Restaurant

Energy Efficiency Training
and Information Project

Commercial Buildings

Tahbilk
VIC

Research group

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

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Cover image:
Tahbilk restaurant at Tahbilk Winery, Victoria.

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1. Executive Summary

A complete renovation package ... will lead to energy savings of 61.6%

Global climate change is exposing existing buildings to conditions they were not designed to face, with a growing need for increased efficiency, to reduce the operational cost and carbon dioxide emissions. To meet these goals, established buildings need energy retrofits. Almost 80% of 2050 buildings are already established today [1], and we must prioritise improving the efficiency of existing buildings. Among these, restaurants are a relevant and widespread building type. There are 23,218 restaurant businesses in Australia as of 2021, an increase of 2.6% from 2020 [2]. Energy use accounts for at least 15% of the total operational costs in a food and beverage manufacturing business [3]. Restaurants consume nearly three times the energy of the average commercial building [4]. More than half of the energy consumed in restaurants is used for heating, ventilation, cooling and lighting [4]. This report tackles the operational energy consumption challenge for an existing restaurant, using a real-life case study to visualise the impact of each energy optimisation strategy. A high-level framework prioritising different building enhancement methods is presented in this report.

A Restaurant is selected as a case study to explore opportunities to reduce energy consumption. A dynamic thermal model of the restaurant is simulated with the TRNSys software tool, reproducing the thermal features and building services in the real building. This report summarises the findings of the performed analysis on the existing conditions and provides recommendations for the improvement of the building conditions and the minimisation of the energy consumption in the case study building located at 142 Mulberry Dr, Tahbilk, VIC 3608. The Tahbilk Winery in Tahbilk includes a restaurant that is selected as the case study. The structural and energy performance features of the studied restaurant are representative of the typology and construction period (2000s).

Natural light levels in the restaurant are high, and they can contribute to substantial energy savings for artificial lighting. The use of daylight linked controls led to a decrease in energy consumption of 89% compared to the base case scenario lighting system and energy consumption.

With values of 16.1 and 11.9 kWh/(m^{2}a) for heating and cooling, respectively, the baseline scenario for determining practical actions indicates that energy consumption for heating and cooling is the most critical issue to solve. Nonetheless, lighting and appliance energy usage are critical. As a result, the primary focus is on lowering heating and cooling requirements. The windows and glazed sections, in general, are not up to date with current regulations, and because they make up such a large portion of the envelope's overall surface, they contribute significantly to energy losses during the cooling season. As a result, retrofitting is a possibility. The poorly insulated walls and roof, which substantially impact energy performance in such a low-rise building, are also focal targets for reducing heating loads. The HVAC&R system can be replaced with a state-of-the-art heat pump will impact energy consumption.

Based on the results, the following recommendations are technically viable and considered feasible:

- Improvement of the lighting systems.
- Refurbishment of the windows, double glazed ones, of high energy efficiency to reduce solar loads in summer and achieve airtightness throughout the year.
- Installation of ceiling fans to reduce cooling loads.
- Installation of mechanical ventilation with heat recovery to reduce heating loads. →

- Fitting 100 mm of mineral wool under the existing roof, reducing heating and cooling loads.
- Applying insulation on external walls. The proposed intervention includes the installation of 100 mm of mineral wool covered with plasterboard for the stone wall (potentially with a veneer to retain architectural features) and 80 mm of mineral wool covered with plasterboard for timber walls, leading to a reduction of both heating and cooling loads.
- Installation of an air-to-water heat pump (AWHP) or a ground source heat pump (GSHP) could drastically reduce final energy consumption for space heating and cooling.

In conclusion, a complete renovation package includes the replacement of the building's windows and glazed surfaces, insulation of the external walls and roof, combined with an upgrading of the lighting system, the installation of ceiling fans and the use of mechanical ventilation with heat recovery, and eventually the use of a GSHP or, if this is not possible, of AWHP. Such a package will lead to energy savings of 61.6%, resulting in an energy consumption of 28.6 kWh/m^2 a, compared to the baseline of 74.3 kWh/m^2a.

2. Regulations, Standards, and guidelines

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

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

3. Introduction

The selected case study building is a typical restaurant built in Australia in 2004, representative of many other restaurants constructed in the same period. In fact, the aim of selecting Tahbilk restaurant is the potential for methodology replication and findings expansion to other similar buildings.

Clearly, one sample restaurant cannot be representative of all restaurant types, which display highly variegated features. However, even though the required procedure may differ, the logic and methodology presented here offer a high-quality framework to improve the energy efficiency in such buildings.

Assessing the energy performance of a restaurant is a complicated task. It starts with determining the building's construction features, including the efficiency of the building envelope, lighting, HVAC&R and other equipment. Considering the building's features, all calculations were based on the 'as-built' condition of the building elements (U-values, shading, air-permeability, etc.). The efficiency of the HVAC&R system (Coefficient of Performance (COP) and Seasonal Energy Efficiency Rating (EER) were selected based on the provided information by their manufacturers, and installed lighting and plug loads were determined either by data provided by the building operators or in accordance with standards and regulations.

Additionally, two types of specific conditions that have a significant impact on the energy 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. Tahbilk restaurant

4.1. Case study description

4.1.1. Climate

The Tahbilk restaurant is located at 142 Mulberry Dr, Tahbilk VIC 3608 (36.824S, 145.105E). Tahbilk is 140 km north of Melbourne, and it is 131 m above sea level. In Köppen's climate classification, Tahbilk is categorised as Cfa, meaning that it has a humid subtropical climate with mild to cool, short winters and warm, sometimes hot, prolonged summers [5]. Rainfall is relatively evenly spread throughout the year. Precipitation is slightly higher between May and September, with an annual mean rainfall of 510 mm. July has the highest rainfall (53.7 mm). Due to its geographical location, the relative humidity is higher in winter (68-76%). The winters are cold, with overnight minimums averaging 3.0°C and daily maximums climbing to only 13.4°C. Moreover, summers are warm, and the average maximum temperature reaches 30.3°C in January. The climatic data provided by Meteonorm is considered for building modelling. The primary climatic information for Tahbilk is illustrated in Figure 1. →

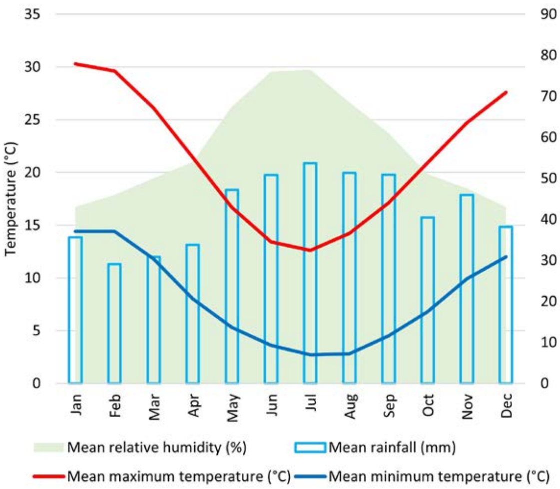

Figure 1. Climatic data of Tahbilk [6].

