Office

Energy Efficiency Training and Information Project

Commercial Buildings

Spring Hill
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

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Cover image:
Office in Spring Hill in the CBD of Brisbane, Queensland.

Contents

1. Executive Summary

A complete renovation package ... can lead to energy savings of 47.9%

The World climate is changing due to climate change, and existing buildings need to adapt to the upcoming climatic conditions. Almost 80% of 2050 buildings already exist today [1], and we must prioritise improving the efficiency of buildings we already have.

The largest fraction of the energy consumption in an office building is related to energy uses for heating, ventilation, air conditioning and refrigeration (HVAC&R) applications, lighting, and appliances [2]. This report tackles the operational energy consumption challenge for existing offices, using a real-life case study to visualise the impact of each energy optimisation strategy. A high-level framework prioritising different building enhancement methods is presented in this report.

An office building is selected as a case study to explore opportunities to reduce energy consumption. A dynamic thermal model of the office buildings is simulated with the TRNSys software tool, reproducing the actual building's thermal features and building services.

This report summarises the findings of the performed analysis on the existing conditions. It provides recommendations for improving the centre conditions and minimising the energy consumption in the office located in Spring Hill, Qld. The structural and energy performance features of the studied building are representative of the typology and construction of the early 2000s.

The analysis showed that many continuously occupied spaces are autonomous (receive enough daylight to perform the required tasks without artificial lighting) for more than 50% of the occupied time of the day. The spaces facing East could significantly benefit from the addition of exterior shading.

The baseline scenario to determine possible interventions is based on the fact that consumption for cooling requirements is the main problem to tackle since the cooling demand is 154.3 kWh/m²a. Still, the consumption of lighting and appliances is also important, with 15.9 kWh/m²a and 31.3 kWh/m²a, respectively. Heating and domestic hot water electricity consumption requirements are not significant.

Hence, the main effort lies in reducing cooling and lighting requirements. The windows and glazed areas, in general, are not up to date with contemporary standards, and since they account for a significant percentage of the envelope's overall surface, their contribution to energy losses in the cooling period is significant.

Based on the modelling of the buildings thermal properties the following recommendations are considered feasible:

- Replace existing windows with new windows with solar control (i.e., low solar heat gain coefficient) to reduce solar loads in summer and achieve air-tightness throughout the year.
- Installation of ceiling fans, the introduction of night ventilation patterns in the operation of the HVAC&R system and window shading during the cooling period 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.
- Finally, installation of a solar reflective coaging with albedo of 0.75 (i.e., solar absorbance 0.25).
- East-facing windows should be shaded with exterior elements, such as vertical louvres, to reduce the natural lighting levels close to the windows, minimise the glare issues and result in more uniform lighting levels in the open-plan office spaces. →

In conclusion, a complete renovation package that includes replacement of the building's windows and glazed surfaces, combined with an upgrading of the lighting system, the installation of ceiling fans and the use of night-time ventilation and window shading patterns, linked all with the implementation of a state-of-the-art BAC system, can lead to energy savings of 47.9%, resulting in an energy consumption of 45.2 kWh/m²a, compared to the baseline of 86.8 kWh/m²a. Besides, a PV system of 30 kWp could be installed in the available roof space, producing approximately 10.5 kWh/m²a.

The building is currently rated 4.5 stars NABERS for energy, and is already performing close to 5 stars. Considering the simulated portion of the building, with the proposed interventions, the NABERS rating can be improved from 4.92 to 6.31 stars (i.e., comfortably 6 stars), computed with NABERS reverse calculator based on simulation results. ■

2. Regulations, Standards, and guidelines

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

- National Construction Code of Australia 2019 Volume One.
- ANSI/ASHRAE 62.1-2019 Ventilation for acceptable indoor air quality
- ANSI/ASHRAE 55-2020 Thermal environmental conditions for human occupancy
- ASHRAE Handbook Fundamentals 2017, Chapter 18: Non-residential cooling and heating load calculation
- 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.
- tAS/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 office building built in Australia in the 2000s, representative of many other offices constructed in the same period. In fact, the aim of selecting a case study office building is the potential for methodology replication and findings expansion to other similar buildings.

Clearly, one sample office building cannot completely fit all similar buildings. Each office 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 an office building is a complicated task. It starts with determining the building's constructional 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.) 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. Office Building in Spring Hill

4.1. Case study description

4.1.1. Climate

The building is located at in Spring Hill, Qld , in the CBD of Brisbane. In Köppen's climate classification, Brisbane is categorised as Cfa, meaning that it has a humid subtropical climate [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. The primary climatic information for Brisbane is illustrated in Figure 1. →

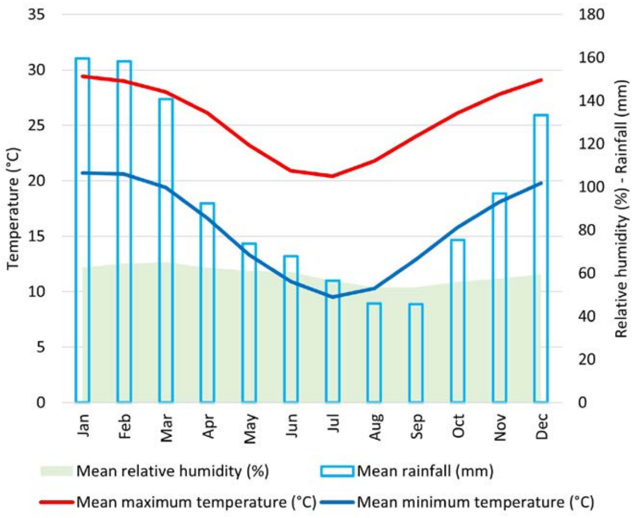

Figure 1. Climatic data for Brisbane [4].

4.1.2. Building description

This case study office building is in Brisbane CBD, and it was completed in the early 2000s. In 2015, the mechanical services of the building were retrofitted. The digital National Construction Code of the case study building is Class 6: office building used for professional or commercial purposes' [5]. The office building has a capacity of 225 people, and the under-ceiling height of each floor is 3.24m. Figure 3 illustrates the treemap chart of the gross internal area of case study buildings. The total gross floor area is 3,839 m².

4.1.3. NABERS rating

The building was certified by NABERS Energy 4.5 star in June 2021. Based on the NABERS database, this building energy performance is categorised between 'good' and 'excellent'. Its annual energy use is 269,059 kWh (90.5 kWh/m²). The annual greenhouse gas emissions for the building are 250,225 kg CO_2 (84.4 kg CO_2/m²). →

Figure 2. Northern view of case study building.

