UNSW
SYDNEY

Hotel

Energy Efficiency Training and Information Project

Commercial Buildings

Perth
WA

Research group

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

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

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

International contributors

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

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

Project contact

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

Contract management contact

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

Acknowledgements

The research group thanks the Australian Department of Industry, Science, Energy and Resources for funding this project entitled “Energy Efficiency Training and Information”. The research group thankfully acknowledges Vass Tzavaras (Director of Engineering Australia | Frasers Hospitality Australia) for providing building documentation and data on the case study analysed in this report.

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

CRICOS Provider Code 00098G

Cover image:
Western view of Fraser Suites, Sydney.

Contents

1. Executive Summary

A complete renovation package ... can result in a 59.9% energy saving

Existing buildings need to be retrofitted to adapt to global climate change, and their energy efficiency must be improved to avoid vulnerability to volatility in the energy market. Almost 80% of 2050 buildings already exist today [1], and retrofitting of these will be required to meet net-zero ready buildings as outlined in the Trajectory for Low Energy Buildings. The travel and tourism industry has been one of the largest industries in Australia, usually accounting for a 10% share of the GDP in Australia [2], and it is now recovering from the COVID-19 pandemic. Nowadays, hotels are delivering more facilities and provide many services to customers, causing higher energy consumption. More than 80% of the energy consumed in hotels is used for heating, ventilation, cooling, lighting, and appliances [3]. This report tackles the operational energy consumption challenge for an existing hotel, using a real-life case study to visualise the impact of each energy optimisation strategy. A high-level framework prioritising different building enhancement methods is presented in this report.

A typical hotel building is considered as a case study to explore opportunities to reduce the site energy. A dynamic thermal model of the hotel building is simulated with TRNSys software, reproducing the characteristics of the real building. This report summarises the findings of the performed analysis on the existing conditions and provides recommendations for the improvement of the building conditions and the minimisation of the energy consumption in the Fraser Suites Perth located at 10 Adelaide Terrace, East Perth, 6004. It is a high-rise building with structural and energy performance features typical for buildings of this type and age.

The analysis showed that most of the spaces close to the perimeter of the building receive high levels of natural lighting. The glazed areas of the facades are shaded to some degree by exterior shading elements or neighbouring buildings. The use of more efficient light sources and daylight linked controls in the common spaces can achieve a reduction of the total lighting load (kW) and the annual energy (kWh) ranging between 55 and 80%.

The baseline scenario for determining feasible interventions is based on the fact that energy consumption for cooling is the most significant issue to address, with values of 39.8kWh/m^{2}a. Still, hot water production is also important, whilst one cannot fail to notice the electricity consumption due to the operation of fans and pumps of the heating, ventilation and air conditioning and refrigeration (HVAC&R) and domestic hot water (DHW) systems.

The problem in high-rise buildings with a large number of diverse users and patterns is to improve not only the efficiency of the numerous component systems but also the overall performance of the systems by interlocking them so that they can operate optimally. Building Automation and Control systems have advanced dramatically in the previous decade, and so has their retrofitting potential. Based on the results, the following recommendations are considered feasible and relatively easy to implement progressively:

- Installation of external shading devices to prevent excessive solar loads in the cooling period through the windows.
- Improvement of the lighting systems by increasing natural lighting uniformity.
- Installation of ceiling fans and introduction of night ventilation patterns in the operation of the HVAC&R system to reduce cooling loads. →

- Installation of cutting-edge building automation and controls (BAC), together with a building management system (BMS), to interlock the use of HVAC&R, DHW and lighting systems with both the weather conditions and operational requirements.
- Installation of water-efficient faucets, so as to reduce water consumption as such and by means of this also energy consumption for hot water. In addition, the installation of heat exchangers to recover heat from the wastewater.
- Finally, the installation of a ground source heat pump (GSHP) could lead to a drastic reduction of final energy consumption for space heating and DHW.

In conclusion, a complete renovation package that includes the installation of a GSHP, water-efficient faucets, DHW heat recovery exchangers and ceiling fans, combined with an upgrading of the lighting system and the use of night-time ventilation and window shading patterns, all linked to the implementation of a state-of-the-art BAC system, can result in a 59.9% energy savings, resulting in an energy consumption of 41.6 kWh/m²a, when compared to the baseline of 103.8 kWh/m²a. Considering the simulated portion of the building, the NABERS rating can be improved from 3.0 to 4.38 stars (estimated). It is noted that the existing building is already being improved by the property since the last NABERS rating. ■

2. Regulations, Standards, and guidelines

The regulatory documents and Standards used for the analysis and the proposals are:

- National Construction Code of Australia 2019 Volume One.
- ANSI/ASHRAE 62.1-2019 Ventilation for acceptable indoor air quality
- ANSI/ASHRAE 55-2020 Thermal environmental conditions for human occupancy
- ASHRAE Handbook Fundamentals 2017, Chapter 18: Nonresidential cooling and heating load calculation
- ISO 17772-1-2017 Energy performance of buildings -Indoor environmental quality, Part 1: Indoor environmental input parameters for the design and assessment of energy performance of buildings
- AS 1668.2-2012 The use of ventilation and air conditioning in buildings, Part 2: Mechanical ventilation in buildings
- AS/NZS 1680.1-2006: Interior and workplace lighting, Part 1- General principals and recommendations.
- AS/NZS 1680.2.1-2008: Interior and workplace lighting, Part 1- Specific applications. Circulation spaces and other general areas.
- AS/NZS 1680.2.2-2008: Interior and workplace lighting, Part 1- Specific applications. Office and screen-based tasks.

3. Introduction

The selected case study building is a typical hotel built in Australia in 2012, representative of many built in the same period. In fact, the aim of selecting Fraser Suites Perth is the potential for methodology replication and findings expansion to other similar buildings.

Clearly, one sample hotel building cannot completely fit all similar buildings, and each hospitality facility has differences; however, even though the required procedure may differ, the logic and methodology presented here offer a high-quality framework to improve the energy efficiency in such buildings.

Assessing the energy performance of a hotel building is a complicated task. It starts with determining the building's features, including the efficiency of the building envelope, the lighting, the 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 in accordance with standards and regulations.

Additionally, two types of specific conditions that have a significant impact on the hotel building's performance must be considered: (a) the operational parameters (hours of operation, set temperatures for heating and cooling, natural ventilation patterns, use of artificial lighting, etc.) and (b) the microclimate on the building's site (shading by natural obstructions and other buildings, albedo and thermal storage of surrounding areas, etc.). ■

4. Fraser Suites Perth

4.1. Case study description

4.1.1. Climate

The case study hotel is located at 10 Adelaide Terrace, East Perth 6004 (31.960S, 115.876E). The building is in the central part of Perth, and it is 25 m above sea level. In Köppen's climate classification, Perth is categorised as Csa, meaning that it has a Mediterranean hot-dry summer and cool-wet winters [4]. The climate of Perth displays moderate seasonal differences. 77.3% of rain in Perth falls between May and September. The annual mean rainfall of 60.9 mm, and July has the highest rainfall (146.8 mm). Due to its geographical location, the relative humidity is distributed unevenly throughout the year (50-80% in the morning and 38-57% in the afternoon). The winters are cool, with overnight minimums averaging 8.3°C and daily maximums climbing to 19.5°C. Moreover, summers are warm, and the average maximum temperature reaches 31.5°C in February. The primary climatic information for Perth is illustrated in Figure 1. →