Figure 2. Southern view of Tahbilk restaurant.

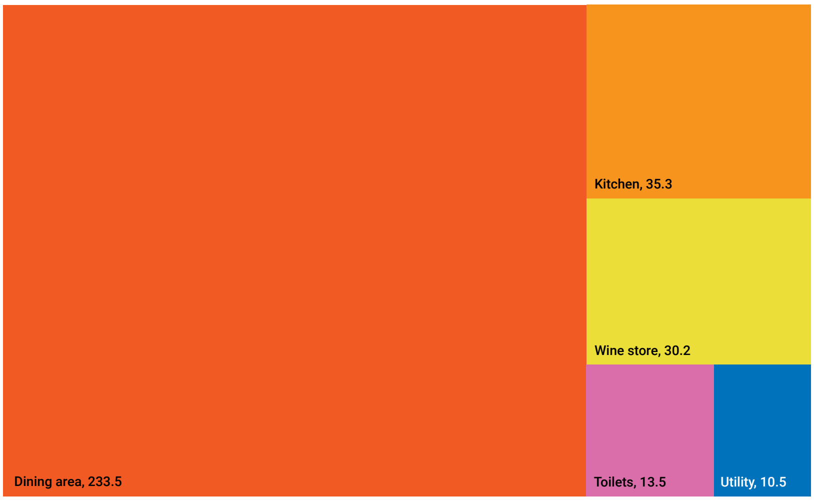

Figure 3. Gross floor divided area of case study building.

4.1.2. Tahbilk restaurant description

This case study building is a restaurant within the Tahbilk Winery complex, and it was completed in 2004 (Figure 2), having capacity for 120 people. The classification of Tahbilk restaurant according to the National Construction Code is Class 6: a shop or other building used for the sale of goods by retail or the supply of services direct to the public [7]. The under-ceiling height of the mentioned restaurant varies between 2.9 and 3.3 m. Figure 3 illustrates the treemap chart of the gross internal area of case study buildings. The total gross floor area is 323.0 m².

4.1.3. 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, with electricity used for heating, cooling, lighting, appliances, and water heating. Also, free-standing gas is used for cooking. ➔

4.2. Building modelling input parameters

The modelling parameters combine collected data from the building inspection, utility bills and Australian and global standards. Each modelling assumption will be briefly explained in this section, and relative references will be presented.

4.2.1. Occupancy

Currently, the Tahbilk restaurant has capacity for 120 people, and the occupancy schedule is selected based on the national code of construction [7].

4.2.2. Geometric data

The case study building has only one floor. Table 1 shows the main purpose of each part of the Tahbilk restaurant.

Table 1. Building geometric information.

Spaces	Air-conditioned area (m^2)	Not air-conditioned area (m^2)	Gross floor area (m^2)
Dining area	233.5	0	233.5
Kitchen	35.3	0	35.3
Wine store	30.2	0	30.2
Toilets	0	13.5	13.5
Utility room	0	10.5	10.5
Total	**299.0**	**24.0**	**323.0**

4.2.3. Building Components

A significant part of the energy consumed to maintain comfort leaks through the building envelope. As a key step in assessing the potential benefits of improving windows, walls, roofs and floors, the current thermal performance should be determined. In surveying the case study restaurant, the thermal properties of the building envelope are assessed based on construction features and age. This information is used to model the building and develop a thermal model. Here, the performance descriptors of external walls, roof and windows are introduced.

4.2.3.1. External walls

The External wall of the case study building can be divided into two parts. There is a stone wall on the northern side of the building and timber studs in the upper part. The stone wall is made of 300 mm granite stone on the northern side of the building. The R-value of the external wall is 0.277 m^2.K/W, with a solar reflectance of 0.277. Also, using the average annual wind velocity in Tahbilk (4.2 m/s) [6], the convective heat transfer coefficient is calculated as 17.6 W/(m^2.K) [8].

The other walls are timber stud walls, composed of timber panels on the exterior, an air gap in the middle, and interior timber panels. The R-value of these external walls is 0.850 m^2.K/W, and the solar reflectance coefficient is 0.20. Also, using the average annual wind velocity in Tahbilk (4.2 m/s) [6], the convective heat transfer coefficient is calculated as 17.6 W/(m^2.K) [8]. ➔

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

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m^3)	Resistance (m^2.K/W)	Ref.	Section and page
Granite Stone	300	2.8	1	2500	-	[9]	Table 3, page 11

R-value: 0.277 m^2.K/W

Table 3. Building Components - Performance Descriptors – Construction – External Timber stud walls.

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m^3)	Resistance (m^2.K/W)	Ref.	Section and page
Metal sheeting	1	50	450	7,500	-	[9]	Section 8.3, page 9
Thermal insulation	50	0.038	1	55	-	[10]	page 3
Air space	50	-	-	-	0.23	[8]	Section 5.3, page 5
Plasterboard	10	0.17	1	880	-	[6]	Section J, page 388

R-value: 0.850 m^2.K/W

4.2.3.2. Roof

The roof of the case study restaurant consists of metal sheeting, with insulation and an air gap within the cavity, before the internal lining in corrugated metal. The R-value of the roof is 0.917 m^2.K/W. A field-applied coating over the metal sheeting had initial solar reflectance of 0.683 and a thermal emittance of 0.90 (a thick coating increases the thermal emittance of the corrugated metal). In this case, we considered an aged solar reflectance of 0.60, which is a reasonable assumption in line with the literature. Also, using the average annual wind velocity for the area (4.2 m/s) [6], the convective heat transfer coefficient is calculated as 17.6 W/(m^2.K) [8].

