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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C

1. E

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 largest fraction of the energy consumption in an

ventilation, air conditioning and refrigeration (HVAC&R) applications, lighting, and appliances [2]. This report tackles the operational energy consumption challenge

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. R

The regulatory documents and Standards used for the

- 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. I

building built in Australia in the 2000s, representative

expansion to other similar buildings.

however, even though the required procedure may
differ, the logic and methodology presented here
offer a high-quality framework to improve the energy

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4.1. Case study description

4.1.1. Climate

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

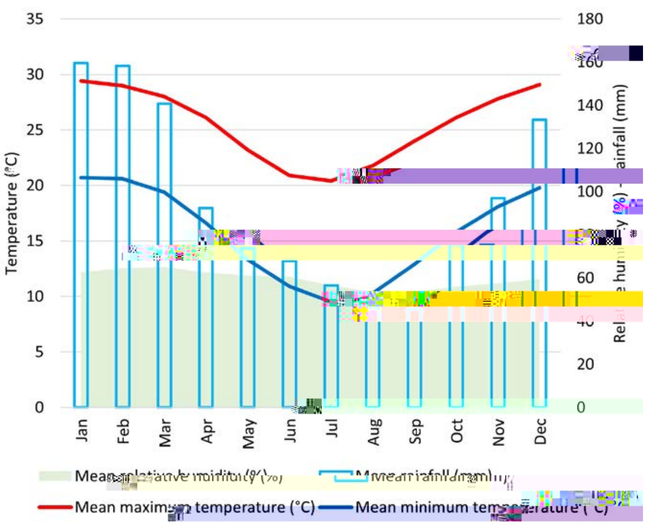

Figure 1. Climatic data for Brisbane [4].

4.1.2. Building description

and it was completed in the early 2000s. In 2015, the

The digital National Construction Code of the case

building has a capacity of 225 people, and the under-

the treemap chart of the gross internal area of case

4.1.3. NABERS rating

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/m^2). The annual greenhouse gas emissions for the building are 250,225 kg CO (84.4 kg CO /m^2). ➔

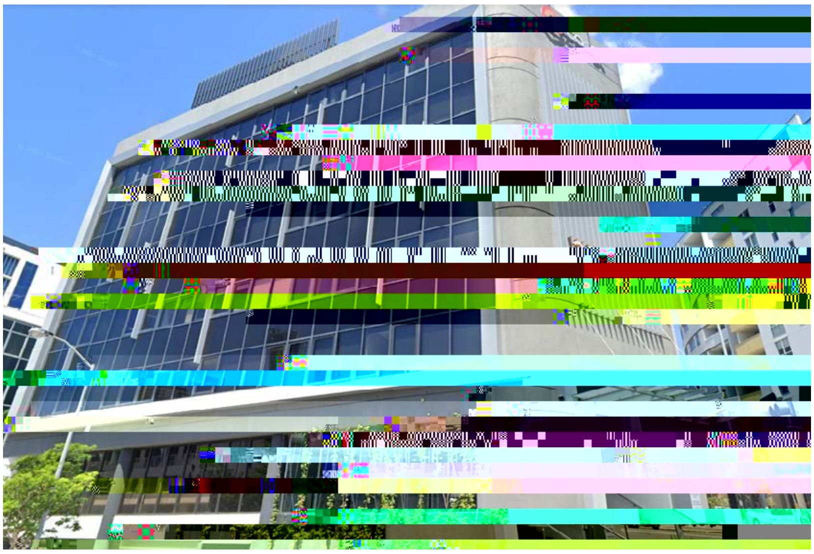

Figure 2. Northern view of case study building.

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

4.2.5. Internal gains

The information regarding the thermal comfort in

facility management. Lighting and personal heat gain assumptions in the model are based on Australian and international standards.

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

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 7. Ventilation and infiltration.

	On	10	L/s.person	[12]	Appendix A, Table A1
	Off	0	L/s.person		
Infltration	On	1	ACH	[13]	Section 2.7
	Off	0.5	ACH		

Table 8. Comfort factors.