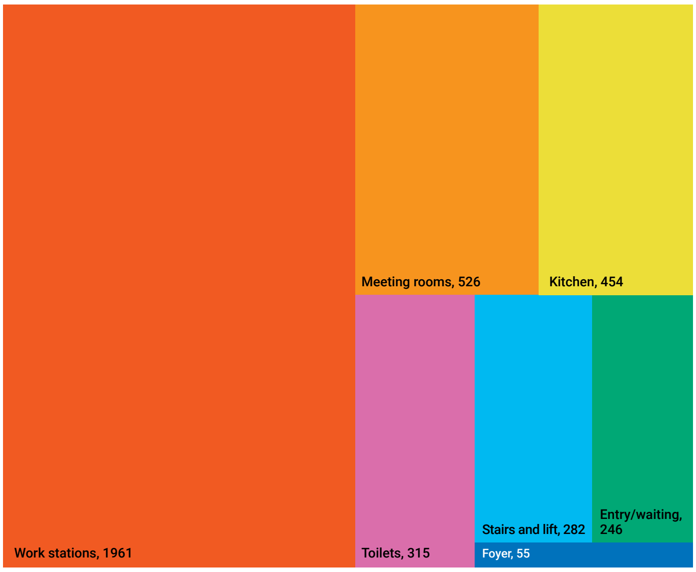

Figure 3. Gross floor divided area of case study building.

4.1.4. Energy consumption and sources

One of the best ways to decrease the operational cost of buildings is to improve energy efficiency. This building does not use any renewable resources. Electricity is used for HVAC&R purposes, lighting, appliances, water heating.

4.2. Building modelling input parameters

The modelling parameters combine 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

The case study office building has a capacity of 225 people [6], and the occupancy schedule is selected based on the national code of construction [5].

4.2.2. Geometric data

The case study building has six floors. Table 1 shows the main purpose of each part of the building.

4.2.3. Building Components

A significant part of energy consumption is to maintain comfort leaks through the building envelope. As a key step to assess the potential benefits of improving windows, walls, roofs and floors, the current thermal performance should be determined. Surveying the case study office building, the thermal properties of the building envelope is 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 External wall of the case study building includes three main layers. There are: concrete blocks as outer layer, an airgap in the middle, and plasterboard inside. The R-value of the external walls is 0.580 m².K/W, and the solar absorbance coefficient is 0.60. Also, using the average annual wind velocity in Brisbane (2.8 m/s) [4], the convective heat transfer coefficient is calculated as 17.6 W/(m².K) [7].

➔

Table 1. Building geometric information.

Spaces	Air-conditioned area (m²)	Not air-conditioned area (m²)	Gross floor area (m²)
Foyer	55	0	55
Stairs and lifts	282	0	282
Entry/waiting	246	0	246
Kitchen/breakout	454	0	454
Meeting rooms	526	0	526
Workstations	1,961	0	1,961
Toilets	0	315	315
Total	3,524	315	3,839

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
Air space	100	-	-	-	0.18	[8]	Section 5.3, page 5
Plaster board	10	0.17	1	880	-	[5]	Section J, page 388

R-value: 0.580 m^2.K/W

4.2.3.2. Roof

The roof of the case study community centre consists of 6 layers. There is waterproofing on the top layer. After that, a concrete slab and an airgap are in the middle. Mineral wool and plasterboard are the inside layers. The R-value of the roof is 1.285 m².K/W, and the solar absorbance coefficient is 0.70 (based on data from the literature). Also, using average annual wind velocity (2.8 m/s) [4], the convective heat transfer coefficient is calculated as 17.6 W/(m².K) [7]. Only the mechanical room is covered by metal roof sheeting.

4.2.3.3. Windows

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

4.2.4. Domestic hot water

The required hot water for the office building in Spring Hill is calculated based on Table 2m, NCC volume 1 page 355 [5]. Therefore, considering the need for a 50°C temperature increase and water heat capacity (4.19 KJ/kg.°C), and occupancy schedule of the office building, 132.0 MJ heating energy is required for daily heating domestic water. ➔

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
Waterproofing	4	0.23	1	1100	-	[9]	Section 8.3, page 5
Concrete	200	0.85	1	1250	-	[5]	Section J, page 388
Air space	100	-	-	-	0.16	[8]	Section 5.3, page 5
Mineral wool	20	0.042	1.03	50	-	[9]	Section 8.2, Table 4, p 18
Plaster board	10	0.17	1	880	-	[5]	Section J, page 388

R-value: 1.285 m^2.K/W

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

Shading type & material	External Shading is applied on the entrance on the northern side of building		
Glazing	**Value**	**Unit**	**Ref.**
Thickness	10	mm	[10]
Glazing U-value	2.78	(W/m².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	46	%	
Glazing type	Double glazed	N/A	

Table 5. Domestic hot water.

Demand-side	Occupancy	Unit Hot water demand	Daily hot water demand (lit)
	225	4 lit/person	900

4.2.5. Internal gains

The information regarding the thermal comfort in the studied office building is provided by the building facility management. Lighting and personal heat gain assumptions in the model are based on Australian and international standards.

4.2.6. Ventilation and infiltration

The supplied fresh air flow rates and the infiltration rates are assumed based on international standards.

4.2.7. Thermal Comfort

The thermal comfort parameters have been considered as in Table 8, using the PMV method, according to the National Construction Code.

4.2.8. Energy resources and HVAC&R systems

The total energy demand of this building is provided by electricity. Based on the information supplied by building facility management, the coefficient of performance (COP) and energy efficiency ratio (EER) of the heating and cooling systems are considered as 2.5 and 4.5, respectively. The foyer, hall and kitchen are air-conditioned by split systems. →

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

	Building	Value	Unit	Ref.	Section and page
Cooling setpoint temperature	All	23	°C	[6]	Annex O, page 53
Heating setpoint temperature	All	22	°C	[6]	Annex O, page 53t
Personal latent gain	All	55	W/person	[11]	Chapter 18, page 4
Personal sensible gain	All	75	W/person	[11]	Chapter 18, page 4
Appliances and equipment gain	All	11	W/m²	[5]	Section J, page 355
Lighting gain	Office spaces	4.5	W/m²	[5]	Section J, page 379
	Foyer	9.0	W/m²		
	Stairways	5.0	W/m²		
	Corridors	5.0	W/m²		
	Toilets	3.0	W/m²		

Table 7. Ventilation and infiltration.

	HVAC&R system	Value	Unit	Ref.	Section and page
Fresh air	On	10	L/s.person	[12]	Appendix A, Table A1
	Off	0	L/s.person		
Infiltration	On	1	ACH	[13]	Section 2.7
	Off	0.5	ACH		

Table 8. Comfort factors.