4.2.3.3. Windows

External windows in the case study buildings are single glazed with aluminium frame. The selected shading and glazing in the model are presented in Table 5.

4.2.4. Domestic hot water

The needed hot water for the Tahbilk restaurant is calculated based on page 55 of ISO 17772 [13]. Therefore, considering the need for a 50°C temperature increase and water heat capacity (4.19 KJ/kg.°C), and the occupancy schedule of the restaurant, 14.8 MJ of heating energy is needed for daily use of domestic hot water. ➔

Table 4. Building Components - Performance Descriptors – Construction – Roof.

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m^3)	Resistance (m^2.K/W)	Ref.	Section and page
Reflective coating	1	0.23	1	1100	-	[9]	Section 8.3, page 9
Metal sheeting and structure	1	50	0.45	7500	-	[7]	Section J, page 388
Anti-con blanket	20	0.24	1	14	-	[11]	Page 1
Air space	200	-	-	-	0.16	[10]	Section 5.3, page 5
Mineral wool	20	0.04	1.03	20	-	[9]	Section 8.2, Table 4, Page 18
Internal lining	1	50	1	7500	-	[7]	Section J, page 388

R-value: 0.917 m^2.K/W

Table 5. Building Components - Performance Descriptors - Openings Shading.

Shading type & material	External Shading is applied to the windows on the eastern side			
Glazing	**Value**	**Unit**	**Ref.**	**Section and page**
Thickness	14.8	mm	[12]	Page 4
Glazing U-value	5.4	(W/m^2.K)		
Glazing solar heat gain coefficient	0.7	N/A		
Window frame material	Aluminium	N/A		
Window frame ratio or width	15	%		
Glazing type	Single glazed	%		

Table 6. Domestic hot water.

Demand-side	Area	Unit Hot water demand	Daily hot water demand (lit)
	323 m^2	100 lit/m^2.year	88.5

4.2.5. Internal gains

The information regarding the thermal comfort in the studied restaurant is provided by the Tahbilk Wine Club Manager (TWCM). Lighting and personal heat gain assumptions in the model are based on Australian and international standards [13].

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 9, 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 and freestanding gas. Based on the information provided by TWCM, the coefficient of performance (COP) and energy efficiency ratio (EER) of the heating and cooling systems are considered as 2.8 and 2.6, respectively. The dining area, wine store and kitchen are air-conditioned by split systems. →

Table 7. Temperature setpoints, lighting and personal heat gain.

	Building	Value	Unit	Ref.	Section and page
Cooling setpoint temperature	All	25	°C	TWCM	-
Heating setpoint temperature	All	19	°C	TWCM	-
Personal latent gain	All	6.2	W/m^2	[13]	Page 55
Personal sensible gain	All	13.2	W/m^2	[13]	Page 55
Appliances and equipment gain	All	4	W/m^2	[13]	Page 55
Lighting gain	Dining area	14.0	W/m^2	[7]	Section J, page 379
	Kitchen	4.0	W/m^2		
	Wine store	1.5	W/m^2		
	Toilets and utility room	2.5	W/m^2		

Table 8. Ventilation and infiltration.

	HVAC&R system	Value	Unit	Ref.	Section and page
Fresh air	On	10	L/s.person	[14]	Appendix A, Table A1
	Off	0	L/s.person		
Infiltration	On	1	ACH	[15]	Section 2.7
	Off	0.5	ACH		

Table 9. Thermal comfort parameters.

Factor	Value	Unit	Ref.	Section and page
Clothing Factor	Summer 0.6 – Winter 1	clo	[15]	Section 5, page 8
Metabolic rate	1.0	Met	[15]	Section 5, page 7
Relative air velocity	Less than 0.2	m/s	[15]	Section 5, page 11

4.2.9. Schedules

The schedules of occupancy, lighting and appliances of the Tahbilk restaurant are selected based on pages 350-351 of the Australian national construction code with some modifications due to provided documents by TWCM [7]. The plug load of appliances is also derived from standards. →

Table 10. Occupancy, lighting and appliances schedules.

Time	Occupancy	Lighting	Appliances and equipment	Air-conditioning
00:00-01:00	0.00	0.05	0.15	Off
01:00-02:00	0.00	0.05	0.15	Off
02:00-03:00	0.00	0.05	0.15	Off
03:00-04:00	0.00	0.05	0.15	Off
04:00-05:00	0.00	0.05	0.15	Off
05:00-06:00	0.00	0.05	0.15	Off
06:00-07:00	0.05	0.40	0.40	Off
07:00-08:00	0.05	0.40	0.40	Off
08:00-09:00	0.05	0.60	0.60	On
09:00-10:00	0.05	0.60	0.60	On
10:00-11:00	0.20	0.90	0.90	On
11:00-12:00	0.50	0.90	0.90	On
12:00-13:00	0.80	0.90	0.90	On
13:00-14:00	0.70	0.90	0.90	On
14:00-15:00	0.40	0.90	0.90	On
15:00-16:00	0.20	0.90	0.90	On
16:00-17:00	0.05	0.05	0.05	Off
17:00-18:00	0.05	0.05	0.05	Off
18:00-19:00	0.05	0.05	0.05	Off
19:00-20:00	0.05	0.05	0.05	Off
20:00-21:00	0.00	0.05	0.05	Off
21:00-22:00	0.00	0.05	0.05	Off
22:00-23:00	0.00	0.05	0.05	Off
23:00-00:00	0.00	0.05	0.05	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 the interior spaces of Tahbilk restaurant. 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. Using the information provided by TWCM, the building was modelled in the software environment 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 NCC [7]. Due to the lack of as-built information on the lighting system currently used in the restaurant, an assumption was made on the lighting power density. This is that the NCC values are used, depending on the use of the space. Based on this assumption, three scenarios were tested. These scenarios are described in Table 11. →

Table 11. Scenarios for reduced energy consumption for lighting.

Base-case scenario	The existing power density for lighting is set to the maximum permitted by NCC. No daylight linked controls are used.
Scenario 1	The lighting power density is reduced with the use of efficient light sources. No daylight linked controls are used.
Scenario 2	Scenario 2 has the same lighting power density as Scenario 1. However, daylight controls are used in the restaurant.