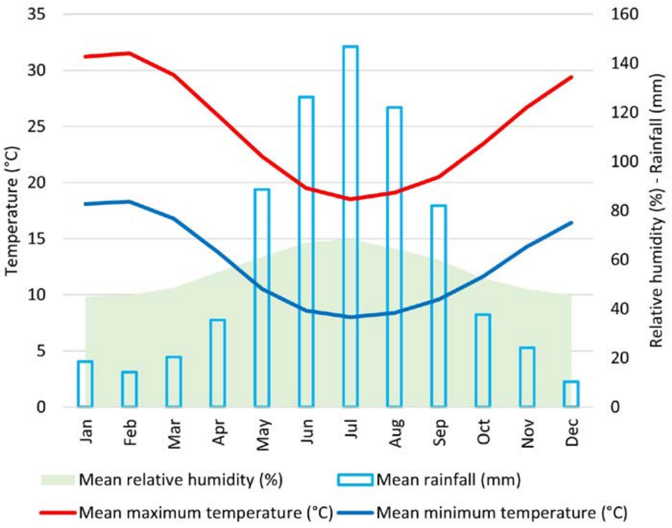

Figure 1. Climatic data of Perth [5].

4.1.2. Building description

The building was constructed in 2012 (Figure 2). Its classification, according to the National Construction Code, is ‘Class 3: residential building providing long-term or transient accommodation for a number of unrelated persons’[6]. Fraser Suites Perth has 21 floors. The under-ceiling height for the residential part of Fraser Suites is 2.7m. The total gross floor area is 24,060 m². Figure 3 illustrates the treemap chart of the gross internal area of the case study building.

Figure 2. Southern view of Fraser Suites Perth.

4.1.3. NABERS rating

The hotel building was certified by NABERS Energy 3 star in May 2021. Based on the NABERS database, this building energy performance is categorised as “Average”. Its annual energy use is 4,742,318 kWh (20,094 kWh/room) and its annual greenhouse gas emission is 2,743,332 kg CO_2 (11,624 kg CO_2/room) [7].

4.1.4. Energy consumption and sources

The best way to decrease buildings’ operational costs is to improve energy efficiency. The case study building uses energy as follows:

- For cooling purposes of Fraser suites, 2 cooling towers were used together with ducted water-cooled packaged air conditioners.
- Also, 2 water heaters were used for space and domestic water heating. →

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 presented.

4.2.1. Occupancy

Currently, the Fraser Suites Perth has 236 guestrooms, and the occupancy schedule is selected based on the national code of construction [6].

4.2.2. Geometric data

The Fraser Suites hotel in Perth is divided into ten major zones for further energy calculation. The considered zones are presented in Table 1. ➔

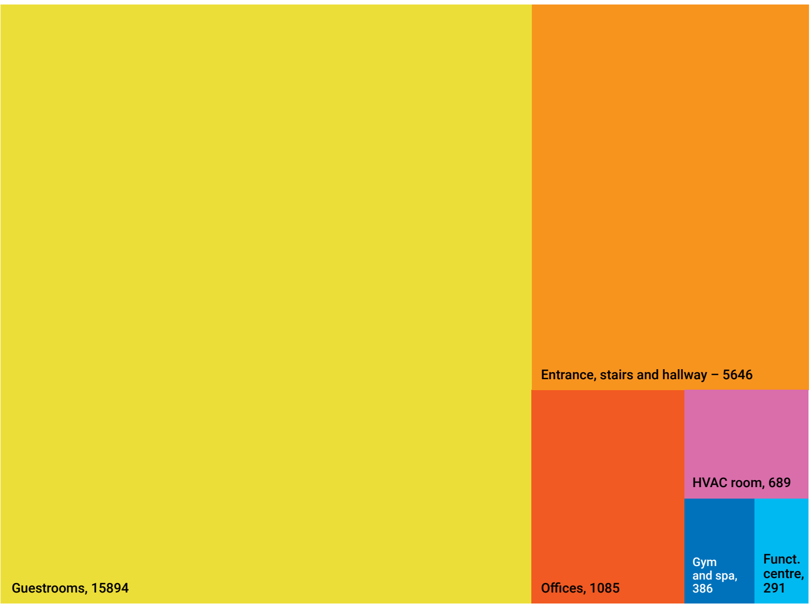

Figure 3. Gross floor divided area of case study building.

Table 1. Building geometric information.

Zone	Name	Level	Orientation	Area (m^2)
1	Entrance	GF	All	1774.5
2	Function centres	1	South	291.2
3	Offices	GF- 3	West	1803.0
4	Kitchen	1	-	37.7
5	Gym	1	North	118.4
6	Pool and spa	1	North	268.8
7	Stairs and hallway	1	-	271.9
8	Guestrooms	2 - 19	South	9859.0
9	Guestrooms	2 - 19	North	6035.2
10	Stairs and hallway	2 - 19	-	3600.5

4.2.3. Building Components

A significant part of the energy is consumed to maintain comfort because of heat transmission 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 hotel 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 of the case study building includes three main layers: concrete blocks as the outer layer, mineral wool insulation in the middle, and plasterboard inside. The overall R-value of the external walls is determined as 1.117 m^2.K/W, and the solar reflectance is assumed equal to 0.45. Also, using the average annual wind velocity in Perth (3.9 m/s) [5], the convective heat transfer coefficient is calculated as 17.6 W/(m^2.K) [8].

4.2.3.2. Roof

The roof of the case study building consists of six layers. There are ballast gravel and waterproofing bitumen on top, after that concrete and air gap in the middle, and mineral wool insulation and plasterboard inside. The overall R-value of the roof is 1.368 m^2.K/W, while the solar reflectance is 0.25. Also, using the average annual wind velocity in Perth (3.9 m/s) [5], the convective heat transfer coefficient is calculated as 17.6 W/(m^2.K) [8].

4.2.3.3. Windows

External windows in the case study hotel building are double glazed with an aluminium frame. The selected shading and glazing in the model are presented in Table 4. →

Table 2. Building Components - Performance Descriptors – Construction – External Walls.

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m^3)	Resistance m^2.K/W)	Ref.	Section and page
Concrete block	200	0.85	1	1250	-	[6]	Section J, page 388
Mineral wool insulation	30	0.042	1.03	50	-	[9]	Section 8.2, Table 4 Page 18
Plaster board	10	0.17	1	880	-	[6]	Section J, page 388

R-value: 1.117 m^2.K/W

Table 3. Building Components - Performance Descriptors – Construction – Roof.

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m^3)	Resistance (m^2.K/W)	Ref.	Section and page
Ballast gravel	150	2.0	0.91	1700	-	[9]	Section 8.3, page 10
Water proofing	4	0.23	1	1100	-	[9]	Section 8.3, page 9
Concrete	200	0.85	1	1250	-	[6]	Section J, page 388
Air space	100	-	-	-	0.16	[10]	Section 5.3, page 5
Mineral wool	40	0.042	1.03	50	-	[9]	Section 8.2, Table 4 Page 18
Plaster board	10	0.17	1	880	-	[6]	Section J, page 388

R-value: 1.368 m^2.K/W

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

Shading type & material	External shading on the western and eastern sides of building		
Glazing	**Value**	**Unit**	**Ref.**
Thickness	10	mm	[11]
Glazing U-value	2.78	(W/m^2.K)	
Glazing solar heat gain coefficient	0.59	N/A	
Window frame material	Aluminium	N/A	
Window frame ratio or width	15	%	
Glazing layout – WWR	43	%	
Glazing type	Double glazed	N/A	

4.2.4. Domestic hot water

The required hot water for the guestrooms is calculated based on Table 6, Chapter 50 of ASHRAE Handbook 2015 [12]. Therefore, considering the need for a 50°C temperature increase and water heat capacity (4.19 KJ/kg.°C), 2,010 MJ heating energy is needed for daily heating domestic water.