Factor	Value	Unit	Ref.	Section and page
Clothing Factor	Summer 0.6 – Winter 1	clo	[14]	Section 5, page 8
Metabolic rate	1.0	Met	[14]	Section 5, page 7
Relative air velocity	Less than 0.2	m/s	[14]	Section 5, page 11

4.2.9. Schedules

The occupancy schedules, lighting and appliances of the case study office building are selected based on pages 348-349 of the Building Code of Australia (Vol 1) with some modifications due to the building facility management documents [5]. →

Table 9. Occupancy, lighting and appliances schedules.

Time	Weekday occupancy	Weekday lighting	Weekday equipment	Weekend occupancy	Weekend lighting & equip.	Air-conditioning
00:00-01:00	0.00	0.10	0.10	0.00	0.10	Off
01:00-02:00	0.00	0.10	0.10	0.00	0.10	Off
02:00-03:00	0.00	0.10	0.10	0.00	0.10	Off
03:00-04:00	0.00	0.10	0.10	0.00	0.10	Off
04:00-05:00	0.00	0.10	0.10	0.00	0.10	Off
05:00-06:00	0.00	0.10	0.10	0.00	0.10	Off
06:00-07:00	0.00	0.10	0.10	0.00	0.10	Off
07:00-08:00	0.10	0.40	0.65	0.00	0.10	On
08:00-09:00	0.20	0.90	0.80	0.05	0.10	On
09:00-10:00	0.70	1.00	1.00	0.05	0.10	On
10:00-11:00	0.70	1.00	1.00	0.05	0.10	On
11:00-12:00	0.70	1.00	1.00	0.05	0.10	On
12:00-13:00	0.70	1.00	1.00	0.05	0.10	On
13:00-14:00	0.70	1.00	1.00	0.05	0.10	On
14:00-15:00	0.70	1.00	1.00	0.05	0.10	On
15:00-16:00	0.70	1.00	1.00	0.05	0.10	On
16:00-17:00	0.70	1.00	1.00	0.05	0.10	On
17:00-18:00	0.35	0.80	0.80	0.00	0.10	On
18:00-19:00	0.10	0.60	0.65	0.00	0.10	On
19:00-20:00	0.05	0.60	0.55	0.00	0.10	Off
20:00-21:00	0.05	0.50	0.10	0.00	0.10	Off
21:00-22:00	0.00	0.10	0.10	0.00	0.10	Off
22:00-23:00	0.00	0.10	0.10	0.00	0.10	Off
23:00-00:00	0.00	0.10	0.10	0.00	0.10	Off

4.3. Evaluating Lighting Condition

This section aims 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 the case study office building in Brisbane. 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 data provided by the building facility management were general architectural drawings without details of the layout of each floor. More specifically, the layout of the interior spaces of the ground floor was provided, while the drawings of the upper levels included level 3 layout, part of level 2 and part of level 5. Information about the artificial lighting equipment in the building was not provided. Due to the lack of information about the interior layout of each floor, the layout of level 3 has been adopted for levels 1-5. The exterior of the building and the neighbouring structures were identified from Google Maps. 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 [5]. Based on this comparison, areas with installed power that exceeded the required were identified. Based on the findings of the assessment, two scenarios were tested. These scenarios are described in Table 10. →

Table 10. Scenarios for reduced energy consumption for lighting.

Base-case scenario	The Lighting Power Density (W/m²) is the maximum allowed by NCC for the type of space. No lighting controls are used.
Scenario 1	The Lighting Power Density (W/m²) is reduced with the use of more efficient sources. No lighting controls are used.
Scenario 2	Scenario 2 has the same lighting power density as Scenario 1; however, daylight controls are used in all spaces with daylight availability.

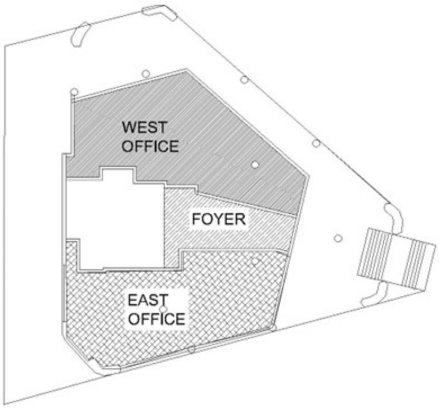

Figure 4. Coding of ground floor spaces.

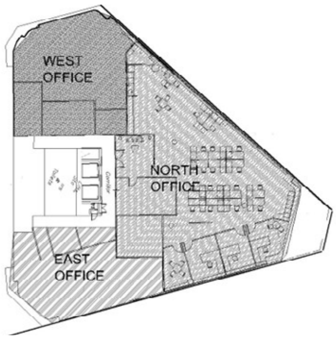

Figure 5. Areas on levels 1-5.

Figure 6. Coding of spaces of levels 1-5.

4.3.2. Lighting analysis result

The results are analysed in two parts:

1. the assessment of the existing natural lighting conditions and the artificial lighting conditions and energy consumption for lighting, and
2. The proposed scenarios for improving lighting conditions and minimising the energy consumption for lighting.

4.3.2.1. Natural lighting

The building has stripes of horizontal openings facing east and west and smaller windows facing south. There are no external shading elements. However, the glazing used is tinted to reduce the light transmission and probably the solar gains as well. The natural lighting has been analysed in levels 1, 3 and 5, as the identical interior layout provides comparable results in levels 2 and 4.

Very few continuously occupied spaces in the building have average Daylight Factors above 2%. These are the small-area offices or meeting rooms close to the perimeter. The main open-plan office spaces have Daylight Factors ranging from 0.5 to 5%, with the “darkest” being the spaces of the west office and the lower floors.

The Spatial Daylight Autonomy (sDA) of the spaces shows that the spaces have sufficient light from the windows, despite the low Daylight factors. The open plan working spaces of the North and East offices will be autonomous for more than 50% of the occupied time, while the open space of the West office will be autonomous for much less time (Table 11). Spaces close to the east façade will receive direct sunlight for a few hours every morning and would benefit from interior shading (which might already be present) or exterior shading devices. These spaces have Annual Sunlight Exposure (ASE) of over 10%, as seen in Table 11.

4.3.2.2. Artificial lighting

Since no information about the artificial light sources, lighting power density, and controls used in the building was provided, it was assumed that the artificial lighting system of the building complies with the NCC. However, lower power density can be achieved with more efficient light sources, and further energy savings can result with the use of daylight linked controls.

Table 11. Average Daylight Factor (DF) and Spatial Daylight Autonomy (coding according to Figure 4 and Figure 6).

