ABN: 48 628 897 870
info@dqcs.com.au

NCC Section J in the NT

Potential for Adoption

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Prepared For:	Building Advisory Services Policy Northern Territory Government Department of Infrastructure, Planning and Logistics (DIPL)
Author(s):	DeltaQ – Grace Foo, Joyce Yeoh Hoogland Consult – Matt Hoogland EnerEfficiency – Hongsen Zhang Strategy Policy Research – Philip Harrington
Reviewer:	Dr Paul Bannister, Grace Foo
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ABN: 48 628 897 870
info@dqcs.com.au

Executive Summary

Energy efficiency requirements in the Australian National Construction Code, Volume One Section J aim to lower energy use and in turn reduce consumers' electricity costs and greenhouse gas emissions. Whilst states and territories have adopted these minimum requirements, the Northern Territory (NT) have only adopted the 2009 version of these minimum standards for Class 1 and 2 buildings and a Class 4 part of a building. In the NT, Section J does not apply to Class 3 and 5 – 9 buildings. The NT commercial building sector incurs high cooling energy costs to battle hot exterior conditions which are expected to worsen in future with the impacts of climate change. The NT is now considering adoption of these energy efficiency requirements (Section J).

Prior to making the decision to adopt Section J it is important to have a clear understanding of the potential changes to design and construction practices for NT buildings and the associated costs and benefits of these at consumer and societal levels. It is within this context that the DeltaQ consortium (DeltaQ, Hoogland Consult, EnerEfficiency and Strategy Policy Research) was engaged to conduct a cost benefit analysis regarding the possible adoption of Section J of the National Construction Code for commercial buildings in the NT. The consortium was assisted in the development of NT specific construction cost estimates by Sunbuild as well as FRM and Coldzap refrigeration contractors.

Policy Options

The policy options considered under this study include three options:

1. Business as usual (BAU) – this is an option where the energy efficiency requirements (Section J) are not adopted for commercial buildings in NT Tier 1 and 2 building control areas in 2022. The BAU provides a baseline (base case) against which the impacts of Option A and Option B below are evaluated.
2. Option A - Adoption of NCC2016 Section J requirements
3. Option B - Adoption of NCC2019 Section J requirements

Approach

The analysis considers six commercial building archetypes (of classes 3, 5 6, 9a and 9b) in Darwin (Climate Zone 1) and Alice Springs (Climate Zone 3). The costs and benefits of adopting NCC2016 and NCC2019 were modelled and compared with the base case (current situation) in the NT, from the owner-occupier and NT-economy wide perspectives.

The development of the base case is an important step in this study because it is used to assess the incremental costs and benefits associated with Section J compliance. For this study, the specific construction methods and heating, ventilation and air conditioning (HVAC) systems were customised to Darwin and Alice Springs standard practice in consultation with local construction companies. The general approach was to deem the "base case" as the typical construction of a private development for each respective archetype, where the developer has no specific requirements for energy performance. Multiple construction methods to achieve Section J compliance were considered and a least cost analysis was conducted to select the cheapest compliance construction method used in the cost benefit analysis.

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Comparison of the base case construction to the Deemed-To-Satisfy (DTS) NCC2016 and NCC2019 Section J requirements found that the largest change introduced by adoption of the NCC Section J is adding or increasing insulation for building envelope (walls, roofs and some floors) to counteract impacts of thermal bridging and high heat transfer across the building fabric from the exterior. By contrast, only relatively minor adjustments to building services were required, mostly related to controllability and monitoring of equipment. A summary of the changes required to meet Section J requirements for each building type is provided in Appendix K, p. 199.

Typical changes to current building envelop construction methods that would result from introduction of Section J were found to be:

- Increased insulation (including insulation spacing systems) and introduction of reflective air gaps in roof constructions
- Addition of insulation and reflective air gaps in wall constructions
- Higher performance glazing specifications and
- Addition of insulation under floors in some instances.

An alternate approach to the use of the Deemed-To-Satisfy requirements is the use of alternative verification paths in which building compliance can be proven using energy modelling. Investment in upfront energy modelling can result in savings in lower construction costs.

Estimated Impacts

Costs and benefits were estimated in Net Present Value (NPV) and Benefit Cost Ratio (BCR) terms across the 40-year economic life of buildings constructed across an 8-year regulatory period (FY2023 to FY2030). This was assessed from the social and owner-occupier perspectives. The social perspective considers costs and benefits that arise for parties not directly involved in a building project, such as government costs (which implies lower taxes for all), reduced greenhouse gas emissions (which lowers to risk of climate damage for everyone), and reduced electricity system capacity requirements (which implies reduced energy bills for all users of the network). Owner-occupier costs and benefits are those that accrue directly to parties involved in a building, such as higher construction costs and lower building operation costs.

At a building level, the least cost analysis indicates that both NCC2016 and NCC2019 Section J compliant buildings can be achieved at an incremental construction cost of no more than 2.6% (2.6% for NCC2016 and 2.4% for NCC2019). While these incremental construction costs are similar between NCC2016 and NCC2019, the difference in modelled energy savings is significantly larger: 6 – 27% energy savings are available if NCC2016 is adopted, compared to 13 – 40% energy savings should NCC2019 be adopted instead (NCC2019 average energy savings of 23% across all building archetypes in Darwin, and 29% for Alice Springs). The greater NCC2019 energy savings, compared to NCC2016 savings, were consistent for both Alice Springs and Darwin.

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ABN: 48 628 897 870
info@dqcs.com.au

Table 1: Energy savings per sqm (kWh/m²) for each building form relative to the base case, for all fuels, Darwin and Alice Springs.

Building Type	NCC2016		NCC2019	
	Darwin	Alice Springs	Darwin	Alice Springs
Hotel (3A)	16.5 (13.1%)	17.8 (14.7%)	16.6 (13.1%)	29.0 (24.1%)
Multi-Storey Office (5A)	26.1 (27.3%)	13.0 (22.8%)	32.5 (34.1%)	12.0 (21.1%)
Single Storey Office (5)	6.9 (6.4%)	11.4 (10.9%)	16.9 (15.7%)	26.6 (25.4%)
Retail (6B)	22.9 (11%)	22.7 (15.4%)	68.0 (32.6%)	37.7 (25.6%)
Hospital Ward (9aC)	10.9 (6.1%)	14.9 (14.7%)	24.5 (13.7%)	40.4 (39.9%)
School (9bH)	15.6 (10.5%)	16.4 (15.6%)	20.6 (13.9%)	32.1 (30.5%)
Simple Average Savings:	16.5 (12.4%)	16.0 (15.7%)	29.8 (20.5%)	29.6 (27.8%)
Weighted Average Savings[1]:	**17.7 (11.7%)**	**18.8 (16.7%)**	**34.3 (22.7%)**	**32.4 (28.9%)**

NCC2019 was found to be cost-effective from both the social and owner-occupier perspectives under all scenarios and assumptions examined. NCC2019 significantly outperforms NCC2016 under all scenarios considered, including best- and worst-case scenarios where the percentage of expected savings realised, real discount rates, learning rates, and social cost of carbon were varied.