4.2.5. Internal gains

The information regarding the thermal comfort in case hotel is provided by the Fraser Suites Facility Management (FSFM). Lighting and personal heat gain assumptions in the model are based on Australian and international standards. The assumed heat gain for appliances in Fraser Suites is presented in Table 7. The heat rates are based on NCC volume 1, page 355 [6], and chapter 18.12 of ASHRAE Fundamental 2017 [13]. ➔

Table 5. Domestic hot water.

Demand-side	Value	Unit Hot water demand	Daily hot water demand (lit)
Guestrooms	236 rooms	38 lit/unit	8,968
Office, meeting rooms	165 occupants	3.8 lit/person	627
Total hot water demand			8,426

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

	Zone(s)	Value	Unit	Ref.	Section and page
Cooling setpoint temperature	All	22	°C	FSFM	-
Heating setpoint temperature	All	20	°C	FSFM	-
Personal latent gain	1,2,3,7,10	55	W/person	[13]	Chapter 18.4
	4,5,6	185	W/person		
	8,9	45	W/person		
Personal sensible gain	1,2,3,7,10	75	W/person	[13]	Chapter 18.4
	4,5,6	110	W/person		
	8,9	70	W/person		
Lighting heat gain	1	9	W/m²	[6]	Section J, page 379
	2,3,7,10	4.5	W/m²		
	4,8,9	4	W/m²		
	5,6	3	W/m²		

Table 7. Building appliances heat gains.

Zone		Microwave	Refrigerator	Cool room	Icemaker	TV 40"	Dishwasher	Oven	Computer	Projector	Vending machine	Sensible (W)
1	Entrance	0	0	0	0	1	0	0	6	0	1	1,741
2	Function centres	0	0	0	0	0	0	0	10	4	0	4,532
3	Offices	2	2	0	0	1	2	0	10	2	1	4,711
4	Kitchen	1	0	1	1	0	1	2	0	0	0	8,416
5	Gym	0	0	0	0	0	0	0	1	0	1	1,070
6	Pool & spa	0	0	0	0	0	0	0	0	0	0	0
7	Stairs and hallway	0	0	0	0	0	0	0	0	0	0	0
8	Guestrooms	116	116	0	0	116	0	0	0	0	0	20,184
9	Guestrooms	120	120	0	0	120	0	0	0	0	0	20,880
10	Stairs & hallway	0	0	0	0	0	0	0	0	0	0	0

4.2.6. Ventilation and infiltration

The fresh air supplied to each zone and the infiltration are assumed based on international standards.

4.2.7. Thermal Comfort

The thermal comfort parameters have been considered using the PMV method (Table 9, following the NCC).

4.2.8. Energy resources and HVAC systems

In this building, energy is supplied with electricity and natural gas. Natural gas is used for domestic water heating and space heating, while electricity is consumed for lighting, appliances and fans, pumps, cooling system, etc. The guestrooms have a central HVAC system, while the other parts of the building have a separate HVAC system. Based on the provided drawings and specification, and considering the age of the building, the efficiency of the water boiler is considered as 78%, and EER of cooling units are considered as 2.0.

4.2.9. Schedules

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

→

Table 8. Ventilation and infiltration.

	Schedule	Value	Unit	Ref.	Section and page
Fresh air	Occupied period	10	L/s.person	[14]	Appendix A, Table A1
	Unoccupied period	5	L/s.person		
Infiltration	Occupied period	1	ACH	[15]	Section 2.7
	Unoccupied period	0.5	ACH		

Table 9. Thermal comfort parameters.

Factor	Value	Unit	Ref.	Section and page
Clothing Factor	Summer 0.6 – Winter 1	clo	[16]	Section 5, page 8
Metabolic rate	1.0	Met	[16]	Section 5, page 7
Relative air velocity	Less than 0.2	m/s	[16]	Section 5, page 11

Table 10. Occupancy, lighting and appliances schedules for zones 8-10.

Time	Occupancy	Artificial lighting	Appliances and equipment	Air-conditioning
00:00-01:00	0.90	0.05	0.20	On
01:00-02:00	0.90	0.05	0.20	On
02:00-03:00	0.90	0.05	0.15	On
03:00-04:00	0.90	0.05	0.15	On
04:00-05:00	0.90	0.05	0.15	On
05:00-06:00	0.80	0.25	0.15	On
06:00-07:00	0.70	0.80	0.40	On
07:00-08:00	0.60	0.50	0.80	On
08:00-09:00	0.6r0	0.20	0.50	On
09:00-10:00	0.30	0.20	0.30	On
10:00-11:00	0.10	0.20	0.20	Off
11:00-12:00	0.10	0.20	0.20	Off
12:00-13:00	0.10	0.20	0.20	Off
13:00-14:00	0.10	0.20	0.20	Off
14:00-15:00	0.10	0.20	0.20	Off
15:00-16:00	0.10	0.20	0.20	Off
16:00-17:00	0.20	0.20	0.20	On
17:00-18:00	0.30	0.50	0.40	On
18:00-19:00	0.40	0.50	0.40	On
19:00-20:00	0.50	0.50	0.50	On
20:00-21:00	0.60	0.50	0.60	On
21:00-22:00	0.70	0.50	0.60	On
22:00-23:00	0.90	0.50	0.40	On
23:00-00:00	0.90	0.50	0.20	On

4.3. Evaluating Lighting Conditions

The aim of this section is to recommend appropriate solutions for the improvement of the natural and artificial lighting environment and for minimising the energy consumption for lighting of the interior spaces of Fraser Suites hotel in Perth. The steps taken in this regard are:

1. The analysis and simulations of the existing lighting conditions, based on information from the building management;

2. The assessment of the compliance of the energy performance and the lighting conditions established with relevant regulations, standards and guidelines; and

3. Research, simulation and presentation of appropriate techniques and methods to achieve minimum energy consumption for lighting and heating loads from artificial lighting while complying with standards & regulations. →

Table 11. Occupancy, lighting and appliances schedules for zones 1-7.

