UNSW SYDNEY

Library

Energy Efficiency Training and Information Project

Commercial Buildings

Aitkenvale QLD

Research group

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

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

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

International contributors

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

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

Project contact

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

Contract management contact

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

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Cover image:
Aitkenvale Library in Townsville, Queensland.

Contents

1. Executive Summary

A complete renovation package ... can lead to energy savings of 84.4%

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 already exist today [1], and we must prioritise improving the efficiency of the existing building stock.

There are 1,664 public libraries in Australian States and Territories [2], with more than 9.3 million registered members and thus users of public libraries, representing 36% of the total Australian population [2]. More than half of the energy consumed in library buildings is used for heating, ventilation, and cooling [3]. This report tackles the operational energy consumption challenge for an existing library, using a real-life case study to simulate the impact of each energy optimisation strategy. A high-level framework prioritising different building enhancement methods is presented in this report.

A library building is selected as a case study to explore opportunities to reduce energy consumption. A dynamic thermal model of the library buildings 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 centre conditions and the minimisation of the energy consumption in the Aitkenvale Library located at 4 Petunia St, Aitkenvale QLD 4814. The structural and energy performance features of the studied library building are representative of the typology and construction period (1990s).

The analysis showed that most of the continuously occupied spaces receive high levels of natural lighting, except the spaces in the core of the building. Considering artificial lighting, which currently consists of fixtures with fluorescent tubes and some with LEDs without daylight linked controls, it was found that more efficient equipment can reduce the energy consumption for lighting ranging between 50 and 90%.

The cooling load (147.3 kWh/m²a) is the most significant load component, representing 66% of the total site energy consumption. The site energy consumption of lighting, heating and domestic hot water and appliances, at 32 kWh/m² in total, is not insignificant either. These components are considered in the building performance simulations.

The primary focus is on lowering cooling requirements. The windows and glazed areas, in general, are not up to date with contemporary standards, and since they account for a significant percentage of the envelope's overall surface, their contribution to energy losses in the cooling period is significant. The advances in Building Automation and Control systems over the last decade have been dramatic, and so has the retrofitting potential. Based on the results, the following recommendations are technically viable and relatively easy to implement:

- Replacement of the lighting systems with more energy-efficient ones and installation of daylight controls.
- 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. →

- Installation of ceiling fans, the introduction of night ventilation patterns in the operation of the HVAC&R system and window shading during the cooling period to reduce cooling loads.
- Installation of state-of-the-art Building Automation and Controls, together with a Building Management System, to interlock the use of HVAC&R, DHW and lighting systems with both the weather conditions and the operational requirements.
- Installation of a ground source heat pump (GSHP) could lead to a drastic reduction of energy consumption.
- Finally, application of a solar reflective roof coating with solar absorbance of 0.25 (lower than the maximum set by the NCC to 0.45).

In conclusion, a complete renovation package that includes the replacement of the building's windows and glazed surfaces, combined with an upgrading of the lighting system, the installation of a GSHP and ceiling fans and the use of night-time ventilation and window shading patterns, linked all with the implementation of a state-of-the-art BAC system, can lead to energy savings of 84.4%, resulting in an energy consumption of 14.6 kWh/m²a, compared to the baseline of 93.4 kWh/m²a.

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 library building built in Australia in the 1990s, representative of many other libraries constructed in the same period. In fact, the aim of selecting the Aitkenvale Library is the potential for methodology replication and findings expansion to other similar buildings.

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

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

Additionally, two types of specific conditions that have a significant impact on such a centre's performance must be considered:

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

(b) the microclimate on the building's site (shading by natural obstructions and other buildings, albedo and thermal storage of surrounding areas, etc.).

4. Aitkenvale Library

4.1. Case study description

4.1.1. Climate

The Aitkenvale library is located at 4 Petunia St, Aitkenvale QLD 4814 (19.291S, 146.773E). The building is in the central part of Townsville, 14 m above sea level. In Kappen's climate classification, Townsville is categorised as Aw, meaning that it has a tropical savanna climate with a dry winter [4]. Rainfall is more frequent between January and March, with an annual mean rainfall of 1136 mm, and February has the highest rainfall amount (303.7 mm). Due to its geographical location, the relative humidity is distributed evenly throughout the year (60-75% in the morning and 51-67% in the afternoon). The winters are dominated by blue skies, warm days and cool nights, with overnight minimums averaging 14.4°C and daily maximums climbing to 25.7°C.

Summers in Townsville are hot and humid, and the average maximum temperature reaches 31.6°C in December. The primary climatic information for Townsville is illustrated in Figure 1. →

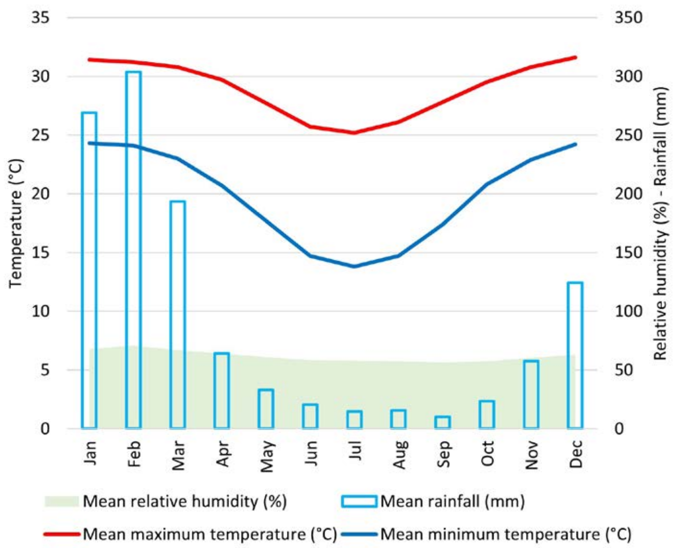

Figure 1. Climatic data of Townsville [5].

Figure 2. Eastern view of the Aitkenvale Library.

4.1.2. Aitkenvale library description

This case study library had a major refurbishment in 2000 (Figure 2). Its classification, according to the National Construction Code, is Class 9b [6]. The library provides services to 150 people at busiest hours. The under-ceiling height of this two-story library building varies between is 3.1-3.3m. Figure 3 illustrates the treemap chart of the gross internal area of case study buildings. The total gross floor area is 1,980 m².

4.1.3. Energy consumption and sources

Electricity is used for HVAC&R purposes, lighting, appliances, and water heating of the case study library. A 57.6 kW PV system was installed at the Aitkenvale Library in July 2021, providing a part of the electricity demand (Figure 4). ➔

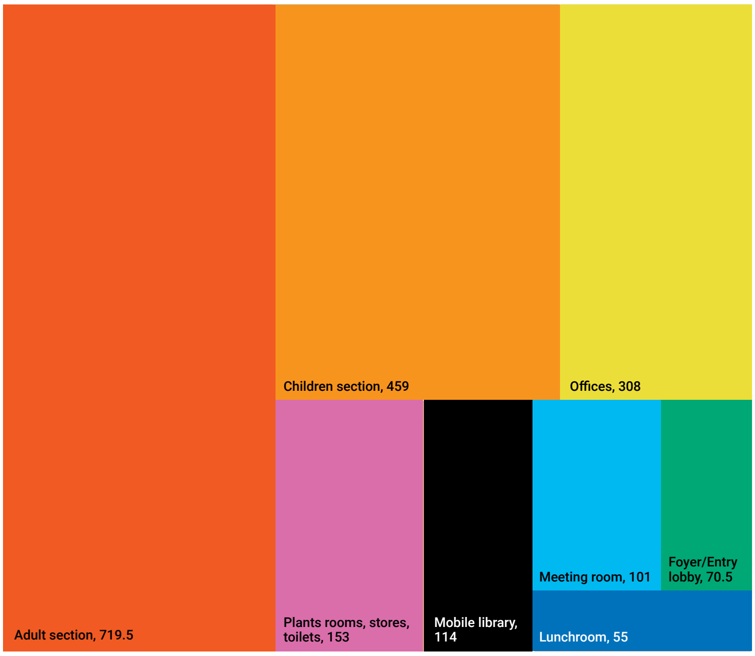

Figure 3. Gross floor divided area of case study building.