Level	Space	Area (m²)	Average DF (%)	Uniformity	sDA (%)	ASE (%)
Ground floor	Foyer	3.50	0.59	0.85	66.67	0.00
	East office	63.60	3.16	0.25	100.00	10.67
	West office	3.00	0.77	0.92	100.00	0.00
Level 1	East small office	3.50	0.59	0.85	66.67	0.00
	East open plan office	63.60	3.16	0.25	100.00	10.67
	East reception	3.00	0.77	0.92	100.00	0.00
	North reception	7.90	0.12	0.08	0.00	0.00
	North open plan office	119.70	1.71	0.33	99.33	0.34
	North meeting room	13.20	0.26	0.63	0.00	0.00
	Boardroom	11.30	0.14	0.61	0.00	0.00
	North office 1	7.10	0.99	0.62	100.00	0.00
	North office 2	7.70	4.29	0.42	100.00	16.67
	North office 3	7.90	3.87	0.45	100.00	0.00
	North small meeting room	5.50	3.38	0.41	100.00	0.00
	West reception	4.20	0.09	0.81	0.00	0.00
	West office	7.10	1.33	0.84	100.00	0.00
	West open plan office	51.50	0.54	0.40	25.36	0.00
Level 3	East small office	3.50	0.81	0.94	100.00	0.00
	East open plan office	63.60	4.40	0.25	100.00	34.00
	East reception	3.00	0.99	0.90	100.00	0.00
	North reception	7.90	3.71	0.56	0.00	0.00
	North open plan office	119.70	1.73	0.35	99.33	0.00
	North meeting room	13.20	0.29	0.73	0.00	0.00
	Boardroom	11.30	0.18	0.55	0.00	0.00
	North office 1	7.10	1.31	0.54	100.00	0.00
	North office 2	7.70	5.56	0.44	100.00	50.00
	North office 3	7.90	5.46	0.50	100.00	55.00
	North small meeting room	5.50	5.05	0.43	100.00	38.46
	West reception	4.20	0.10	0.86	0.00	0.00
	West office	7.10	2.32	0.84	100.00	0.00
	West open plan office	51.50	0.63	0.50	28.26	0.00
Level 5	East small office	3.50	1.26	0.94	100.00	0.00
	East open plan office	63.60	5.14	0.30	100.00	34.67
	East reception	3.00	1.57	0.88	100.00	0.00
	North reception	7.90	0.14	0.67	0.00	0.00
	North open plan office	119.70	1.85	0.38	99.66	0.00
	North meeting room	13.20	0.32	0.65	0.00	0.00
	Boardroom	11.30	0.23	0.61	0.00	0.00
	North office 1	7.10	1.44	0.57	100.00	0.00
	North office 2	7.70	5.96	0.50	100.00	66.67
	North office 3	7.90	5.92	0.53	100.00	60.00
	North small meeting room	5.50	5.58	0.47	100.00	53.85
	West reception	4.20	0.13	0.80	0.00	0.00
	West office	7.10	5.46	0.66	100.00	0.00
	West open plan office	51.50	0.91	0.41	74.64	0.00

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, 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 7).

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. [15]. After importing the case study office building model into TRNSys, all building structural parameters (walls, windows, doors, etc.), schedules (occupancy, lighting, and appliances), internal loads, and HVAC&R systems (setpoint, ventilation, infiltration, and comfort) were defined in TRNBuild. The model was finalised by adding the proper climatic data (temperature, relative humidity, radiation, etc.) using the CSIRO weather database. →

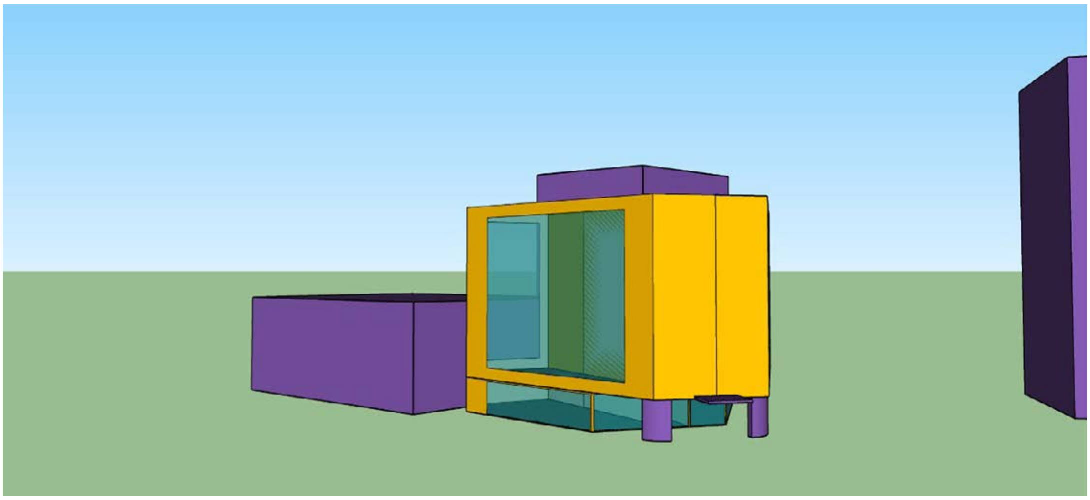

Figure 7. SketchUp model

5.3. Retrofit approaches

Evaluating the energy performance of a building is a complicated task. It initiates with determining the building's constructional characteristics, including the efficiency of the building envelope, lighting, HVAC&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.), 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 in accordance with NCC, ASHRAE and ISO standards. Simulations were carried out on an hourly basis, 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 next step of the study aimed 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 the lack of information about the installed lighting sources, the base-case scenario has the maximum allowed by NCC for the type of space. Proposed scenarios reduced the total lighting load (kW) and the annual energy (kWh), ranging from 32 to 92%.

5.3.2. Windows retrofit

The windows now installed in the case study office building are single glazed with aluminium frame. The thermal break (insulation within a window) is a constant barrier between the inside and outside window frames that avoid conductive thermal energy loss. This barrier securely bonds the interior and exterior metal frames of the window. This thermal break creates thermal energy loss resistance and, combined with double-pane glazing, keeps the interior space of the window at a more comfortable temperature. The proposed window is thermally-broken aluminium framed, double glazed, with Low-E external glass pane, with an average U-value of 1.5 W/m²K, an SHGC value of 0.33 and Air-tightness values of Class 3 with less than 2.5 L/s.m² at 100 Pa. The latter reduces the infiltration rate of the building to 0.30 1/h.

5.3.3. Cool roof coating

Insulation is a cost-effective way to save energy and improve the indoor environment. Concerning the painting of the external roof with a new coating having an albedo of 0.75 (i.e., solar absorbance) or replacement of the roofing membrane with a solar reflective one, if the existing one is deteriorated.

5.3.4. Ceiling fans

Ceiling fans are a cost-effective and straightforward method to enhance the indoor air quality in summer and 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 to be 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. →

Table 12. Illumination power density and energy consumption for the base case and the proposed scenarios.

