The Innovation Hub

for Affordable Heating and Cooling

Technology Evaluation Report

Healthcare Living Laboratories: Fernhill Residential Aged Care – Application of honeycomb Blinds

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QUT

About i-Hub

The Innovation Hub for Affordable Heating and Cooling (i-Hub) is an initiative led by the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) in conjunction with CSIRO, Queensland University of Technology (QUT), the University of Melbourne and the University of Wollongong and supported by Australian Renewable Energy Agency (ARENA) to facilitate the heating, ventilation, air conditioning and refrigeration (HVAC&R) industry’s transition to a low emissions future, stimulate jobs growth, and showcase HVAC&R innovation in buildings.

The objective of i-Hub is to support the broader HVAC&R industry with knowledge dissemination, skills-development and capacity-building. By facilitating a collaborative approach to innovation, i-Hub brings together leading universities, researchers, consultants, building owners and equipment manufacturers to create a connected research and development community in Australia.

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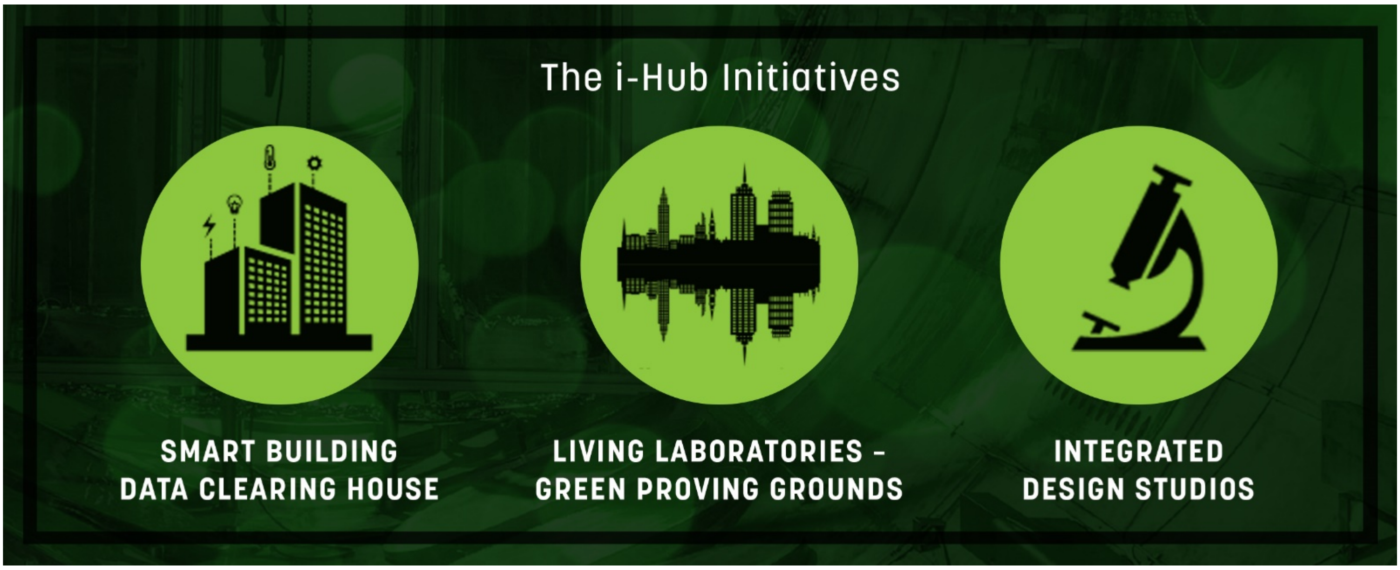

Honeycomb Blinds

Honeycomb blinds is a type of window dressing that have a cellular structure that can trap air and make it act as an additional layer of insulation. The unique honeycomb shape increases thermal resistance, and reduce the thermal transmittance and solar heat gain through windows. Due to its effective thermal properties, Honeycomb blinds can help reduce heat gain/loss. Therefore, when operated correctly, they can keep internal spaces warm in winter and cool in summer, which leads to enhancing thermal comfort while reducing heating and cooling energy loads. This report demonstrates the results of testing the U-value of different honeycomb blind types and simulating their impact on reducing energy consumption and carbon emissions in current and future weathers.

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Contact name

Dr. Sherif Zedan

Email

s2.zedan@qut.edu.au

Living Lab Activity Leader

Associate Professor Wendy Miller
W2.miller@qut.edu.au

Project website

www.ihub.org.au

VERSION HISTORY

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4.0					

Table of contents

List of Tables

List of Figures

EXECUTIVE SUMMARY

I. Introduction and objectives

Honeycomb blinds are an ‘advanced technology’ internal window dressing. Known also as cellular shades. Due to their honeycomb-shaped design, air gets trapped inside the ‘cells’, thereby creating a layer of insulation. There are single, double, or triple layered designs that trap air between the layers of the shade in individual cells. These types of internal blinds are promoted as increasing the total R-value of the window system and reducing the conduction of heat. Insulating shades can also potentially reduce solar heat gains if managed properly.

This report tests the benefits of cellular (honeycomb) blinds through focusing on two main objectives:

1- In-situ identification of the impact of different honeycomb blind types on thermal transmission through windows, and
2- The impact of different closing/opening scenarios of the honeycomb blinds on the heating and cooling energy consumption.

Norman Australia, an Australian based window furnishing supplier provided five types of Portrait™ Honeycomb Shades, to be tested: 25mm, 45mm, and 62mm single cell, and 45mm, and 62mm double cell blinds. The five types were installed in 6 living lab rooms located in a Bolton Clarke Residential Aged Care in Caboolture and in Norman Australia Showroom in Brisbane. The 6 living lab rooms are equipped with multiple sensors to monitor temperature, relative humidity, lux, motion, and opening closing of windows.

ii- Phase 1a: Thermal transmittance of different blind types

Thermal transmittance testing of the five blind types were conducted in Norman Australia’s showroom in Brisbane, on south east windows to limit the effect of solar heat gain.

The heat flux method (Equation 1) was used to identify the U-value of the glass only and the effect of different types of blinds on it.

$$U = Q/Tin - Tout$$

Equation 1: U-value calculation

Where T_{in} and T_{out} are the inside temperature and outside temperature in Kelvin and Q is the corresponding heat flux through the measured element (W/m2).

The heat flux data (Q) was obtained from a heat flux sensor attached to the inside of the glass. The inside temperature (Tin) and outside temperature (Tout) were measured with two temperature sensors.

All test procedures and results were compliant with section 7.1 of ISO9869-1:2014 Thermal insulation — Building elements — In-situ measurement of thermal resistance and thermal transmittance.

ii- Phase 1b: Whole building simulation

An energy model of the existing building at Fernhill was built to simulate the effect of the added blinds on energy and CO_2 reduction. The model utilised the same building elements and HVAC plant in the existing building. The simulated zone temperature set points ranged between 21-24 °C to replicate the settings in the actual building. The whole building energy consumption was simulated once with the assumption that no blinds are installed, and once with the 62mm double cell blinds assumed to be closed the whole time in all residential rooms. The results from both simulations were compared and analysed to evaluate the effect of the blinds.

iii- Phase 1 Findings

Phase one a results shows that:

- There is a correlation between the size/number of cells and the thermal resistance/transmittance where bigger cell size/number are associated with higher thermal resistance.
- Average reduction in thermal transmittance through window was 56% with a maximum of 62% when 62mm double cell was used and a minimum of 50% when 25mm single cell is used.
- Average U-value of honeycomb blinds only was 4.21 with a highest of 5.27 for the 25mm single cell, and a lowest of 3.13 for the 62mm double cell.

Phase one b whole building simulation results show that:

- The majority of energy consumption is for heating and cooling purposes, accounting for 38% of the total energy consumption in the case with no blinds.
- Total energy consumptions and emissions were reduced by 4.6% when the blinds were used.
- The most effective reduction was in reducing cooling energy (12.5%) due to major reduction in solar heat gain (57.7%) and heat loss (64.3%) as a result of closing the blinds the whole time.
- The reduction in energy consumption is correlated with external temperature rise, with a maximum reduction of in summer (January) reaching 6.6% and in winter (July) reaching 2.8%.
- Closing the blinds (reducing solar heat gain), has very little effect on increasing heating loads, due to the nature of climate with mild temperature during winter.
- Estimated environmental and cost benefits show that the yearly savings can reach $10,233, with the most significant reductions being in summer with a maximum of $1,622 savings in January, based on $0.15c/kWh tariff. Yearly CO_2 savings is estimated to be 63(kg)x10^3 based on greenhouse gas emission factor of 256 $kgCO_2$.

iv- Phase 2a: User feedback and insights

Findings from interviews with the residents of Fernhill show that very few operate the blinds as a response to solar radiation or external temperature.

Most interviewed residents never close the blinds, mainly due to reliance on air conditioner. Few of the residents close the blinds at night-time for privacy reasons, however as shown in the simulation results that scenario have very little effect on reducing energy consumption.

In terms of ease of use, most interviewees had no trouble using the remote control to operate the window blinds, however one interviewee mentioned that blinds were installed in the opposite direction of the sliding door, which makes it difficult to access the terrace unless the blinds are completely open the whole time.

Findings from the interviews show the importance of having solar radiation automation for the blinds to maximise their benefits in aged care buildings, since manually operating the blinds in an informed manner was rare and difficult to implement.

v- Phase 2b: Impact of honeycomb blinds operational patterns on energy

Based on findings from interviews with the RAC residents about their operational patterns, multiple scenarios were simulated for opening/closing blinds. 8 scenarios (Table 1) were simulated for level 3 residential rooms to capture various opening/closing patterns effect on energy use, compare between the effect of honeycomb blinds and regular drapes used in non-living lab rooms, and investigate the benefits of using honeycomb blinds in future climate.