4.2. Building modelling input parameters

The modelling parameters are a combination of collected data from the building inspection, utility bills and Australian and global standards. In this section, each modelling assumption will be briefly explained, and relative references will be presented.

4.2.1. Occupancy

Currently, the Aitkenvale Library has capacity for 150 people, and the occupancy schedule is selected based on the national code of construction [6].

4.2.2. Geometric data

The case study building has two floors. Table 1 shows the main purpose of each part of the Aitkenvale library. →

Figure 4. Installed solar panels on the Aitkenvale Library.

Table 1. Building geometric information.

Zone	Spaces	Air-conditioned area (m²)	Unconditioned area (m²)	Gross floor area (m²)
1	Foyer/Entry lobby/ Adult section	790.0	0	790.0
2	Children section	459.0	0	459.0
3	Meeting room	101.0	0	101.0
4	Delivery bay	114.0	0	114.0
5	Offices	308.0	0	308.0
6	Staff room	55.0	0	55.0
7	Plants rooms, stores, toilets	0	153.0	153.0
	Total	1,827	153.0	1,980

4.2.3. Building Components

A significant part of energy consumption is 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. Surveying the case study library building, 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 is brickwork. The brickwork wall includes five layers. There are plaster and face brick in the outer layer. An air gap is in the middle, and a layer of brick covered by plaster is inside. The R-value of the external walls is determined as 0.75 m².K/W, with a solar reflectance equal to 0.3. Also, using the average annual wind velocity in Townsville (4.5 m/s) [5], the convective heat transfer coefficient is calculated as 17.6 W/(m².K) [7].

4.2.3.2. Roof

The roof of the case study library building consists of 4 layers. There is metal sheeting as top layer, then insulation, an air gap, and plasterboard inside. The R-value of the roof is determined as 1.754 m².K/W, with a solar reflectance of 0.25, as common for uncoated metal sheeting. Also, using average annual wind velocity (4.5 m/s) [5], the convective heat transfer coefficient is calculated as 17.6 W/(m².K) [7].

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 4. ➔

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

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m³)	Resistance (m².K/W)	Ref.	Section and page
Plaster	10	0.17	1	880	-	[6]	Section J, page 388
Brick	110	0.78	0.8	1,950	-	[6]	Section J, page 389
Air space	50	-	-	-	0.18	[8]	Section 5.3, page 5
Brick	110	0.78	0.8	1,950	-	[6]	Section J, page 389
Plaster	10	0.17	1	880	-	[6]	Section J, page 388

R-value: 0.75 m².K/W

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

Material	Thickness (mm)	Conductivity (W/m.K)	Capacity (kJ/kg.K)	Density (kg/m³)	Resistance (m².K/W)	Ref.	Section and page
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: 1.754 m².K/W

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

Glazing	Value	Unit	Ref.
Thickness	14	mm	[11]
Glazing U-value	5.44	(W/m².K)	
Glazing solar heat gain coefficient	0.73	N/A	
Window frame material	Aluminium	N/A	
Window frame ratio or width	15	%	
Glazing layout – WWR	40	%	
Glazing type	Single glazed	N/A	

4.2.4. Domestic hot water

The required hot water is calculated based on Table 2m, NCC volume 1 page 355 [6]. Therefore, considering the need for a 50°C temperature increase and water heat capacity (4.19 KJ/kg.°C), 62.7 MJ of heating energy is required for daily heating of domestic water.

4.2.5. Internal gains

The information regarding the thermal comfort in the studied library building is provided by the Townsville Property Management (TPM). Lighting and personal heat gain assumptions in the model are based on Australian and international standards. The appliances heat production in the case study library is calculated based on chapter 18 of the ASHRAE Fundamentals Handbook [12].

4.2.6. Ventilation and infiltration

The supplied fresh air flow rates and the infiltration rates are assumed based on international standards with some modifications based on documents provided by TPM. →

Table 5. Domestic hot water.

Demand-side	Occupancy	Unit Hot water demand	Daily hot water demand (lit)
	150	4 lit/person	600

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

	Building	Value	Unit	Ref.	Section and page
Cooling setpoint temperature	All	23.0	°C	TPM	-
Heating setpoint temperature	All	23.0	°C	TPM	-
Personal latent gain	All	45	W/person	[12]	Chapter 18, page 4
Personal sensible gain	All	70	W/person	[12]	Chapter 18, page 4
Lighting gain	Foyer – adult section	11.8	W/m²	[6]	Section J, page 379

Table 7. Appliances heat gain.

Zone		Microwave	Refrigerator	TV 40"	Computer	Projector	Vending machine	Printer	Sensible (W)
1	Entrance and Adult section	0	0	1	27	0	1	2	1,976
2	Children section	0	0	1	5	0	0	0	198
3	Meeting room	0	0	0	2	1	0	0	368
4	Delivery bay	0	0	0	5	0	0	0	150
5	Offices	0	0	0	6	0	0	2	508
6	Staff room	2	1	0	0	0	0	0	1,483

Table 8. Ventilation and infiltration.

	HVAC&R system activity	Value	Unit	Ref.	Section and page
Fresh air	On	20	L/s.person	[13]	Appendix A, Table A1
	Off	0	L/s.person		
Infiltration	On	2	ACH	[14]	Section 2.7
	Off	1.5	ACH		

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. Based on the information provided by TPM, the coefficient of performance (COP) and energy efficiency ratio (EER) of the heating and cooling systems are considered as 2.8 and 2.4, respectively. The foyer, hall and kitchen are air-conditioned by split systems.

4.2.9. Schedules

The schedules of occupancy, lighting and appliances of the Aitkenvale library are selected based on documentation provided by TPM [6]. The library is closed on Sundays and public holidays. →

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

Table 10. Occupancy, lighting and appliances schedules.