Under the expected or most likely scenario, NCC2019 produces a net social benefit for the NT of $276million (present value). This is 2.7 times the net present value (NPV) associated with implementing NCC2016 ($103million). The benefit-to-cost ratios for adopting NCC2019 and NCC2016 were 3.6 and 2.0 respectively. From an owner-occupier perspective, NCC2019 will have a NPV of $295 million (BCR of 3.8) which is also 2.7 times larger than that of NCC2016 ($108million at a BCR of 2.0).

Even under the worst-case scenario – which assumes that all variables in the analysis turn out at the least favourable end of a plausible spectrum – NCC2019 remains cost-effective from both the social and owner-occupier perspectives ($89million and at $104million, and BCRs of 1.9 and 2.0, respectively). The net social and private benefits of NCC2016 under the same worst-case scenario assumptions would be significantly lower (at $5million net social benefits and $8million private benefits), achieving benefit-to-cost ratios of 1.1 in both cases.

The social cost benefit analysis results include an assumed $500,000 NT Government funding a year for three years to upskill industry and tailor training resources to the Territory. If this cost is not incurred, then the social benefit cost analysis (for NCC2016 and NCC2019) would be very slightly improved.

[1] Weightings, based on the projected building type floor areas to be constructed in the NT in the 2023-2030 period assessed, are applied to the expected energy savings.

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Table 2: Net Present Value and Benefit Cost Ratios of adopting NCC2016 and NCC2019 Section J in the NT (Tier 1 and Tier 2 areas) from FY2023, Societal Perspective

Scenario (Social)	NCC2016		NCC2019	
	NPV	BCR	NPV	BCR
Best Case[1]	$368million	4.3	$775million	7.8
Reference Case[2]	$103million	2.0	$276million	3.6
Worst Case[3]	$5million	1.1	$89million	1.9

1. 100% modelled energy savings, 3% real discount rate, 5% learning rate, high cost of carbon
2. 100% modelled energy savings, 7% real discount rate, 2% learning rate, average cost of carbon
3. 75% modelled energy savings, 10% real discount rate, 0% learning rate, low cost of carbon

Table 3: Net Present Value and Benefit Cost Ratios of adopting NCC2016 and NCC2019 Section J in the NT (Tier 1 and Tier 2 areas) from FY2023, Owner Occupier Perspective

Scenario (Owner-Occupier)	NCC2016		NCC2019	
	NPV	BCR	NPV	BCR
Best Case[1]	$186million	2.9	$438million	5.4
Reference Case[2]	$108million	2.0	$295million	3.8
Worst Case[3]	$8million	1.1	$104million	2.0

1. 100% modelled energy savings, 3.9% real discount rate, 5% learning rate, 1% real electricity cost escalation
2. 100% modelled energy savings, 4.7% real discount rate, 2% learning rate, 0.4% real electricity cost escalation
3. 75% modelled energy savings, 6.3% real discount rate, 0% learning rate, 0% real electricity cost escalation

Reductions in greenhouse gas emissions and peak electrical demand are also greater under NCC2019. The adoption of NCC2019 generates the largest greenhouse gas savings of 891,000 tonnes of CO_2-e (tCO_2-e) cumulatively over the life of the buildings built (FY2023 – FY2070); this is almost double the greenhouse gas emissions savings generated from NCC2016 compliance (469,000 tCO_2-e). Under NCC2016, reductions in peak electrical demand would reach 17.1 MW by FY2030, compared to business-as-usual, while under NCC2019, reductions in peak demand would reach 27.3 MW by the same date.

Conclusion

Based on the analysis presented in the study, the preferred option is to adopt the NCC2019 energy efficiency requirements for new NT commercial buildings.

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Disclaimer: *Readers should keep in mind that the results in this report are based on simulated building models with predetermined forms and geometries. Specific building designs may perform differently depending on their designed form, servicing and geometry.*

Key Findings

- **There is a strong case for adoption of the NCC2019 Section J in the NT Tier 1 and 2 areas.**
- **NCC2019 significantly outperforms NCC2016, whilst incurring similar additional costs.**
- **Under all core scenarios considered, NCC2019 is cost-effective from both the social and owner-occupier perspective.**
- **NCC2019 produces a net social benefit for the NT of $276million (present value), 2.7 times the net present value (NPV) associated with implementing NCC2016 ($103million).**
- **From an owner-occupier perspective, NCC2019 will deliver a NPV of $295million (BCR of 3.8), 2.7 times larger than that of NCC2016 ($108million at a BCR of 2.0).**
- **At a building-level, NCC2016 and NCC2019 Section J compliant buildings can be achieved at an incremental construction cost of less than 3% (2.6% maximum for NCC2016 and 2.4% maximum for NCC2019).**
- **Modelled energy savings at a building-level for NCC2019 compliant buildings range from 12 to 68 kWh/m^2 (13% - 40% relative to base case). This is larger than the energy savings modelled for NCC2016 compliant buildings of 7 to 26 kWh/m^2 (6%-27%).**
- **It is recommended that dedicated budget be set aside by Government to support the administration and roll-out of NCC2019 Section J in the NT.**

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info@dqcs.com.au

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info@dqcs.com.au

Acronyms & Definitions

Acronym	Definition
ABCB	Australian Building Codes Board
ACH	Air Change per Hour
AEMO	Australian Energy Markets Operator
AER	Australian Energy Regulator
AHU	Air Handling Unit
AIRAH	Australian Institute of Refrigeration, Air conditioning and Heating
BCA	Building Code of Australia
BCR	Benefit Cost Ratio
BMS	Building Management System
BMT	Base Metal Thickness
CBA	Cost Benefit Analysis
CHW	Chilled Water system
CIBSE	Chartered Institution of Building Services Engineers
CIE	The Centre for International Economics
CLF	Conservation Load Factor
COAG	Council of Australian Governments
COP	Coefficient of Performance
CZ	Climate Zone
DHW	Domestic Hot Water
DIPL	Department of Infrastructure, Planning and Logistics
DISER	Australian Department of Industry, Science and Resources
DKIS	Darwin-Katherine Interconnect System
DX	Direct Expansion Cooling
EMS	Energy Management System
ESD	Ecologically Sustainable Development