Time	Occupancy	Artificial lighting	Appliances and equipment	Air-conditioning
00:00-01:00	0.0	0.15	0.25	Off
01:00-02:00	0.0	0.15	0.25	Off
02:00-03:00	0.0	0.15	0.25	Off
03:00-04:00	0.0	0.15	0.25	Off
04:00-05:00	0.0	0.15	0.25	Off
05:00-06:00	0.0	0.15	0.25	Off
06:00-07:00	0.0	0.15	0.25	Off
07:00-08:00	0.1	0.40	0.65	On
08:00-09:00	0.2	0.90	080	On
09:00-10:00	0.7	1.00	1.00	On
10:00-11:00	0.7	1.00	1.00	On
11:00-12:00	0.7	1.00	1.00	On
12:00-13:00	0.7	1.00	1.00	On
13:00-14:00	0.7	1.00	1.00	On
14:00-15:00	0.7	1.00	1.00	On
15:00-16:00	0.7	1.00	1.00	On
16:00-17:00	0.7	1.00	1.00	On
17:00-18:00	0.35	0.80	0.80	On
18:00-19:00	0.1	0.60	0.65	Off
19:00-20:00	0.05	0.60	0.55	Off
20:00-21:00	0.05	0.50	0.25	Off
21:00-22:00	0.0	0.15	0.25	Off
22:00-23:00	0.0	0.15	0.25	Off
23:00-00:00	0.0	0.15	0.25	Off

4.3.1. Lighting evaluation method

Proposing strategies for improving lighting conditions or reducing energy use requires a detailed analysis of the existing natural and artificial lighting conditions. The data provided for the Frasers Suites included: 1. The architectural drawings for all levels apart from the ground (reception) floor, 2. Drawings of the lighting installations on the guestroom levels and on levels 2 and 3. photographs of some types of lamps used in the guestrooms and the gym/pool areas. However, the lighting drawings had annotations that were indicative and not representative of the actual installation. Using the provided data, the building was modelled in the software Rhinoceros, and the lighting conditions were simulated in the add-on tool Climate Studio. Climate Studio is an environmental performance analysis software with advanced lighting calculation capabilities. The simulation results were then compared to the requirements and recommendations of the Australian NCC [6]. Based on the simulation findings, three scenarios were tested. These scenarios are described in Table 12.

4.3.2. Lighting analysis result

The results are analysed in two parts:

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

4.3.2.1. Natural lighting

The building has large openings on all elevations. The North-East façade is partly shaded by neighbouring buildings, while the glazed surfaces of working or common spaces are shaded by various elements, such as horizontal overhangs, vertical louvres and pergolas. The natural lighting conditions have been studied in indicative common or working spaces: the lobby/reception, the level 1 office, the gym/pool area and the meeting rooms. The guestrooms are considered to have interior shading elements, and the view outside is necessary, so their natural lighting conditions are not analysed, and exterior shading elements are not recommended. All the spaces studied have average Daylight Factors above 2%, as they have large windows facing west. However, the uniformity of the natural lighting levels is satisfactory, as the depth of the spaces is not excessive. Further shading of the hotel common or working spaces is not considered necessary.

4.3.2.2. Artificial lighting

The management of the hotel provided some information on the artificial lighting of the building. However, the exact positions of the light sources are not determined. Due to the minimum information on artificial lighting, no lighting level simulations were performed, as they would require a great number of assumptions that would result in inaccurate results.

Table 12. Scenarios for reduced energy consumption for lighting.

Base-case scenario	The lighting power density was considered equal to the maximum density permitted by the NCC for the specific type of space.
Scenario 1	The data provided by the building management for the installed light sources were used, where possible.
Scenario 2	More efficient light sources and appropriate lighting controls were used.

Table 13. Average Daylight Factor of communal and working spaces in Fraser Suites Perth.

Space	Average Daylight Factor (%)	Uniformity
Entrance/lobby	3.8	0.53
Level 1 – Offices (close to the perimeter)	4.9	0.9
Level 1 – Gym/pool	6.5	0.83
Level 1 – Meeting rooms	6	0.75

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). As discussed previously,10 zones were defined in the SketchUp model due to the importance of load determination (Figure 4). →

Figure 4. SketchUp model.

5.2. TRNSys

TRNSys software is used to simulate the behaviour of transient systems. TRNSYS has an extensive library of components, which can help model the performance of all parts of the system. TRNBuild is the tool used to enter input data for multizone buildings. It allows specifying all the building structure details, as well as everything that is needed to simulate the thermal behaviour of the building, such as windows optical properties, heating and cooling schedules, etc. [17]. After importing the building model into TRNSys, all building structural parameters (walls, windows, doors, etc.), schedules (occupancy, lighting, and appliances), internal loads, and HVAC systems (setpoint, ventilation, infiltration, and comfort) were defined in TRNBuild. Climate data (temperature, relative humidity, radiation, etc.) are retrieved from the CSIRO weather database.

5.3. Retrofit approaches

Evaluating the energy performance of a building is a complicated task. It initiates with determining the building's constructional characteristics, including the efficiency of the building envelope, lighting, HVAC equipment, etc. Considering the building's features, all calculations were based on the 'as-built' condition of the building elements (U-values, shading, air-permeability, etc.), of the HVAC system (Coefficient of Performance and Seasonal Energy Efficiency Rating as provided by manufacturers or (for older systems) by regulations), whilst installed lighting and plug loads were determined either by data provided by the building operators or in accordance with standards.

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

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

(b) the microclimate on the building's site (shading by natural obstructions and other buildings, albedo and thermal storage of surrounding areas, etc.). Finally, a baseline or reference condition should be determined, against which the effectiveness of interventions can be evaluated.

This baseline condition cannot be straightforwardly derived from metered energy consumption since the latter is affected by the aforementioned building's specific operational and microclimate conditions, as well as by the weather conditions of the specific period. In that sense, while the metered consumption values are real, they do not necessarily represent a base for an objective assessment. Therefore, the building has to adopt standard reference conditions, as foreseen by national regulations and standards, which allow a good degree of replicability for the simulative calculations that allow a detailed breakdown of energy consumption by source and use and a reliable assessment of the improvements achieved by the interventions considered.

In this line of approach, all operational parameters for the baseline scenario were considered in accordance with national standards, regulations and recommendations or in accordance with NCC, ASHRAE and ISO standards. Simulations were carried out on an hourly base, hence resulting in a high temporal analysis, whilst the thermal zoning was based on the differentiation of thermal conditions. This approach not only allows a reliable and cohesive assessment for the specific building but enables using the outcomes as a pilot for further similar projects. →

5.3.1. Lighting retrofit

The aim of this section is to develop scenarios that would enable reduced energy consumption for lighting and would provide an approximation of how much energy can be saved. Due to insufficient information on the installed lighting sources, the base-case scenario considers the maximum lighting power density permitted by the NCC for each type of space [6]. For the cases where a range of power densities is allowed, the maximum value is taken.

On the contrary, retrofit scenarios 1 and 2 aimed to achieve minimum energy consumption. As a result, for scenario 1, the illumination power density was decreased in many spaces, adopting the minimum power density as required by the NCC [6]. In spaces where the NCC maximum lighting power density is high, i.e., the entrance/lobby and the mezzanine floor, the assumption that the existing light sources can be replaced with LEDs achieving 2/3 of the NCC maximum permitted lighting power density was made. In spaces where no information was provided for the existing lighting equipment, and the NCC maximum lighting power density is relatively low, i.e., the kitchen and the gym, the lighting power density remains the same for all scenarios. For scenario 2, the power density of Scenario 1 was used and combined with a continuous dimming of the light sources depending on daylight availability. The proposed scenarios resulted in a reduction of the total lighting load (kW) and the annual energy (kWh) ranging from 55 to 80% (Table 14).

5.3.2. Windows shading

The current windows installed in the Fraser Suites Perth are double glazed with aluminium frame and 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. While changing the windows of the Fraser Suites Perth with more effective ones can reduce the amount of energy waste, the large amount of replacement cost makes it a not financially acceptable option. Instead, the installation of external shading devices is recommended to prevent excessive solar loads in the cooling period. ➔

Table 14. Illumination power density and energy consumption for the base case and the proposed scenarios.