4.3.2. Lighting analysis result

The results are analysed in two parts:

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

4.3.2.1. Natural lighting

The building has a glazed façade facing East and two large, glazed elements on the South, one of them being the restaurant entrance. The entrance is shaded by an overhang and by part of the building on the East. The large East facing transparent side of the restaurant is shaded by retractable canvas elements. The building is surrounded by high vegetation and trees. The only space with daylight availability is the main restaurant space. The average Daylight Factor is 5.60% which shows that the space will have adequate daylight throughout the year and under almost any sky conditions (Table 12).

Spatial Daylight Autonomy (sDA) is the percentage of the regularly occupied floor area that is “daylit.” In this context, “daylit” locations are those meeting target illuminance levels (300 lux) using daylight alone for at least 50% of occupied hours. Such locations are said to be 50% daylight autonomous. sDA calculations are based on annual, climate-based simulations.

The sDA of the main space is 100%, which means that the whole main restaurant space will receive daylight adequate to cover 50% of the required lighting levels throughout the year. The east-facing elevation is already effectively shaded, and no additional shading elements are recommended, as these would reduce the view and the daylight autonomy of the space.

4.3.2.2. Artificial lighting

Due to the minimum information on artificial lighting, no lighting level simulations were performed, as they would require a great number of assumptions that would result in inaccurate results. The lighting power densities of the restaurant’s spaces have been set according to the NCC requirements, depending on the space use.

Table 12. Average Daylight Factors and Spatial Daylight Autonomy.

Level	Average Daylight Factor (%)	Uniformity	sDA (%)
Dining area	5.63	0.35	0.15

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 4).

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, as well as everything that is required to simulate the thermal behaviour of the building, such as windows' optical properties, heating and cooling schedules, etc. [17].

After importing the restaurant building model into TRNSys, all building structural parameters (walls, windows, doors, etc.), schedules (occupancy, lighting, and appliances), internal loads, and HVAC&R system (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 Meteonorm weather database. →

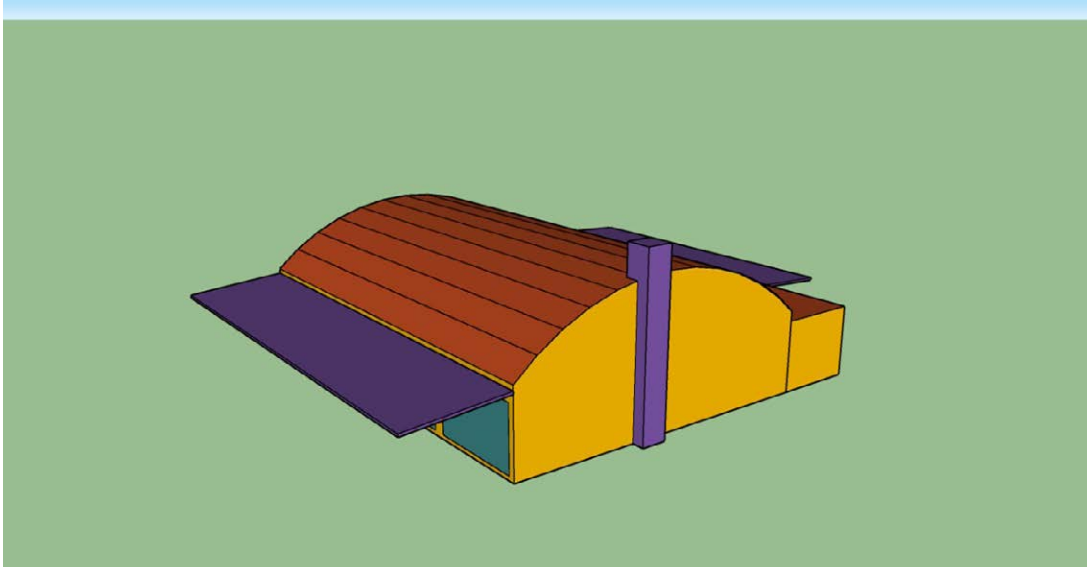

Figure 4. SketchUp model.

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, hence resulting in a high temporal analysis, whilst the thermal zoning was based on the differentiation of thermal conditions. This approach not only allows a reliable and cohesive assessment for the specific building but enables using the outcomes as a pilot for further similar projects. →

5.3.1. Lighting retrofit

This section aims to develop scenarios that would enable reduced energy consumption for lighting and provide an approximation of how much energy can be saved. Scenario 1 includes the reduction of the power density in the main space from 14 W/m² to 9 W/m², which results in a 36% reduction in energy consumption. Since the restaurant space receives high levels of natural light, daylight linked controls could be used. Scenario 2 includes continuous dimming of the artificial lighting sources according to the available daylight levels. Scenario 2 leads to a reduction in the energy consumed for artificial lighting by 89% compared to the base case scenario.

5.3.2. Windows retrofit and wall insulation

The next step relates to replacing windows with thermally-broked double-glazed Low-E windows, with an average U value of 1.78 W/m²K, a solar heat gain coefficient of 0.66 and good airtightness.

A further level of intervention on the building envelope is the improvement of thermal insulation, with the application of 100 mm of mineral wool on the stone wall. It is possible to realise a stone veneer to retain the architectural features. The addition of 80 mm of insulation to the external timber walls is recommended. This would bring the R-value of walls above 2.78 m²K./W. The average cost of wall insulation is expected to be around 40 $/m² and of roof insulation around 50 $/m² respectively.

Finally, a refurbishment of the roof, fitting 80 mm of mineral wool under the existing roof, would increase the R-value to 2.98 m².K/W.

5.3.3. New cool roof coating

The reflective coating currently applied to the roof is a first-generation cool roof and has been affected by weathering and soiling, which depreciated its initial reflectance. Applying a new generation of cool roof coating with enhanced solar reflectance (albedo 0.80 and thermal emittance 0.90) and resistance to soiling can further reduce cooling energy needs.

5.3.4. Ceiling fans

Ceiling fans are a simple and cost-effective method to enhance the indoor air quality in summer and also to receive points in energy rating stars. They provide additional air movement by increasing the relative air velocity resulting in the apparent temperature felt on exposed skin being 3° C colder than the actual air temperature, thereby reducing the need for additional cooling. The proposed scenario will be modelled by increasing the cooling setpoint temperature to 26°C. Currently, the restaurant has only one line of ceiling fans mounted centrally in the dining room. More evenly distributed fans with increased performance can deliver enhanced comfort more homogeneously.