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info@dqcs.com.au

Acronym	Definition
FCU	Fan Coil Unit
GEMS	Greenhouse and Energy Minimum Standards
GHG	Greenhouse Gas
GSP	Gross State Product
GSP	Gross State Product
HHW	Heating Hot Water system
HVAC	Heating, Ventilation, and Air Conditioning
Internal Walls	Walls in a building that divide rooms
IPLV	Integrated Part Load Value
ISP	Integrated System Plan
LGA	Local Government Area
NABERS	National Australian Built Environment Rating System
NCC	National Construction Code NCC2016, NCC2019, NCC2022 refers to the National Construction Code released in 2016, 2019, and 2022
NEM	National Electricity Market
NPV	Net Present Value
NT	Northern Territory
NWIS	North West Interconnect System
OA	Outdoor Air
OBPR	Australian Government's Office of Best Practice Regulation's
PAC	Package Air-Conditioning Unit
PIR	Polyisocyanurate (insulation)
PV	Present Value
PWC	Power and Water Corporation
Regulated Energy Intensity	Regulated energy intensity is the annual energy consumed, per sqm of total floor area, that is associated with maintaining the regulated services of a building (e.g. HVAC systems and lighting. It excludes plug-in loads).
RIN	Regulation Information Notices

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info@dqcs.com.au

Acronym	Definition
RIS	Regulatory Impact Statement
R-Value	R-value is a measure of resistance to the flow of heat through the thickness of a material. A higher R-value indicates better insulating properties. For a construction material made of multiple different layers/materials, the R-value is referred to as the Total R-Value; this is the overall R-value accounting for the insulative property of each material present.
SHGC	Solar Heat Gain Coefficient - a measure of how much solar radiation passes through a window. Windows with a higher SHGC value allow more solar radiation to pass through.
Solar Absorptance	The fraction of solar radiation that a surface absorbs (typically converted to heat). A higher solar absorptance value indicates that the surface/ material absorbs more a larger fraction of solar radiation, and heats up more when exposed to solar radiation.
Solar Admittance	The fraction of incident irradiance on a wall-glazing construction that adds heat to a building space. A building that has wall-glazing construction with higher solar admittance values is more likely to heat up more than one that has wall-glazing construction with lower solar admittance values. The method of calculating the solar admittance value is defined in the National Construction Code, and takes into account the window-to-wall ratio, the solar heat gain coefficient of glazing and presence of shading.
sqm	Area in square metres (m^2)
SWIS	South West Interconnect System
Appendix A	Tonnes (t) of carbon dioxide (CO_2) equivalent (e)
U-Value	U-value is the measure of how much heat is transferred through a window. A lower U-value indicates better insulation properties. U-value is the inverse of R-value.
VAV	Variable Air Volume
VRF	Variable Refrigerant Flow
VSD	Variable Speed Drive
WWR	Window-to-Wall Ratio
XPS	Extruded Polystyrene (insulation)

ABN: 48 628 897 870
info@dqcs.com.au

1 Introduction

1.1 Project Context

Since the introduction of the energy efficiency requirements in the Australian National Construction Code, Volume One Section J, states and territories have adopted these minimum requirements; however, the NT has only adopted the 2009 version of these minimum standards for class 2 buildings and a class 4 part of a building. In the NT Section J does not apply to class 3 and classes 5-9 buildings The NT is now reconsidering this position due to the high cooling energy demands of the commercial building sector which is expected to further increase with the warming climate.

The DeltaQ Consortium (including DeltaQ, Hoogland Consult, EnerEfficiency and Strategy Policy Research) was engaged to conduct a cost benefit analysis regarding the possible adoption of Section J of the National Construction Code in the NT for commercial buildings. The analysis considers six commercial building archetypes (class 3, 5, 6, 9a and 9b) in Darwin[2] and Alice Springs[3].

It should be noted that since May 2021, all new NT Government building works that either exceed a value of $3 million, require 24/7 air-conditioning, or have new conditioned floor areas over 750 m^2 must meet Section J[4]. Prior to this initiative, the NT Government applied Section J requirements to multiple government building projects including Zucolli Primary School and Palmerston Regional Hospital.

1.2 Objective

This study aims to determine if the benefits associated with adopting either NCC2016 or NCC2019 Section J for NT commercial buildings outweigh the associated costs.

The three policy options considered under this study are:

1. Business as usual (BAU) – this is an option where the energy efficiency requirements (Section J) are not adopted for commercial buildings in NT building control areas[5]. The BAU provides a baseline (base case) against which the impacts of Option A and Option B below are evaluated.
2. Option A - Adoption of NCC2016 Section J requirements
3. Option B - Adoption of NCC2019 Section J requirements

[2] Located within Climate Zone 1 in the Section J.

[3] Located within Climate Zone 3 in the Section J.

[4] DIPL Sustainability Minimum Design Standards (MDS), Department of Infrastructure, Planning and Logistics, 2021, accessed on 1 October 2021, https://dipl.nt.gov.au/__data/assets/pdf_file/0004/996376/dipl-sustainability-minimum-design-standard-mds.pdf

[5] The NT, certain areas are declared building control areas. Building control areas are divided into two tiers. In general, there are more requirements for Tier 1 areas than Tier 2 areas. For more info, refer to https://nt.gov.au/property/building/build-in-a-controlled-area/

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info@dqcs.com.au

1.3 Methodology

The overall impact of adopting Section J NCC2016 and NCC2019 for commercial buildings in the NT is assessed by conducting a cost benefit analysis. This analysis compares the impacts of the changes required for the selected building archetypes to be compliant with Section J NCC2016 and Section J NCC2019 to the base case, which is representative of typical construction practices in the NT.

The works completed to assess the impact of adopting Section J can be divided into four stages. These are as summarised below:

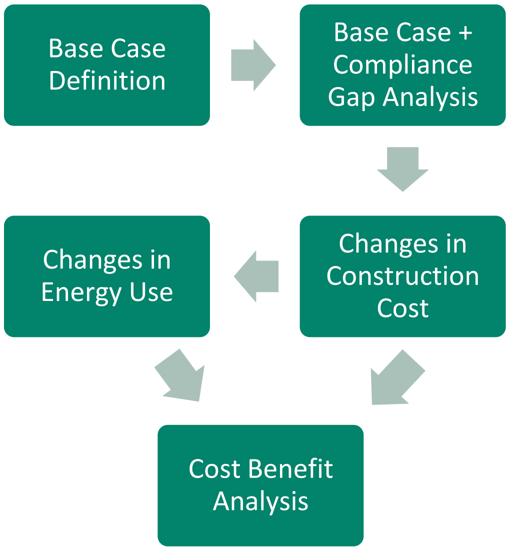

Figure 1-1: Methodology used to assess the impact of the NT adopting NCC2016 and NCC2019 Section J.