Space	Base case		Scenario 1		Scenario 2	Maximum energy savings achieved (%)
	Max illumination power density (W/m²)	Energy consumption (kWh/year)	Max illumination power density (W/m²)	Energy consumption (kWh/year)	Energy consumption (kWh/year)	
Entrance (Ground floor)	9	11,150	6	7,434	2,030	81.8
Function centre (Lvl 1)	4.5	2,662	2.5	1,479	583	78.1
Offices (Lvl 1)	4.5	10,152	2.5	5,640	2,351	76.8
Kitchen, toilets and changing rooms (Lvl 1)	4	4,316	4	4,316	4,316	0.0
Gym, pool and spa (Lvl 1)	3	3,296	3	3,296	755	77.1
Meeting lobby (Lvl 1)	4.5	1,312	2	583	583	55.6
Guestrooms (Lvl 4)	4	5537	4	5537	5537.00	0.0
Stairs/ lift lobbies (Lvl 4)	4.5	2312	2	1028	1028.00	55.5
Café (Ground Floor)	9	18,492	6	12,328	4,551	75.4

5.3.3. Automation and controls

Even HVAC 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 combination of sensors, automation and control systems that interlock the use of HVAC, DHW and lighting systems with both weather conditions and operational requirements.

The impact of Building Automation And Control Systems (BACS), along with Building Management Systems (BMS), is 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

Table 15 shows the typical features for the four mentioned classes. The impact of the automation level on the building's energy consumption is also quantified according to Standard 15232, as it can be seen in Table 16. 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.

Table 15. 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

The result of the evaluation is two sets of BAC efficiency factors ($f_{BAC,hc}$ and $f_{BAC,e}$). The first one estimates the energy for heating and cooling, and the second one the electric energy for lighting and auxiliary factors.

Fraser Suites Perth is between Class D and C and can fairly easily be upgraded to Class B, by installing:

- Individual room controls with communication between them
- Time-dependent controls of ventilation
- Variable control of setback temperatures
- Humidity control of the ventilation and
- Lighting controls

In that way, even if the building is not of Class C (which is an assessment to be on the safe side), heating, cooling and DHW loads can be reduced by at least 25%, apart from savings achieved due to the refurbishment of building's envelope. Similarly, electrical loads can be reduced by a further 15%.

5.3.4. Ceiling fans

Ceiling fans are a simple and cost-effective method to enhance the indoor air quality in summer and also to receive points in energy rating stars. They provide additional air movement by increasing the relative air velocity resulting in the apparent temperature felt on exposed skin being 3°C colder than the actual air temperature, thereby reducing the need for additional cooling. The proposed scenario will be modelled by increasing the cooling setpoint temperature to 26°C.

5.3.5. Night ventilation

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. The proposed scenario will be auto night ventilation between 20:00 and 8:00 in summer with a volume flow rate of 4 ACH and is activated only when the difference between indoor and outdoor temperature is greater than 3°C. Also, it only works when the outdoor temperature is greater than 15°C (outdoor humidity less than 60%) and the indoor temperature is greater than the heating setpoint. →

Table 16. 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%

5.3.6. Domestic hot water intervention

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

5.3.7. Ground Source heat pump (GSHP)

The GSHP cycle exchanges heat between two thermal reservoirs, one at a relatively high temperature and another at a lower one. Actually, the building and the underground temperatures are assumed to be high and low-temperature reservoirs during the hot season, respectively. In the winter period, the building is regarded as a high-temperature reservoir, and the underground is the low- temperature one. Each GSHP system consists of many components. The evaporator, compressor, condenser, and expansion valve are the main components of every GSHP system. Heat gained from the underground is released into the building by means of the condenser in cold seasons, while in summer, the evaporator extracts heat from the area, which should be cooled [18].

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

6. Results

6.1. Base building modelling

The result of the Fraser Suites simulation in Perth is presented in this section. Hourly energy demand for heating and cooling (sensible and latent) is illustrated in Figure 5, while the monthly energy demand is shown in Figure 6. ➔

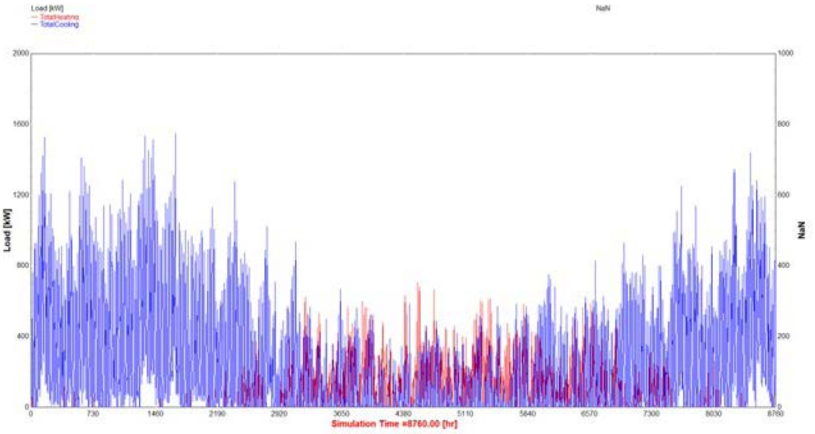

Figure 5. Hourly energy demand for HVAC&R purposes.

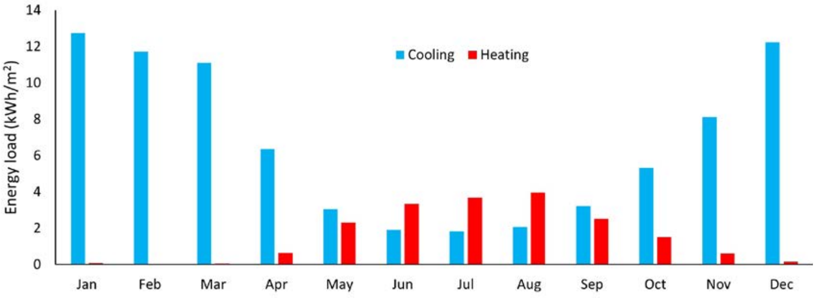

Figure 6. Monthly energy demand for HVAC purposes.

TRNSys calculates thermal loads through an energy balance that affects the air temperature inside the building:

$$q_{BAL} = q_{DQAIRdt} + q_{HEAT} - q_{COOL} + q_{INF} + q_{VENT} + q_{TRANS} + q_{GINT} + q_{WGAIN} + q_{SOL}$$

q_{BAL}: the energy balance for a zone and should always be close to 0;

$q_{DQAIRdt}$ is the change of internal energy of the zone (calculated using the combined capacitances of the building and the air within it);

q_{INF} is the gains by infiltration;

q_{VENT} is the gains by ventilation;

q_{TRANS} is transmission into the surface from an inner surface node;

qG_{INT} is internal gains by convection and radiation;

q_{WGAIN} represents gains by convection and radiation through walls, roof and floor;

q_{SOL} is absorbed solar gains on all inside surfaces;

q_{HEAT} is the power of ideal heating;

q_{COOL} is the power of ideal cooling.