Table 1: Blinds operation scenarios

Simulated zone	Simulation Scenario
Residential rooms on level 3	62mm double cell blinds always closed
	Normal drapes always closed
	62mm double cell blinds closed when solar radiation incident on windows exceeds 120 W/m2
	62mm double cell blinds are closed when outside air temperature is above 24 degrees
	62mm double cell blinds are closed at night and when solar radiation incident on windows exceeds 120 W/m2
	62mm double cell blinds are always open during the day and closed at night when outside temperature is below 22 degrees
	Blinds are always open in the year 2050
	62mm double cell blinds closed when solar radiation incident on windows exceeds 120 W/m2 in the year 2050

vi- Findings

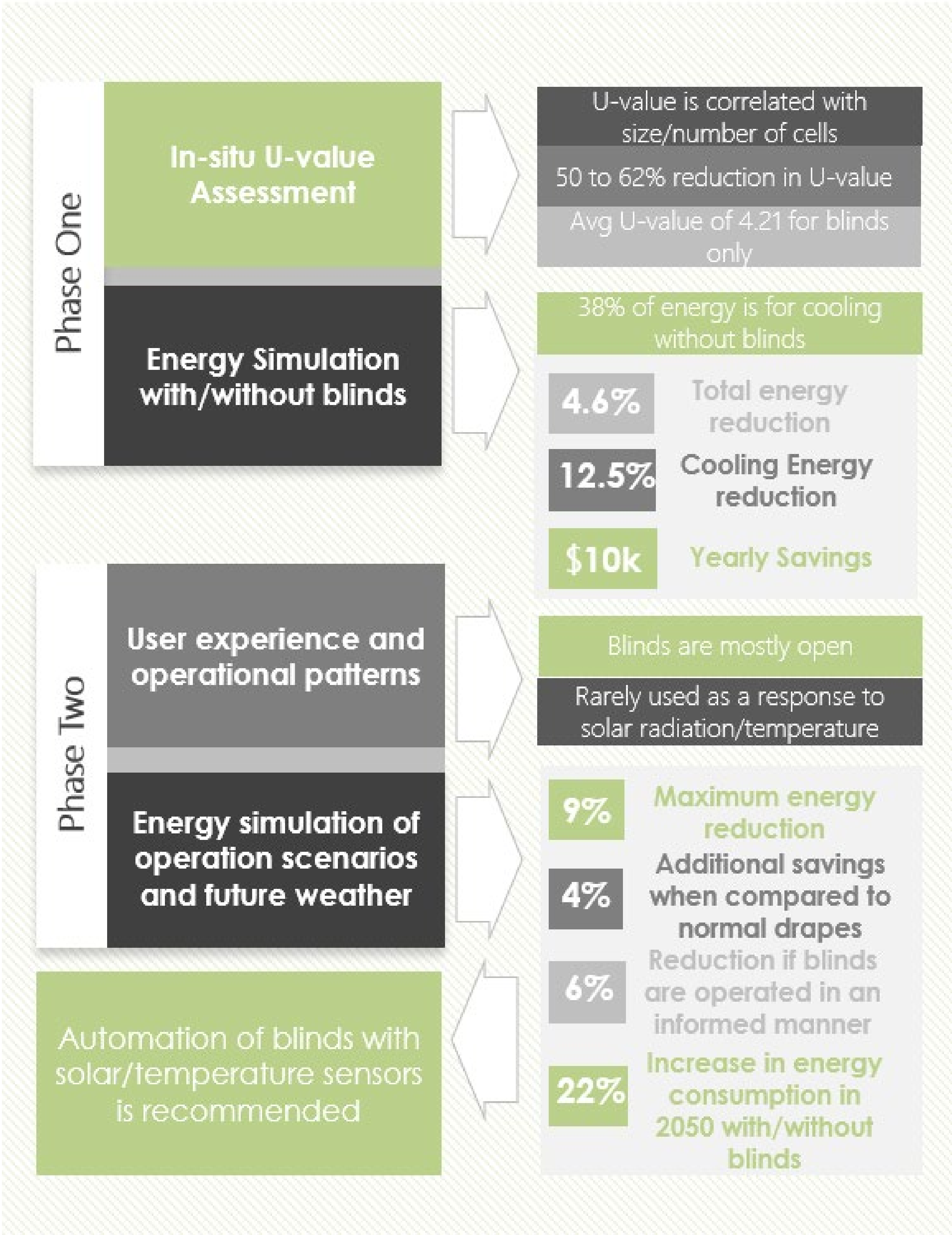
Phase 2b level 3 simulation results show that:

- Heating and cooling energy consumption dropped by 9% when honeycomb blinds are always closed, compared to 5% when normal drapes are always closed.
- Blinds have more impact on reducing cooling loads when compared to reducing heating loads in sub-tropical climates.
- Informed opening/closing behaviour as a response to solar radiation and/or external temperature helped reduce cooling energy use by approximately 6% per year.
- Honeycomb blinds can save 3.3% on energy costs per year when compared to the drapes already installed in the rooms. This reduction is in addition to a 3.6% reduction in initial cost.

- Simulation of the blinds in future climate did not show additional benefit in energy savings when compared to what they are providing in current climate.
- Energy consumption with or without blinds being is estimated to increase by 22% in the year 2050.

Findings from the interviews and simulation show that having solar radiation automation for the blinds and implementing them to both residential and communal areas might result in significant reduction in energy consumption and maximise their benefits in aged care buildings.

HONEYCOMB BLINDS TESTING AND OUTCOMES



1 INTRODUCTION

1.1 Problem Statement

Heat transfer through building envelopes is one of the most important parts of air conditioning load, and window systems are the weakest insulation component of building envelopes. Windows are a very significant component of heating and cooling energy use and costs: they can lose more heat per square meter in winter and gain more heat in summer than any other surface in a building. For existing buildings, retrofit actions for reducing heat losses and gains through windows can be applied externally (e.g. external blinds, shutters and shade devices) and internally (e.g. secondary window treatments, curtains and blinds). Internal blinds and curtains can be seen as a relatively lost cost option for existing buildings, particularly residential buildings. In residential settings, internal window treatments have multiple purposes: management of heat transfer, control of natural light, provision of privacy, aesthetics (interior design), and personal control of connection with the outside world (e.g. views). Very little experimental (in-situ) research exists, however, that quantifies the impact of these retrofit actions on internal heat loads and associated energy use and costs.

Fitton et al[1] conducted a study in a whole house environmental test facility, investigating the impact of window dressings on heating energy efficiency in the UK. The purpose of that study was to establish U values for windows and their coverings and compare with the values used in building simulation and regulation models, such as the values used by CIBSE (Table 1).

Table 2 *R* and *U* values for window coverings given in CIBSE Guide A 2015 (as shown in Fitton, 2017)

Description	Thermal resistance (*R* value) of covering layer (m^2 K/W)	Thermal transmittance (*U* value) of covering layer (W/m^2 K)	Thermal transmittance (*U* value) of window with curtains or blinds (W/m^2 K)
Single glazing only	0.19	–	5.16
Roller blind	0.14	7.14	3.03
Heavy curtains	0.16	6.25	2.86
Secondary glazing	0.18	5.55	2.70
Honeycomb insulated blind	0.24	4.17	2.33
Roller blind with low emissivity film on outside face	0.3	3.33	2.04
Low emissivity secondary glazing	0.32	3.13	1.96
Well-fitting shutters	0.33	3.03	1.92
Low emissivity secondary glazing and shutters	0.39	2.56	1.72

Their results confirm differences between dressing types, due to fabric weight and type, and the way the window dressing is installed (i.e. does it trap a layer of air against the window; and what is the depth of this insulative barrier). These characteristics are difficult to accurately describe and define in standards and performance indicators. The study also found, however, that the *U* values differed between homogenous heat distribution (assumed by steady-state simulation models) and heterogeneous heat distribution (more commonly found in occupied homes). The study reported that window dressings of any type can positively contribute to energy savings when installed on windows in close proximity to radiators. Window dressings can also affect the rate of convection around a room, and prevent some air infiltration and exfiltration (if there

[1] Fitton, Richard et al. 2017. The thermal performance of window coverings in a whole house test facility with single-glazed sash windows. Energy Efficiency, 10, 1419-1431. https://doi.org/10.1007/s12053-017-9529-0

are leaky windows). Their research highlights the need to better understand the characteristics of the window dressings, the building envelope, the heating and cooling technologies, and the occupants (how people live in buildings). It should also be noted that the focus of their report was on quantifying the role of window dressings on reducing heat loss and the impact of dressings on internal heat distribution.

1.2 Technology Overview

Honeycomb blinds are an ‘advanced technology’ internal window dressing. Known also as cellular shades, they are made from multiple hexagonal shaped cells like a honeycomb (Figure 1). These shades are made from one continuous piece of fabric, and they either roll up or fold up along their pleats. Fabric is then bonded together to form the honeycomb-shaped cells. Due to their honeycomb-shaped design, air gets trapped inside the ‘cells’, thereby creating a layer of insulation. There are single, double, or triple layered designs that trap air between the layers of the shade in individual cells. The insulating air pockets may also include a layer of metallized Mylar, which minimizes radiant heat transfer, like the effect that a low-emissivity coating has on windows. These types of internal blinds are promoted as increasing the total R-value of the window system and reducing the conduction of heat. Insulating shades can also potentially reduce solar heat gains if managed properly.

In 2015 the USA’s Pacific Northwest National Laboratory (PNNL) compared the performance of a range of cellular blinds in an experimental home with the ‘undressed’ windows, and windows dressed with typical white vinyl blinds, in an identical baseline home[2]. They measured air leakage, energy use and interior temperatures during both the winter heating and summer cooling seasons. They found that window dressings affected heating, ventilation and air conditioning energy by reducing conductive heat transfer, reducing radiative energy losses, and optimising solar gains (with advanced operational scheduling). Using an operating schedule to maximise winter sun, HVAC use for winter heating was reduced by 17.6 +/- 8.1% compared to no blinds. Using the same operating schedule approach to minimising summer sun, the cellular blinds reduced HVAC energy use for cooling by 10.4+/- 6.5% when compared to vinyl blinds. Savings were also recorded for the cooling season, without an optimised operation schedule. The cellular blinds had little impact on air leakage (as the double glazed windows were already well sealed).

[2] Petersen, J.M et al. 2015. Evaluation of Cellular Shades in the PNNL Lab Homes. PNNL-24857, Rev 1. Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830

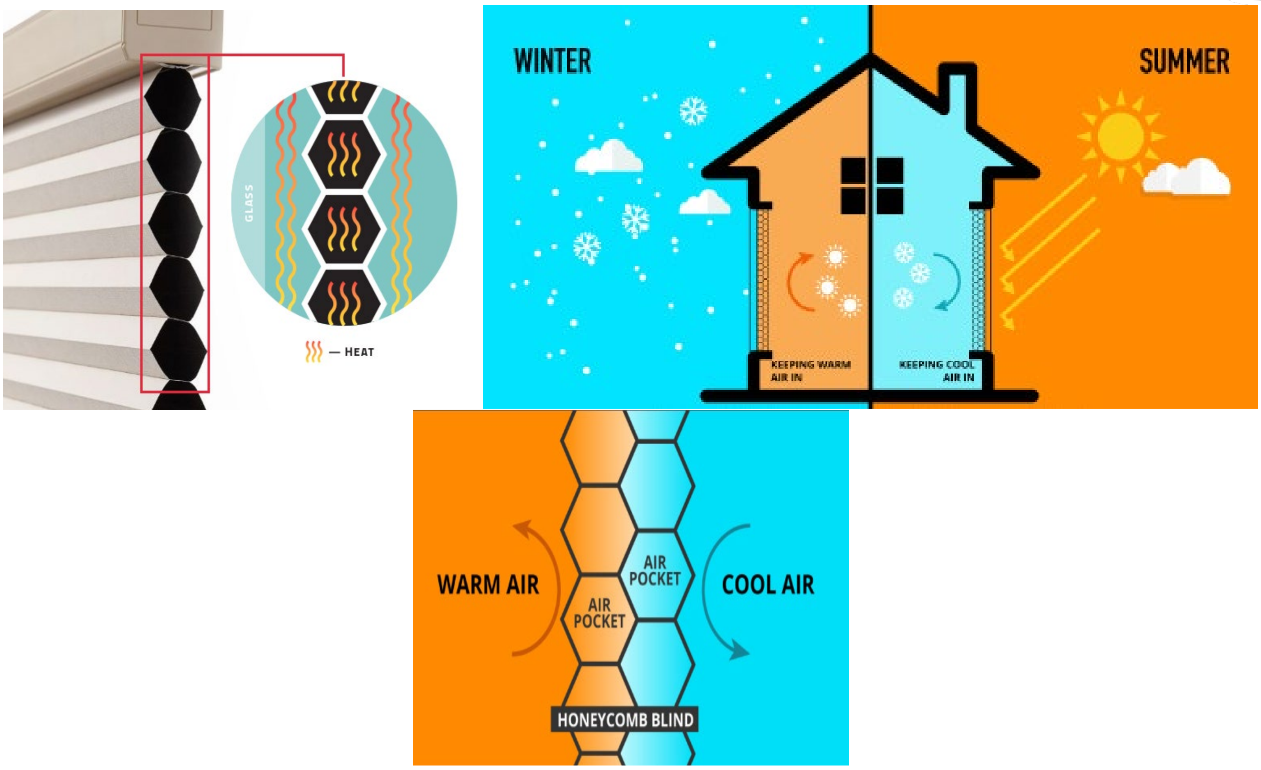


Figure 1 Honeycomb blind technology

1.3 Objectives

The main objective of this project is to identify, through simulation and in-situ experimentation, the extent to which Norman Australia's honeycomb blinds can reduce heat loss or gain through window and door glazing, and hence determine the impact of that reduction on air-conditioning energy use (kWh). This involve a comparison of the performance of the blinds against untreated windows (no internal dressing) and windows with an alternative dressing, in a number of operational patterns/scenarios.