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	Default / Building		

4.2.9. Schedules

The occupancy schedules, lighting and appliances

on pages 348-349 of the Building Code of Australia

facility management documents [5].

Table 9. Occupancy, lighting and appliances schedules.

4.3. Evaluating Lighting Condition

5.

The simulation includes two main parts. First,

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

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

all building structural parameters (walls, windows, doors, etc.), schedules (occupancy, lighting, and appliances), internal loads, and HVAC&R systems

the proper climatic data (temperature, relative humidity, radiation, etc.) using the CSIRO weather database. →

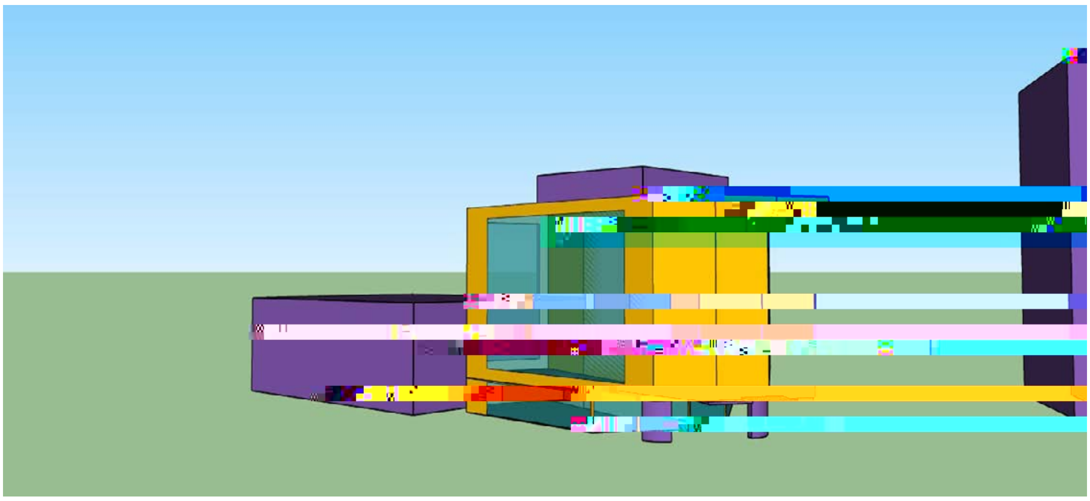

Figure 7. SketchUp model

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

equipment, etc. Considering the building's features, all calculations were based on the 'as-built' condition of the building elements (U-values, shading, air-

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.

(a) the operational parameters (hours of operation, set temperatures for heating and cooling, natural

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

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

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%.

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.

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

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.

f oor	East O f ce					
	West O f ce –					
f oor	East O f ce					
	North O f ce					
	West O f ce					
f oor	East O f ce					
	North O f ce					
	West O f ce					
f oor	East O f ce					
	North O f ce					
	West O f ce					
f oor	East O f ce					
	North O f ce					
	West O f ce					
f oors						

5.3.5. Auto night ventilation, window shading

Intensive ventilation through windows during the

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

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

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

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

EN ISO 52127 and 15232. According to those standards,

evaluate the performance of the building automation:

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

Table 13 depicts typical features of the four mentioned classes. The impact of the automation level on the

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. →

The result of the evaluation is two sets of BAC

BAC,hc and fBAC,e

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

considered to be 1350 kWh/(kWp*a), and the PV system would be able to cover around 25% of the total

