,907.0	91.1
Offices	4.5	5,027.0	2.5	2,793.0	2.5	2,793.0	44.4
Secure room	4.5	177.0	2.5	98.0	2.5	98.0	44.6
Toilets	3.0	545.0	2.5	454.0	2.5	454.0	16.7
Receiving area	4.0	2,403.0	1.5	901.0	1.5	901.0	62.5

5.3.4. Automation and controls

Even HVAC&R systems of the highest efficiency do not run optimally if they do not consider variations in ambient air temperature and solar radiation, the presence of users in the various rooms and the thermal response of the building's envelope. In that sense, one of the most important tools to improve energy efficiency is the use of sensors, automation and control systems that interlock the use of HVAC&R, DHW and lighting systems with both weather conditions and operational requirements.

The impact of Building Automation And Control Systems (BACS) and Building Management Systems (BMS) are expressed and quantified by a series of standards, like the EN ISO 52127 and 15232. According to those standards, four energy efficiency classes (A, B, C, D) are defined to evaluate the performance of the building automation:

- A: high energy performance BACS and BMS
- B: systems with advanced BACS and BMS
- C: standard BACS
- D: non-energy-efficient BACS

Class C is the estimated class for the baseline, and it is considered that class A is reached after the improvements.

Table 11 depicts typical features of the four mentioned classes. The impact of the automation level on the building's energy consumption is also quantified according to EN 15232 (Table 12). This approach allows a rough evaluation of the impact of BACS systems on the energy performance of the building in a period of a year. The impact of each function (e.g. cooling/heating and lighting) is calculated using the pertinent standards. Class C is the estimated class for the baseline, and it is considered that class A is reached after the improvements.

Table 11. Functions and assignments to energy performance classes.

	Heating/Cooling control	Ventilation / Air conditioning control	Lighting Control	Solar protection
A	• Individual room & communication between controllers • Indoor temperature control of distribution network water temperature • Total interlock between heating & cooling control	• Demand/presence dependent airflow control at room level • Variable setpoint with load-dependent compensation of supply temperature • Room/exhaust/supply-air humidity control	Automatic • Daylight control • Occupancy detection manual on / auto off • Occupancy detection manual on / dimmed • Occupancy detection auto on / auto off • Occupancy detection auto on / dimmed	Combined light/blind/HVAC&R control
B	• Individual room control with communication between controllers • Indoor temperature control of distribution network water temperature • Partial interlock between heating & cooling control (dependent on HVAC system)	• Time-dependent airflow control at room level • Variable setpoint with outdoor temperature compensation of supply temperature control • Room/exhaust/supply-air humidity control	Automatic • Daylight control • Occupancy detection manual on / auto off • Occupancy detection manual on / dimmed • Occupancy detection auto on / auto off • Occupancy detection auto on / dimmed	Motorized operation with automatic blind control
C	• Individual room automatic control by thermostatic valves or electronic controller • Outdoor	• Time-dependent airflow control at room level • Constant setpoint of supply temperature control • Supply-air humidity limitation	Manual • Daylight control • On/off switch + additional sweeping extinction signal • Manual on/off	Motorized operation with manual blind control
D	• No automatic control • No control of distribution network water temperature • No interlock between heating and cooling control	No airflow control at room level No supply temperature control No air humidity control	Manual • Daylight control • On/off switch + additional sweeping extinction signal • Manual on/off	Manual operation of blinds

5.3.5. Auto night ventilation and heat recovery

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. ➔

Night ventilation takes place between 20:00 and 8:00 with an additional flow rate of 4 ACH and is activated during the cooling period and only when the difference between indoor and outdoor temperature is greater than 3°C, the outdoor temperature is greater than 15°C, and indoor temperature is greater than 18°C. The efficiency of the heat recovery ventilation is 30%.

5.3.6. New air-cooled chiller

Installation of a state-of-the-art air-cooled chiller with a coefficient of performance COP=3.5, which takes into account the distribution and terminal units losses. Here, by state-of-the-art chiller, we refer to top-tier technology available on the market, with high efficiency and flexible configuration, to adapt to the project-specific requirements.