			Base Case	Scenario 1	Scenario 2	
	Space	Area (m²)	Max. illumination power density - NCC (W/m²)	Illumination power density (W/m²)	Illumination power density (W/m²)	Percentage of energy savings (%)
Ground floor	Foyer	52.80	9.00	7.00	3.17	32.60
	East Office	149.70	4.50	2.50	0.90	80.74
	West Office – Supermarket	151.6	14.00	10.00	2.78	75.20
1st floor	East Office	108.60	4.50	2.50	0.70	85.04
	North Office	304.60	4.50	2.50	0.77	83.52
	West Office	135.30	4.50	2.50	0.90	80.82
2nd floor	East Office	108.60	4.50	2.50	0.46	90.19
	North Office	304.60	4.50	2.50	0.78	83.37
	West Office	135.30	4.50	2.50	0.89	80.99
3rd floor	East Office	108.60	4.50	2.50	0.45	90.34
	North Office	304.60	4.50	2.50	0.76	83.80
	West Office	135.30	4.50	2.50	0.86	81.62
4th floor	East Office	108.60	4.50	2.50	0.41	91.20
	North Office	304.60	4.50	2.50	0.63	86.58
	West Office	135.30	4.50	2.50	0.79	83.11
All floors	Toilets	129	3.00			
	Stairways	113.5	5.00			
	Corridors	181.5	5.00			

5.3.5. Auto night ventilation, window shading

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 K, the outdoor temperature is greater than 15°C, and indoor temperature is greater than the heating setpoint. Window shading is modelled by applying a shading factor of 0.7 during the cooling period (October-April).

5.3.6. 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) 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 13 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 Standard 15232, as can be seen in Table 14. This approach allows a rough evaluation of the impact of BACS systems on the energy performance of the building in a year. The impact of each function (e.g. cooling/heating and lighting) is calculated using the pertinent standards. →

Table 13. 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. Class C is the estimated class for the baseline, and it is considered that class A is reached after the improvements.

- Individual room controls with communication between them and the chillers/boilers and air handling units
- 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%.

5.3.7. PV system

Installation of a 30 kWp net metering PV system on the external roof to cover part of the electricity consumption of the building. Considering the roof's space constraints and its partial coverage by other facilities, a mixed east and west orientation of the PV panels is considered. The installed PV efficiency is considered to be 1350 kWh/(kWp*a), and the PV system would be able to cover around 25% of the total electricity consumption of the building after retrofit.

Table 14. Functions and assignments to energy performance classes for non-residential buildings. Standard automation is used as reference.

	BAC efficiency factors $f_{BAC,hc}$ BAC efficiency factors $f_{BAC,e}$							
	D	C	B	A	Energy saving adopting classes			
Building use	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 case study office building simulation in Spring Hill is presented in this section. Hourly energy demand for heating and cooling (sensible and latent) is illustrated in Figure 8. Also, the monthly energy demand is presented in Figure 9. →

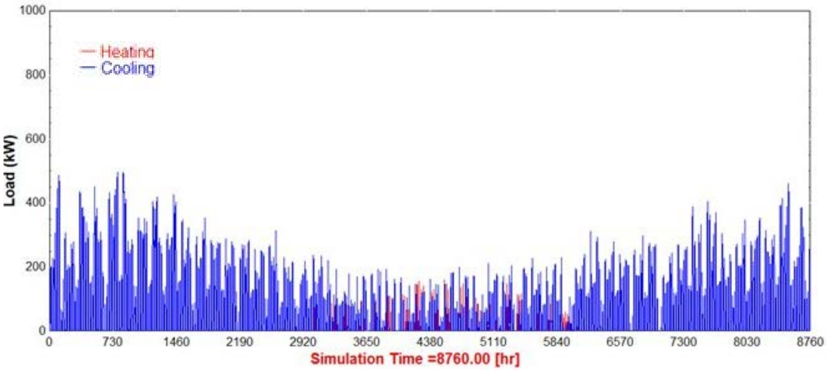

Figure 8. Hourly energy demand for HVAC&R purposes.

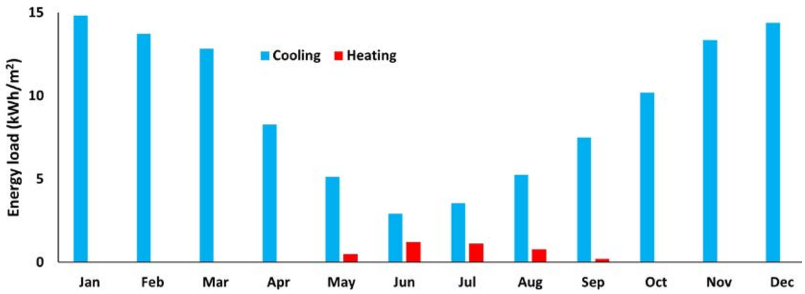

Figure 9. Monthly energy demand for HVAC&R purposes.

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 10 and 12). Also, the amount of heating and cooling energy is illustrated in Figures 11 and 13).

The monthly energy gain of the office building and the influence of each factor in the total energy demand is presented in Figure 14. ➔

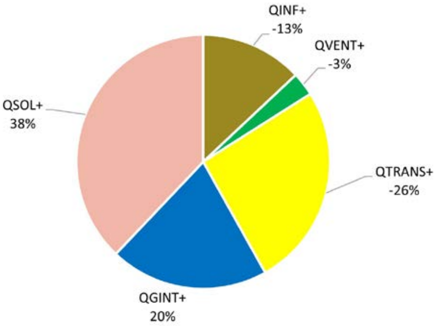

Figure 10. Whole building energy gain – heating season (May-September).

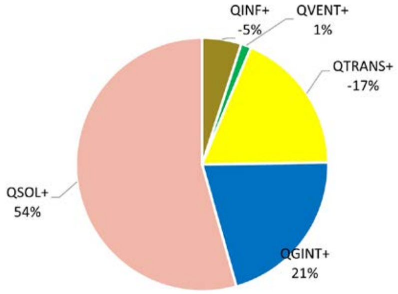

Figure 12. Whole building energy gain – cooling season (October-April).

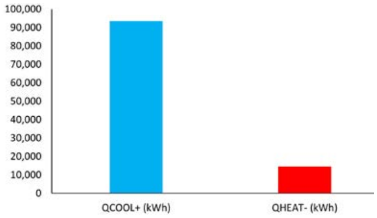

Figure 11. Whole building energy gain for heating and cooling load- heating season (May-September).

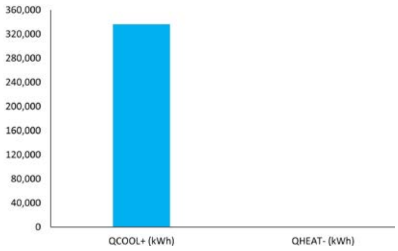

Figure 13. Whole building energy gain for heating and cooling load- cooling season (October-April).