Time	Occupancy (Mon-Fri)	Occupancy (Sat)	Lighting and Equipment (Mon-Fri)	Lighting and Equipment (Sat)	Air-conditioning (Mon-Fri)	Air-conditioning (Sat)
00:00-01:00	0.00	0.00	0.05	0.05	Off	Off
01:00-02:00	0.00	0.00	0.05	0.05	Off	Off
02:00-03:00	0.00	0.00	0.05	0.05	Off	Off
03:00-04:00	0.00	0.00	0.05	0.05	Off	Off
04:00-05:00	0.00	0.00	0.05	0.05	Off	Off
05:00-06:00	0.00	0.00	0.05	0.05	Off	Off
06:00-07:00	0.05	0.05	0.10	0.10	On	On
07:00-08:00	0.05	0.05	0.10	0.10	On	On
08:00-09:00	0.05	0.05	0.15	0.15	On	On
09:00-10:00	0.50	0.50	0.20	0.20	On	On
10:00-11:00	0.60	0.60	0.60	0.60	On	On
11:00-12:00	0.70	0.70	0.60	0.60	On	On
12:00-13:00	0.30	0.30	0.60	0.60	On	On
13:00-14:00	0.65	0.65	0.60	0.60	On	On
14:00-15:00	0.60	0.60	0.60	0.60	On	On
15:00-16:00	0.50	0.00	0.60	0.05	On	On
16:00-17:00	0.40	0.00	0.60	0.05	On	Off
17:00-18:00	0.30	0.00	0.60	0.05	On	Off
18:00-19:00	0.00	0.00	0.05	0.05	On	Off
19:00-20:00	0.00	0.00	0.05	0.05	Off	Off
20:00-21:00	0.00	0.00	0.05	0.05	Off	Off
21:00-22:00	0.00	0.00	0.05	0.05	Off	Off
22:00-23:00	0.00	0.00	0.05	0.05	Off	Off
23:00-00:00	0.00	0.00	0.05	0.05	Off	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 used interior spaces of the Aitkenvale Library. The steps taken in this regard are:

1. The analysis and simulations of the existing lighting conditions, based on information from building management;
2. The assessment of the compliance of the energy performance and the lighting conditions established with relevant regulations, standards and guidelines; and
3. Research, simulation, and presentation of appropriate techniques and methods to achieve minimum energy consumption for lighting and heating loads from artificial lighting, complying with the Australian building regulations.

4.3.1. Lighting evaluation method

Proposing strategies for improving lighting conditions or reducing energy use requires a detailed analysis of the existing natural and artificial lighting conditions. The assistance of the building management was crucial in acquiring the necessary information on the quality and quantity of the light sources in the used spaces. A report from Sustainable Focus, conducted in 2013, was utilised to get information about the installed lighting power density, the types of lighting used and the available lighting levels in the Library. Photographs of the interior spaces were also used.

The building was modelled in the software Rhinoceros, and the lighting conditions were simulated in the add-on tool Climate Studio. Climate Studio is an environmental performance analysis software with advanced lighting calculation capabilities. The simulation results were then compared to the requirements and recommendations of the Australian NCC [6]. Based on this comparison, areas with poor lighting conditions or with installed power that was exceeding the required were identified. Based on the findings of the assessment, two scenarios were tested. These scenarios are described in Table 11.

According to the report from Sustainable Focus, the company undertook a lighting energy retrofit of the library. Several conventional lamps were replaced with LEDs, but the majority of fluorescent lamps remained. The total lighting load of the building after the retrofit is 20.4 kW.

Even though the report describes the type of luminaires used in the Library spaces, the names of the spaces do not match the architectural drawings. Thus, a detailed assignment of power density to each space was not possible, and an overall power density value of 11.8 W/m² was adopted (total Lighting Load (kW)/ Building area). This value is much higher than the recommended by the NCC levels, and this is partly due to the use of luminaires with upward emission, which present lower lighting output, compared to downward emitting luminaires of the same power.

4.3.2. Lighting analysis result

The results are analysed in two parts:

1) the assessment of the existing natural lighting conditions, the artificial lighting conditions and energy consumption for lighting, and

2) The proposed scenarios for improvement of the lighting conditions and minimising the energy consumption for lighting.

4.3.2.1. Natural lighting

The building has many openings in the south, north and east facades. The continuously occupied spaces close to the perimeter of the ground level receive adequate daylight and have Daylight Factors above 2%. The spaces where the daylight availability should be higher are the adult section (Magazines, Catalogue, adult non-fiction and adult fiction) on the ground level and the offices (Technical services area) on the 1st floor. However, the adult fiction area is not close to the building skin and cannot benefit from the daylight →

Table 11. Scenarios for reduced energy consumption for lighting.

Base-case scenario	The total Lighting Load (kW), as stated in the report from Sustainable Focus, was divided by the total building area. The power density calculated is 11.8W/m².
Scenario 1	Achieve the existing artificial lighting levels with more efficient lighting sources. 291 luminaires with upward emission were replaced with LED luminaires with upward and downward emission.
Scenario 2	Scenario 2 has the same lighting power density as Scenario 1; however, daylight controls are used in all spaces with daylight availability.

entering from the windows. Also, this space is below the 1s floor, so skylights cannot be added.

The 1st floor spaces generally have lower daylight availability; however, the uses of these spaces do not require high daylight availability. Depending on the activities carried out in the space named "Technical services work area", skylights or light pipes on the roof could increase the daylight availability significantly.

Due to the deep plan of the Library's ground floor, additional (side) windows would not offer an increase in the daylight levels. An efficient solution that could be adopted for the spaces not directly under the 1st floor spaces would be the addition of light pipes or skylights.

The most common type of light pipe (passive zenithal tubular light guide) consists of three basic elements: 1. the light collector, 2. the tube and 3. an element that distributes daylight and/or sunlight into the space. Light pipes are used to channel daylight into the core of a building when access to the building skin (perimeter) is not possible. The advantages of light pipes compared to skylights are that 1) They do not affect the thermal load of the building significantly, and 2) They usually cause fewer glare issues than skylights with clear glazing. Light pipes or skylights with insulating glass can increase the Daylight Factor of the deeper spaces significantly (Table 12). As an example, the Daylight Factor of the 1st floor Technical services work area is increased from 0.24 to 0.95% by adding four 0.40 x 1.00 m skylights. On the contrary, the Librarian's office receives excessive daylight. It is recommended that the size of the full-height east-facing windows of the room be significantly reduced.

The library spaces' Spatial Daylight Autonomy (sDA) is relatively high, except for the Adult fiction area on the ground level and the Technical services work area on the 1st level. High levels of sDA consist proof of the use-fulness of daylight linked controls in the library spaces.

4.3.2.2. Artificial lighting

The artificial lighting equipment, i.e., the number, type and wattage of the used lighting fixtures, as well as the artificial lighting levels in the Library, were provided in the lighting retrofit report carried out by Sustainable Focus. The artificial lighting levels are between 300 and 400 lux, while both LED and fluorescent lighting fixtures exist. During the 2013 lighting retrofit, some fluorescent luminaires were replaced by LEDs, while 219 upward emitting fixtures hosting 2 x 36W fluorescent tubes remained.

Table 12. Average Daylight Factor of the spaces in Aitkenvale Library.

Level	Zone	Space	Average Daylight Factor (%)	Uniformity	sDA (%)
Ground floor	1	Lobby	4.61	0.63	100
		Foyer	1.42	0.42	99.3
		Librarian's office	12.35	0.68	100
		Tutorial room	0.98	0.77	100
		Magazines – Catalogue – Adult non-fiction	1.30	0.18	66.5
		Reference	5.64	0.35	100
		Adult fiction	0.12	0.42	0.4
	2	Children's library – Youth space	2.12	0.18	89.6
	3	Meeting room	2.63	0.30	100
	4	Delivery bay	0.77	0.29	39.5
1st level	5	Book binding	1.58	0.50	100
		IT room	0.97	0.35	46.67
		Manager	0.96	0.31	61.10
		Reader services librarian	2.47	0.30	100
		Staff meeting room	1.19	0.49	59.2
		Technical services work area	0.24	0.13	5.17
		Technical services librarian	0.55	0.33	17
	6	Staff room	1.56	0.16	100

5. Simulation approach

The simulation includes two main parts. First, the building was defined in SketchUp software and then energy modelling was conducted in TRNSys.