Stage 1: Defining the Base Case

This study first defines the base case construction of six building archetypes in Alice Springs and Darwin. Using the building forms defined by the NT Government[6], the process involves the creation of a base case representing typical construction practices in the NT. This was determined in consultation with a major builder and building services providers in Darwin and Alice Springs.

Stage 2: Determining Changes in Construction Costs

The incremental construction cost is one of the cost benefit analysis inputs. Changes to the base case construction and construction costs were determined as part of this stage. A gap analysis between the base case and NCC2016 and NCC2019 was conducted to identify components of the base case archetypes that were compliant or non-compliant. The base case construction was revised to achieve 2016 and 2019 Section J compliant buildings, respectively. Several options to comply with the NCC2016 and NCC2019 Section J requirements were considered, and the least-cost[7] Section J compliant construction options, from those assessed, were used for the cost benefit analysis.

The change in construction costs associated with adopting NCC2016 or NCC2019 was determined by comparing the least-cost compliant construction options against the base case, with the base case construction cost provided by a construction company operating in both Darwin and Alice Springs. Costings of Section J compliant options were developed with input from local builders, services contractors and a glazing supplier. Architects and consultants servicing Darwin and Alice Springs were also consulted.

Stage 3: Modelling Changes in Energy Use

The energy savings, represented by change in whole building energy intensity (eg. kWh/m^2) driven by regulated building elements, are one of the cost benefit analysis inputs. Changes to the energy used were

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[6] These building forms (shape and number of stories) were referenced by the NT Government from the ABCB, NCC2019 Decision Regulatory Impact Statement (RIS).

[7] Least-cost from a financial perspective, or lowest incremental construction cost relative to the base case.

ABN: 48 628 897 870
info@dqcs.com.au

determined by comparing the predicted energy intensity of the base case building archetypes to the corresponding NCC2016 or NCC2019 Section J compliant building forms. Predicted energy intensities were based on simulations performed using dynamic thermal and energy simulation software IES<VE>. Modelled equipment control sequences, applied to the simulation, were confirmed by local consultants and services contractors to be representative of a building in Darwin or Alice Springs.

Stage 4: Cost Benefit Analysis

The cost benefit analysis was performed at the economy-wide level, from an owner-occupier perspective and a social perspective. The change in construction costs and energy use at the building-level[8], calculated in Stages 2 and 3 for the Section J compliant building archetypes , were inputs for assessing the cost and benefits of adopting Section J NCC2016 and NCC2019. The analysis was performed using a methodology consistent with Regulatory Impact Statements (RIS) prepared for the Australian Building Codes Board (ABCB), and COAG Energy Council Code Trajectory for new commercial buildings. The method complies with the Australian Government's Office of Best Practice Regulation's (OBPR) RIS and Cost Benefit Analysis Guidance Notes. All values used in the analysis reflect local NT conditions and pricings.

This stage consists of a core study and multiple smaller sensitivity analyses.

- The **core study/policy case** focuses on the base case models developed and uses them as the reference point for determining the impact of adopting NCC2016 and NCC2019.
- The **sensitivity analysis studies** look at the effect of adopting the Section J requirements if economic parameters are varied and if the building form and construction are altered. **Economic parameters** varied include different social costs of carbon, percentage of modelled energy savings realised, discount rates, and the building control areas. Sensitivity analyses focusing on **building changes** include changes to the building geometries (variation of window-to-wall area ratios) and wall construction (cladded steel frame walls and use of external shading to compensate uninsulated walls).

[8] Relative to the base case

DELTA Q
ABN: 48 628 897 870
info@dqcs.com.au

1.4 Report Structure

This report consists of seven sections, in addition to the introduction:

- Section 2 provides a brief background on Section J of the National Construction Code.
- Section 3 introduces the building forms modelled in this study
- Section 4 provides a summary of the gap between the present-day building forms and building forms required to be compliant with the NCC2016 and NCC2019 regulations. It also summarises the incremental construction costs associated with adopting NCC2016 and NCC2019 Section J.
- Section 5 summarises the predicted energy use for the base case, NCC2016 and NCC2019 compliant building forms. Results included in this section pertain to the core study.
- Section 6 and 7 provide results of the cost benefit analysis associated with the core analysis (policy case) from a societal perspective (Section 6) and from a owner-occupier perspective (Section 7). Sensitivity analysis results associated with the variation in economic parameters are also included in this section.
- Section 8 focuses on sensitivity analysis studies that investigate the effects of varying the building geometry and construction. The incremental construction costs, predicted energy use, and cost benefit analysis results are presented and discussed. Scenarios of changes to the wall construction, variation in window-to-wall ratios, and the impacts of replacing wall insulation with external shading are considered.
- Section 9 provides a discussion on the impacts and practicality of implementing NCC2016 and NCC2019 Section J in the Northern Territory.

ABN: 48 628 897 870
info@dqcs.com.au

2 The Evolution of Section J

2.1 General History

The National Construction Code (NCC) is Australia's primary set of technical design and construction provisions for buildings, outlining the minimum performance levels that a building needs to achieve. The energy efficiency provisions for non-residential buildings are contained within the NCC Volume One Section J, with its stated objective to reduce greenhouse gas emissions.

The Building Code of Australia (BCA) was first launched in 1996 with the first energy efficiency provisions introduced in 2005 for Class 2, 3 and 4 buildings. In 2006, energy efficiency provisions coverage was expanded to all building classes 2 to 9. In 2016, the building code and plumbing codes were consolidated into a three-volume 'National Construction Code', which were adopted by the Commonwealth, States and Territories. Volume One covers non-residential buildings, Volume Two covers residential buildings and Volume Three is the Plumbing Code.

While minor updates and clarifications have occurred regularly since 2006, there have only been two major stringency changes to energy efficiency provisions for non-residential buildings – in 2010 and 2019. The NCC2016 was the most recent edition before the release of NCC2019.

> ***Note:***
> *In 2009, the Northern Territory adopted NCC2009 minimum energy efficiency requirements for Class 1 and 2 buildings. These are a separate set of requirements to those for non-residential buildings assessed in this study.*

Under the current NCC,[9] regulated buildings must satisfy the Performance Requirements set out in Section JP. Compliance can be achieved through either:

- The Deemed-To-Satisfy (DTS) prescriptive requirements laid out in Section J0 to J8.
- Performance solutions, either through:
  i. A Verification Method in Section JV, or
  ii. Other evidence of suitability is described in Section A2.2.