Further research, beyond the initial findings of this report, may include:

- analysis of the impact of the blinds on occupants and other building users (e.g. ease of operation, impact on daylighting, impact on thermal comfort, ease of cleaning and maintenance);
- the potential to implement an automated control system to optimise the energy benefits of the blinds while meeting the occupants' preferences for natural light and ventilation.

2 TEST DESCRIPTION

2.1 Facility, Room and Window Descriptions

Norman Australia's Honeycomb Blinds are evaluated based on their performance on an existing building. This test investigates the blinds' performance on both simulated and actual conditions, to identify the impact of realistic occupancy and operations patterns when compared to estimated ones. The test site is Fernhill Residential Aged Care (RAC) located in Caboolture, approximately 42 kilometres north of Brisbane's CBD. The site (shown in Figure 2) consists of a range of old and new buildings offering independent, semi-supported and fully supported accommodation for elderly residents.

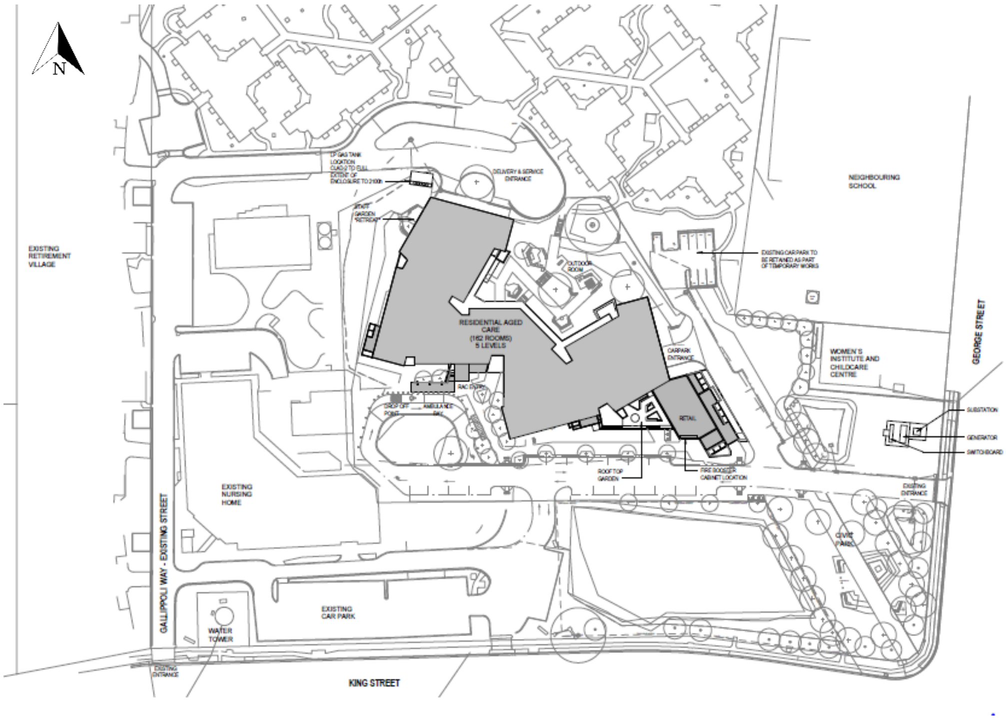


Figure 2 Fernhill Aged Care site

The RAC is a new building that was completed in August 2020. It was designed and built to comply with Australia's National Construction Code 2016 Volume 1. Current residents of the existing nursing home and hostels located on the same site will move into the new building from late October 2020. The building comprises:

- 144 bed RAC across 4 levels; 36 beds per floor; all rooms have ensuites and are either 26m2 (standard) or 35m2 (accessible rooms and premium rooms)
- 18 bed memory support unit
- Resident facilities (café, day spa, library, wellness centre, reflection room)
- Communal dining and sitting areas on each level
- Reception area and staff, management, training and consultation rooms
- Commercial kitchen and laundry to service this RAC and future SLAs
- Workshop, loading dock and ambulance bay
- Basement facilities: 57 bike end-of-trip facility and 46 car parks
- Day Therapy Centre and Day Care area
- Café / Retail space (for residents, family and visitors)

The building is a 'W' shape, with good solar access (equatorial facing) and access to prevailing north-easterly cooling breezes. A set of 6 rooms in the NW wing of the building were selected as 'living lab resident rooms' (Figure 3), to enable testing of a range of emerging products that can impact on occupant comfort, energy efficiency, HVAC operation and renewable energy potential. As each of the floor plates are exactly the same, monitoring the same set of rooms on each of 3 floors allows for products to be tested on one level and simultaneously compared with the 'control' rooms above and below. These rooms were specifically selected to encompass west, north and east orientations (the orientations most affected by solar radiation). The building was designed to enable mixed-mode ventilation and cooling. Resident rooms therefore have operable louvres and ceiling fans (occupant controlled) and ducted air conditioning (some occupant control with building management system (BMS) control.

Each of the six living lab resident rooms has the same size ‘composite window’ that consists of fixed glass and operable louvres, and two of the rooms also have sliding glass doors leading to a small balcony (Figure 4 and Figure 5). All windows, regardless of orientation, have an external horizontal awning (shading shelf) that projects 600mm out from the external wall and is placed 300mm above the top of the window.

The window and door frames are powder coated aluminium (100mm depth, 50mm width) and the frames are not thermally broken. Glazing is monolithic (single glazing). The whole of system (glass and frame) specifications used in the RAC’s energy design (NCC JV3) was *U* 4.2 and SHGC 0.47.

The specified glazing is ComfortPlus Neutral (for fixed glazing and for doors) and SolTech Neutral for the louvre blades. Both products are made by Viridian Glass. Technical specifications of this glazing (thermal transmittance, shading coefficient and visible light transmittance), as per the manufacturer, are shown in Table 2. All glass complies with AS1288.

Table 3 Technical specifications of window glazing in resident test rooms

	U-Value	SHGC	VLT
ComfortPlus Neutral (6.38mm)	3.6	0.52	59
Soltec Neutral (6mm)	3.7	0.54	63

Figure 3 Typical RAC floor – levels 3-5, with ‘living lab resident rooms’ circled

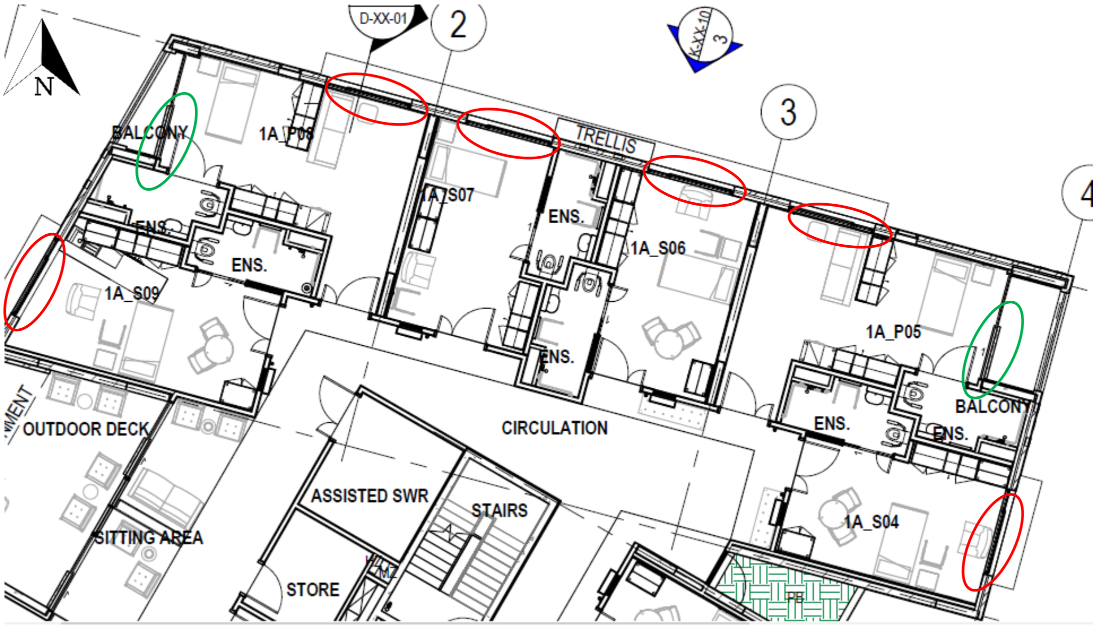
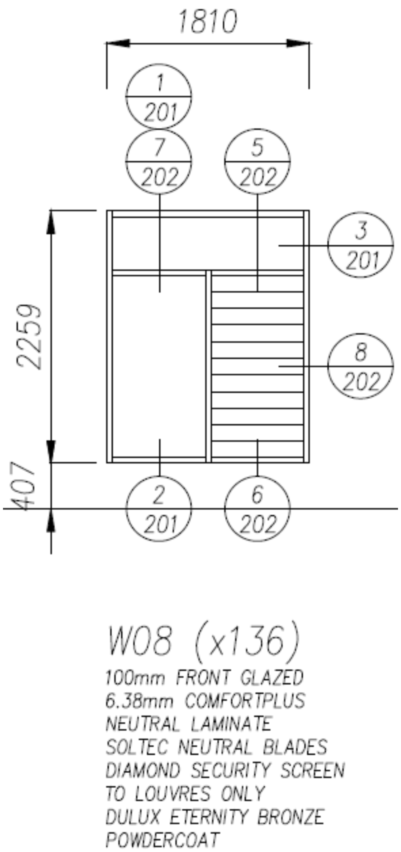


Figure 4 Detail of test rooms, showing combination windows (red) and sliding doors (green)



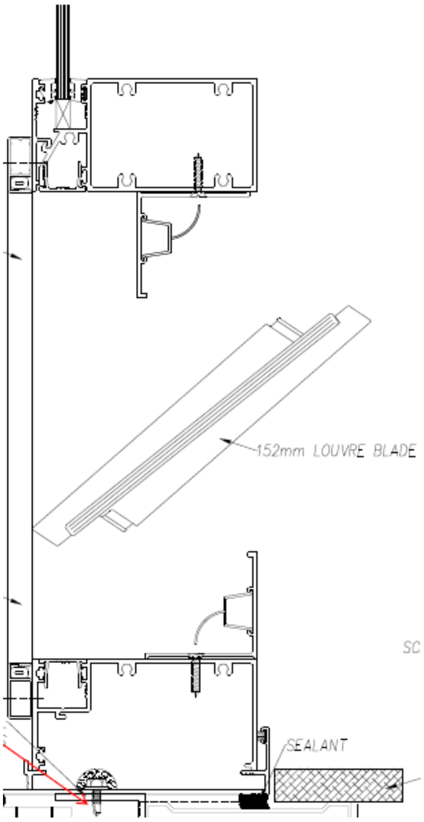


Figure 5 Composite window specifications (left) and louvre window (right)

2.2 Tested item description

The tested items are Portrait^{TM} Honeycomb Shades, supplied by Norman Australia. The specifications of these blinds are shown in Table 3. The dimensions relate to the blinds (not the windows),and were determined by Norman Australia from measurements taken on a site visit.