Therefore, the ratio of each parameter in total energy gain can be decided for heating and cooling seasons (Figure 7 and Figure 9). Also, the amount of heating and cooling energy is illustrated in Figures 8 and 10. →

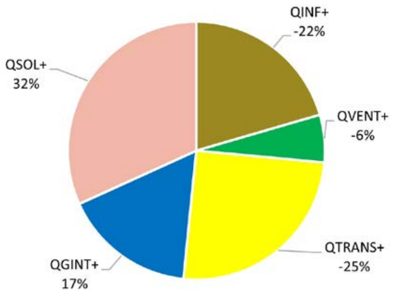

Figure 7. Whole building energy gain – heating season (May - September).

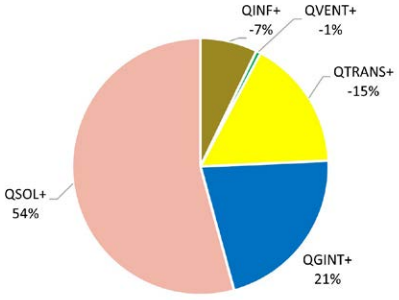

Figure 9. Whole building energy gain – cooling season (October - April).

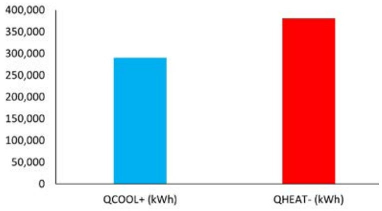

Figure 8. Whole building energy gain for heating and cooling load – heating season (May-September).

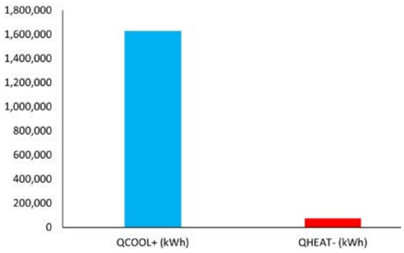

Figure 10. Whole building energy gain for heating and cooling load - cooling season (October-April).

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

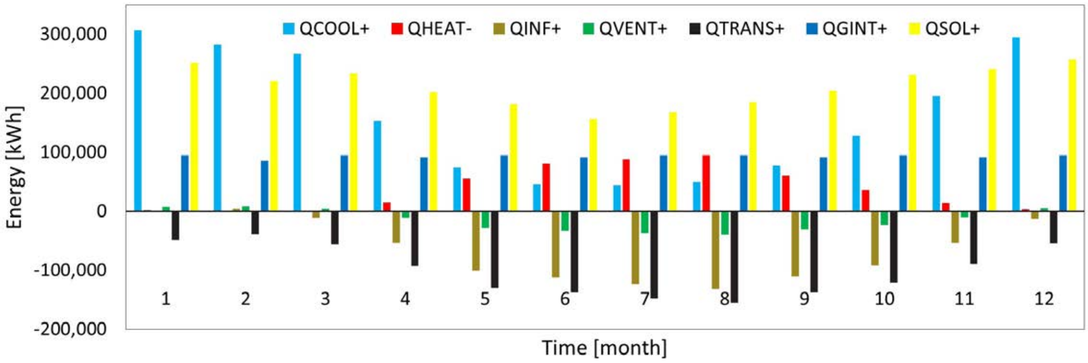

Figure 11. Monthly building energy gain.

6.2. Retrofit scenarios

The investigated retrofit cases in this report are presented in Table 17. ➜

Table 17. Retrofit scenarios.

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. Heating and cooling setpoint and setback temperatures are set according to the NCC.
Case A	**Baseline + windows shading:** Window shading is modelled by applying a shading factor of 0.7 during the cooling period (October-April).
Case B	**Case A + 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 C	**Case B + + night ventilation + Installation of ceiling fans:** 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 K, the outdoor temperature is greater than 15°C (outdoor humidity less than 60%) and indoor temperature is greater than the heating setpoint. Ceiling fans are modelled by increasing the cooling setpoint temperature to 26°C.
Case D	**Case C + + DHW interventions:** Installation of water-efficient faucets and water heat recovery systems.
Case E	**Case D + GSHP:** The GSHP meets space heating, cooling and DHW demands, and it has an average COP=3 and EER=2.8, including losses of the distribution network and terminal units.
Case F	**Case E + 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 G	**Case F + lighting scenario 2:** The power density of lighting scenario 1 was used and combined with continuous dimming of the light sources depending on daylight availability in: building entrance, function centre, offices, gym, pool and spa.

Between the presented scenarios, Case G has the most retrofitting steps. Table 18 shows the influence of different retrofitting cases on heating and cooling loads. Also, Table 19 demonstrates the impact of different retrofit scenarios on electricity and natural gas consumption in the case study hotel. The result indicates that by improving the building condition, 55.2% of the required electricity can be reduced without any need for natural gas. A more detailed illustration of the retrofitting impact is presented in Figures 12-14. →

Table 18. Simulation results – heating and cooling loads.

	Heating loads	Cooling loads	Heating + Cooling	Heating loads	Cooling loads	Heating + Cooling
Unit	kWh/(m^{2}a)			difference (%)		
Baseline	18.9	79.7	98.6	-	-	-
Case A (Baseline + windows shading)	20.0	45.1	65.1	6	-43	-34
Case B (Case A + Automation and Controls)	20.0	45.1	65.1	6	-43	-34
Case C (Case B + night ventilation + Installation of ceiling fans)	20.0	23.7	43.8	6	-70	-56
Case D (Case C + DHW interventions)	20.0	23.7	43.8	6	-70	-56
Case E (Case D + Installation of GSHP)	20.0	23.7	43.8	6	-70	-56
Case F (Case E + Lighting scenario 1)	20.7	22.6	43.3	9	-72	-56
Case G (Case E + Lighting scenario 2)	21.1	22.0	43.1	12	-72	-56

Table 19. Simulation results - Site energy.

	Heating	Cooling	Lighting	DHW	Appliances	Pumps & Fans	Total	Total difference	Total difference	Total gas	Total electricity
Unit	kWh/(m^{2}a)								%	kWh/(m^{2}a)	
Baseline	9.0	39.8	16.3	10.9	9.1	18.7	103.8	0.0	0%	10.9	92.9
Case A (Baseline + windows shading)	9.5	22.6	16.3	10.9	9.1	15.3	83.7	-20.1	-19.3%	10.9	72.9
Case B (Case A + Automation and Controls)	6.5	15.3	16.3	10.9	9.1	13.3	71.4	-32.4	-31.3%	10.9	60.5
Case C (Case B + night ventilation + ceiling fans)	6.5	8.1	16.3	10.9	9.1	11.8	62.6	-41.2	-39.7%	10.9	51.8
Case D (Case C + DHW interventions)	6.5	8.1	16.3	8.1	9.1	11.6	59.7	-44.1	-42.5%	8.1	51.6
Case E (Case D + Installation of GSHP)	4.5	5.8	16.3	2.1	9.1	10.3	48.1	-55.7	-53.7%	0.0	48.1
Case F (Case E + Lighting scenario 1)	4.7	5.5	12.5	2.1	9.1	10.2	44.1	-59.7	-57.5%	0.0	44.1
Case G (Case E + Lighting scenario 2)	4.8	5.4	10.1	2.1	9.1	10.2	41.6	-62.2	-59.9%	0.0	41.6