5.1. SketchUp

SketchUp is a 3D modelling computer program for a wide range of drawing applications such as architectural, interior design, landscape architecture, and civil and mechanical engineering. The model was designed based on actual building dimensions, rotation, and shadings (adjacent building and external shadings). The case study building is defined in the SketchUp model because of the importance of load determination (Figure 5).

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

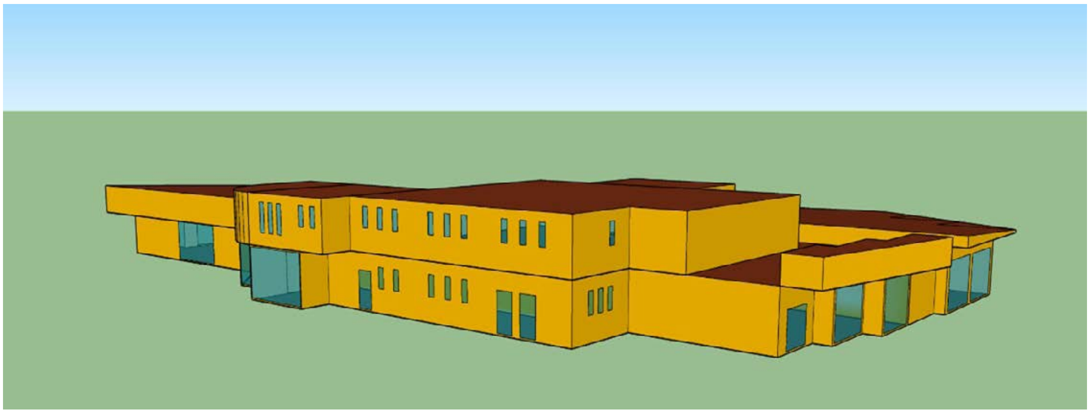

Figure 5. SketchUp model.

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 (COP and EER 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, as well as by the weather conditions of the specific period. In that sense, while the metered consumption values are real, they do not necessarily represent a base for an objective assessment. Therefore, the building has to adopt standard reference conditions, as foreseen by national regulations and standards, which allow a good degree of replicability for the simulative calculations that allow a detailed breakdown of energy consumption by source and use and a reliable assessment of the improvements achieved by the interventions considered.

In this line of approach, all operational parameters for the baseline scenario were considered in accordance with national standards, regulations and recommendations or in accordance with NCC, ASHRAE and ISO standards. Simulations were carried out on an hourly 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

The aim of the next step of the study was to develop scenarios that would enable reduced energy consumption for lighting and would provide an approximation of how much energy can be saved. The potential for lighting energy savings in this building lies in the replacement of 219 upward emitting fixtures hosting 2 x 36W fluorescent tubes with more efficient ones.

The 219 fluorescent upward emitting fixtures and their tubes (providing 300-400 lux) were replaced with 119 LED luminaires, emitting light both upwards and downwards, with a system power of 47.6 Watts each (Attachment 1). These luminaires were able to provide average illuminance of approximately 500 lux to the same area as the 219 fluorescent luminaires. Since the spaces where the 219 fluorescent luminaires were used is not identified, the reduced power density from the replacement with the more efficient sources is applied to the whole building, reducing the total lighting power density from 21.W/m² to 5.7W/m². The energy consumption for each of the scenarios is provided in Table 13.

The proposed scenarios resulted in a reduction of the total lighting load (kW) and the annual energy (kWh) ranging from 50 to 90% (Table 16). The use of light pipes or skylights in spaces with low daylight factors will further reduce the energy consumption for artificial lighting.

Table 13. Illumination power density and energy consumption for the base case and the proposed scenarios.

Level	Space	Base case		Scenario 1		Scenario 2		Maximum energy savings achieved (%)
		Max. illumination power density (W/m²)	Energy consumption (kWh/year)	Max. illumination power density (W/m²)	Energy consumption (kWh/year)	Max. illumination power density (W/m²)	Energy consumption (kWh/year)	
Ground floor	Lobby	11.8	1194	5.7	577	0.86	87	92.71
	Foyer	11.8	15356	5.7	7418	1.73	2249	85.35
	Librarian's office	11.8	1473	5.7	711	0.92	115	92.19
	Adult section	11.8	6859	5.7	3313	5.70	3313	51.70
	Young people – Children	11.8	19048	5.7	9201	1.29	2081	89.07
	Meeting room	11.8	2668	5.7	1289	0.67	152	94.30
	Delivery bay	11.8	3434	5.7	1659	2.65	770	77.58
1st floor	Offices	11.8	2323	5.7	648	1.59	313	86.53
	Staff room	11.8	2017	5.7	930	2.63	449	77.74
	Staff meeting room	11.8	7665	5.7	6391	4.75	3087	59.73
	Technical services	11.8	505	5.7	199	2.25	96.0	80.99

5.3.2. Windows retrofit and wall insulation

The windows now installed in the Aitkenvale Library are single glazed with aluminium frame. The thermal break (insulation within a window) is a constant barrier between the inside and outside window frames that avoid conductive thermal energy loss. This barrier securely bonds the interior and exterior metal frames of the window. This thermal break creates thermal energy loss resistance and, combined with double-pane glazing, keeps the interior space of the window at a more comfortable temperature. The proposed window is thermally-broken aluminium framed, double glazed, with Low-E external glass pane, with an average U-value of 1.78 W/m²K, an SHGC value of 0.66 and Airtightness values of Class 3 with less than 2.5 L/s.m² at 100 Pa. The latter reduces the infiltration rate of the building to 0.30 1/h.

5.3.3. Automation and controls

Even HVAC&R systems of the highest efficiency do not run optimally if they do not consider variations in ambient air temperature and solar radiation, the presence of users in the various rooms and the thermal response of the building's envelope.

In that sense, one of the most important tools to improve energy efficiency is the combination of sensors, automation and control systems that interlock the use of HVAC&R, DHW and lighting systems with both weather conditions and operational requirements.

The impact of Building Automation And Control Systems (BACS), along with Building Management Systems (BMS), is expressed and quantified by a series of standards, like the EN ISO 52127 and 15232. →

According to those standards, four energy efficiency classes (A, B, C, D) are defined to evaluate the performance of the building automation:

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

Table 14 shows the typical features for the four mentioned classes. The impact of the automation level on the building's energy consumption is also quantified according to Standard 15232, as can be seen in Table 15 (next page). This approach allows a rough evaluation of the impact of BACS systems on the energy performance of the building in a period of a year. The impact of each function (e.g., cooling/heating and lighting) is calculated using the pertinent standards.

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

The building automation is between Class D and C and can fairly easily be upgraded to Class B, by installing:

- Individual room controls with communication between them and the chillers/boilers and air handling units
- Time-dependent controls of ventilation
- Variable control of setback temperatures
- Humidity control of the ventilation and
- Lighting controls

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

Table 14. Functions and assignments to energy performance classes.