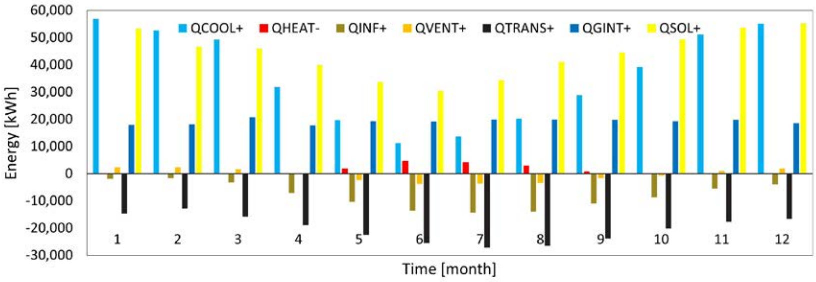

Figure 14. Monthly building energy gain.

6.2. Retrofit scenarios

The investigated retrofit cases in this report are presented in Table 15.

Between the presented scenarios, Case G has the most retrofitting steps. Table 16 shows the influence of different retrofitting cases on heating and cooling loads. Also, Table 17 demonstrates the impact of different retrofit scenarios on electricity consumption in the case study office building. The result shows that by improving the building condition, 47.9% of the required electricity can be reduced. A more detailed illustration of the retrofitting impact is presented in Figures 15-17.

➔

Table 15. 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. Heating and cooling setpoint and setback temperatures are set according to the NCC.
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:** Power density of lighting scenario 1 combined with continuous dimming of the light sources depending on daylight availability.
Case C	**Case B + 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 D	**Case C + Installation of ceiling fans:** Ceiling fans are modelled by increasing the cooling setpoint temperature to 26°C.
Case E	**Case D + night ventilation + window shading:** 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, outdoor temperature is greater than 15°C, and indoor temperature is greater than the heating setpoint. Window shading is modelled by applying a shading factor of 0.7 during the cooling period (October-April).
Case F	**Case E + cool roof coating:** New solar reflective coating with albedo 0.75 (i.e., solar absorbance 0.25).
Case G	**Case F + windows retrofit:** New windows are aluminium framed, with a thermal break in the frame, double glazed, with low-e external glass pane, with an average U-value of 1.50 W/m²K, a glazing g-value of 0.33 and Air-tightness values of Class 3 with less than 9 m³/h.m² at 100 Pa. The latter reduces the infiltration rate of the building to 0.30 1/h.
*	**PV system:** Installation of a 30 kWp net metering PV system on the external roof to cover part of the electricity consumption of the building. Taking into account the space constraints of the roof and its partial coverage by other facilities a mixed east and west orientation of the PV panels is considered. The installed PV efficiency is considered to be 1350 kWh/(kWp*a) and the PV system would be able to cover around 25% of total electricity consumption of the building after retrofit.

Table 16. Simulation results – Heating and cooling loads

	Heating loads	Cooling loads	Heating + Cooling	Heating loads	Cooling loads	Heating + Cooling
	kWh/(m^{2}a)			difference (%)		
Baseline	3.6	154.3	157.8	-	-	-
Case A (Baseline + lighting scenario 1)	3.8	149.7	153.5	6%	-3%	-3%
Case B (Baseline + lighting scenario 2)	4.0	145.8	149.8	12%	-6%	-5%
Case C (Case B + automation & controls)	4.0	145.8	149.8	12%	-6%	-5%
Case D (Case C + ceiling fans)	3.7	104.0	107.7	5%	-33%	-32%
Case E (Case D + night ventilation +window shading)	3.9	53.2	57.1	11%	-66%	-64%
Case F (Case E + cool roof coating)	4.1	51.7	55.7	15%	-67%	-65%
Case G (Case F + windows retrofit)	2.3	38.1	40.4	-36%	-75%	-74%

Table 17. Simulation results – Site energy.

	Heating	Cooling	Lighting	DHW	Appliances	Total	Total difference	Total difference
	kWh/(m^{2}a)							%
Baseline	1.4	34.3	15.9	3.9	31.3	86.8	0.0	0%
Case A (Baseline + lighting scenario 1)	1.5	33.3	9.5	3.9	31.3	79.4	-7.4	-8.5%
Case B (Baseline + lighting scenario 2)	1.6	32.4	3.4	3.9	31.3	72.6	-14.2	-16.4%
Case C (Case B + automation & controls)	1.1	22.7	3.4	3.9	31.3	62.4	-24.4	-28.1%
Case D (Case C + ceiling fans)	1.0	16.2	3.4	3.9	31.3	55.9	-31.0	-35.7%
Case E (Case D + night ventilation +window shading)	1.1	8.3	3.4	3.9	31.3	48.0	-38.8	-44.7%
Case F (Case E + cool roof coating)	1.1	8.0	3.4	3.9	31.3	47.8	-39.0	-44.9%
Case G (Case F + windows retrofit)	0.6	5.9	3.4	3.9	31.3	45.2	-41.6	-47.9%

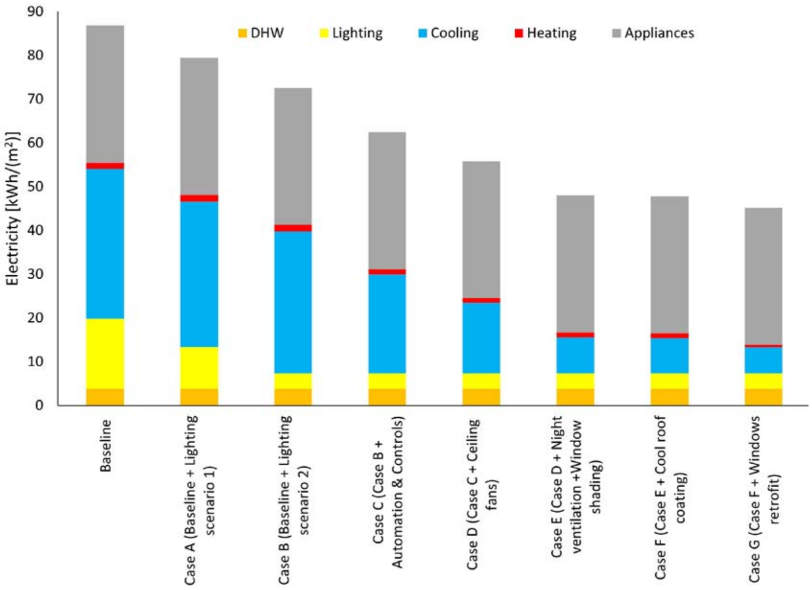

Figure 15. Site energy of the retrofit scenarios.