Energy efficiency plays an important role in lowering energy bills for households and businesses; improving occupant comfort, health and productivity; saving energy (reducing wastage) for the wider economy; improving resilience to extreme weather and blackouts (peak demand); and reducing emissions[10].

The National Energy Productivity Plan (NEPP), agreed by the former Council of Australian Governments (COAG) in 2015, aims to improve Australia's energy productivity by 40% between 2015 and 2030. The NEPP also supports the Australian Government's commitment under the Paris Agreement to reducing greenhouse gas emissions to 26%-28% below 2005 levels by 2030. Looking forward into the future, the COAG-endorsed *Trajectory for Low Energy Buildings* work plan involves the implementation of cost-effective stringency changes for energy efficiency requirements in 2022, 2025 and 2028. Beyond 2028, the Trajectory

[9] NCC2019 at the time that this report was being prepared

[10] Trajectory for Low Energy Buildings, Commonwealth of Australia 2018. Accessed 1 October 2021, https://consultation.abcb.gov.au/engagement/energy-efficiency-scoping-study-2019/supporting_documents/Trajectory%20for%20Low%20Energy%20Buildings.pdf

ABN: 48 628 897 870
info@dqcs.com.au

recommends the progression of triennial revisions to building energy efficiency to keep pace with changing technologies and energy prices.

2.2 Key Differences Between NCC2016 and NCC2019 Section J

2.2.1 Summary

Section J energy efficiency provisions underwent their first major overhaul since 2010 in 2019, consistent with the COAG National Energy Productivity Plan. The package of changes to the NCC2019 Section J Deemed-To-Satisfy measures was anticipated to reduce energy consumption by a potential 35% relative to the NCC2016 Section J, representing a step-change for commercial buildings. From a Performance Requirement (JP) perspective, the dispensation to gas systems in the form of JP3 in NCC2016 was removed in the NCC2019, and new quantified performance requirements (kJ/m^2.hr) were introduced in the NCC2019 JP1.

While the existing Verification Method JV3 in NCC2016 was retained, new Verification Methods were introduced in NCC2019 to demonstrate compliance with the relevant Performance Requirement by way of NABERS (for Class 5 offices only) and Green Star building environmental performance rating systems. To avoid building designs trading off building fabric performance at the expense of reduced occupant thermal comfort, new thermal comfort standards were introduced in the NCC2019. The use of any verification method JV1, JV2 or JV3 must meet thermal comfort requirements (predicted mean vote, PMV, of ±1 achieved 98% of the time in 95% of occupied zones) in NCC2019.

Prescriptive requirements are listed in the Deemed-To-Satisfy sections Parts J1 to J8. In NCC2019, the focus was on simplification and increased flexibility of design, at the same time as increased efficiency stringency levels. The largest change is attributable to the whole-of-system compliance approach introduced for wall-glazing systems with the flexibility to demonstrate compliance across the whole building (as opposed to an orientation-by-orientation basis) as well as energy efficiency requirements for pumping and fan systems.

> ***Note:***
> NCC Section J requirements vary across climates zones with climate zones 1 and 3 applying to the Northern Territory.

Details of the changes between NCC2016 and NCC2019 are further discussed in the sections below.

2.2.2 Building Fabric

The main differences in building fabric Deemed-To-Satisfy provisions between NCC2016 and NCC2019 are summarised in Table 2-1.

DELTA Q
ABN: 48 628 897 870
info@dqcs.com.au

Table 2-1: Comparison of NCC2016 and NCC2019 specifications related to building fabric.

NCC Section J Parts	NCC2016	NCC2019
J1- Building Fabric	• **Roof/Ceilings:** i. No limit on roof upper surface solar absorptance values. ii. R-values range from R3.2 to R4.2 depending on solar absorptance values, with further R-value adjustments due to loss of ceiling insulation.	• **Roof/Ceilings** i. Roof solar absorptance values are limited to 0.45, except for climate zone 8. ii. R-values are simplified into a single requirement (R3.7) and slightly more stringent.
	• **Roof lights** solar heat gain coefficient (SHGC) and U-values differ depending on roof light shaft index and total roof lights area proportion of total room floor area.	• **Roof lights** SHGC requirements are similar but simplified and stringency increased. Maximum allowable U-value simplified to a single value (3.9).
	• **Wall and glazing** i. Assessed separately in Part J1 and J2 respectively. Requirements must be assessed separately for each orientation. ii. Minimum R-value of the wall is adjusted depending on wall thermal mass, external shading projections or solar absorptance of wall, ranging from 1.8 to 3.3. Furring channels provide a dispensation on R-value at 1.4 depending on the glazing energy index requirements. iii. Internal envelope walls minimum R-value at R1.0 (Climate Zone 1 only) or R2.3	• **Wall and glazing** i. Total U-value and solar admittance for wall-glazing construction are assessed holistically (Part J1) to determine the whole of façade thermal performance. ii. Where the window-to-wall ratio is at least 20%, total maximum U-value stringency increased to 2.0 for daytime buildings and 1.1 for 24/7 buildings (classes 3, 9a and 9c). Maximum display glazing U-value set at 5.8. U-value adjustments removed and minimum R-value on wall is 1.0. iii. Two methods are introduced to allow compliance on a single orientation basis or using area-weighted performance on a whole-of-building façade basis. iv. Where the window-to-wall ratio <20%, minimum R-value of the wall is R2.4 (Climate Zone 1 (e.g. Darwin)) or 1.4 (Climate Zone 3 (e.g. Alice Springs)) or R3.3 for 24/7 building classes 3, 9a and 9c – no dispensation for internal envelope walls.
	• **Floors** i. Floor insulation requirements allowed to be offset by higher roof/ceiling insulation. ii. No insulation required for floors without in-slab/screed heating/cooling and R1.25 for floors with in-slab/screed heating/cooling.	• **Floors** i. R-value requirement is R2.0 for floors without in-slab/screed heating/cooling and R3.25 for floors with in-slab/screed heating or cooling. CIBSE Guide A calculation method, impact of external wall and sub-floor insulation requirements introduced. Impact of ground contact resistance integrated into the total R-value requirement.
	• The requirement to consider thermal bridging when calculating total R-values	• The requirement to consider thermal bridging when calculating total R-values are explicit through the referencing NZS 4214 (2006),

(Table continued on next page)

NCC Section J Parts	NCC2016	NCC2019
	was implicit (via reference to the AS4859.1[11])	with supporting material such as the ABCB Façade Calculator[12].
J2-Glazing	• Glazing compliance is assessed using 'air-conditioning energy value' which is an area-weighted calculation using window-to-wall ratio, orientation-specific energy constants, the SHGC of each window, external shading multipliers for heating and cooling impacts and the U-value. • Eight orientations are assessed.	• Part J2 was removed, and the wall-glazing construction is assessed as a whole system under Part J1. The number of orientations assessed is simplified to four aspects – North, East, West and South.
J3-Building Sealing	• Details requirements for sealing conditioned spaces, with the intent of minimising air leakage. • Elements forming the building envelop such as roofs, ceilings, walls, floors, windows, doors, window frames, and door frames must be constructed to minimise air leakage. • Dampers or flaps are required for chimneys and flues, exhaust fans, and evaporative coolers. Roof lights must be/ capable of being sealed.	• No fundamental changes between NCC2016 and NCC2019. Added requirement for loading dock entrance, if leading to a conditioned space, to be fitted with a rapid roller door.