5.3.7. Ground Source heat pump (GSHP)

The GSHP cycle exchanges heat between two thermal reservoirs, one at a relatively high temperature and another at a lower one. The building and the underground temperatures are assumed to be high and low-temperature reservoirs during the hot season, respectively. In the winter period, the building is regarded as a high-temperature reservoir, and the underground is the low-temperature one. Each GSHP system consists of many components. The evaporator, compressor, condenser, and expansion valve are the main components of every GSHP system. Heat gained from the underground is released into the building by means of the condenser in cold seasons, while in summer, the evaporator extracts heat from the area, cooling the indoor air [14].

The GSHP considered in retrofitting of case study retail store meets space cooling demands of the building, and it has an average EER=4.8.

Table 12. Functions and assignment to energy performance classes for non-residential buildings. Standard automation is used as reference.

Building use	BAC efficiency factors $f_{BAC,hc}$ / BAC efficiency factors $f_{BAC,e}$							
	D	C	B	A	Energy saving adopting classes			
	No autom.	Standard autom.	Advanced autom.	Full autom.	D→A	D→B	C→A	C→B
Offices	1.51	1	0.80	0.70	54%	47%	30%	20%
	1.10		0.93	0.87	36%	27%	30%	20%
Lecture Hall	1.24	1	0.75	0.35	60%	40%	50%	25%
	1.06		0.94	0.89	53%	29%	50%	25%
Education buildings (schools)	1.20	1	0.88	0.80	33%	27%	20%	12%
	1.07		0.93	0.86	25%	18%	20%	12%
Hospitals	1.31	1	0.91	0.86	34%	31%	14%	9%
	1.05		0.95	0.90	18%	13%	14%	9%
Hotels	1.31	1	0.85	0.68	48%	43%	32%	25%
	1.04		0.96	0.92	36%	21%	32%	15%
Restaurants	1.23	1	0.77	0.68	45%	37%	32%	23%
	1.08		0.95	0.91	35%	26%	32%	23%
Wholesale and retail	1.56	1	0.73	0.47	62%	53%	40%	27%
	1.08		0.95	0.91	44%	32%	40%	27%

6. Results

6.1. Base building modelling

The result of the Officeworks retail store simulation in Underwood is presented in this section. Hourly energy demand for heating and cooling (sensible and latent) is illustrated in Figure 5. Also, the monthly energy demand is presented in Figure 6. →

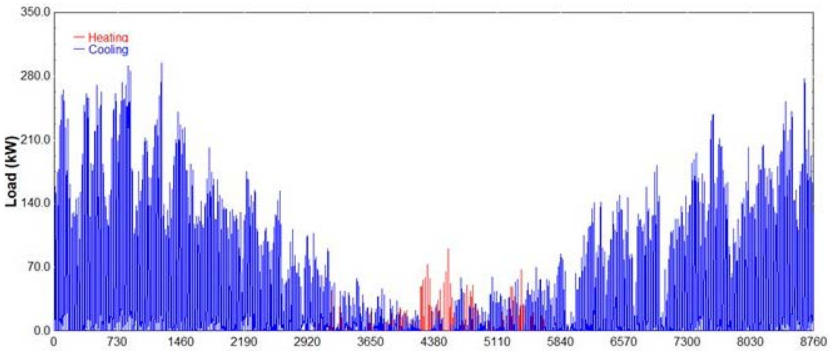

Figure 5. Hourly energy demand for HVAC&R purposes.

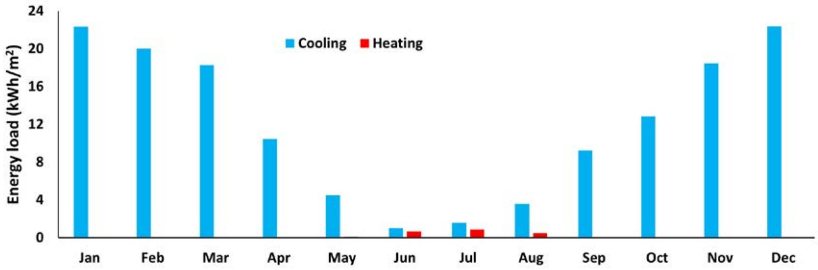

Figure 6. Monthly energy demand for HVAC&R purposes.