All blinds have the same fabric (room darkening – 100% UV Blockage) and colour (Desert), as approved by the RAC's interior designer. All window blinds are motorised with horizontal controls. Sliding doors blinds are operated manually.

Table 4 Test item descriptions

Room	Blind type	Type Tag	Cell size	Number of items	Dimensions
304	Single cell	BT1	25mm	1	1770 x 2195
305	Single cell	BT2	45mm	2	1777 x 2200 3230 x 2845
306	Single cell	BT3	62mm	1	1773 x 2200
307	Double cell	BT4	45mm	1	1775 x 2200
308	Double cell	BT5	62mm	2	1772 x 2200 3025 x 2855
309	Double cell	BT5	62mm	1	1775 x 2200

2.3 Qualification for testing

Norman Australia has completed the required Expression of Interest form for technology testing in the i-HUB Living Labs. The technology has been deemed as meeting the goals of the i-HUB and as being suitable for testing in this specific Living Lab. It is expected that the honeycomb blinds will assist in reducing the site's energy use, CO2 emissions and electricity demand, mostly due to a reduction in heating and cooling loads. Norman Australia installed all the blinds. QUT provided adequately trained staff for undertaking the testing.

3 METHODOLOGY

3.1 Test approach and description

The project tests the effect of using honeycomb blinds on thermal transmittance and heating/cooling energy consumption. To do so, this test collects data about the external temperature, internal temperature of the room, the heat flow through the window covered by the tested blind, and the operational patterns of the users.

This research combines quantitative and qualitative methods, utilizing experimental data (in-situ data) and building simulation. Performance of the blinds is be evaluated via four streams:

1. Qualitative and quantitative data that include temperature difference, operational patterns, occupancy schedules, and energy consumption.
2. Comparison with baseline data and 'control' rooms
3. Calculation of performance (*U* value)
4. Simulation of extrapolation of effects for the whole building (building modelling)

These four streams are divided into two main phases:

Phase one aims to identify the baseline, thermal performance of blinds, and glazing, and simulation of opening/closing the blinds for 100% of the time.

Phase two aims to investigate the actual control/operation of the blinds onsite, and simulate its impact on energy consumption to identify the limitations of inefficient operational patterns.

Before testing the honeycomb blinds, a series of baseline measurements were taken to verify performance with the settings and seasonal conditions under which the experiments were performed. Data were collected via sensors and stored on data loggers or on a cloud-based storage system.

Phase one measurements were undertaken for the case when the blind is fully open and the case when the blind is fully closed. The effective U-value / R-value of the blinds were tested through using temperature and heat flux sensors.

Phase two focused on comparing the different scenarios of operation, that were identified from interviews with the residents, and assumptions of informed operational schedules.

Table 5 describes the data to be collected and the categories for data analysis.

Table 5 Detailed test description

Category	Description / Purpose
Phase one: Quantitative data– using test equipment, sensors and BMS	
Baseline data	Measuring the external/internal temperature of the rooms with and without blinds
Thermal conduction/resistance	Measuring the U-value of windows without and with different blind types
Building energy simulation	Simulating the building energy consumption with and without the blinds. Tested thermal performance of the blinds is used in the simulation model with assumptions of NCC occupancy schedules.
Phase Two: Quantitative and qualitative data in-situ – user feedback and operational schedules	
User experience and operational patterns (open/close actions; occupant preferences re views, natural light, ventilation, thermal comfort, acoustic comfort, ease of control)	To identify the impact of inefficiently using the blinds, and aspects that can influence operation patterns
Airconditioning use (kWh per month & year)	Impact of window dressings and operational patterns on monthly and yearly kWh
Financial analysis (year)	Analysis of cost of different window dressings v costs of AC
CO_2 emissions (Kg)	Calculating the reduction in CO2 emissions through applying the energy source conversion factor used in Queensland
Air conditioner load (KW, MJ) under different climate conditions Compare the future weather file for the informed closing scenario- how much improvement will the blinds be in the future.	Impact of window dressings on AC load under different current and future weather conditions

3.2 Excluded Items

Items specifically excluded from testing are summarised in Table 5.

Table 6 Excluded items

Item Not to be Tested	Comment
Air leakage	Not relevant, as the blinds used will not be sealed from the sides (i.e. will not create a static pocket of air against the window). It is unlikely they will impact on air permeability.
UV Blockage and Solar Heat Gain Coefficient	While relevant to energy performance, neither the glass nor the window dressings will be tested for UV or SHGC. Manufacturer's claims for these, where provided, will be taken as correct.
VOC Testing	Not relevant for evaluating the energy impact of window dressings.

Colour fastness	Not relevant for evaluating the energy impact of window dressings.

3.3 Instrumentation

The resident test rooms (section 2.1) have the following equipment connected to the BMS:

- Automated Logic sensors (ZS20-HCM-ALC) to measure temperature, relative humidity, CO2 and motion, connected to the BMS
- Steinel True Presence sensors (six rooms, one level only) to measure presence/movement, brightness, temperature, relative humidity, air pressure, VOC and CO2
- Nube Lora WAN sensors including Temp/RH, CO2, Lux, and Reed switches on louvres to identify when the doors/windows are open and the impact of their operation on temperature and lux.
- Data from Heat flux sensors are combined with internal and external temperature sensors to identify the U-value of the envelope elements.
- BMS provides site-specific weather data. Onsite data loggers and/or cloud based systems are used as to supplement data extracted from the BMS.
- Building simulation software is used to extrapolate results to a whole of building level. It will also enable extrapolation of results to under different climate files.

4 ROLES AND RESPONSIBILITIES

4.1 Roles and assigned responsibilities

The roles and responsibilities are provided in Table 7.

Table 7 Roles and responsibilities

Role	Responsibility
Wendy Miller (QUT)	Project Leader; oversee the test regime and report writing / distribution
Sherif Zedan (QUT)	Project manager of the test and research living lab; organise and conduct the testing; write the test report; distribute the test report according to contractual arrangements
Nima Izadyar (QUT)	Assist in procuring and installing sensors
Yunlong Ma (QUT)	Assist with building simulation model
Aaron Liu (QUT)	Assist with energy simulation and extrapolation of results
Norman Australia (Matthew Willmot)	Supply and install the blinds (to remain after testing); provide training to QUT and Bolton Clarke on operation and maintenance of the blinds
Bolton Clarke (James Chiou)	Living lab host, facilitate access to the building. Coordinate the research requirement with QUT. Report any problems that might hinder/stop the testing.

5 TEST RESULTS AND DISCUSSION

5.1 Baseline analysis

Baseline data analysis was done to investigate the impact of external weather on heating and cooling energy consumption, and the effect of using blinds on internal temperature of unconditioned rooms.

5.1.1 Testing of Building envelope

Figure 6 shows a comparison between the internal temperature, external temperature, and HVAC heating and cooling set points, to examine the quality of the building envelope. The comparison was conducted while the room air conditioner was on (from 8/11/2020 to 18/11/2020) then off (from 18/11/2020 to 2/1/2021). When the air conditioner is on set points can be adjusted by user between 22 to 24 degrees.

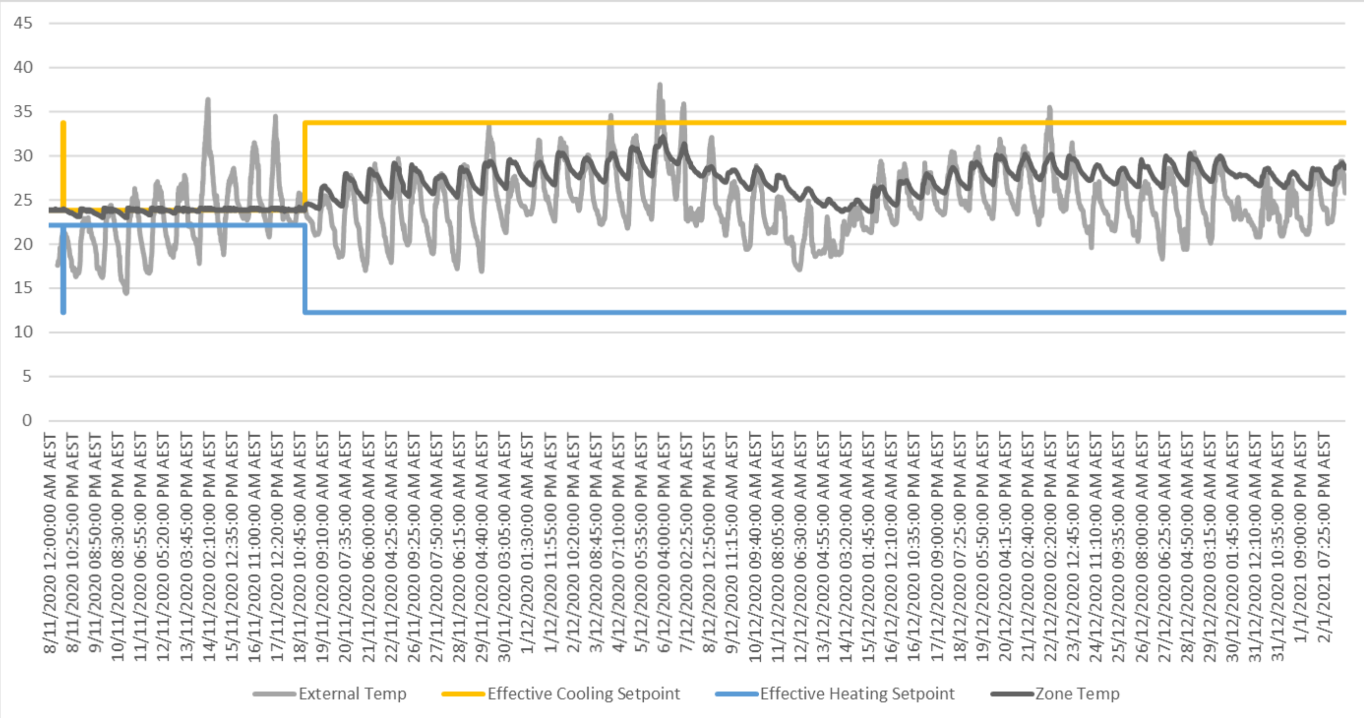


Figure 6: Comparing internal/external temperature and HVAC set points

The graph shows that internal temperature to be more stable than external temperature. It can be up to 4.65 degrees warmer and up to 6.8 colder than external temperature when the room is unconditioned. Internal temperature ranges between 20.2 to 32.2 degrees, compared to 14.4 to 38.1 for external temperature. Despite the lower fluctuation of internal temperature when compared to external one, the internal temperature was above 25 degrees for the whole month of December, with the exception of the period from 13-15 Dec, which was a predominantly cold period, with highest temperature of 23.7 and lowest of 18.8 Degrees. The internal temperature during the hottest day of the month (6/12/2020) was above 30 degrees for 15 hours, between 28 to 30 degrees for 6 hours, and between 27 to 28 degrees for 3 hours.