2.2.3 Building Services

The main differences in building services Deemed-To-Satisfy provisions between NCC2016 and NCC2019 are summarised in Table 2-2.

Table 2-2: Comparison of NCC2016 and NCC2019 specifications related to building services.

NCC Section J Parts	NCC2016	NCC2019
J5 - Air-conditioning and ventilation systems	• Prescribes requirements for selecting the mechanical systems. • Pump and fans efficiency requirements assessed based on W/m^2 conditioned space.	• Pumps and fan efficiency compliance can be assessed using two methods – a system-based approach W/(L/s), or a component-based approach. i. For fans, all ductwork fittings to meet Section J limits for pressure drops; and ii. For pumps, all straight pipework pressure drops to meet Section J limits depending on hours of operation and configuration. Pump efficiency must meet the EU standards (Minimum Efficiency Index or Energy Efficiency Index).

(Table continued on next page)

[11] AS/NZS 4859.1:2018 Thermal insulation materials for building General criteria and technical provisions, accessed on 3 July 2021, https://infostore.saiglobal.com/en-au/Standards/AS-NZS-4859-1-2018-116009_SAIG_AS_AS_2685445/

[12] Façade Calculator - Façade Volume One 2019, ABCB 2019, accessed on October 2021, https://abcb.gov.au/resource/calculator/facade-volume-one-2019

DELTA Q
ABN: 48 628 897 870
info@dqcs.com.au

NCC Section J Parts	NCC2016	NCC2019
	• Outside air i. Generally, the minimum threshold of outside air treatment is 1,000 L/s.	• Outside air i. Minimum threshold of treatment of outside air via modulating control for Darwin reduced to 500 L/s.
	• Air-side economy cycle requirement for Alice Springs (climate zone 3) linked to total system capacity (kWr).	• Air-side economy cycle requirement for Alice Springs (climate zone 3) linked to total air flow (L/s).
	• Chillers i. Two levels of compliance for chillers < 350kWr – full load and integrated part load performance levels – for water-cooled chiller and air-cooled chiller.	• Chillers i. Chiller efficiency stringency increased with two options to comply – option 1 with greater focus on full load performance; option 2 with greater focus on integrated part load performance. Explicit reference to Minimum Energy Performance Standards (MEPS) set via the Commonwealth Greenhouse and Energy Minimum Standards Act (GEMS).
	• Unitary air conditioning units with capacities greater than or equal to 65 kWr i. Minimum energy efficiency ratio for unitary air conditioning units set at 2.7 to 2.8 depending on equipment type and capacity.	• Unitary air conditioning units with capacities greater than or equal to 65 kWr i. Minimum energy efficiency ratio for unitary air conditioning units stringency increased to 2.9 or 4.0, depending on air-cooled or water-cooled heat rejection.
J6 - Artificial lighting and power	• Prescribes requirements for artificial lighting, power control, boiling water and chilled water storage units. • Maximum illumination power density (W/m^2) specified. This is adjusted based on room aspect ratio and control device.	• Maximum illumination power density reduced. Adjustment of the maximum illumination power density based on light colour introduced, and adjustment factors for control devices revised. • Subcategories for carparks spaces are introduced. • Vertical transport and moving walkway efficiency requirements are introduced. These largely reference the International Standard ISO 25745.
J7 - Heated water supply and swimming pool and spa pool plant	• Prescribes requirements for selecting heated water systems based on the minimum targets. • Swimming pools heated by gas or heat pump, and spas heated by gas or heat pump are required to have a cover and time switch operation for the heater.	• Additional requirements for increased system efficiency, insulation and control introduced. • Added requirement for covers for heated swimming pools and spas to have a minimum R-value of 0.05. • Added requirement for pipework carrying heated or chilled water for a spa pool or swimming pool must comply with insulation requirements specified in J5.
J8 - Facilities for energy monitoring	• Specifies the requirements for buildings to have the facility to monitor gas and electricity consumption, and individual energy consumption of artificial lighting, appliance power, central hot water supply, internal transport devices, air-	• Introduces the need for energy monitoring facilities to have time-of-use data capturing capability.

(Table continued on next page)

ABN: 48 628 897 870
info@dqcs.com.au

NCC Section J Parts	NCC2016	NCC2019
	conditioning plants, heating and cooling plants, air handling units, and other ancillary plants	

2.3 Anticipated NCC2022 changes

At the time of writing, the NCC2022 was in Stage 2 of its public consultation period. Based on the NCC2022 Public Comment Draft released on 6 September 2021, it is anticipated that the final Deemed-to-Satisfy provisions in Section J of NCC2022 Volume 1 will be largely similar to Section J NCC2019 Volume 1.

The following adjustments are anticipated:

- New verification methods using the NABERS pathway (JV1) have been introduced for apartment buildings, hotels and shopping centres – with emissions of the proposed design mapped to levels better than 4 or 4.5 stars. This was previously only available for office buildings in NCC2019.
- New requirements introduced to ensure that all new developments can be readily retrofitted with electric vehicle charging equipment, solar photovoltaic and battery systems. These includes new provisions to ensure capability of electrical systems to accommodate future installations of electric vehicle chargers for 10 to 25% of car parks and at least 20% of roof area left clear to install solar PV.
- Technical clarification regarding the applicability of wall and glazing thermal requirements depending on whether the construction is external or wholly internal.
- Clarification regarding the deemed thermal performance (R-value) of slab on ground floors without in-slab heating or cooling system.[13]
- Significant changes to residential components of Class 2 (apartments) and Class 4 part of the building including building fabric, air tightness and ceiling fan requirements.

2.4 Forward Trajectory of NCC

At time of writing, the Trajectory for Low-Energy Commercial Buildings[14] agreed by the Energy Ministers in February 2019, is being updated by the Australian Department of Industry, Science and Resources (DISER). The Trajectory was developed in close consultation with stakeholders to outline policies that deliver cost-effective energy efficiency improvements to businesses and households. This update will inform policy changes required in the NCC2025 and beyond.