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 (Figures 7 and 9). Also, the amount of heating and cooling energy is illustrated in Figures 8 and 10). The monthly energy gain of the shopping centre building and the influence of each factor on the total energy demand is presented in Figure 11. ➔

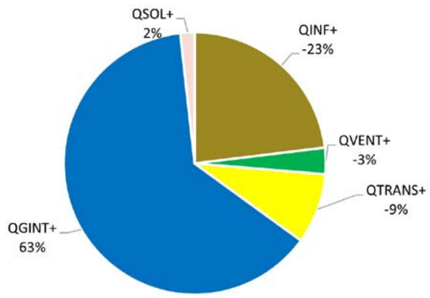

Figure 7. Whole building energy gain - heating season (May-September).

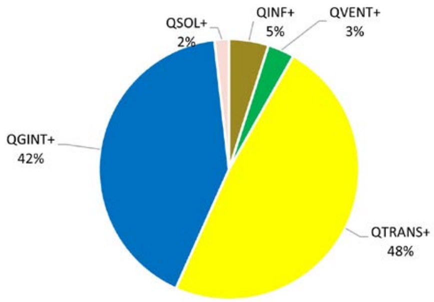

Figure 9. Whole building energy gain - cooling season (October-April).

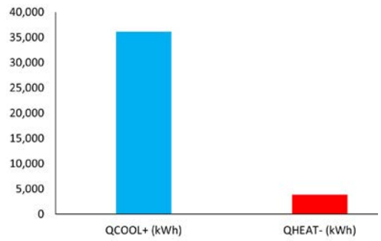

Figure 8. Whole building energy gain for heating and cooling load- heating season (May-September).

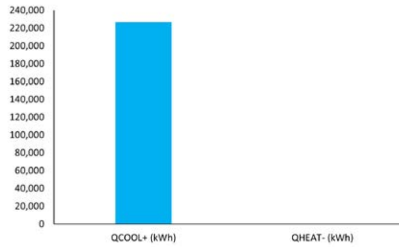

Figure 10. Whole building energy gain for heating and cooling load- cooling season (October-April).

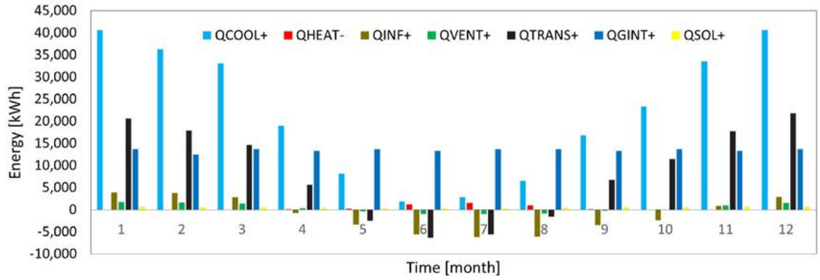

Figure 11. Monthly building energy gain.

6.2. Retrofit scenarios

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

Table 13. Retrofit cases.