5.3.5. Heat recovery ventilation

As the restaurant is located in a rural area that is relatively cold during winter, heat recovery ventilation can deliver savings by reducing heat losses for ventilation. In case a smokers' area is established in a restaurant, losses for mechanical ventilation can be substantial due to the required increased air change rates to retain safe air quality. The efficiency of the heat recovery ventilation system modelled in this case is set to 80%. →

5.3.6. Air-to-water heat pump (AWHP)

Improving the HVAC&R system by adding one air-to-water heat pump for each building can prevent a large amount of energy loss. Such an HVAC&R system will have COP=3.5 and EER=3.8. Also, it can be used for DHW preparation with COP=2.6 (including storage and distribution losses).

5.3.7. Ground Source heat pump (GSHP)

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

The GSHP here considered meets space heating, cooling and DHW demands, and it has an average COP=4.8 and EER=5.0. Also, it can be used for DHW preparation with COP=3.2 (including storage and distribution losses). ■

6. Results

6.1. Base building modelling

The simulation result of the restaurant in Tahbilk is presented in this section. Hourly energy demand for heating and cooling (sensible and latent) is illustrated in Figure 5, while the monthly energy demand is offered in Figure 6. →

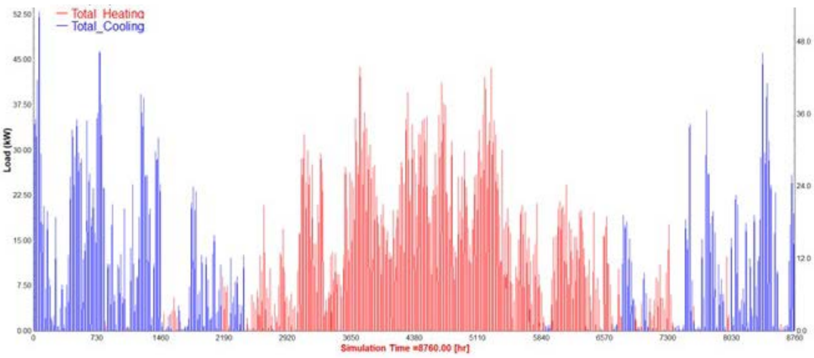

Figure 5. Hourly energy demand for HVAC&R purposes.

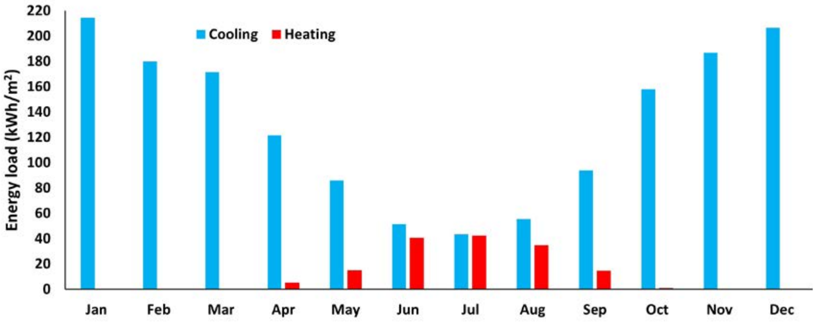

Figure 6. Monthly energy demand for HVAC&R purposes.

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

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

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

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

q_{INF} is the gains by infiltration;

q_{VENT} is the gains by ventilation;

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

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

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

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

q_{HEAT} is the power of ideal heating;

q_{COOL} is the power of ideal cooling.

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

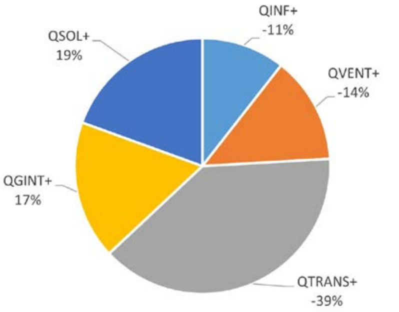

Figure 7. Whole building energy gain - heating season (May-September).

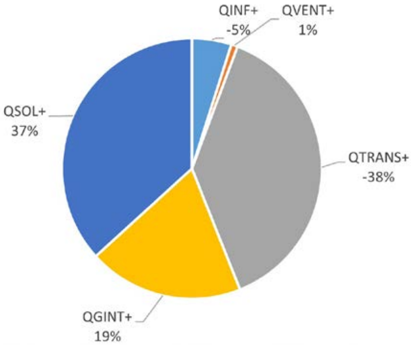

Figure 9. Whole building energy gain - cooling season (October-April).

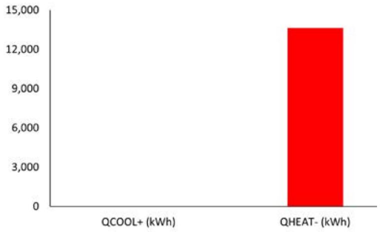

Figure 8. Whole building energy gain for heating and cooling load – heating season (May-September).

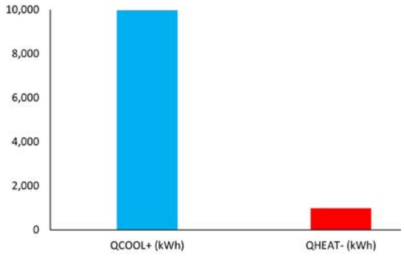

Figure 10. Whole building energy gain for heating and cooling load – cooling season (October-April).

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

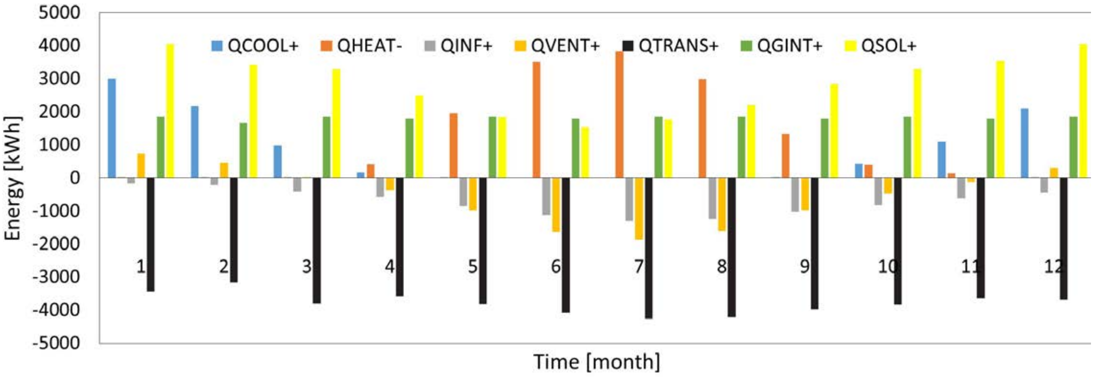

Figure 11. Monthly building energy gain.