6. R

6.1. Base building modelling

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. ➔

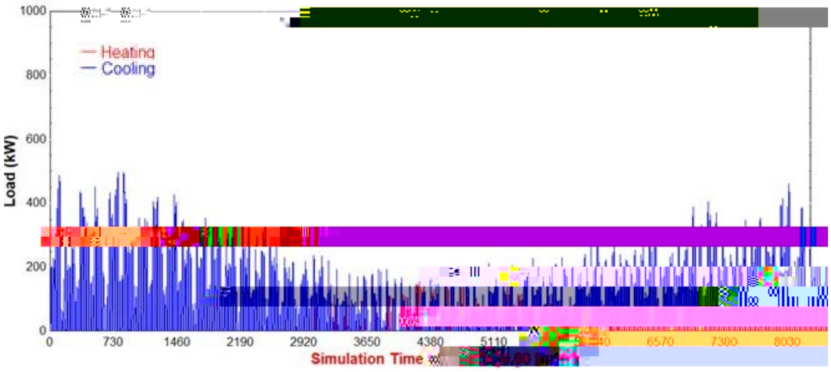

Figure 8. Hourly energy demand for HVAC&R purposes.

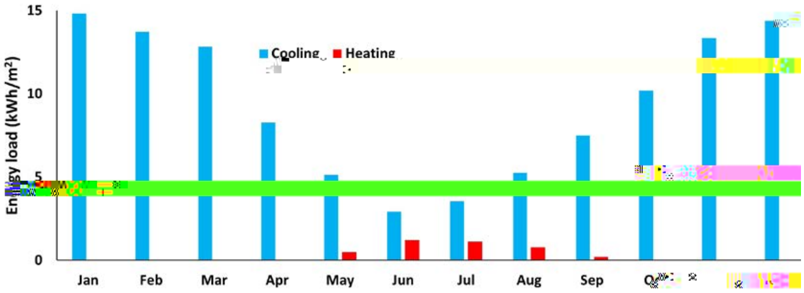

Figure 9. Monthly energy demand for HVAC&R purposes.

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

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

q_{BAL}: the energy balance for a zone and should

q is the change of internal energy of the zone (calculated using the combined capacitances of the building and the air

q_{INF}

q_{VENT}

q_{TRANS} is transmission into the surface from an

qG_{INT}

q_{WGAIN} represents gains by convection and radiation

q_{SOL}

q_{HEAT}

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).

presented in Figure 14. →

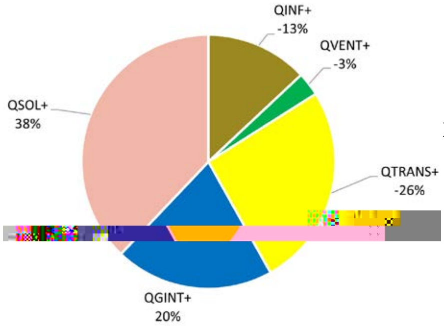

Figure 10. Whole building energy gain – heating season (May-September).

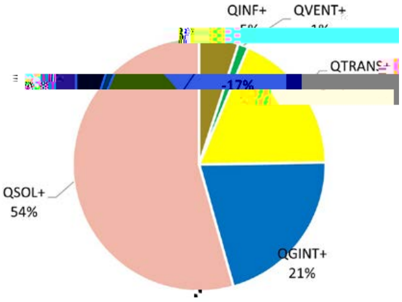

Figure 12. Whole building energy gain – cooling season (October-April).

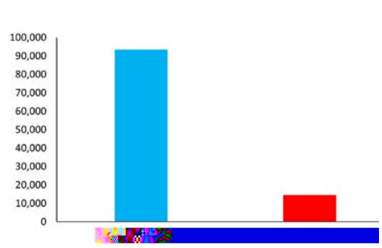

Figure 11. Whole building energy gain for heating and cooling load- heating season (May-September).

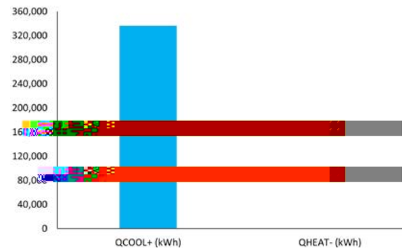

Figure 13. Whole building energy gain for heating and cooling load- cooling season (October-April).