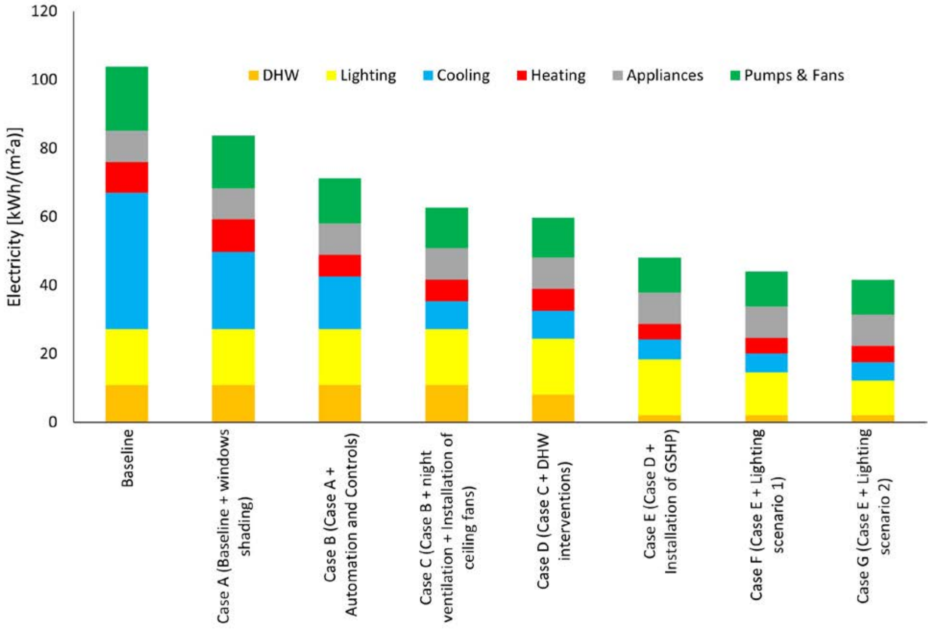

Figure 12. Site energy of the retrofit scenarios.

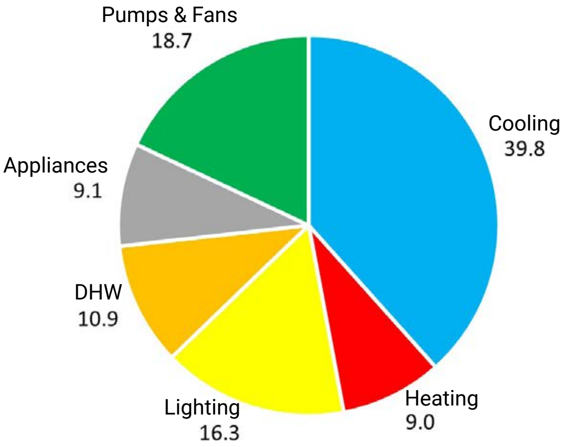

Figure 13. Share of site energy for the baseline (kWh/m²a).

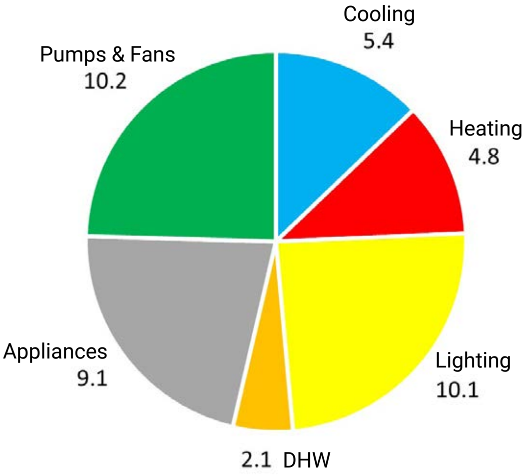

Figure 14. Share of Site energy for retrofit scenario – case G (kWh/m²a).

6.3. Future climate simulation

In this section, the case study hotel building is simulated in 8 representative cities in Australia. CSIRO has current and future weather models. Therefore this database is selected to investigate the impact of geographical locations and global warming on the case study building energy demand. Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases are called Representative Concentration Pathways (RCPs)[19]. 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 20 presents the energy load and final energy demand by the hotel building in 8 representative cities. Results indicate that in all representative cities, the cooling site energy will rise between 5.6%-15.0% by 2030. This considerable amount of energy demand for cooling would cause up to a 4.3% rise in total electricity demand in representative cities by 2030.

To evaluate the impact of retrofitting the case study hotel building, the base case and highly retrofitted scenario (Case G) were simulated in Perth. As presented in Table 21, the total base case site energy will rise sharply until 2030. This is because of the global warming impact, which causes a considerable increase in the cooling demand. The simulation results demonstrated that the unretrofitted hotel's total electricity demand will rise by 3.8%, while the natural gas needs will decrease by 8.0% since heating requirements are expected to drop. ➔

Table 20. Current and future energy demand of the case study hotel building based on CSIRO weather database.

		Water heating	Heating site energy	Space cooling	Cooling site energy	Lighting site energy	Appliances site energy	Pumps & fans	Total site electricity demand	Natural gas demand	Cooling site energy increase	Heating site energy increase	Total site electricity increase
Location	Period	(kWh/m²)									%		
Adelaide	Present	10.9	10.9	64.2	32.1	16.3	9.1	17.5	85.9	10.9	-	-	-
	2030	10.9	9.1	71.6	35.8	16.3	9.1	17.9	88.2	10.9	11.5	-16.4	2.7
Brisbane	Present	10.9	4.2	93.2	46.6	16.3	9.1	19.1	95.3	10.9	-	-	-
	2030	10.9	3.5	101.2	50.6	16.3	9.1	19.7	99.2	10.9	8.6	-18.4	4.0
Canberra	Present	10.9	24.1	46.8	23.4	16.3	9.1	18.6	91.5	10.9	-	-	-
	2030	10.9	21.5	51.2	25.6	16.3	9.1	18.5	91.0	10.9	9.4	-10.6	-0.5
Darwin	Present	10.9	0.0	177	88.5	16.3	9.1	26.5	140.4	10.9	-	-	-
	2030	10.9	0.0	187	93.5	16.3	9.1	27.5	146.4	10.9	5.6	-	4.3
Melbourne	Present	10.9	17.8	41.2	20.6	16.3	9.1	16.7	80.5	10.9	-	-	-
	2030	10.9	15.3	47.4	23.7	16.3	9.1	16.8	81.2	10.9	15.0	-14.4	0.8
Perth	Present	10.9	9.0	79.7	39.8	16.3	9.1	18.7	92.9	10.9	-	-	-
	2030	10.9	7.4	88.4	44.2	16.3	9.1	19.2	96.2	10.9	11.1	-17.4	3.6
Sydney	Present	10.9	5.8	66.6	33.3	16.3	9.1	16.7	81.2	10.9	-	-	-
	2030	10.9	4.6	73	36.5	16.3	9.1	17.1	83.6	10.9	9.6	-19.4	3.1
Hobart	Present	10.9	21.4	27	13.5	16.3	9.1	16	76.3	10.9	-	-	-
	2030	10.9	19.5	30	15	16.3	9.1	16	75.9	10.9	11.1	-9.0	-0.6

Table 21. The comparison between the base case and fully retrofitted scenario.