[13] The draft NCC2022 code (public comment version, Section J4D7 (2)) specifies that a slab-on-ground without in-slab heating or cooling system is considered to achieve a total R-Value of 2.0. In this study, the provision affects the single-storey office, retail, hospital ward and school models, in that the base case floor would not require additional insulation for NCC2022. (NCC 2022 Volume One - Version 20210906.pdf, accessed on 20 February 2022)

[14] Government Priorities – Commercial Buildings, Department of Industry, Science, Energy and Resource, 2021, accessed on 1 October 2021,: https://www.energy.gov.au/government-priorities/buildings/commercial-buildings

ABN: 48 628 897 870
info@dqcs.com.au

3 Building Forms Modelled

The following six building forms were considered as part of this study:

- A hotel (archetype 3A)
- A 200 m² single-storey office building (archetype 5)
- A multi-storey office building (archetype 5A)
- A retail building (archetype 6B)
- A hospital ward (archetype 9aC)
- A school (archetype 9bH)

The morphologies of each building form, including the number of floors, building shape and window-to-wall ratios (WWR), were either defined by DIPL or referenced from the 2018 Regulatory Impact Statement (RIS)[15] undertaken by the ABCB. The modelled building geometries are shown in Figure 3-1 and further described in Table 3-1. Unless otherwise specified, these building configurations are kept constant between the base case and Section J compliant building forms.

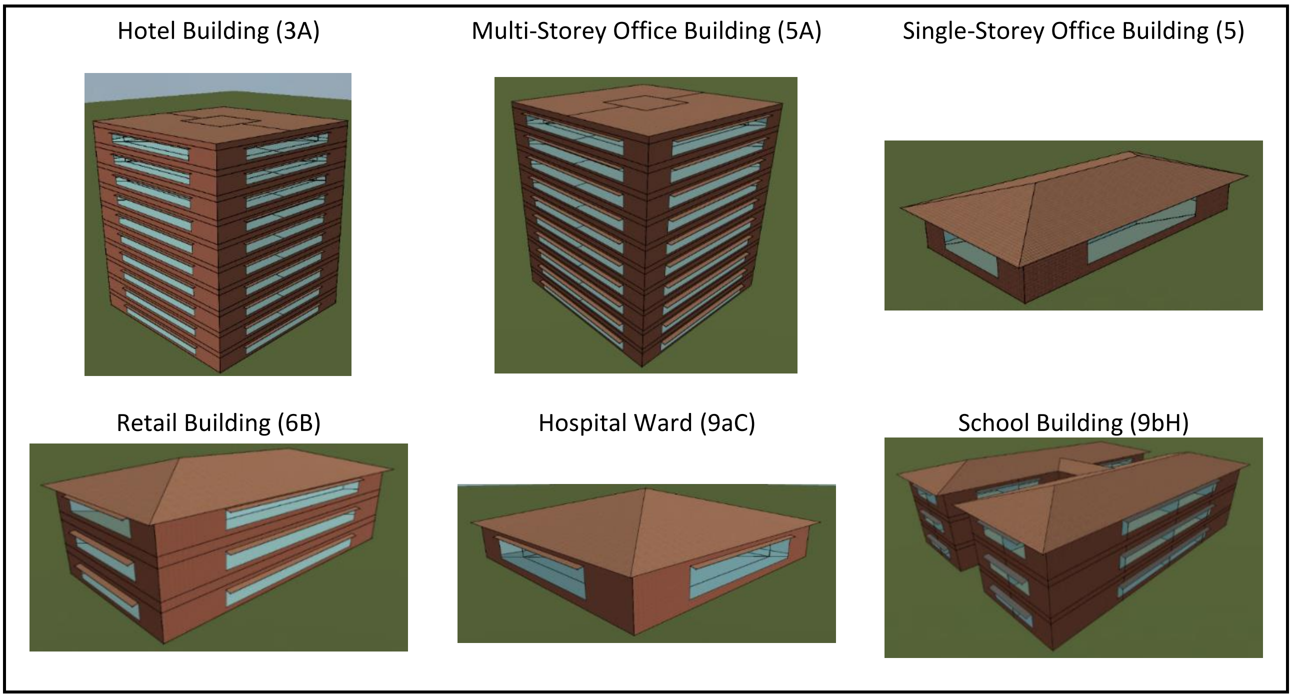

Figure 3-1: Modelled geometry of the different building archetypes considered.

[15] Decision Regulation Impact Statement (RIS) - Energy Efficiency of Commercial Buildings, Prepared for Australian Building Codes Board, The CIE, 2018 <https://www.abcb.gov.au/sites/default/files/resources/2020//Final_RIS_Energy_efficiency_of_commercial_buildings_DOC.docx >

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ABN: 48 628 897 870
info@dqcs.com.au

Table 3-1: Building configuration for selected building archetypes in Darwin and Alice Springs.

	Hotel (3A)	Single-Storey Office (5)	Multi-Storey Office (5A)	Retail (6B)	Hospital Ward (9aC)	School (9bH)
Building Shape	Square	Rectangle	Square	Rectangle	Square	H shape
Floor Plate Aspect Ratio	1:1	2:1	1:1	2:1	1:1	1.3:1
Gross Floor Area (m^2)	10,000	200	10,000	2,000	1,000	2,880
Levels	10	1	10	3	1	3
Windows to Wall Ratio	30%	30%	40%	30%	30%	30%^
Floor to Ceiling Height (m)	2.7	2.7	2.7	2.7	4.8	3
Ceiling Space Height (m)	0.9	N/A	0.9	0.9	1.2	0.6
Roof	Flat	15° pitched	Flat	15° pitched	15° pitched	15° pitched
Underground Carpark	Y	N	Y	N	N	N
Annual HVAC Operating Hours (h)*	6570	2860	2860	4004	8760	2600

***** Further details on the assumed occupancy and operating hours are available in Appendix B.2.1.
^ Value rounded to one significant figure – the actual WWR for this model is 26%, which includes additional wall area associated with ceiling space.

4 Building-Level Construction Gap Analysis and Costing

This section aims to provide information regarding Section J compliance status of base case constructions and incremental construction costs, at a building level, associated with meeting NCC2016 and NCC2019 Section J requirements.

4.1 Base Case Construction - Determination

The base case was generally deemed to be the typical construction of a private development for each archetype, where the developer has no specific requirements for energy performance. This approach enables the cost benefit analyses to be targeted at developments on which Section J would have the greatest regulatory impact, rather than higher-end commercial or government developments that may already be comparable to Section J. Note, however, that the base cases were not designed to represent the lowest end of the market either, but rather “fit-for-purpose” average developments that represent industry contractors’ business-as-usual experiences in each location.