Cases	Description
Baseline	The base-case scenario considers the maximum lighting power density permitted by the NCC for each type of space. For the cases where a range of power densities is allowed by NCC, the maximum value is considered. Cooling setpoint and setback temperatures are set according to the NCC. There is no heating system, so extremely low setpoint and setback temperatures are set for heating.
Case A	Baseline + lighting scenario 1: The illumination power density was decreased in many spaces, either using the information for the actual lighting systems of the building or by adopting the minimum power density as required by the NCC. No controls.
Case B	Baseline + lighting scenario 2: The power density of lighting scenario 1 was combined with continuous dimming of the light sources depending on daylight availability.
Case C	Case B + cool roof solution: New cool roof coating with albedo 0.8 (i.e., solar absorbance 0.20) and thermal emittance 0.90. A field-applied solar-reflective coating can be sprayed onto the metal sheeting.
Case D	Case C + Installation of ceiling fans: Ceiling fans are modelled by increasing the cooling setpoint temperature to 25°C.
Case E	Case D + Automation and Controls: The baseline class of automation is estimated according to EN15232, and then the new class and energy efficiency are estimated according to the potential improvements. Class C is the estimated class for the baseline, and it is considered that class A is reached after the improvements.
Case F	Case E + night ventilation + heat recovery ventilation: Night ventilation takes place between 20:00 and 8:00 with an additional flow rate of 4 ACH and is activated during the cooling period and only when the difference between indoor and outdoor temperature is greater than 3°C, the outdoor temperature is greater than 15°C and indoor temperature is greater than 18°C. The efficiency of the heat recovery ventilation is 30%.
Case G	Case F + New air-cooled chiller: Installation of a state-of-the-art air-cooled chiller with a coefficient of performance COP=3.5, including distribution and terminal units losses.
Case H	Case F + GSHP: Installation of one ground source heat pump with fan coils for cooling, with energy-efficient rating EER=4.8, including distribution and terminal units losses.

Among the presented scenarios, Case H has the most retrofitting steps. Table 14 shows the influence of different retrofitting cases on heating and cooling loads. Also, Table 15 demonstrates the impact of different retrofit scenarios on electricity consumption in the case study shopping centre. The results show that by improving the building condition, 76.6% of the required electricity can be reduced. A more detailed illustration of the retrofitting impact is presented in Figures 12-14. ➔

Table 14. Simulation results – Heating and cooling loads.

	Heating loads	Cooling loads	Heating + Cooling	Heating loads	Cooling loads	Heating + Cooling
Unit	kWh/(m²a)			difference (%)		
Case A (Baseline + lighting scenario 1)	2.1	185.6	187.8	-	-	-
Case B (Baseline + lighting scenario 2)	3.0	170.7	173.7	40%	-8%	-7%
Case C (Case B + cool roof tiles)	3.6	163.0	166.6	68%	-12%	-11%
Case D (Case C + ceiling fans)	6.4	106.7	113.1	197%	-43%	-40%
Case E (Case D + automation & controls)	6.4	52.6	59.0	197%	-72%	-69%
Case F (Case E + night ventilation + heat recovery ventilation)	6.4	52.6	59.0	197%	-72%	-69%
Case G (Case F + new air-cooled chiller)	6.2	50.5	56.7	187%	-73%	-70%
Case H (Case F + GSHP)	6.2	50.5	56.7	187%	-73%	-70%
Case H (Case G + External walls insulation)	6.2	50.5	56.7	187%	-73%	-70%

Table 15. Simulation results - Site energy.

	Heating	Cooling	Lighting	DHW	Appliances	Total	Total difference	Total difference
Baseline	kWh/(m²a)							%
Case A (Baseline + Lighting scenario 1)	1.0	92.8	60.2	0.9	21.4	176.2	0.0	0%
Case B (Baseline + Lighting scenario 2)	1.4	85.4	26.0	0.9	21.4	135.0	-41.2	-23.4%
Case C (Case B + Cool roof coating)	1.6	81.5	6.8	0.9	21.4	112.2	-64.0	-36.3%
Case D (Case C + Ceiling fans)	2.9	53.3	6.8	0.9	21.4	85.3	-90.9	-51.6%
Case E (Case D + Automation & Controls)	2.9	26.3	6.8	0.9	21.4	58.3	-117.9	-66.9%
Case F (Case E + Night ventilation + Heat recovery ventilation)	2.6	24.0	6.8	0.9	21.4	55.7	-120.6	-68.4%
Case G (Case F + New air-cooled chiller)	2.5	23.0	6.8	0.9	21.4	54.6	-121.6	-69.0%
Case H (Case F + GSHP)	2.5	13.1	6.8	0.9	21.4	44.7	-131.5	-74.6%
Case H (Case G + External walls insulation)	2.5	9.6	6.8	0.9	21.4	41.2	-135.0	-76.6%