	Heating/Cooling control	Ventilation / Air conditioning control	Lighting Control	Solar protection
A	• Individual room & communication between controllers • Indoor temperature control of distribution network water temperature • Total interlock between heating & cooling control	• Demand/presence dependent airflow control at room level • Variable setpoint with load-dependent compensation of supply temperature • Room/exhaust/ supply-air humidity control	Automatic • Daylight control • Occupancy detection manual on / auto off • Occupancy detection manual on / dimmed • Occupancy detection auto on / auto off • Occupancy detection auto on / dimmed	Combined light/blind/ HVAC&R control
B	• Individual room control with communication between controllers • Indoor temperature control of distribution network water temperature • Partial interlock between heating & cooling control (dependent on HVAC system)	• Time-dependent airflow control at room level • Variable setpoint with outdoor temperature compensation of supply temperature control • Room/exhaust/ supply-air humidity control	Automatic • Daylight control • Occupancy detection manual on / auto off • Occupancy detection manual on / dimmed • Occupancy detection auto on / auto off • Occupancy detection auto on / dimmed	Motorized operation with automatic blind control
C	• Individual room automatic control by thermostatic valves or electronic controller • Outdoor	• Time-dependent airflow control at room level • Constant setpoint of supply temperature control • Supply-air humidity limitation	Manual • Daylight control • On/off switch + additional sweeping extinction signal • Manual on/off	Motorized operation with manual blind control
D	• No automatic control • No control of distribution network water temperature • No interlock between heating and cooling control	No airflow control at room level No supply temperature control No air humidity control	Manual • Daylight control • On/off switch + additional sweeping extinction signal • Manual on/off	Manual operation of blinds

5.3.4. Ceiling fans

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

5.3.5. Night ventilation and window shading

Intensive ventilation through windows during the night is a cost-saving and energy-efficient method of cooling buildings in summer. It uses the natural pressure differences between at least two openings (e.g. windows, doors) of a building to the outside for air exchange. Such a pressure gradient already exists in weak winds. The proposed scenario will be auto night ventilation between 20:00 and 8:00 in summer with a volume flow rate of 4 ACH and is activated only when the difference between indoor and outdoor temperature is greater than 3°C. Also, it only works when the outdoor temperature is greater than 15°C (outdoor humidity less than 60%), and the indoor temperature is greater than the heating setpoint. Window shading is modelled by applying a shading factor of 0.7 during the cooling period (October-April).

5.3.6. Cool roof coating

A new coating with albedo 0.75 (or solar absorbance 0.25) will be added in this retrofit scenario.

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 [16].

The GSHP considered in retrofitting Aitkenvale Library meets each building's space heating, cooling and DHW demands, and it has an average COP=4.8 and EER=5.0.

Table 15. Functions and assignment to energy performance classes for non-residential buildings. Standard automation is used as reference.

	BAC efficiency factors $f_{BAC,hc}$ / BAC efficiency factors $f_{BAC,e}$							
	D	C	B	A	Energy saving adopting classes			
Building use	No autom.	Standard autom.	Advanced autom.	Full autom.	D→A	D→B	C→A	C→B
Offices	1.51	1	0.80	0.70	54%	47%	30%	20%
	1.10		0.93	0.87	36%	27%	30%	20%
Lecture Hall	1.24	1	0.75	0.35	60%	40%	50%	25%
	1.06		0.94	0.89	53%	29%	50%	25%
Education buildings (schools)	1.20	1	0.88	0.80	33%	27%	20%	12%
	1.07		0.93	0.86	25%	18%	20%	12%
Hospitals	1.31	1	0.91	0.86	34%	31%	14%	9%
	1.05		0.95	0.90	18%	13%	14%	9%
Hotels	1.31	1	0.85	0.68	48%	43%	32%	25%
	1.04		0.96	0.92	36%	21%	32%	15%
Restaurants	1.23	1	0.77	0.68	45%	37%	32%	23%
	1.08		0.95	0.91	35%	26%	32%	23%
Wholesale and retail	1.56	1	0.73	0.47	62%	53%	40%	27%
	1.08		0.95	0.91	44%	32%	40%	27%

6. Results

6.1. Base building modelling

The result of the Aitkenvale Library simulation is presented in this section. The hourly energy demand for heating and cooling (sensible and latent) is illustrated in Figure 6. Also, the monthly energy demand is presented in Figure 7. ➔

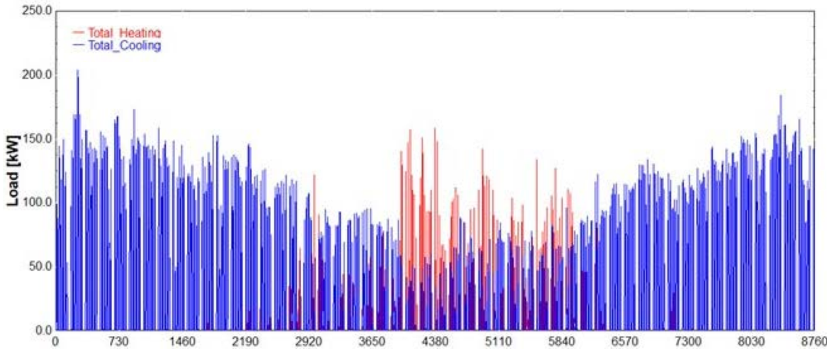

Figure 6. Hourly energy demand for HVAC&R purposes.

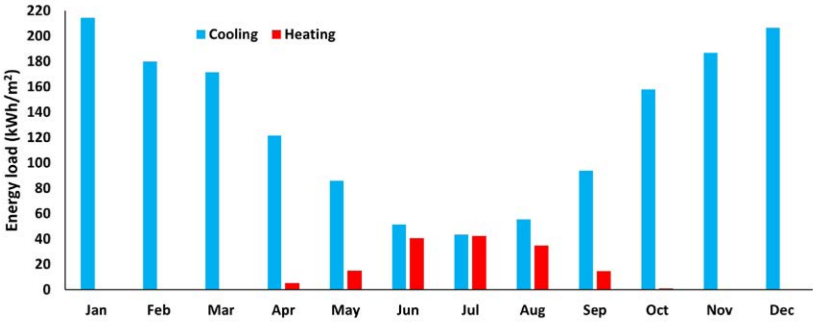

Figure 7. Monthly energy demand for HVAC&R purposes.

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 8 and Figure 10). Also, the amounts of heating and cooling energy are illustrated in Figures 9 and 11.
➔

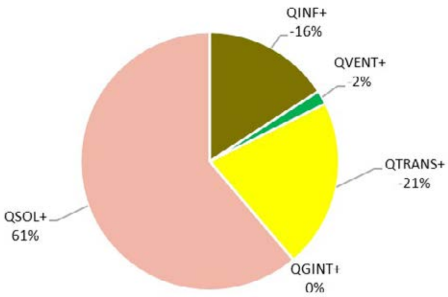

Figure 8. Whole building energy gain – heating season (May-September).

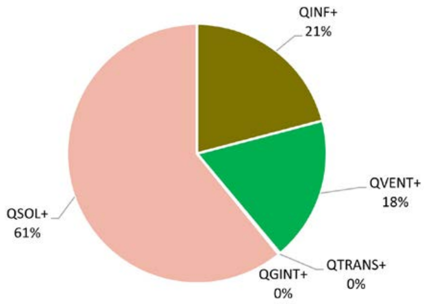

Figure 10. Whole building energy gain – cooling season (October-April).

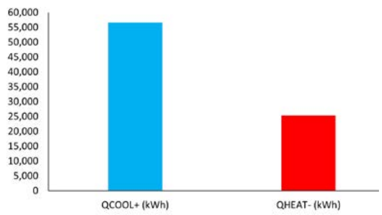

Figure 9. Whole building energy gain for heating and cooling load – heating season (May-September).

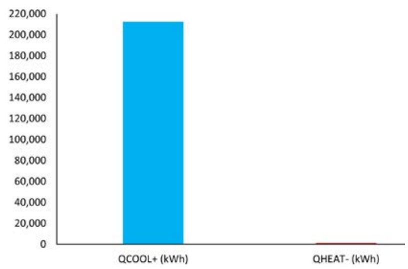

Figure 11. Whole building energy gain for heating and cooling load – cooling season (October-April).