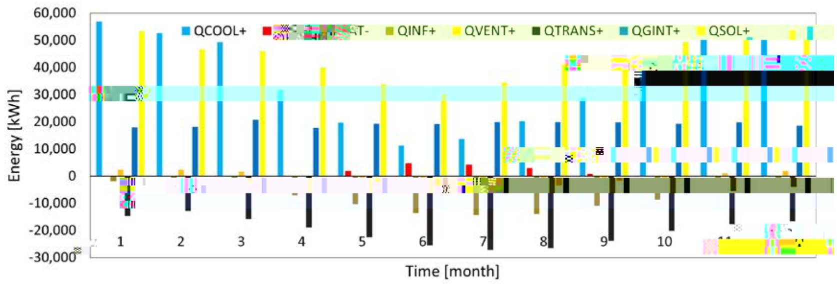

Figure 14. Monthly building energy gain.

6.2. Retrofit scenarios

presented in Table 15.

Between the presented scenarios, Case G has the

loads. Also, Table 17 demonstrates the impact of

improving the building condition, 47.9% of the required electricity can be reduced. A more detailed illustration

➔

Table 15. Retrofit cases.

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	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	Power density of lighting scenario 1 combined with continuous dimming of the light sources depending on daylight availability.
Case C	The baseline class of automation is estimated according to EN15232, 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	Ceiling fans are modelled by increasing the cooling setpoint temperature to 26°C.
Case E	Night ventilation takes place between 20:00 and 8:00 with an additional

Table 16. Simulation results – Heating and cooling loads

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

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

R

1. UK Green Building Council, , in

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2. Residovic, C.,

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Procedia Engineering, 2017. **180**: p. 303-310.

3. Peel, M.C., B.L. Finlayson, and T.A. McMahon,

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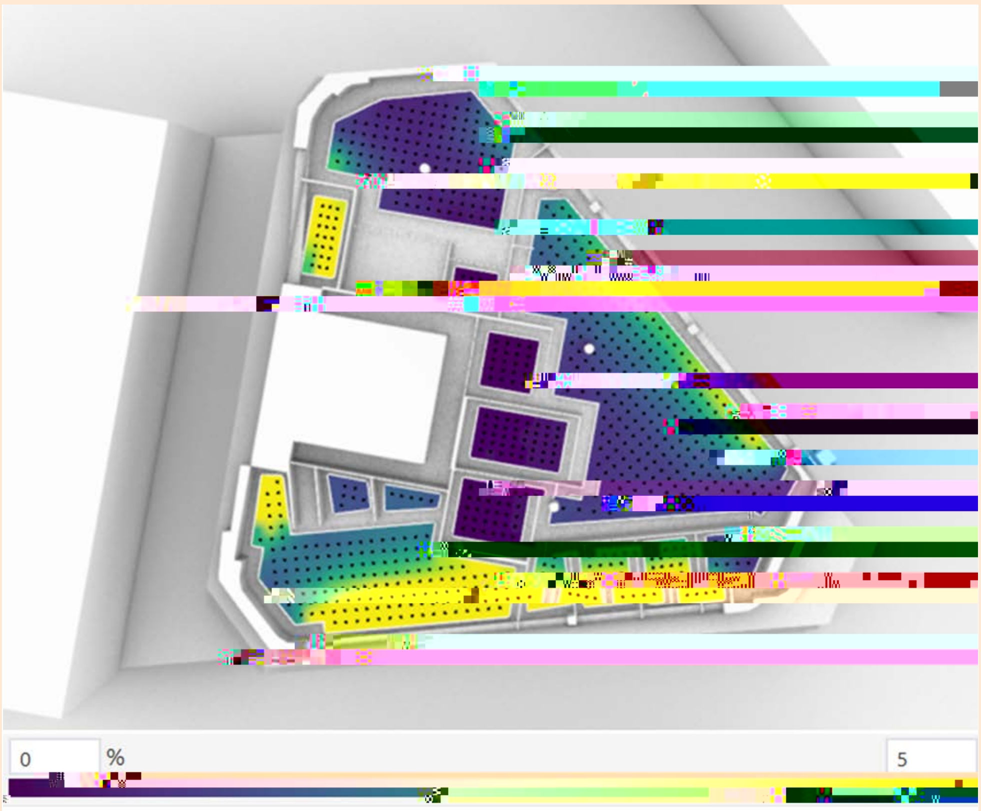

Fig. A1. Distribution of Average Daylight Factor (%) distribution on Level 5.