This indicates good performance of building envelope; however, air conditioner is still needed to maintain 100% of the time within a comfortable threshold.

5.1.2 Testing effect of existing blinds in-situ

The effect of closing/opening existing curtains (before the installation of honeycomb blinds) on the internal temperature of temperature was analysed through comparing typical rooms that have the same orientation but on different levels.

To compare the effect of the existing blinds on the internal temperature of the rooms, all rooms air conditioners were turned off, and the curtains in a number of rooms were closed. Table 8 shows the level which typical rooms are located, and the rooms with the closed blinds (grey cells).

Table 8: Tested rooms

Level 4	405	408
Level 3	305	
Level 2	205	208

Comparison of room 405 with 305 (Figure 7), and room 208 with room 408 (Figure 8) on 30/01/21 shows that temperature difference can be reduced by 1 degree at the hottest hour of the day when the blinds are closed .

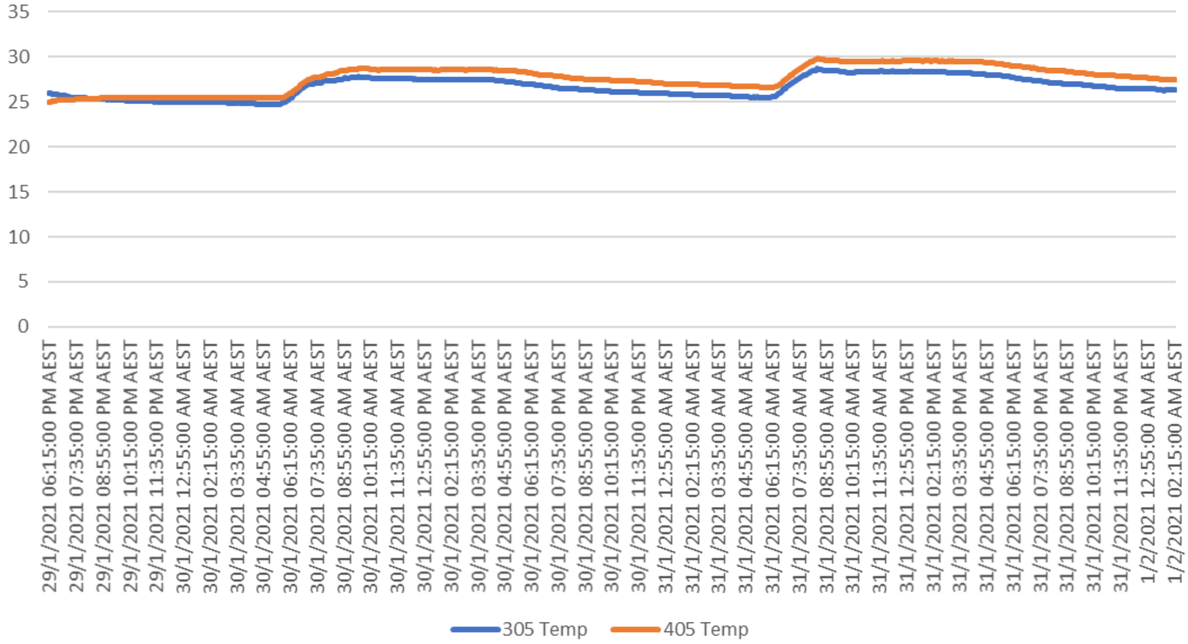


Figure 7: Internal temperature with (room 305) and without (room 405) blinds

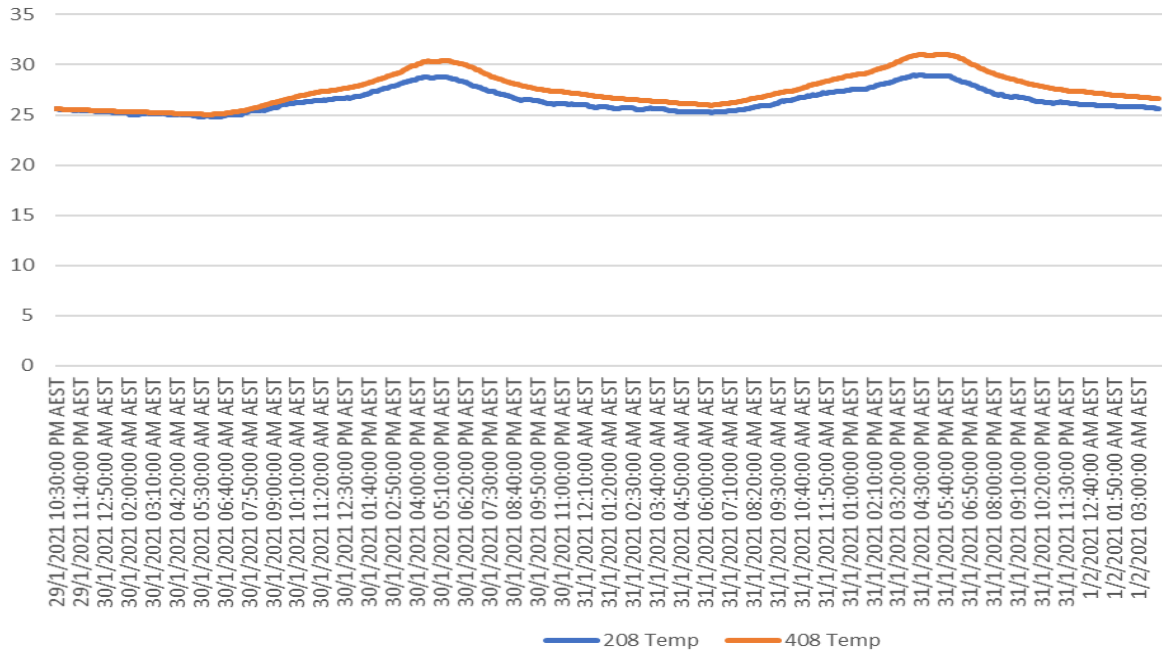


Figure 8: : Internal temperature with (room 208) and without (room 408) blinds

The gap between the closed and open blinds room temperature increased by the second day. Possibly due to trapped solar heat gain accumulation.

5.2 Testing Honeycomb blinds performance

The thermal specifications of the blinds (e.g U-value) is not affected by the location. Therefore, due to COVID lockdown restrictions and difficulty in accessing the aged care, similar blinds were installed in Norman Australia's showroom in Brisbane (Figure 9), to enable ongoing testing of the different blinds' performance. The blinds were applied to a window oriented towards southeast, with no external shading.

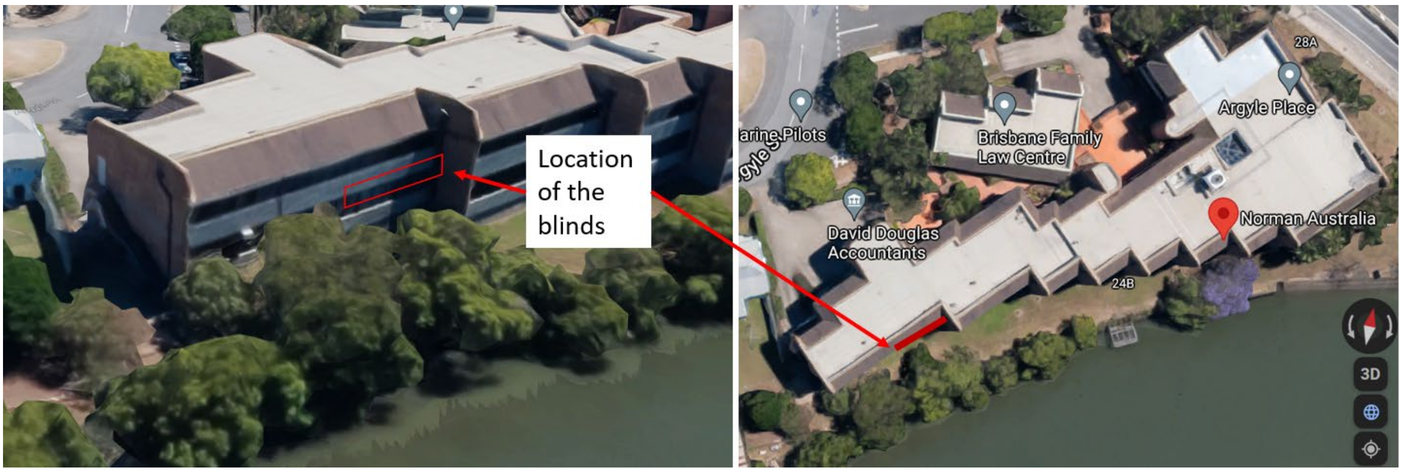


Figure 9: U value testing site

The heat flux method (HFM) was used To measure the U value of the blinds following Equation 1.

$$U = Q/T_{in} - T_{out}$$

Equation 2: U-value calculation

Where T_{in} and T_{out} are the inside temperature and outside temperature in Kelvin and Q is the corresponding heat flux through the measured element (W/m2).

The heat flux data (Q) was obtained from a heat flux sensor attached to the inside of the glass. The inside temperature (Tin) and outside temperature (Tout) were measured with two temperature sensors (Figure 10).

Figure 10: HFM setup

The data was collected in a 1 minute intervals for 72 hours, and all test results were compliant with section 7.1 of ISO9869-1:2014.

The in-situ measurement showed that the glass only U-value is 5.2 W/(m^{2}K). This value corresponds to the single glass only value as shown in Table 2 . The measurements were done in July/August 2021 with an average temperature of 27°(High) / 4°(Low). Central air conditioner was turned on during the whole testing period to keep internal temperature at a 24°C. The stable internal air temperature is to ensure that heat transfer only in one direction and limit U-value fluctuations, which could render the test invalid.

Figure 10 illustrates the test results for BT5 (62mm double cell). The highest difference in temperature between T_{in} and T_{out} was 14.1 °C at 6:30am, where T_{in} was 23.4 °C and T_{out} was 9.3°C. Heat flux ranged between -16 to 30.5 W/m2, and U-value ranged between 1.6 to 2.2 W/m2K. In few occurrences, Heat flux showed a negative value during daytime (from around13:00am to 3:00pm) indicating inward heat flow, as the internal temperature reaches or becomes cooler than the external temperature. These occurrences however had no effect on the validity of the test.