The monthly energy gain of the library and the influence of each factor on the total energy demand is presented in Figure 12.

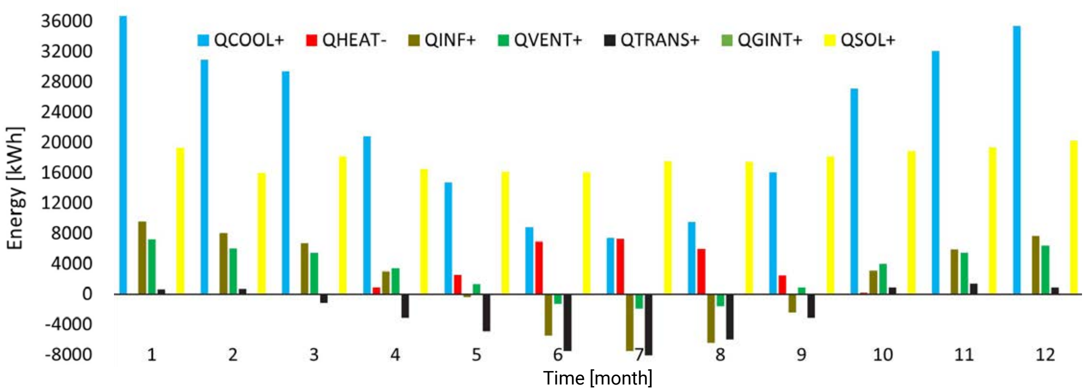

Figure 12. Monthly building energy gain.

6.2. Retrofit scenarios

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

Among the presented scenarios, Case H has the most retrofitting steps. ➔

Table 16. 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 number of lighting fixtures is the same as in the Base case scenario, but the fluorescent lamps are replaced with LEDs.
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, an SHGC value 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.
Case D	Case C + Automation and Controls: The baseline class of automation is estimated according to EN15232, and then the new class and energy efficiency are estimated according to the potential improvements. Class C is the estimated class for the baseline, and it is considered that class A is reached after the improvements.
Case E	Case D + Installation of ceiling fans: Ceiling fans are modelled by increasing the cooling setpoint temperature to 26°C.
Case F	Case E + night ventilation + window shading: Night ventilation takes place between 20:00 and 8:00 with an additional flow rate of 4 ACH and is activated during the cooling period and only when the difference between indoor and outdoor temperature is greater than 3°C, the outdoor temperature is greater than 15°C, and the indoor temperature is greater than the heating setpoint. Window shading is modelled by applying a shading factor of 0.7 during the cooling period (October-April).
Case G	Case F + Installation of GSHP: The GSHP meets space heating, cooling and DHW demands, and it has an average COP=4.8 and EER=5.0, including losses of the distribution network and terminal units.
Case H	Case G + cool roof coating: New cool roof coating with albedo 0.75 (solar absorbance 0.25).

Table 17 shows the influence of different retrofitting cases on heating and cooling loads. Also, Table 18 demonstrates the impact of different retrofit scenarios on electricity and natural gas consumption in the case study library. The result shows that by improving the building condition, 84.4% of the required electricity can be reduced. A more detailed illustration of the retrofitting impact is presented in Figures 13-15. →

Table 17. Simulation results – Heating and cooling loads.

	Heating loads	Cooling loads	Heating + Cooling	Heating loads	Cooling loads	Heating + Cooling
Unit	kWh/(m²a)			difference (%)		
Baseline	14.5	147.3	161.8	-	-	-
Case A (Baseline + lighting scenario 1)	14.5	147.3	161.8	0%	0%	0%
Case B (Baseline + lighting scenario 2)	14.5	147.3	161.8	0%	0%	0%
Case C (Case B + windows retrofit)	6.4	112.3	118.7	-56%	-24%	-27%
Case D (Case C + automation & controls)	6.4	112.3	118.7	-56%	-24%	-27%
Case E (Case D + ceiling fans)	4.9	62.3	67.3	-66%	-58%	-58%
Case F (Case E + night ventilation + Window shading)	5.1	39.1	44.2	-65%	-73%	-73%
Case G (Case F + GSHP)	5.1	39.1	44.2	-65%	-73%	-73%
Case H (Case G + cool roof coating)	5.6	31.3	36.9	-61%	-79%	-77%

Table 18. Simulation results – Site energy.

	Heating	Cooling	Lighting	DHW	Appliances	Total	Total difference	Total difference
Unit	kWh/(m²a)							%
Baseline	5.2	61.4	21.1	1.1	4.6	93.3	0.0	0%
Case A (Baseline + lighting scenario 1)	5.2	61.4	10.2	1.1	4.6	82.4	-10.9	-11.7%
Case B (Baseline + lighting scenario 2)	5.2	61.4	4.5	1.1	4.6	76.7	-16.6	-17.8%
Case C (Case B + windows retrofit)	2.3	46.8	4.5	1.1	4.6	59.2	-34.1	-36.5%
Case D (Case C + automation & controls)	1.6	32.7	4.5	1.1	4.6	44.5	-48.8	-52.3%
Case E (Case D + ceiling fans)	1.2	18.2	4.5	1.1	4.6	29.5	-63.8	-68.3%
Case F (Case E + night ventilation + Window shading)	1.3	11.4	4.5	1.1	4.6	22.8	-70.5	-75.6%
Case G (Case F + GSHP)	0.7	5.5	4.5	0.3	4.6	15.6	-77.7	-83.3%
Case H (Case G + cool roof coating)	0.8	4.4	4.5	0.3	4.6	14.6	-78.7	-84.4%

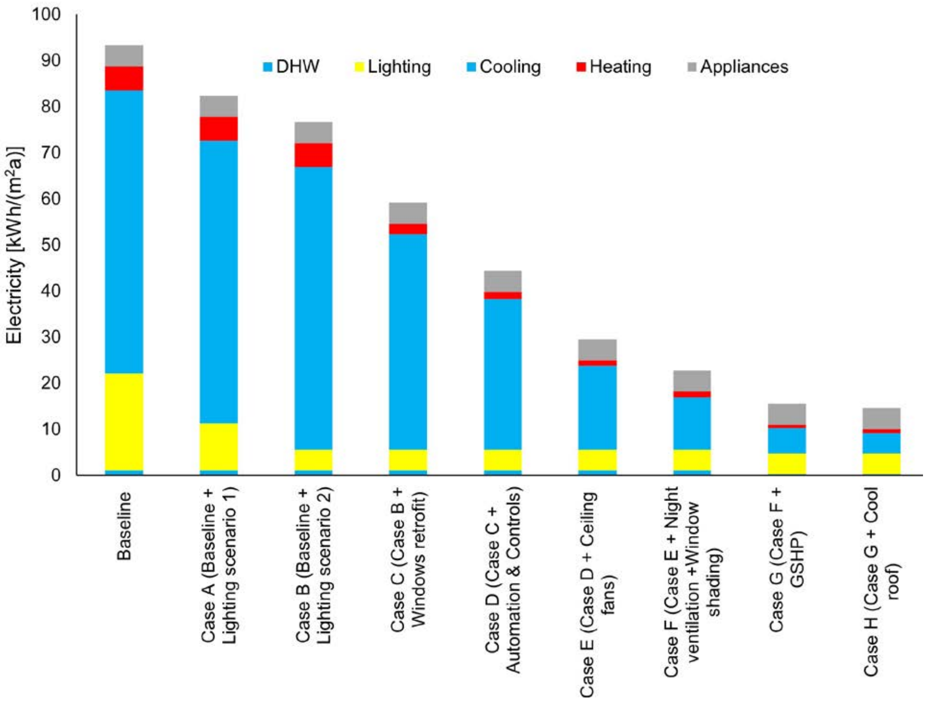

Figure 13. Site energy of the retrofit scenarios.