A– 2

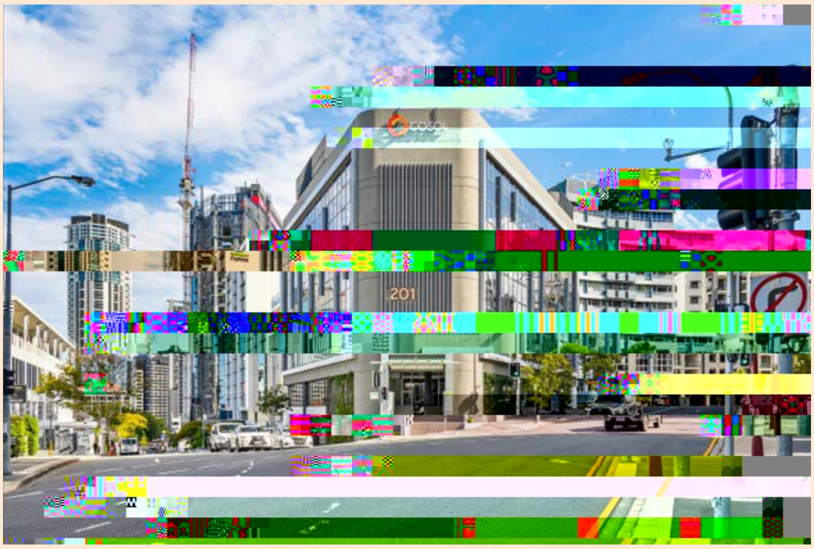

Fig. A2. Front view.

Fig. A3. Exterior view.

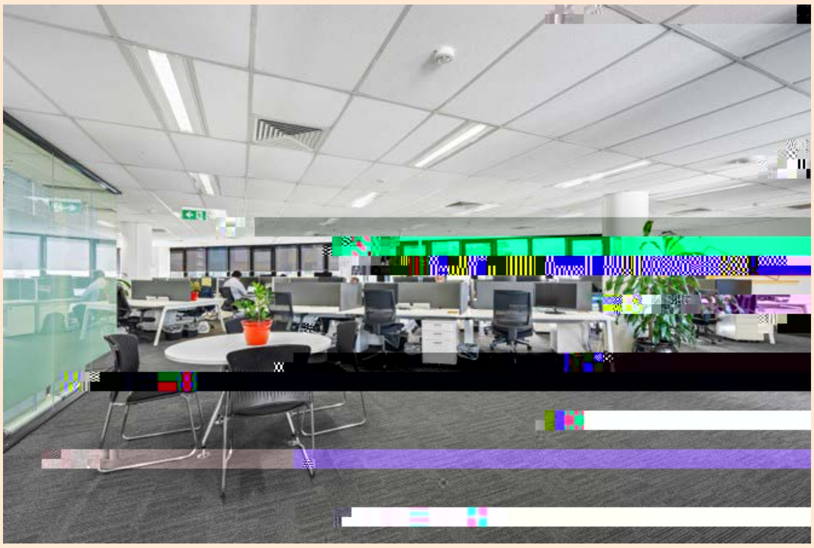

Fig. A4. Interior view: open office space.