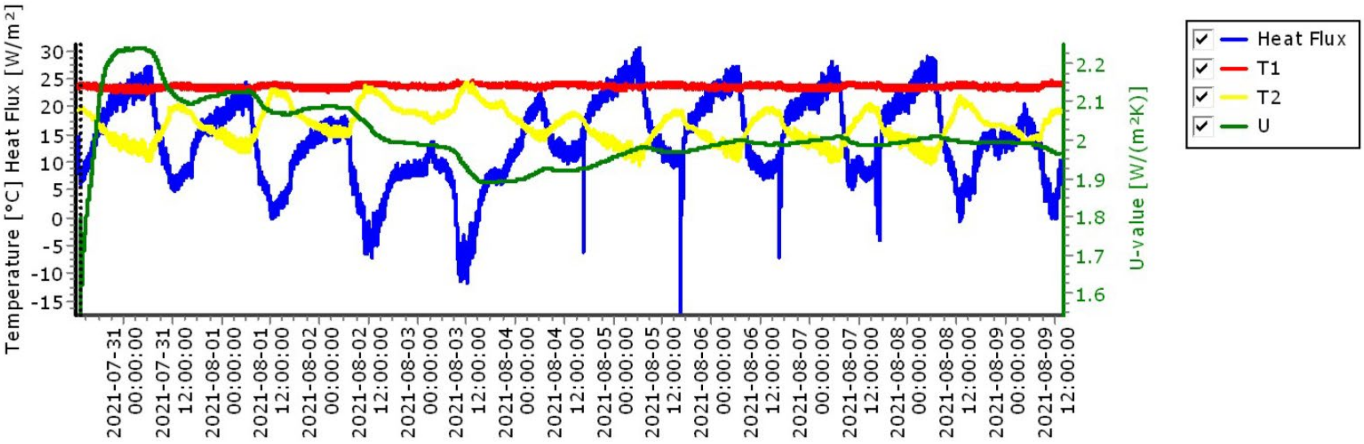


Figure 11: Measurement overview for BT5

Figure 11 shows the external and internal temperature with and without the blinds for two 24 hours periods, with the air conditioner at the showroom turned off. The graph shows that during daytime (from 9 am to 5 pm) the blinds had more effect reducing internal temperature. The temperature reduction reached 2.5 °C with blinds, and only 0.7 °C without blinds.

During night-time (from 6 pm to 5 am), T_{in} with blinds remained close to T_{in} without blinds despite the rise in external temperature by around 1 degree.

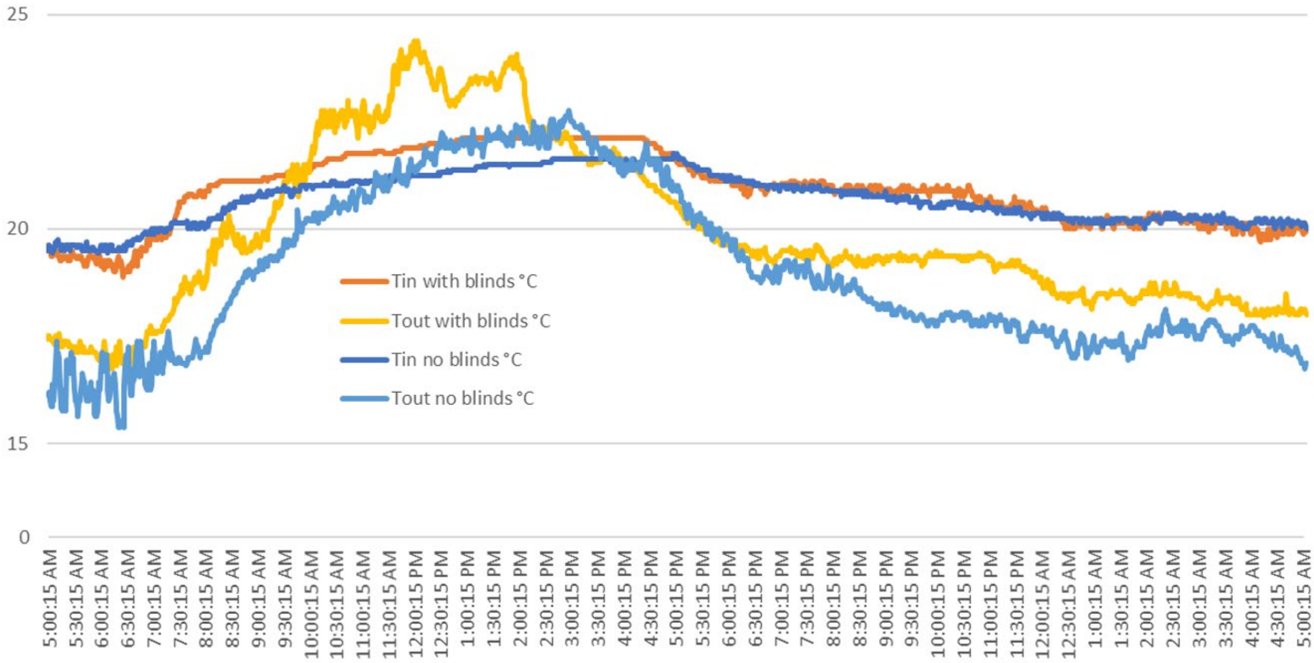


Figure 12: Tin vs Tout with and without the blinds

Table 9 compares between the thermal performance of the glass only and with the blinds. The table shows that there is a correlation between the size/number of cells and the thermal resistance/transmittance. The 45mm single and double cell however showed a very similar thermal transmittance.

The table shows that Average reduction in thermal transmittance through window was 56% with a maximum of 62% when 62mm double cell was used and a minimum of 50% when 25mm single cell is used. Average U-value of honeycomb blinds only is 4.21 with a highest of 5.27 for the 25mm single cell, and a lowest of 3.13 for the 62mm double cell.

Table 9: Tested thermal performance.

Description	Thermal Resistance (R value) of window with blind	Thermal Resistance (R value) of covering layer	Thermal transmittance (U value) of covering layer (W/m2K)	Thermal transmittance (U value) of window with blinds (W/m2K)	Reduction in U value
Glass only	0.19	-	-	5.21	0%
Blinds+BT1-Single-25mm (6)	0.38	0.19	5.27	2.62	50%
Blinds+BT2-Single-45mm (4)	0.42	0.24	4.16	2.34	55%
Blinds+BT3-Single-62mm(1,2)	0.43	0.24	4.16	2.32	55%
Blinds+BT4-Double-45mm (5)	0.42	0.23	4.34	2.35	55%
Blinds+BT5-Double-62mm (3)	0.51	0.32	3.13	1.96	62%

5.3 Building simulation

An energy model of the existing building at Fernhill was built to simulate the effect of the added blinds to the performance of the building envelope, and consequently their impact on energy and CO_2 reduction. The model utilised the same building elements and HVAC plant in the existing building. The simulated zone temperature set points range between 22-24 °C to mimic the settings in the actual building. Multiple simulations were done for a number of scenarios affecting opening/closing the blinds to the bedrooms.

5.3.1 Whole building simulation

The whole building was simulated (Figure 13) with and without the effect of the blinds on the U-value and SHGC of windows in residential bedrooms. Operation, occupancy, and activity schedules were assumed to be like the NCC guidelines in part JVb. The simulated effect was for TB5 (62mm double cell blinds) with a total U-value of 1.96 and SHGC of 0.01, assuming that blinds will be closed all the time. Other scenarios where blinds are open according to certain conditions will be presented at a latter section of this report.

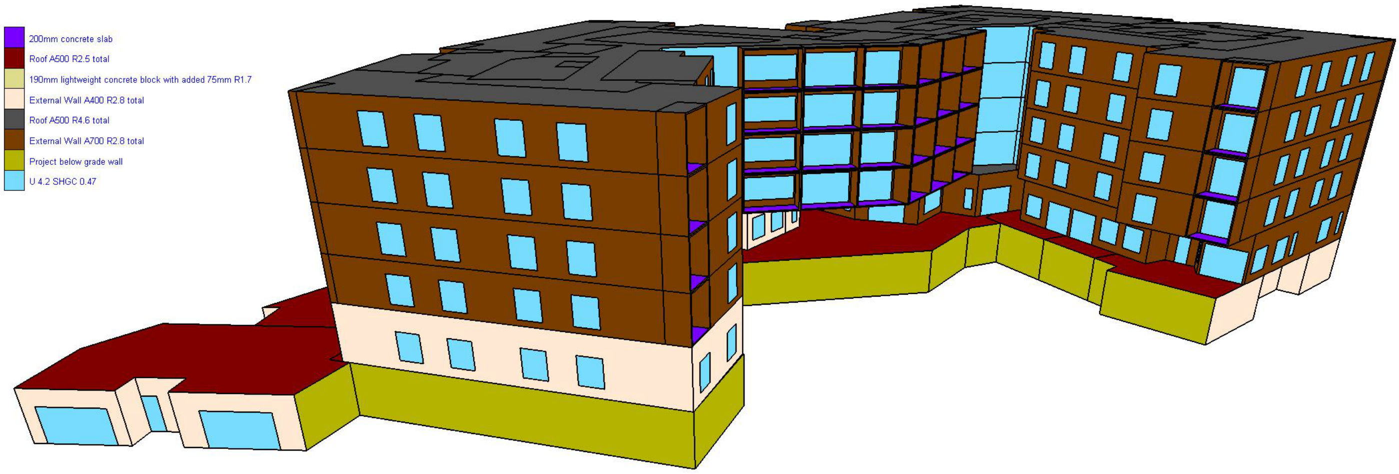


Figure 13: Building simulation model

Whole building simulation shows that the majority of energy consumption is for heating and cooling purposes, accounting for 38% of the total energy consumption in the case with no blinds (Figure 14). Table 10 shows that total energy consumptions and emissions were reduced by 4.6% when the blinds were used. The most effective reduction was in reducing cooling energy (12.5%) due to major reduction in solar heat gain (57.7%) and heat loss (64.3%) as a result of closing blinds the whole time.

5.3.1.1 Energy Consumption Annual Analysis

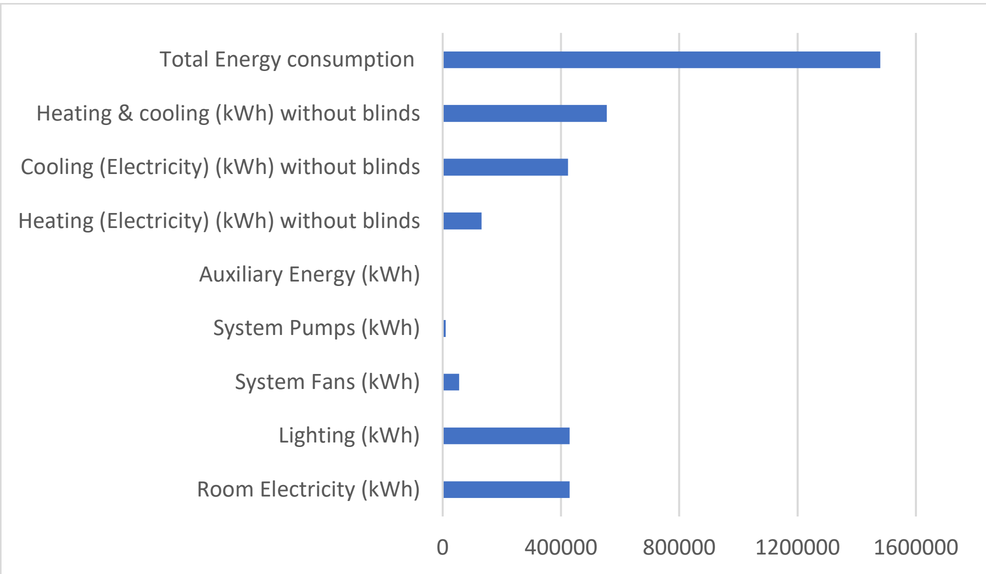


Figure 14: Energy consumption simulation results with no blinds

Table 10: The effect of blinds on reducing energy and CO2 emissions

	Without blinds	With blinds	Reduction percentage
Heating (Electricity) (kWh)	130,925	124,903	4.6%
Cooling (Electricity) (kWh)	423,931	371,012	12.5%

Total Energy Consumption (kWh)	1,479,338	1,411,116	4.6%
CO_2 Emissions (kg)x10^3	1,363,357	1,300,484	4.6%
Solar Gains Exterior Windows (kWh)	209,069	88,518	57.7%
Glazing (kWh)	-23003.7	-64504.61	64.3%
Chiller Load (kWh)	-1,370,409	-1,184,744	13.5%
System Fans (kWh)	55,570	47,673	14.2%
System Pumps (kWh)	10,582	9,201	13.0%
Auxiliary Energy (kWh)	15	12	16.0%

5.3.1.2 Monthly analysis

Figure 15 shows that the maximum total energy consumption is in January (163.3MWh without blinds, and 152.5 MWh with blinds). The minimum total energy consumption was in September (95.8MWh without blinds and 94.2 MWh with blinds). The rise in total energy consumption in July is explained by the rise in heating energy as evidenced by Figure 16.