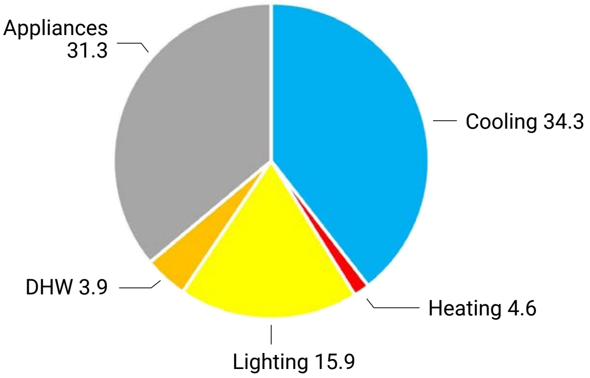

Figure 16. Share of site energy for the baseline (kWh/m²a).

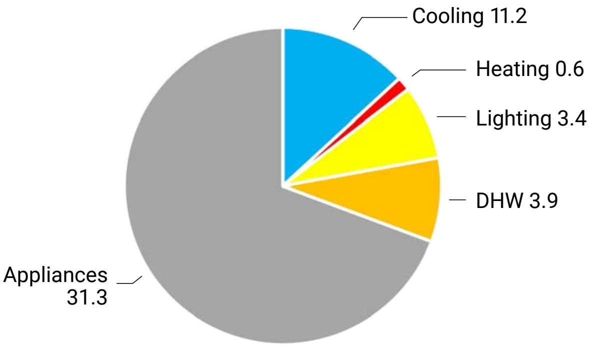

Figure 17. Share of Site energy for retrofit scenario – case G (kWh/m²a).

6.3. Future climate simulations

In this section, the case study office 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 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) [17]. The word representative indicates that each RCP provides one of many possible scenarios that would lead to a specific radiative forcing characteristic. The term pathway denotes that not only the long-term concentration levels are of interest, but also the path taken over time to reach that outcome is important. RCP4.5 is selected as the future pathway to compare different cities. RCP4.5 is an intermediate condition in which radiative forcing is stabilised at approximately 4.5 W/m² after 2100.

Table 18 presents the energy load and final energy demand by the office building in 8 representative cities. The results indicate that in all representative cities, the cooling site energy will rise between 6.3%-15.7% until 2030. This considerable amount of energy demand for cooling would cause up to a 3.5% rise in the total electricity demand in cooling dominant cities. ➔

Table 18. Current and future energy demand of the case study office building based on CSIRO weather database.

Location	Period	Water heating	Heating site energy	Cooling load	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/m^2)							%		
Adelaide	Present	3.9	5.7	49.7	20.7	15.9	31.3	77.5	-	-	-
	2030	3.9	4.7	55.4	23.1	15.9	31.3	78.9	11.6	-17.5	1.8
Brisbane	Present	3.9	1.4	82.3	34.3	15.9	31.3	86.8	-	-	-
	2030	3.9	1.1	90.0	37.5	15.9	31.3	89.7	9.3	-21.4	3.3
Canberra	Present	3.9	12.6	37.9	15.8	15.9	31.3	79.5	-	-	-
	2030	3.9	10.9	41.5	17.3	15.9	31.3	79.3	9.5	-13.5	-0.3
Darwin	Present	3.9	0.0	156.0	65.0	15.9	31.3	116.1	-	-	-
	2030	3.9	0.0	165.8	69.1	15.9	31.3	120.2	6.3	-	3.5
Melbourne	Present	3.9	10.2	32.2	13.4	15.9	31.3	74.7	-	-	-
	2030	3.9	8.6	37.2	15.5	15.9	31.3	75.2	15.7	-15.7	0.7
Perth	Present	3.9	3.9	63.8	26.6	15.9	31.3	81.6	-	-	-
	2030	3.9	3.2	70.8	29.5	15.9	31.3	83.8	10.9	-17.9	2.7
Sydney	Present	3.9	2.9	54.5	22.7	15.9	31.3	76.7	-	-	-
	2030	3.9	2.3	60.2	25.1	15.9	31.3	78.5	10.6	-20.7	2.3
Hobart	Present	3.9	12.8	21.8	9.1	15.9	31.3	73.0	-	-	-
	2030	3.9	11.5	24.5	10.2	15.9	31.3	72.8	12.1	-10.2	-0.3

To evaluate the impact of retrofitting the case study office building, the base case and highly retrofitted scenario (Case G) were simulated in Spring Hill. As presented in Table 19, 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 office's total electricity demand would rise by 3.5%. Also, the results show that the cooling load in 2030 can be reduced by 73.4%, in the case of a complete refurbishment of the office building. The resulting reduction of the total electricity demand of the building is 48.7%. →

Table 19. The comparison between the base case and fully retrofitted scenario.

Location	Period	Water heating	Space heating	Cooling load	Cooling site energy	Lighting site energy	Appliances site energy	Total site electricity demand	Heating site energy increase	Cooling site energy increase	Total site electricity increase
		(kWh/m^2)							%		
Spring Hill Base case	Present	3.9	1.4	154.3	34.3	15.9	31.3	86.8	-	-	-
	2030	3.9	1.1	169.0	37.5	15.9	31.3	89.8	-5.7%	9.3%	3.5%
Spring Hill retrofitted	Present	3.9	0.6	38.1	5.9	3.4	31.3	45.2	-	-	-
	2030	3.9	0.5	44.9	7	3.4	31.3	46.1	-2.2%	18.6%	2.0%

6.4. Discussion and recommendations

We established a baseline for energy consumption and then we undertook a simulation based on various energy efficiency upgrades. According to the data, energy consumption is relatively high, especially when it comes to cooling. Heating, appliances, lighting, and hot water production all consume a significant amount of electricity. As a result, the following energy-saving recommendations are provided:

- The simulations showed that the natural lighting levels in the spaces close to the windows are relatively high, depending on the area and depth of the space. It is recommended that the East facing windows are shaded with exterior elements, such as vertical louvres, to reduce the natural lighting levels close to the windows, minimise the glare issues and result in more uniform lighting levels in the open-plan office spaces.
- The artificial lighting system of the building is not known; thus, specific recommendations cannot be provided. However, energy-efficient lighting sources, such as LED lamps and luminaires of high efficacy, can provide significant energy savings. Also, the use of daylight linked controls in this building can further reduce the energy consumption for lighting and contribute to the uniformity of the lighting levels in the space. The consumption for artificial lighting can be reduced up to 92% with the use of the above measures, depending on the existing lighting system.
- Installation of ceiling fans or replacement of the old ones to reduce cooling demands.
- Implementing night ventilation patterns in the HVAC&R system's operation as well as window shading during the cooling season to reduce cooling demands.
- 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.
- Painting of the external roof with cool roof paint to lower the solar absorbance to 0.25.
- Refurbishment of the windows, with new aluminium framed, double glazed ones, of high energy efficiency, so as to reduce thermal losses in winter, solar loads in summer and achieve air-tightness throughout the year

In conclusion, a complete renovation package that includes replacement of the building’s windows and glazed surfaces, combined with an upgrading of the lighting system, the installation of ceiling fans and the use of night-time ventilation and window shading patterns, linked all with the implementation of a state-of-the-art BAC system, can lead to energy savings of 47.9%, resulting in an energy consumption of 45.2 kWh/m²a, compared to the baseline of 86.8 kWh/m²a. Besides, a PV system of 30 kWp could be installed in the available roof space, producing approximately 10.5 kWh/m²a. Considering the simulated portion of the building, with the proposed interventions, the NABERS rating can be improved from 4.92 to 6.31 stars (i.e., comfortably 6 stars), computed with NABERS reverse calculator based on simulation results. ■

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Attachment 1

The following figure shows daylight factor distribution in case study office building.