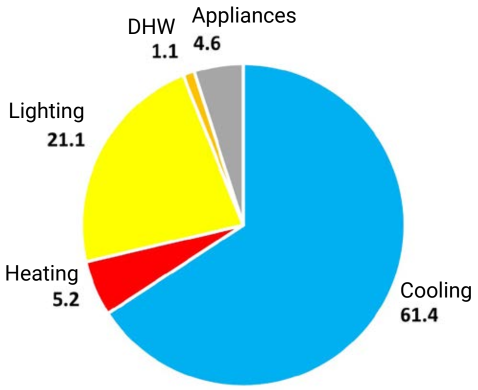

Figure 14. Share of site energy for the baseline (kWh/m²a).

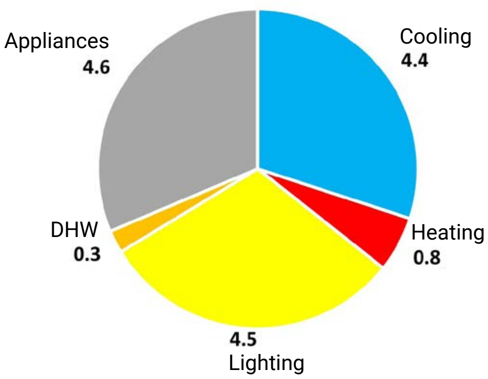

Figure 15. Share of Site energy for retrofit scenario – case H (kWh/m²a).

6.3. Future climate simulation

In this section, the case study library is simulated in 8 representative cities in Australia. CSIRO has current and future weather models. Therefore, this database is selected to investigate the impact of geographical locations and climate change on the case study building energy demand. Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases are called Representative Concentration Pathways (RCPs) [17]. The word representative indicates that each RCP provides one of many possible scenarios that would lead to a specific radiative forcing characteristic. The term pathway denotes that not only the long-term concentration levels are of interest, but also the path taken over time to reach that outcome is important. RCP4.5 is selected as the future pathway to compare different cities. RCP4.5 is an intermediate condition in which radiative forcing is stabilised at approximately 4.5 W/m² after 2100.

Table 19 presents the energy load and final energy demand for the library building in 8 representative cities. The results indicate that in all representative cities, the cooling site energy will rise between 9.5%-30.5% by 2030. The considerable amount of energy demand for cooling would cause a 6.9% rise in the total electricity demand in Darwin by 2030. On the other hand, due to less heating energy demand in heating-dominated cities like Melbourne, the total electricity demand in 2030 would reduce by 4.8%.

To evaluate the impact of retrofitting the case study library, the base case and highly retrofitted scenario (Case H) were simulated in Townsville. As it is presented in Table 20, the total base case site energy will rise sharply (6.5%) until 2030. This is because of the climate change impact, which causes a considerable increase in the cooling demand (11.9%). The results →

Table 19. Current and future energy demand of the case study library based on CSIRO weather database.

Location	Period	Water heating	Heating site energy	Space cooling	Cooling site energy	Lighting site energy	Appliances site energy	Total site electricity demand	Increase in total cooling site energy	Increase in total heating site energy	Increase in total electricity site energy
		(kWh/m²)							%		
Adelaide	Present	1.1	51.4	42.5	17.7	21.1	4.6	95.9	-	-	-
	2030	1.1	45.2	51.4	21.4	21.1	4.6	93.4	20.9	-12.1	-2.6
Brisbane	Present	1.1	21.0	70.3	29.3	21.1	4.6	77.1	-	-	-
	2030	1.1	17.4	82.3	34.3	21.1	4.6	78.5	17.1	-17.1	1.9
Canberra	Present	1.1	79.7	26.2	10.9	21.1	4.6	117.4	-	-	-
	2030	1.1	73.1	31.4	13.1	21.1	4.6	113.0	20.2	-8.3	-3.7
Darwin	Present	1.1	0.6	214.3	89.3	21.1	4.6	116.7	-	-	-
	2030	1.1	0.4	234.0	97.5	21.1	4.6	124.7	9.2	-33.3	6.9
Melbourne	Present	1.1	73.8	19.7	8.2	21.1	4.6	108.8	-	-	-
	2030	1.1	66.0	25.7	10.7	21.1	4.6	103.5	30.5	-10.6	-4.8
Perth	Present	1.1	39.7	65.3	27.2	21.1	4.6	93.7	-	-	-
	2030	1.1	34.0	77.3	32.2	21.1	4.6	93.0	18.4	-14.4	-0.7
Sydney	Present	1.1	35.8	34.8	14.5	21.1	4.6	77.1	-	-	-
	2030	1.1	31.1	42.7	17.8	21.1	4.6	75.7	22.8	-13.1	-1.8
Hobart	Present	1.1	87.3	5.4	2.3	21.1	4.6	116.4	-	-	-
	2030	1.1	81.9	7.0	2.9	21.1	4.6	111.6	28.9	-6.2	-4.0

Table 20. The comparison between the base case and fully retrofitted scenario.

Location	Period	Water heating	Space heating site energy	Space cooling	Cooling site energy	Lighting site energy	Appliances site energy	Total site electricity demand	Heating site energy increase	Cooling site energy increase	Total site electricity increase
		(kWh/m²)							%		
Base case	Present	1.1	5.2	147.3	61.4	21.1	4.6	93.4	-	-	-
	2030	1.1	4.0	164.9	68.7	21.1	4.6	99.4	-23.1%	11.9%	6.5%
retrofitted	Present	0.3	0.8	31.3	4.4	4.5	4.6	14.6	-	-	-
	2030	0.3	0.6	40.0	5.6	4.5	4.6	15.5	-25.0%	27.3%	6.2%

show that the cooling load in 2030 can be reduced by 75.7% in the case of a complete refurbishment of the Aitkenvale library. Also, a complete retrofit of the Aitkenvale Library would result in a reduction of 84.4% of the total electricity demand of the building.

6.4. Discussion and recommendations

We established a baseline for energy consumption, and then we undertook a simulation based on various energy efficiency upgrades for the Aitkenvale Library. According to the data, energy consumption is relatively high, especially with respect to cooling. Heating, appliances, lighting and hot water production require quite a large amount of electricity, too. As a result, the following recommendations for lowering energy use have been made:

- The simulations proved that the natural lighting levels in the spaces close to the windows are adequate. However, daylight in deep space, such as the adult section (Magazines – Catalogue, Adult fiction and Adult non-fiction), is low. The Magazines – Catalogue and Adult non-fiction area have the potential to receive higher daylight levels with the use of light pipes or skylights.
- The artificial lighting analysis showed that if the fluorescent lighting fixtures are replaced by LEDs and daylight linked controls are used, lighting energy savings between 50 and 90% can be achieved.
- Refurbishment of the windows, with new aluminium framed, double glazed ones, of high energy efficiency to reduce thermal losses in winter, solar loads in summer, and achieve airtightness throughout the year.
- Installation of ceiling fans or replacement of the old ones to reduce cooling demands.
- Implementing night ventilation patterns in the HVAC&R system's operation as well as window shading during the cooling season to reduce cooling demands.
- Installing cutting-edge Building Automation and Controls, as well as a Building Management System, to coordinate the use of HVAC&R with both weather and operating requirements.
- Installation of a ground source heat pump (GSHP) to meet the space heating, space cooling and DHW demands so as to reduce final energy requirement.
- Finally, applying a new white cool roof coating on top of the roof sheeting to lower the solar absorbance of the roof to 0.25.