The reduction in energy consumption associated with use of blinds is correlated with external temperature rise, with a maximum reduction in summer (January) reaching 6.6% and in winter (July) reaching 2.8%. This shows that solar heat gain reduction for when the blinds were closed, had very little effect on increasing heating energy consumption, due to the nature of climate with mild temperature during winter. The limited benefit of solar heat gain during winter highlights that closing the blinds the whole time would have positive impact on reducing heating and cooling energy consumption. Lack of daylight will have however, negative impact on other aspects such as the health of occupants and the increase of artificial lighting energy consumption.

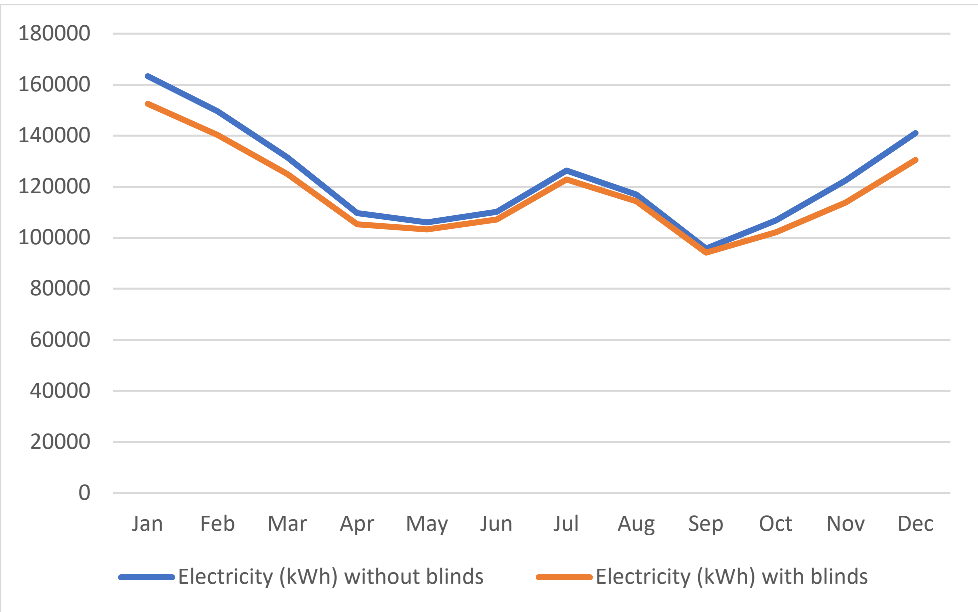


Figure 15: Total energy consumption with and without blinds

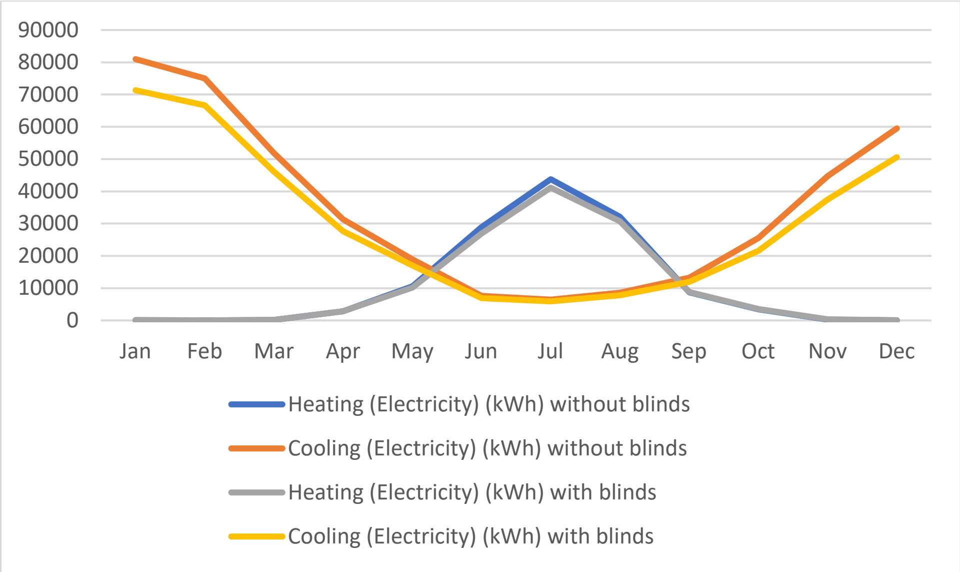


Figure 16: Monthly heating and cooling energy with and without blinds

Figure 17 highlights the difference in heat transfer and solar gains through glazing, with and without blinds. The graph shows that the heat gain during summer and heat loss during winter is lower when the blinds are closed. The reduction in heat transfer has a maximum of 80% in December and a minimum of 8.5% in July. Solar heat gain was also significantly reduced by closing blinds with a monthly average of 58%. This shows that both heat conduction (u-value) and Solar Heat gain (SHGC) were improved with the added blinds.

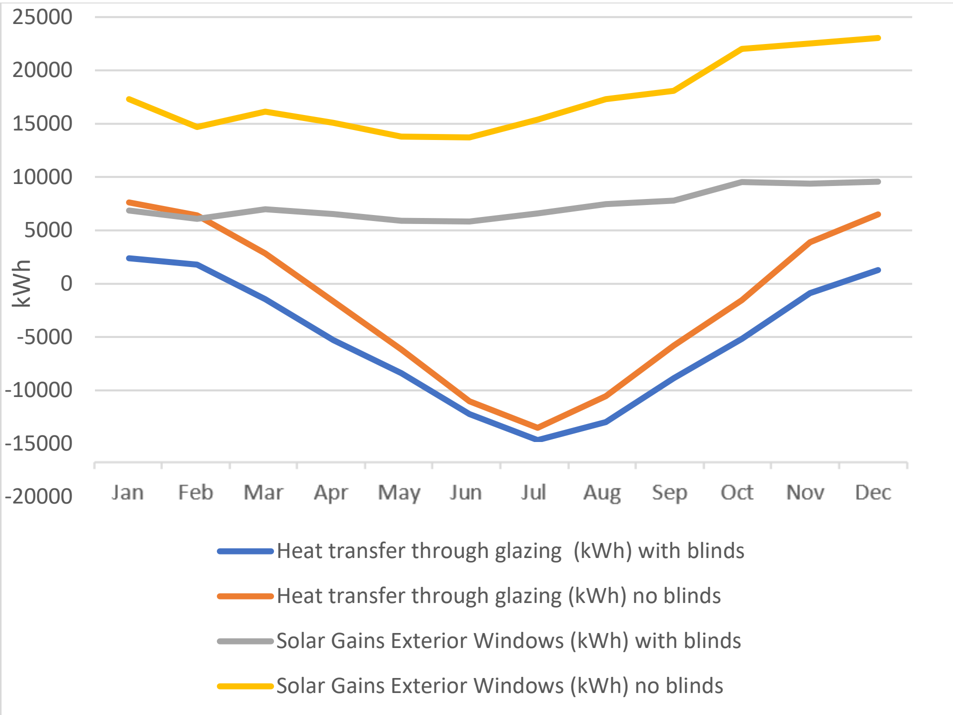


Figure 17: Heat transfer and solar gains with and without blinds

5.3.2 User feedback and insights

Since closing the blinds all the time is unrealistic, the research team conducted interviews with five of the residents of the six rooms with honeycomb blinds to identify their operational pattern/behaviour. Three main questions were asked:

1- At what time/s do you open/close the blinds?
2- What triggers opening/closing the blinds?
3- Does having motorised (remote controlled) blinds affect the way you would normally operate them?

Responses to each of these questions are summarised in Table 10.

Table 11: Residents' feedback summary

Question 1: Operation schedule	
Room 304	Open in the morning and closed at night
Room 305	Open in the morning and closed at night
Room 306	Always open
Room 308	Open/close as response to daylight. Open during night-time
Room 309	Rarely closes it (moves chair to avoid the sun)
Question 2: Reason for opening/closing	
Room 304	To reduce the noise, never closed as a response to the sun
Room 305	For privacy and security at night
Room 306	Always open to see the outside view
Room 308	To let the sun in or keep it out
Room 309	Always open to look at the view
Question 3: Do motorised blinds help	
Room 304	No effect
Room 305	Yes, remote increase the use of blinds. Reverse sliding blinds makes it difficult to operate
Room 306	Never use/close it
Room 308	Remote helps but does not use it since the battery depleted. Sliding blinds are difficult to use
Room 309	Helps, but rarely use it

The responses show that operation patterns vary between open all the time to enjoy the external view or closed during night-time for security/privacy reasons. Most residents rarely close blinds as a response to solar radiation, external temperature, or to optimise reliance on air-conditioning. Most residents find that having motorised blinds with remote control helps operate the blinds more frequent. However, if the remote is unavailable (e.g. lost , or does not have a battery), it may reduce using the blinds significantly.

Findings from the interviews show the difficulty of operating blinds efficiently to optimise energy use, especially when the occupants have the capability to rely on air conditioner the whole time without any cost implications. Due to the difficulty of educating the residents or appointing staff to operate the blinds efficiently, installing solar radiation sensors to automate opening/closing the blinds could be a convenient/cost effective method to maximise energy reduction benefits in aged care buildings.

5.3.3 Operational Scenarios simulation

Following feedback from residents, multiple common opening/closing scenarios were simulated for all residential rooms on level 3 based on the following conditions:

1- Blinds/drapes always open
2- Blinds are always closed

3- Normal drapes are always closed
4- Blinds are closed when solar radiation incident on the window exceeds 120 W/m2
5- Blinds are closed when outside air temperature is above 24 degrees
6- Blinds are closed at night and when solar radiation incident on the window exceeds 120 W/m2
7- Blinds are always open during the day and closed at night

All the scenarios are common operations to reduce cooling loads except for scenario 7 which is common for reducing heating loads in colder climates. Scenario 7 however, was used by some of the residents at Fernhill for security/privacy reasons.

Figure 18 illustrates the effect of the different scenarios on the annual heating and cooling energy consumption for residential rooms on level three, based on the assumption that the air conditioner is open 24/7. Simulation results show that heating and cooling energy consumption dropped by 9% when honeycomb blinds are always closed, compared to 5% when normal drapes are always closed. All the cooling load reduction scenarios had similar results of approximately 6% reduction in kWh/annum. Heating load reduction scenario did not show any reduction when compared to no blinds, which indicates that for sub-tropical climate the benefits of the blinds are evident mainly in reducing cooling loads during daytime.