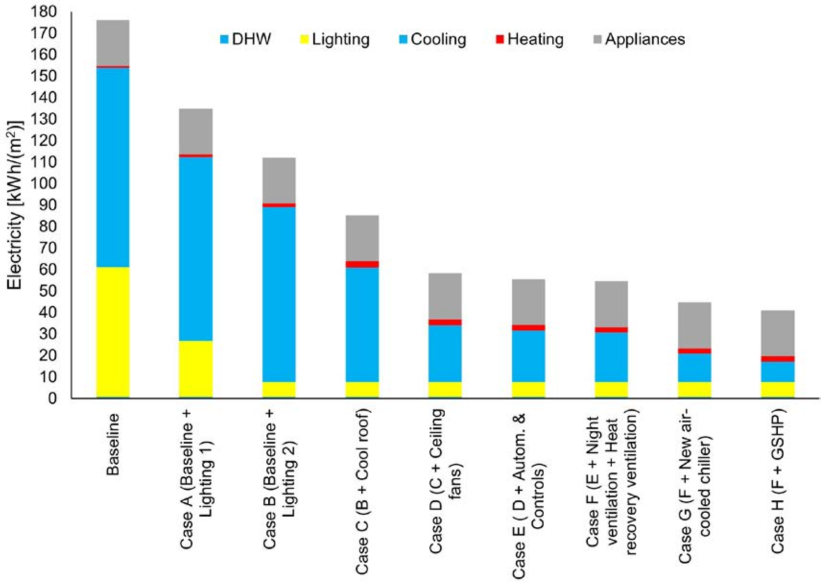

Figure 12. Site energy of the retrofit scenarios.

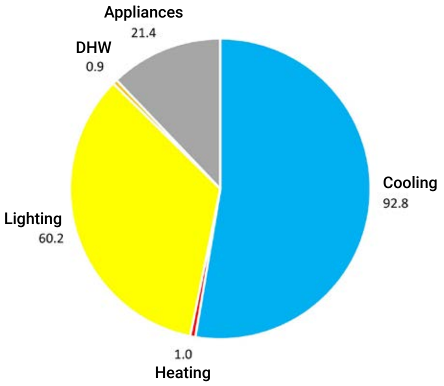

Figure 13. Share of site energy for the baseline (kWh/m²a).

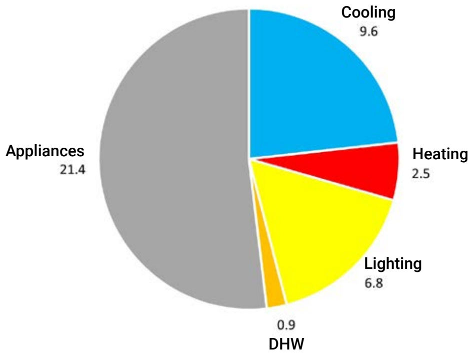

Figure 14. Share of Site energy for retrofit scenario – case H (kWh/m²a).

6.3. Future climate simulation

In this section, the case study shopping centre is simulated in 8 representative cities in Australia. CSIRO has current and future weather models. Therefore, this database is selected to investigate the impact of geographical locations and climate change on the case study building energy demand. Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases are called Representative Concentration Pathways (RCPs) [15]. The word representative indicates that each RCP provides one of many possible scenarios that would lead to a specific radiative forcing characteristic. The term pathway denotes that not only the long-term concentration levels are of interest, but also the path taken over time to reach that outcome is important. RCP4.5 is selected as the future pathway to compare different cities. RCP4.5 is an intermediate condition in which radiative forcing is stabilised at approximately 4.5 W/m² after 2100.