In conclusion, a complete renovation package that includes the replacement of the building's windows and glazed surfaces, combined with an upgrading of the lighting system, the installation of a GSHP and ceiling fans and the use of night-time ventilation and window shading patterns, linked all with the implementation of a state-of-the-art BAC system, can lead to energy savings of 84.4 %, resulting in an energy consumption of 14.6 kWh/m²a, compared to the baseline of 93.4 kWh/m²a. ■

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Attachment 1

The following figures show daylight factor distribution in the Aitkenvale Library.

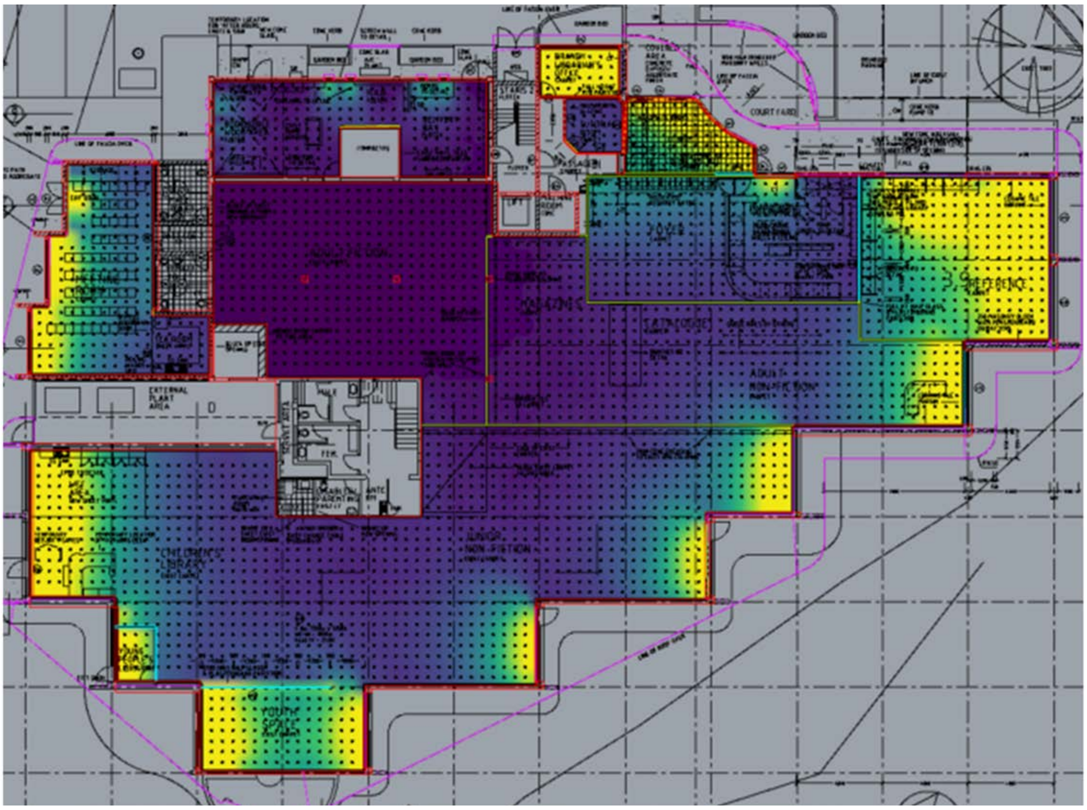

Fig. A1. Distribution of Average Daylight Factor on the ground floor.

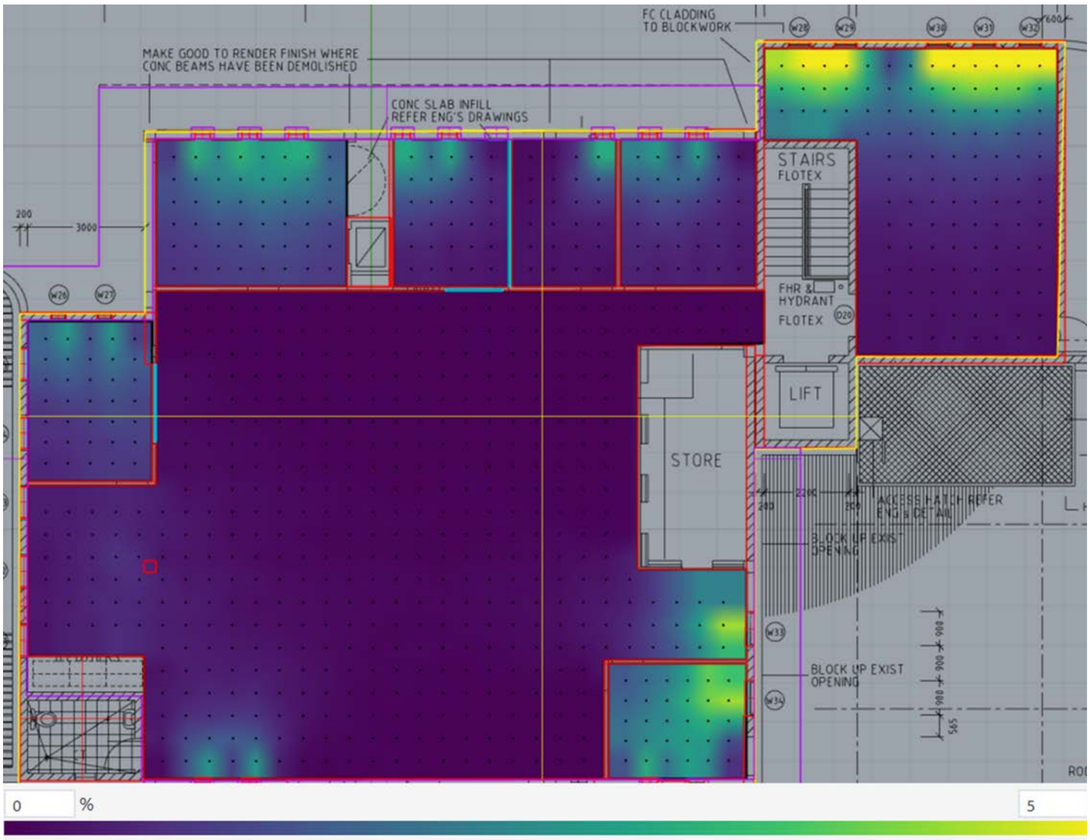

Fig. A2. Distribution of Average Daylight Factor on the ground floor.

General

Ceiling
Suspended
white
IP20
indirect 3630 lm
direct 3180 lm
total 6810 lm
RAL9010

LED

3000 K
CRI ≥ 80
L90 / 50000 h
photobio. safety RG 0 - no Risk

Optical

Microprismatic
UGR < 16

Physical

Cable 1500 mm
length 1507 mm
width 200 mm
height 25 mm

Electrical

non DIM
48 W
142 lm/W
PC1 220-240V

Fig. A3. The properties of the LED lighting fixture used for the proposed scenarios. (Vilo suspended 074-0245517P, www.xal.com)

Attachment 2

Fig. A4. External view of the building.

Fig. A5. External view of the building.