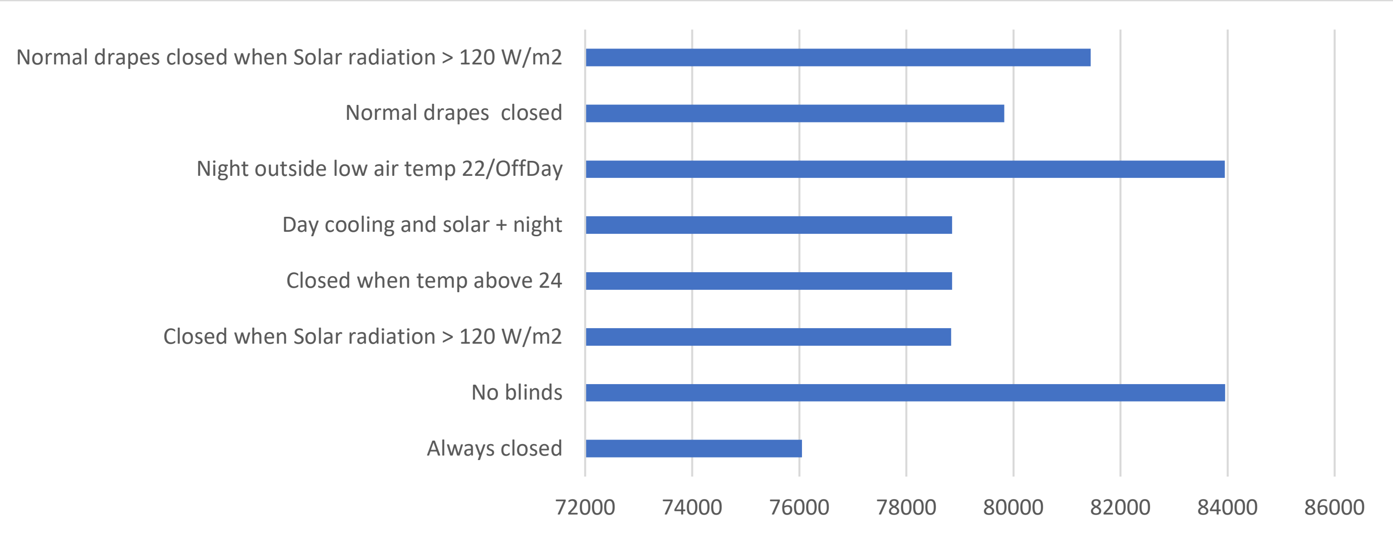


Figure 18: Effect of different shading scenarios on electricity consumption

The effect of blinds on reducing heat gain is highlighted in Figure 19 where the energy reduction resulting from closing the blinds are higher in the summer months and gets less moving towards the colder months

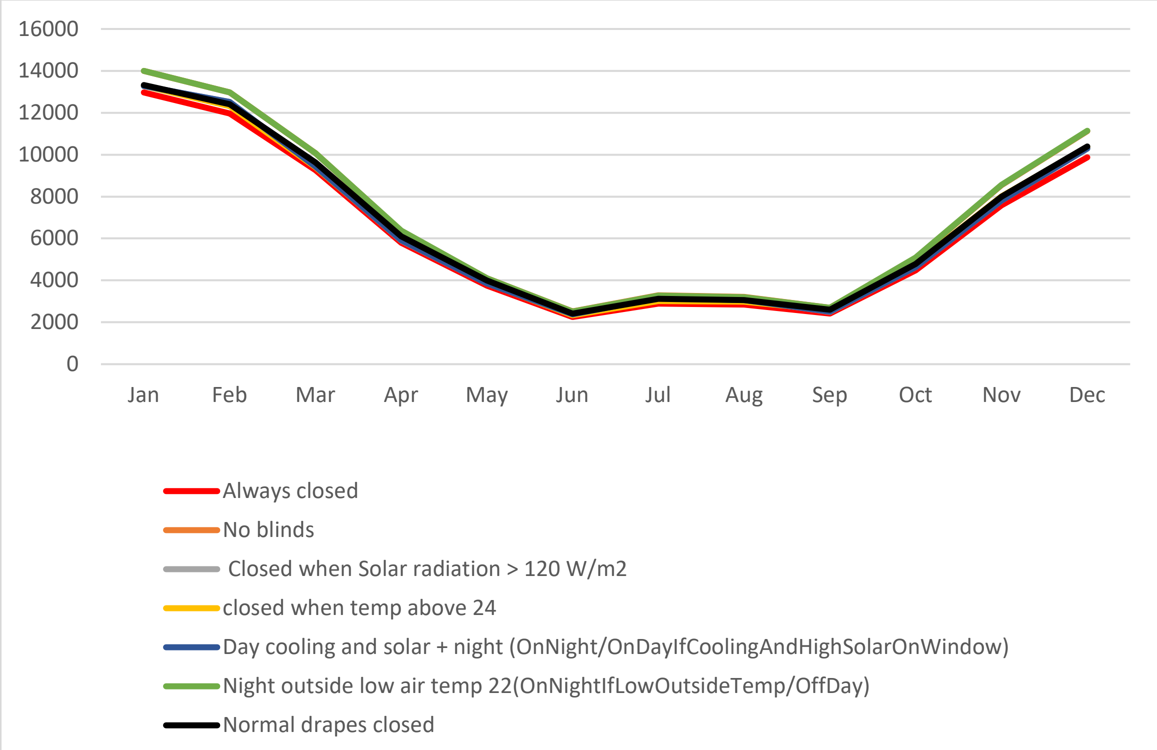


Figure 19: Monthly heating and cooling kWh of different scenarios

6 COST EFFECTIVENESS ANALYSIS

Estimated environmental and cost benefits for the case when blinds are closed the whole time are presented in Table 12. The cost reduction estimate is based on $0.15/kWh, and the CO2 emissions reduction is based on greenhouse gas emission factor of 256 kgCO2-e/GJ for QLD as per the NCC Volume one[3]. The most significant reductions are in summer month with a maximum of $1,622 savings in January, and $10,233 savings yearly.

Table 12: Estimated savings

	Estimated Emissions Reduction (kg)x10^3	Estimated kWh Savings	Estimated Bill Savings $0.15/kWh
Jan	10	10,813	$1,622
Feb	9	9,330	$1,400
Mar	6	6,436	$965
Apr	4	4,353	$653
May	3	2,732	$410

[3] Australian Building Codes Board, National Construction Code Series 2019, Australian Building Codes Board, Canberra, Australia, 2019.

Jun	3	3,014	$452
Jul	3	3,550	$533
Aug	2	2,580	$387
Sep	1	1,603	$240
Oct	4	4,695	$704
Nov	8	8,578	$1,287
Dec	10	10,537	$1,581
Total	63	68,222	$10,233
Mean Monthly	5	5,685	$853

When honeycomb is closed in response to solar radiation the reduction in energy costs per annum can reach 3.3% in comparison to the drapes already installed in the rooms. This reduction is in in addition to a 3.6% reduction in the initial cost of the honeycomb blinds in comparison to the drapes. This report did not include the cost of maintenance and did not analyse visual preferences, life expectancy, quality, ease of maintenance, cleaning, etc.

7 FUTURE WEATHER SIMULATION

Future weather file was used to simulate Informed operation of the blinds as a response to solar radiation. The future weather file predicts the effect of global warming on weather conditions in the year 2050, assuming that efforts to reduce global warming will remain at their current state. Figure 20 show that the future increase in energy consumption without blinds being used is 22.5% compared to 22.7% if blinds were used. Reduction when blinds are used in current weather is 3.4% compared to 3.1% for future weather. This highlight that the blinds will not provide any additional benefits in hotter future weather.

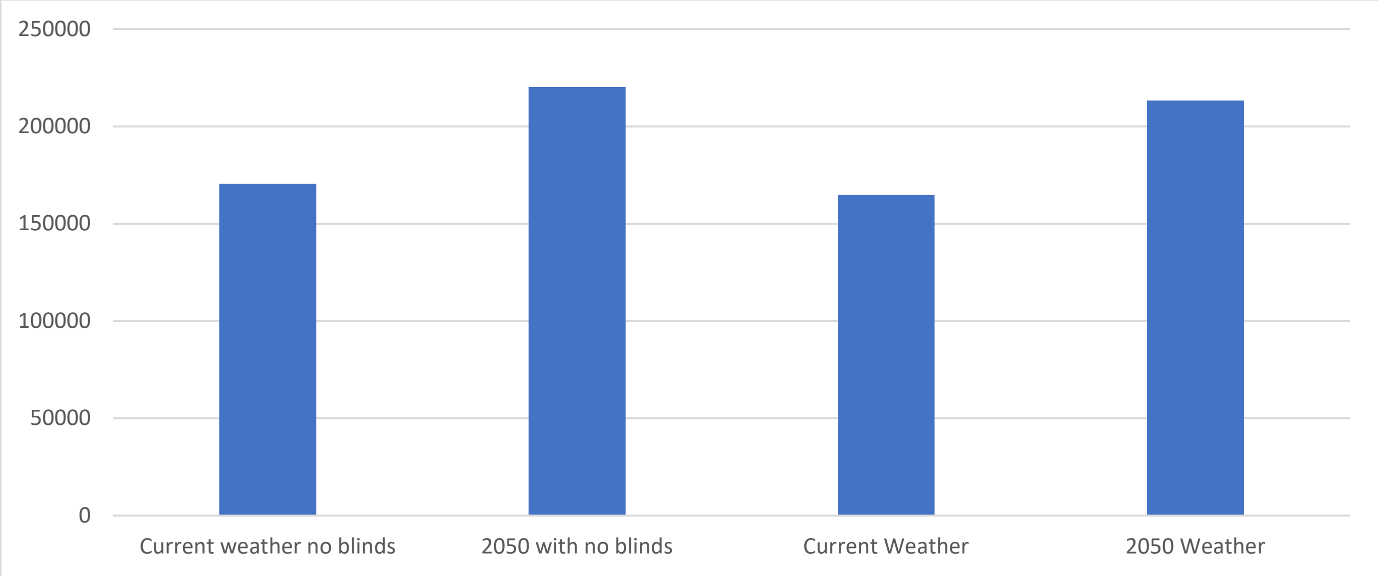


Figure 20: Energy simulation of blinds in current and future weather

8 SUMMARY FINDINGS AND CONCLUSIONS

Internal window dressing is a cost effective and easy to implement method to reduce heat loss in winter and heat gain in summer. There are many aspects that can impact how effective are the window dressing such as its type, shape, material, colour, and installation methods. However, one of the most important aspects to increase the potential of window dressing is informed operational patterns that can maximise daylighting benefits without inhibiting thermal comfort or increase reliance on air conditioning.

Findings of this report confirm that honeycomb blinds can significantly reduce heat transmittance through windows and therefore reduce heating and cooling energy costs. This reduction is correlated with the size and number of cells of the blind. Simulation results show that for subtropical climate, energy savings are maximised when blinds are always closed. Due to the importance of daylighting exposure especially in healthcare facilities, other operational scenarios were simulated. Comparison of these scenarios shows that the most effective way to optimise thermal comfort, visual comfort, and access to daylight is to operate the blinds as response to solar radiation and external temperature.

Interviews with the residents of the rooms with the honeycomb blinds highlight those blinds are rarely operated as a response to external conditions. They remain mostly open or are closed for reasons that are not related to thermal comfort or energy use mitigation. Having motorised blinds increased the ease of use and encouraged some residents to operate the blinds more often. A downside of the motorised blinds, however, is that some residents may choose not to operate them if the remote is missing, faulty, or out of batteries.

Due to the complexity of managing the residents' operational behaviour, A cost effective/easy to implement way to reduce energy costs, is to use blinds that respond automatically to solar radiation and external temperature. Adding those automated blinds to both residential and communal areas might result in significant reduction in energy consumption.

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