6.2. Retrofit scenarios

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

Table 13. Retrofit cases.

Cases	Description
Baseline	The base-case scenario considers the maximum lighting power density permitted by the NCC for each type of space. For the cases where a range of power densities is allowed by NCC, the maximum value is considered. 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: The power density of lighting scenario 1 was used and combined with continuous dimming of the light sources depending on daylight availability.
Case C	Case B + 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 1.78 W/m²K, a solar heat gain coefficient of 0.66 and Airtightness 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. The average cost of new windows is expected to be around 300 $/m².
Case D	Case C + roof insulation+ external walls insulation: Application of 100 mm of mineral wool covered with plasterboard on the external stone wall (with a veneer to retain the architectural features) and 80 mm of mineral wool covered with plasterboard on external timber walls, leading to a total R-value of 2.78 m²K/W and 2.85 m²K/W, respectively. Refurbishment of the roof, fitting 80 mm of mineral wool under the existing roof, leading to an R-value of 2.98 m²K/W. The average cost of wall insulation is expected to be around 40 $/m² and of roof insulation around 50 $/m² respectively.
Case E	Case C + external walls insulation + new cool roof coating: New reflective coating with albedo 0.8 (solar absorbance 0.2) and thermal emittance 0.90.
Case F	Case D + Installation of additional new ceiling fans: Ceiling fans are modelled by increasing the cooling setpoint temperature to 26°C.
Case G	Case F + heat recovery ventilation: The efficiency of the heat recovery ventilation is 80%.
Case H	Case G + ASHP: Installation of one Air-to-water heat pump with fan coils with a coefficient of performance COP=3.5 and energy efficiency rating EER=3.8, including distribution and terminal units losses.
Case I	Case G + GSHP: Installation of one ground source heat pump with fan coils, with a coefficient of performance COP=4.8 and energy efficiency rating EER=5, including distribution and terminal units losses.

Between the presented scenarios, Case I has the most retrofitting steps. Table 14 shows the influence of different retrofitting cases on heating and cooling loads. Also, Table 15 demonstrates the impact of different retrofit scenarios on electricity consumption in the case study restaurant. The result indicates that by improving the building condition, 61.6% of the needed electricity can be reduced. A more detailed illustration of the retrofitting impact is presented in Figures 12-14. →

Table 14. Simulation results – Heating and cooling loads.

	Heating loads	Cooling loads	Heating + Cooling	Heating loads	Cooling loads	Heating + Cooling
Unit	kWh/(m^{2}a)			difference (%)		
Baseline	45.2	30.9	76.1	-	-	-
Case A (Baseline + lighting scenario 1)	47.2	29.4	76.6	4%	-5%	1%
Case B (Baseline + lighting scenario 2)	49.7	27.7	77.4	10%	-10%	2%
Case C (Case B + windows retrofit)	41.2	25.0	66.2	-9%	-19%	-13%
Case D (Case C + roof insulation + walls insulation)	24.8	27.0	51.8	-45%	-12%	-32%
Case E (Case C + new cool roof coating + walls insulation)	31.9	24.0	55.9	-29%	-22%	-26%
Case F (Case D + ceiling fans)	24.8	21.7	46.5	-45%	-30%	-39%
Case G (Case F + MVHR)	7.8	20.2	28.0	-83%	-35%	-63%
Case H (Case G + ASHP)	7.8	20.2	28.0	-83%	-35%	-63%
Case I (Case G + GSHP)	7.8	20.2	28.0	-83%	-35%	-63%

Table 15. Simulation results – Site energy.

	Heating	Cooling	Lighting	DHW	Appliances	Total	Total difference	Total difference
Unit	kWh/(m^{2}a)							%
Baseline	16.1	11.9	32.2	1.4	12.7	74.3	0.0	0%
Case A (Baseline + lighting scenario 1)	16.9	11.3	21.5	1.4	12.7	63.8	-10.5	-14.2%
Case B (Baseline + lighting scenario 2)	17.8	10.6	8.8	1.4	12.7	51.3	-23.0	-31.0%
Case C (Case B + windows retrofit)	14.7	9.6	8.8	1.4	12.7	47.2	-27.1	-36.5%
Case D (Case C + roof insulation + walls insulation)	8.9	10.4	8.8	1.4	12.7	42.1	-32.2	-43.3%
Case E (Case C + new cool roof coating + walls insulation)	11.4	9.2	8.8	1.4	12.7	43.5	-30.8	-41.4%
Case F (Case D + ceiling fans)	8.8	8.3	8.8	1.4	12.7	40.1	-34.3	-46.1%
Case G (Case F + MVHR)	2.8	7.8	8.8	1.4	12.7	33.4	-40.9	-55.0%
Case H (Case G + ASHP)	2.2	5.3	8.8	1.4	12.7	30.4	-43.9	-59.1%
Case I (Case G + GSHP)	1.6	4.0	8.8	1.4	12.7	28.6	-45.8	-61.6%