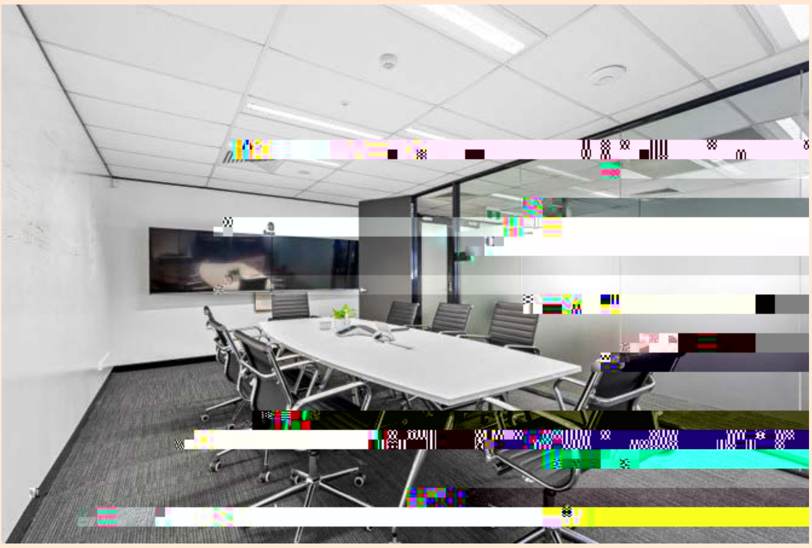

Fig. A5. Interior view: meeting room.

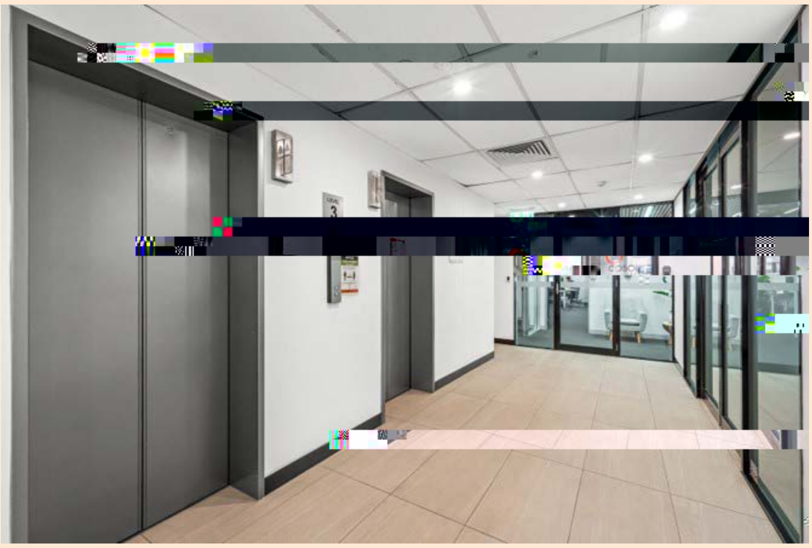

Fig. A6. Interior view: lifts.

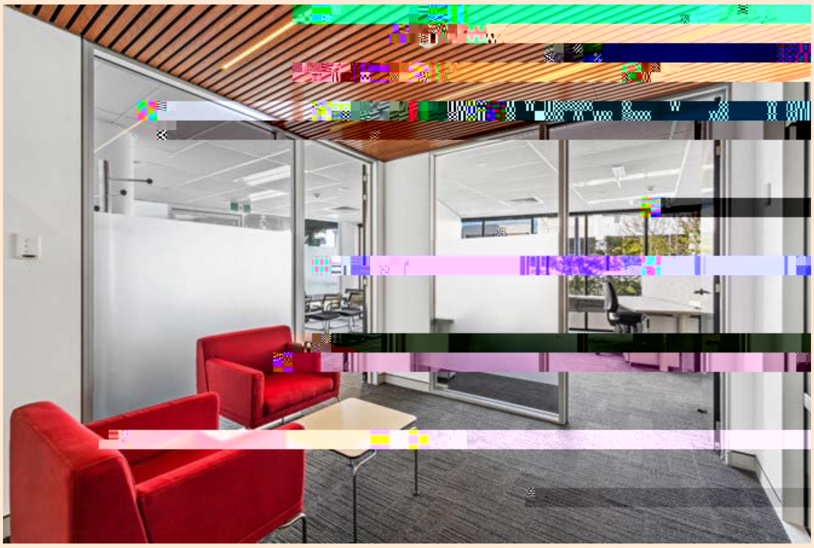

Fig. A7. Interior view: office spaces.