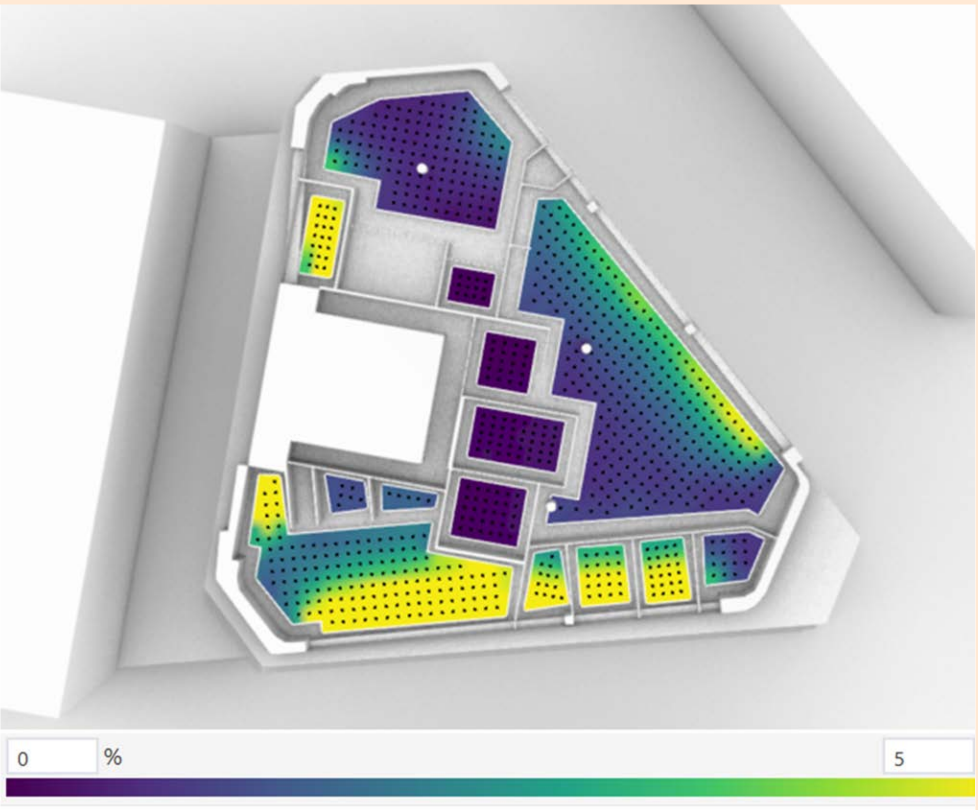

Fig. A1. Distribution of Average Daylight Factor (%) distribution on Level 5.

Attachment 2 – Site photos

Fig. A2. Front view.

Fig. A3. Exterior view.

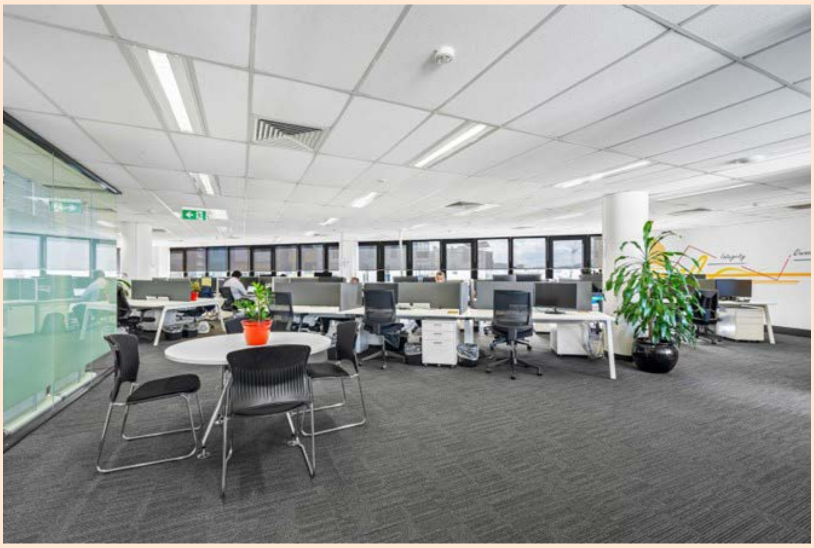

Fig. A4. Interior view: open office space.

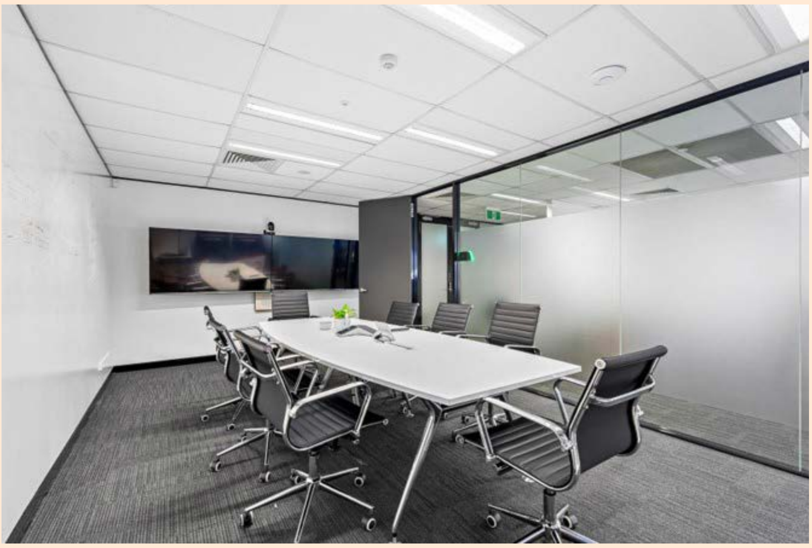

Fig. A5. Interior view: meeting room.

Fig. A6. Interior view: lifts.

Fig. A7. Interior view: office spaces.