		Water heating	Space heating	Space cooling	Cooling site energy	Lighting site energy	Appliances site energy	Pumps & fans	Total site electricity demand	Natural gas demand	Cooling site energy increase	Heating site energy increase	Total site electricity increase
Location	Period	(kWh/m²)									%		
Perth Base case	Present	10.9	9.0	79.7	39.8	16.3	9.1	18.7	92.9	10.9	-	-	-
	2030	10.9	7.4	88.5	44.3	16.3	9.1	19.2	96.4	10.9	11.3	3.8	-8.0
Perth retrofitted	Present	2.1	4.8	22.0	5.4	10.1	9.1	10.2	41.6	0.0	-	-	-
	2030	2.1	3.9	26.7	6.5	10.1	9.1	10.3	42.0	0.0	20.4	1.0	-13.0

Also, the results show that the cooling requirements in 2030 can be reduced by 85.3% in the case of a complete refurbishment of the hotel building. The resulting reduction in the total electricity demand of the building is 56.4%.

6.4. Discussion and recommendations

We established a baseline for energy consumption, and then we undertook a simulation based on various energy efficiency upgrades, with assumptions following the relevant standards and regulations. The findings suggest that heating and cooling energy usage is relatively high. Electricity usage of appliances, HVAC&R and DHW system fans and pumps, lights, and the energy required for hot water generation are also significant. The following suggestions are made to reduce energy consumption:

- The simulations proved that the natural lighting levels in the studied spaces are high.
- The artificial lighting analysis showed that the replacement of inefficient light sources and the use of daylight linked controls can result in a reduction of the total lighting load (kW) and the annual energy (kWh) ranging from 55 to 80%.
- Installation of external shading devices to prevent excessive solar loads in the cooling period through the glazed surface of the windows.
- Installing cutting-edge Building Automation and Controls, as well as a Building Management System, to integrate the use of HVAC&R, DHW, and lighting systems, considering both weather conditions and operating requirements.
- Installation of ceiling fans and incorporation of night ventilation patterns into the HVAC&R system's operation to reduce cooling demands.
- Installation of water-efficient faucets to save water and the energy required for hot water production. In addition, shower drain water heat recovery systems should be installed to make use of waste heat generated during showers.
- Installation of a ground source heat pump (GSHP) which to meet the space heating, cooling and DHW demands so as to reduce final energy requirement.

In conclusion, a complete renovation package that includes the installation of a GSHP, water-efficient faucets, DHW heat recovery exchangers and ceiling fans, combined with an upgrading of the lighting system and the use of night-time ventilation and window shading patterns, all linked to the implementation of a state-of-the-art BAC system, can result in a 59.9% energy savings, resulting in an energy consumption of 41.6 kWh/m^{2}a, when compared to the baseline of 103.8 kWh/m^{2}a. Considering the simulated portion of the building, the NABERS rating can be improved from 3.0 to 4.38 stars (estimated). It is noted that the existing building is already being improved by the property since the last NABERS rating. ■

References

1. UK Green Building Council, *Climate Change*, in https://www.ukgbc.org/climate-change/ [accessed 7 August 2021].
2. Granwal, L. *Travel and tourism industry in Australia – statistics & facts*. 2021.
3. Melbourne City Council. *Energy Wise Hotels*. 2007.
4. Peel, M.C., B.L. Finlayson, and T.A. McMahon, *Updated world map of the Köppen-Geiger climate classification*. Hydrol. Earth Syst. Sci., 2007. 11(5): p. 1633-1644.
5. Bureau of Meteorology. *Climate statistics for Australian locations*, http://www.bom.gov.au/ [Accessed 8 August 2021].
6. Australian Building Codes Board, *National Construction Code Volume One, Amendment 1*,. 2019.
7. NABERS, *Find a current rating*. 2021: www.nabers.gov.au/ratings.
8. Mirsadeghi, M., et al., *Review of external convective heat transfer coefficient models in building energy simulation programs: Implementation and uncertainty*. Applied Thermal Engineering, 2013. 56(1): p. 134-151.
9. British standard, BS EN ISO 10456:2007, in *Building materials and products — Hygrothermal properties – Tabulated design values and procedures for determining declared and design thermal values*. 2007.
10. International Organization for Standardization, ISO 6946:2007, in *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*. 2007.
11. University of Wisconsin, *TRNSys, TRNBuilt Windows Database* [Accessed 11 August 2021].
12. ASHRAE, *Ashrae Handbook, in Heating, Ventilating, and Air-Conditioning APPLICATIONS*. 2015.
13. ASHRAE, *Fundamentals Handbook*. 2017.
14. Standards Australia, AS 1668.2, *Amendment 1, The use of ventilation and airconditioning in buildings – Mechanical ventilation in buildings, in Mechanical ventilation in buildings*. 2012.
15. Daly, D., P. Cooper, and Z. Ma, *Understanding the risks and uncertainties introduced by common assumptions in energy simulations for Australian commercial buildings*. Energy and Buildings, 2014. 75: p. 382-393.
16. ASHRAE, ANSI/ASHRAE Standard 55, in *Thermal Environmental Conditions for Human Occupancy*. 2020: https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy.
17. TRNSYS, *A transient systems simulation program*. 2017, https://sel.me.wisc.edu/trnsys/index.html.
18. Yousefi, H., et al., *Feasibility study and economical evaluations of geothermal heat pumps in Iran*. Geothermics, 2018. 72: p. 64-73.
19. Moss, R.H., N. Nakicenovic, and B.C. O'Neill, *Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies*, ed. IPCC EXPERT MEETING REPORT. 2008, IPCC.

Attachment 1

Fig. A1. Exterior view of the building.

Fig. A2. Exterior view of the building.

Fig. A3. Exterior view of the building.

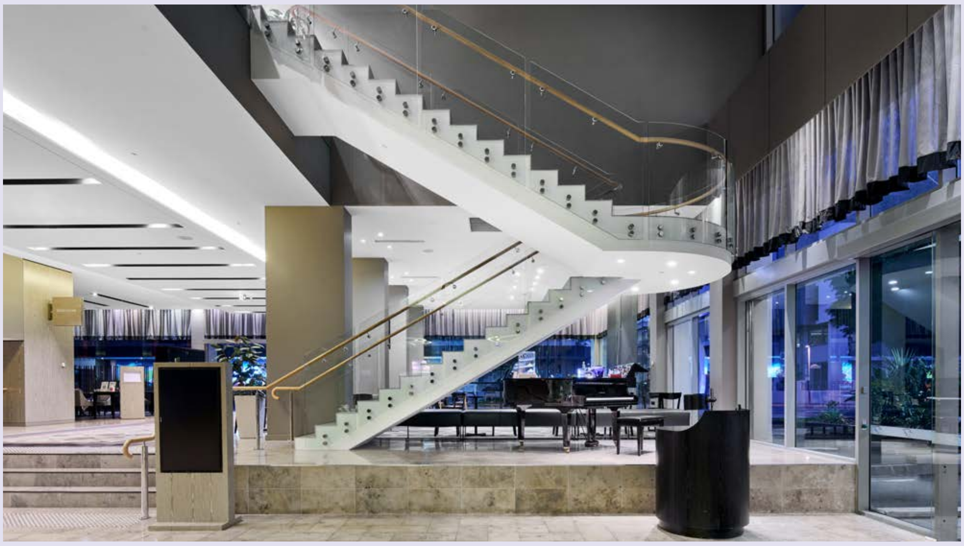

Fig. A4. Lobby of the building.

Fig. A5. Interior view of the building.

Fig. A6. Interior view of the building.