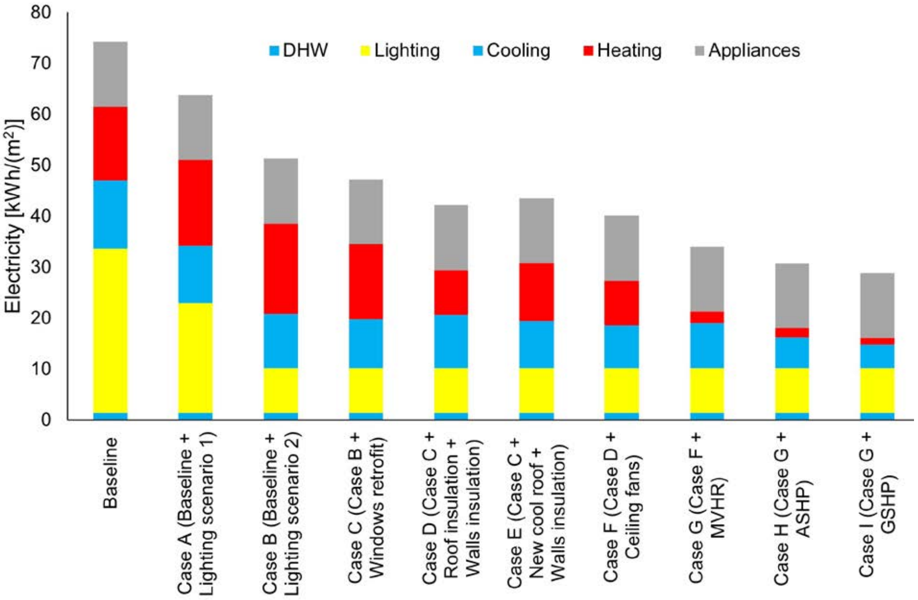

Figure 12. Site energy of the retrofit scenarios.

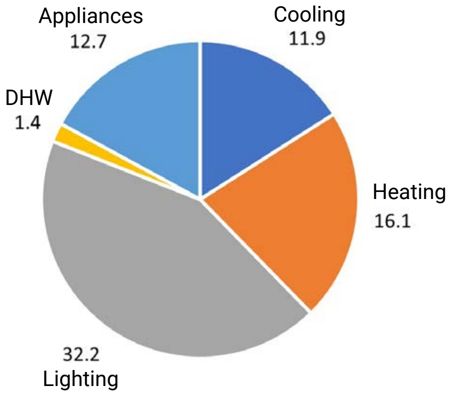

Figure 13. Share of site energy for the baseline (kWh/m²a).

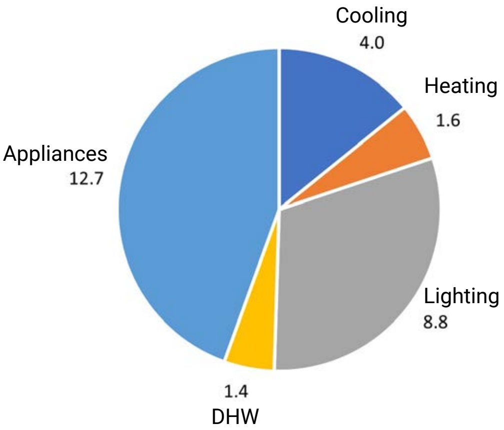

Figure 14. Share of Site energy for retrofit scenario – case H (kWh/m²a).

6.3. Future climate simulation

In this section, the case study 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) [19]. The word representative indicates that each RCP provides one of many possible scenarios that would lead to a specific radiative forcing characteristic. The term pathway denotes that not only the long-term concentration levels are of interest, but also the path taken over time to reach that outcome is important. RCP4.5 is selected as the future pathway to compare different cities. RCP4.5 is an intermediate condition in which radiative forcing is stabilised at approximately 4.5 W/m² after 2100.

Table 16 presents the electricity consumption (site energy) for the restaurant in 8 representative cities. The results indicate that in all representative cities, the cooling site energy will increase between 11% and 30% by 2030, with the largest increase predicted for Melbourne. However, the energy consumption for heating, for this building, would decline sharply and cause a net reduction in the site energy in the future, with the exception of energy uses for such a building if located in a cooling dominated climate (e.g., Brisbane and Darwin). This shift in the energy signature of the building motivates the undertaking of actions that address primarily cooling energy efficiency. →

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

Location	Period	Site energy						Site energy variation (%)		
		DHW	Heating	Cooling	Lighting	Appliances	Total electricity	Heating	Cooling	Total electricity
Adelaide	Present	1.4	103.5	69.8	32.2	12.7	219.6	-	-	-
	2030	1.4	83.6	83.9	32.2	12.7	213.8	-19.2	20.2	-2.6
Brisbane	Present	1.4	12.5	74.0	32.2	12.7	132.8	-	-	-
	2030	1.4	8.7	92.7	32.2	12.7	147.7	-30.4	25.3	11.2
Canberra	Present	1.4	177.3	42.4	32.2	12.7	266.0	-	-	-
	2030	1.4	153.2	53.2	32.2	12.7	252.7	-13.6	25.5	-5.0
Darwin	Present	1.4	0.3	332.0	32.2	12.7	378.6	-	-	-
	2030	1.4	0.2	370.6	32.2	12.7	417.1	-33.3	11.6	10.2
Melbourne	Present	1.4	178.5	33.0	32.2	12.7	257.8	-	-	-
	2030	1.4	149.5	43.0	32.2	12.7	238.8	-16.2	30.3	-7.4
Perth	Present	1.4	56.3	103.9	32.2	12.7	206.5	-	-	-
	2030	1.4	41.4	125.3	32.2	12.7	213.0	-26.5	20.6	3.1
Sydney	Present	1.4	59.8	37.5	32.2	12.7	143.6	-	-	-
	2030	1.4	48.0	46.9	32.2	12.7	141.2	-19.7	25.1	-1.7
Hobart	Present	1.4	217.6	8.5	32.2	12.7	272.4	-	-	-
	2030	1.4	197.8	10.5	32.2	12.7	254.6	-9.1	23.5	-6.5

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

Location	Period	Loads		Site energy					Site energy variation (%)		
		Heating	Cooling	DHW	Cooling	Lighting	Appliances	Total electricity	Heating	Cooling	Total electricity
Base case	Present	16.1	30.9	1.4	11.9	32.2	12.7	74.3	-	-	-
	2030	14.5	34.9	1.4	13.4	32.2	12.7	74.2	-9.1	12.6	-0.1
Retrofit	Present	1.6	20.2	1.4	4.0	8.8	12.7	28.6	-	-	-
	2030	1.4	22.9	1.4	4.6	8.8	12.7	28.8	-6.7	15.0	0.7

As the CSIRO database does not include weather data for the actual building location, we used the data from Meteonorm for both present and 2030 scenarios in the base case and fully retrofitted scenarios. As for CSIRO datasets, we used the climate change pathway given by RCP4.5.

Table 17 presents the restaurant's energy load and final energy demand in the present and future conditions in the unretrofitted and retrofitted scenario. In particular, we see that cooling site energy is expected to increase by more than 12% by 2030, while heating site energy consumption will decrease by more than 7%. Therefore, the retrofit scenarios should consider the future energy consumption profiles and prioritise addressing cooling energy needs.