Table 16 presents the energy load and final energy demand by the shopping centre in 8 representative cities. The results indicate that in all representative cities, the cooling site energy will rise between 7.2%-21.3% by 2030. This considerable amount of energy demand for cooling would cause up to a 6.4% rise in the total electricity demand in representative cities by 2030.

To evaluate the impact of retrofitting the shopping centre, the base case and highly retrofitted scenario (Case H) were simulated in Underwood. As it is presented in Table 17, the total base case site energy will rise sharply until 2030. This is because of the climate change impact, which causes a considerable increase in the cooling demand. The simulation results demonstrated that the unretrofitted shopping →

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

Location	Period	Water heating	Heating site energy	Space cooling	Cooling site energy	Lighting site energy	Appliances site energy	Total site electricity demand	Increase in total cooling site energy	Increase in total heating site energy	Increase in total electricity site energy
		(kWh/m²)							%		
Adelaide	Present	2.6	6.6	55.9	23.3	43.3	28.9	104.7	-	-	-
	2030	2.6	5.4	62.2	25.9	43.3	28.9	106.1	11.2	-18.2	1.3
Brisbane	Present	2.6	1.8	95.0	39.6	43.3	28.9	116.2	-	-	-
	2030	2.6	1.4	104.6	43.6	43.3	28.9	119.8	10.1	-22.2	3.1
Canberra	Present	2.6	14.5	46.1	19.2	43.3	28.9	108.5	-	-	-
	2030	2.6	12.6	49.4	20.6	43.3	28.9	108.0	7.3	-13.1	-0.5
Darwin	Present	2.6	0.0	194.2	80.9	43.3	28.9	155.7	-	-	-
	2030	2.6	0.0	207.1	86.3	43.3	28.9	161.1	6.7	-	3.5
Melbourne	Present	2.6	11.0	39.4	16.4	43.3	28.9	102.2	-	-	-
	2030	2.6	9.3	44.4	18.5	43.3	28.9	102.6	12.8	-15.5	0.4
Perth	Present	2.6	4.7	73.0	30.4	43.3	28.9	109.9	-	-	-
	2030	2.6	3.8	80.9	33.7	43.3	28.9	112.3	10.9	-19.1	2.2
Sydney	Present	2.6	3.6	61.2	25.5	43.3	28.9	103.9	-	-	-
	2030	2.6	3.0	67.9	28.3	43.3	28.9	106.1	11.0	-16.7	2.1
Hobart	Present	2.6	14.3	26.2	10.9	43.3	28.9	100.0	-	-	-
	2030	2.6	13.0	28.1	11.7	43.3	28.9	99.5	7.3	-9.1	-0.5

centre's total electricity demand would rise by 6.4%. Also, the results show that the cooling load in 2030 can be reduced by 89.2%, in the case of a complete refurbishment of the Officeworks shopping centre. The resulting reduction in the total electricity demand of the building is 77.5%.

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

Location	Period	Water heating	Heating site energy	Space cooling	Cooling site energy	Lighting site energy	Appliances site energy	Total site electricity demand	Cooling site energy increase	Heating site energy increase	Total site electricity increase
		(kWh/m²)							%		
Melbourne Base case	Present	2.6	11.0	41.0	16.4	43.3	28.9	102.2	-	-	-
	2030	2.6	9.3	46.3	18.5	43.3	28.9	102.6	-12.5%	12.8%	0.4%
Melbourne retrofitted	Present	2.6	3.1	9.3	2.6	0.8	28.9	38.0	-	-	-
	2030	2.6	2.5	10.9	3.1	0.8	28.9	37.8	-10.5%	19.2%	-0.6%

6.4. Discussion and recommendations

We established a baseline for energy consumption, and then we undertook a simulation based on various energy efficiency upgrades. The findings suggest that, in particular, cooling but also lighting energy usage are relatively high. The following suggestions are made to reduce energy consumption:

- The simulations proved that with more efficient artificial light sources, the energy consumption could be reduced by up to 60%. The building does not have windows; thus, there currently is no daylight availability. However, the addition of skylights or light pipes could reduce the lighting energy consumption of the main retail space by 90% approximately.
- The addition of glazed areas on the building roof would have an important effect on the lighting of the space and the reduction of the energy consumption for artificial lighting. It should, however, be stressed that the impact on the thermal comfort and the energy consumption for cooling has not been considered. Also, the cost of adding skylights or light pipes as modifications would be high.
- Installation of cool roof coating with low solar absorbance will lead to a reduction in cooling loads.
- Installing cutting-edge Building Automation and Controls, as well as a Building Management System, to coordinate the use of HVAC&R with both weather and operating requirements.
- Installation of ceiling fans or replacement of the old ones to reduce cooling demands.
- Installation of mechanical ventilation with heat recovery so as to reduce heating loads.
- Implementing night ventilation patterns in the HVAC&R system's operation during the cooling season to reduce cooling demands.
- Installation of an efficient air-cooled chiller or a ground source heat pump (GSHP) to reduce final energy consumption.

In conclusion, a complete renovation package that includes replacement of the building's windows and glazed surfaces, insulation of the external walls and roof, combined with an upgrading of the lighting system, the installation of ceiling fans and the use of night-time ventilation, mechanical ventilation with heat recovery and window shading patterns, linked all with the implementation of a state-of-the-art BAC system, can lead to energy savings of 62.9%, resulting in an energy consumption of 38.0 kWh/m²a, compared to the baseline of 102.2 kWh/m²a. →

In the last retrofit scenario, the cooling site energy is still close to 10 kWh/m²a, which can be easily covered with onsite renewables. Further savings could be achieved with a solar-reflective coating of the walls, which can be achieved with near-infrared reflective paints without compromising the colour selected by the client. However, this was not considered at this stage as the difference between a conventional blue and a solar-reflective blue is contained, and a small difference in the hue might be involved. Also, further savings can be achieved by further increasing the cooling setpoint to 26°C, which was not considered in this case given the building size and number of required ceiling fans with respect to the occupants. Skylights could deliver further savings in electricity for artificial lighting, but in the case of a retrofit, they would require penetrations through the roof sheeting. Finally, a further measure relates to minimising gaps in the building envelope and more efficient automation and control of the entrance door. In this case, these were not assessed as “low-hanging fruits” as they would require very project-specific cost estimations, which are beyond the scope of this research that uses the case study buildings as generally representative of a building class.

In conclusion, a complete renovation package that includes replacement of the building’s windows and glazed surfaces, insulation of the external walls and roof, combined with an upgrading of the lighting system, the installation of ceiling fans and the use of night-time ventilation, mechanical ventilation with heat recovery and window shading patterns, linked all with the implementation of a state-of-the-art BAC system, can lead to energy savings of 62.9%, resulting in an energy consumption of 38.0 kWh/m²a, compared to the baseline of 102.2 kWh/m²a.

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Attachment 1

This attachement contains information about luminaire product used for the main retail space.

Luminaires

Manufacturer	Thorn
Article number	96632195
Product name	GLAC2 L LED3 5000-830 BC E3 GY AL GY
Product group	Anbau- und Pendelleuchten - CLARIS (Pendel)
Mounting type	Pendant
Mounting place	Ceiling
Test mark	CE

Description

A modern and efficient LED pendant luminaire. Electronic. Wireless controlled via App with Bluetooth® 4.x - basicDim Wireless with 3 hour, manual test, emergency lighting circuit. Housing: die-cast aluminium with satin grey finish. Reflector: grey aluminium with easy bayonet mount connection to housing. Class I electrical. IP20. Suspended via adjustable quick-lock 2.5m single wire suspension (supplied). Pre-wired with braided, flame retardant silicone cable, 8 x 0.75mm². Complete with 3000K LED.

-

Dimensions: Ø349 146 x 485 mm
Total power: 43 W
Weight: 5.1 kg

Model / Variant / Configuration

Number / Name	—

Fig. A1. Luminaire technical sheet.

Attachment 2

Fig. A2. Front view of the building.