6.4. Discussion and recommendations

We established a baseline for energy consumption, and then we undertook a simulation based on various energy efficiency upgrades. The findings suggest that, in particular, heating and cooling loads are relatively high. Electricity usage of appliances and lighting is also significant. Consequently, the following suggestions are made to reduce energy consumption:

- Improvement of the lighting systems.
- 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 airtightness throughout the year.
- Thermal insulation of the roof and external walls, leading to a reduction of both heating and cooling loads.
- Installation of ceiling fans or replacement of the old ones to reduce cooling demands.
- Installation of mechanical ventilation with heat recovery to reduce heating loads.
- Installation of an air-to-water heat pump (AWHP) or a ground source heat pump (GSHP) to meet the space heating and cooling demand to reduce the final energy requirement.

In conclusion, a progressively implemented renovation package is suggested, starting from the low hanging fruits of the replacement of the lighting system before moving to more substantial interventions such as replacing windows and improving insulation.

References

1. UK Green Building Council, *Climate Change*, in https://www.ukgbc.org/climate-change/ [accessed 7 August 2021].
2. IBISWorld. *INDUSTRY STATISTICS – AUSTRALIA*. 2022.
3. Energy.gov.au. *Food and beverage*. 2021.
4. Sustainable food services. *Energy Conservation*.
5. Peel, M.C., B.L. Finlayson, and T.A. McMahon, *Updated world map of the Köppen-Geiger climate classification*. Hydrol. Earth Syst. Sci., 2007. 11(5): p. 1633-1644.
6. Bureau of Meteorology. *Climate statistics for Australian locations*, http://www.bom.gov.au/ [Accessed 8 August 2021].
7. Australian Building Codes Board, National *Construction Code Volume One, Amendment 1*,. 2019.
8. Mirsadeghi, M., et al., *Review of external convective heat transfer coefficient models in building energy simulation programs: Implementation and uncertainty*. Applied Thermal Engineering, 2013. 56(1): p. 134-151.
9. British standard, BS EN ISO 10456:2007, in *Building materials and products — Hygrothermal properties – Tabulated design values and procedures for determining declared and design thermal values*. 2007.
10. International Organization for Standardization, ISO 6946:2007, in *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*. 2007.
11. Bradford. *ANTICON BLANKET– DATA SHEET. 2014.*
12. Dowell, **Technical & Size Supplement**, in http://www.dowell.com.au/media/dowellimages/brochures/Technical_And_Sizes_Brochure_d.pdf. 2017.
13. ISO 17772-1, *Energy performance of buildings — Indoor environmental quality, in Part 1: Indoor environmental input parameters for the design and assessment of energy performance of buildings*. 2017.
14. Standards Australia, *AS 1668.2, Amendment 1, The use of ventilation and airconditioning in buildings-Mechanical ventilation in buildings, in Mechanical ventilation in buildings*. 2012.
15. Daly, D., P. Cooper, and Z. Ma, *Understanding the risks and uncertainties introduced by common assumptions in energy simulations for Australian commercial buildings*. Energy and Buildings, 2014. 75: p. 382-393.
16. ASHRAE, *ANSI/ASHRAE Standard 55, in Thermal Environmental Conditions for Human Occupancy*. 2020: https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy.
17. TRNSYS, *A transient systems simulation program*. 2017, https://sel.me.wisc.edu/trnsys/index.html.
18. Yousefi, H., et al., *Feasibility study and economical evaluations of geothermal heat pumps in Iran*. Geothermics, 2018. 72: p. 64-73.

Attachment 1

The following figures show daylight factor distribution in Tahbilk restaurant.

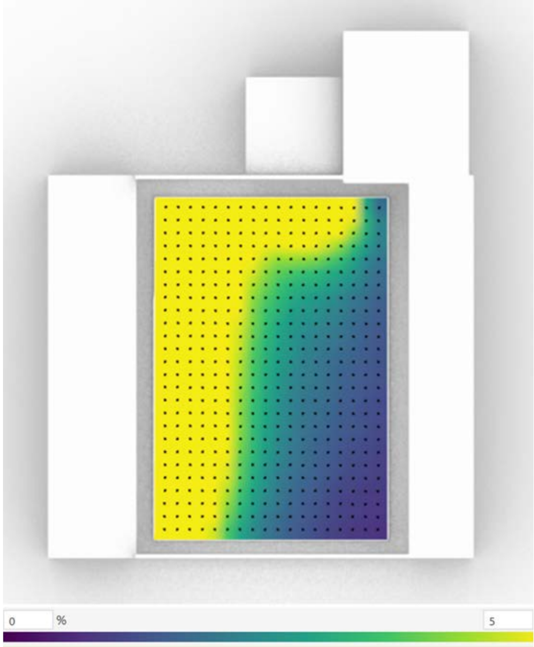

Fig. A1. Distribution of Average Daylight Factor.

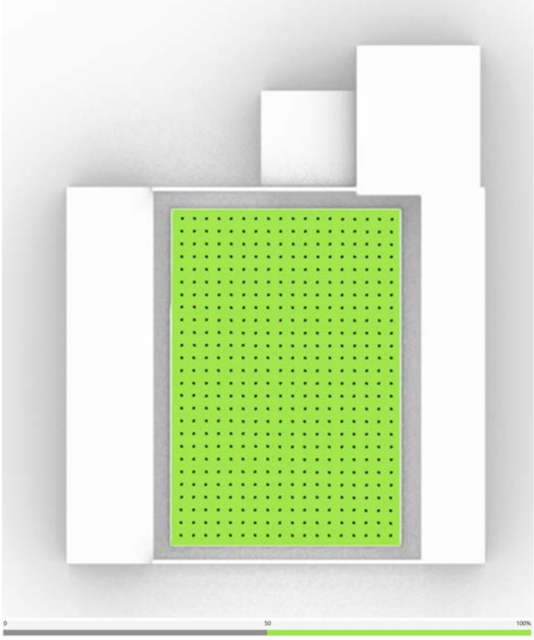

Fig. A2. Spatial Daylight Autonomy distribution

Attachment 2

Fig. A3. Exterior views of the restaurant.

Fig. A4. Interior views of the restaurant.