In the case of the Hospital Ward building (archetype 9aC), the base case building services design concept was developed with a relatively higher focus on energy efficiency than that of the other archetypes, to better represent the reality that NT buildings in this class are most likely developed by private owner-occupiers or government entities.

Note with respect to multi-storey/high-rise building archetypes in Alice Springs.

The scope of this study focussed on six building archetypes in both Alice Springs and Darwin. Two of the archetypes were 10 storeys high. For simplicity of the scope, the general layout of these two buildings were unchanged in the Alice Springs models, despite those buildings being above height restrictions of their jurisdiction. Acknowledging that fact, assumptions regarding the building services of the “high-rise” buildings in Alice Springs were treated as though the buildings were five storeys.

As part of the base case determination, construction details of the components forming the building fabric and building services, for each building archetype in Darwin and Alice Springs, were defined. Table 4-1 summarises the components of the building fabric and building services that were considered. Details of each component were determined in coordination with multiple NT-based building industry professions. The construction and configuration of each building fabric and services element was found to vary depending on the building archetype and location. Consequently, details of the base case building fabric building services results are not included in the main body of the report - readers interested in these details are referred to Appendix B.

Table 4-1: Components of building fabric and building services that were defined during the base case determination.

Building Fabric	Building Services

• Roof
• Ceiling
• Walls
  ○ External walls
  ○ Non-external envelop walls
  ○ Internal non-envelop walls
• Glazing
• Shading of walls and glazing
• Floor
	• HVAC
	  ○ Fan systems
	  ○ Pump systems
	  ○ Ductwork and Pipework insulation
	  ○ Heating systems
	  ○ Refrigerant chillers
	  ○ Unitary air-conditioning equipment
	• Lighting hardware and controls
	• Domestic hot water heating
	• Lifts

4.2 Base Case Construction – Section J Gap Analysis

4.2.1 Summary

A gap analysis of the base case constructions against the energy efficiency requirements of Section J NCC2016 and Section J NCC2019 was performed to determine the changes required for each building form. Table 4-2 and Table 4-3 provide an overview of the areas where each base case archetype complies with NCC2016 and NCC2019 requirements. The base case construction and building services, and the gap analysis are detailed in Appendix B and Appendix C.

Table 4-2: Construction Gap between Base Case and NCC2016 Section J. N indicates non-compliance, Y indicates compliance.

Compliance of base case with NCC2016	Darwin						Alice Springs					
	Hotel (3A)	Single-Storey Office (5)	Multi-Storey Office (5A)	Retail (6B)	Hospital Ward (9aC)	School (9bH)	Hotel (3A)	Single-Storey Office (5)	Multi-Storey Office (5A)	Retail (6B)	Hospital Ward (9aC)	School (9bH)
Building Fabric (Parts J1 and J2)												
• **Roof and ceiling**	N	N	N	N	N	N	N	N	N	N	N	N
• **Walls**	N	N	N	N	N	N	N	N	N	N	N	N
• **Glazing**	N	N	N	N	N	N	N	N	N	N	N	N
• **Flooring**	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Building Sealing (Parts J3)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Building Services												
• **Air Conditioning and Ventilation Systems (Part J5)**	N [1]	Y	N [1]	Y	Y	N [1]	N [1]	Y	Y	Y	Y	Y
• **Artificial lighting and power (Part J6)**	Y	Y	N [2]	N [2]	Y	N [2]	Y	Y	N [2]	N [2]	Y	N [2]
• **Heated Water Supply (Part J7)**	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
• **Facilities for Energy Monitoring (Parts J8)**	N	Y [3]	N	Y [3]	Y [3]	N	N	Y [3]	N	Y [3]	Y [3]	N

Notes:
1: Does not meet Clause J5.2 (c) NCC2016 - Chilled water pumping systems with pump powers larger than 3kW do not have variable speed pump motors.
2: Lights in a natural lighting zone are not separately controlled (from lights not within a natural lighting zone)
3: Smaller than the floor area threshold (2,500 m^2)

Table 4-3: Construction Gap between Base Case and NCC2019 Section J. N indicates non-compliance, Y indicates compliance.

Compliance of base case with NCC2016	Darwin						Alice Springs					
	Hotel (3A)	Single-Storey Office (5)	Multi-Storey Office (5A)	Retail (6B)	Hospital Ward (9aC)	School (9bH)	Hotel (3A)	Single-Storey Office (5)	Multi-Storey Office (5A)	Retail (6B)	Hospital Ward (9aC)	School (9bH)
Building Fabric (Parts J1 and J2)												
• **Roof and ceiling**	N	N	N	N	N	N	N	N	N	N	N	N
• **Walls and Glazing**	N	N	N	N	N	N	N	N	N	N	N	N
• **Flooring**	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y
Building Sealing (Parts J3)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Building Services												
• **Air Conditioning and Ventilation Systems (Part J5)**	N [2,3]	Y	N [2,4]	N [4]	Y	N [2,4]	N [1,2,3]	N [1]	N [1]	N [1]	N [1]	N [1]
• **Artificial lighting and power (Part J6)**	Y[5]	Y[5]	N[5, 6]	N[5,6]	Y[5]	N [5,6]	Y[5]	Y[5]	N[5, 6]	N[5, 6]	Y[5]	N[5, 6]
• **Heated Water Supply (Part J7)**	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
• **Facilities for Energy Monitoring (Parts J8)**	N	Y	N	Y	Y	N	N	Y	N	Y	Y	N

Notes:
1. Does not meet Clause J5.2 (viii) NCC2019 – Minimum requirements for the zone temperature dead band (control) are not met.
2. Does not meet Clause J5.2 (xi) NCC2019 – (Darwin) Chilled water systems do not feature automatic variable control of the chilled water supply temperature setpoint, (Alice Springs) chilled water and heating hot water systems do not feature automatic variable control of the leaving water temperature setpoints.
3. Does not meet Part J5.7 – The pipework pressure losses exceed 170 Pa/m which is higher than allowable for a constant-speed chilled water pumping system operating more than 5,000 hours/year.
4. Does not meet Clause J5.3 (a) (ii) - Fresh Air ventilation systems have airflows over 500 l/s but do not feature demand-controlled ventilation.
5. Does not meet NCC2019 requirement for motion detector controlled lighting in fire-isolated stairways, passageways and ramps. This is not a common practice in the NT and most building are expected to be non-compliant. In this study, the buildings are modelled without fire-isolated areas and hence deemed to be compliant in this regard.
6. Lighting control system (natural light zone adjacent windows are not switched separately)

While none of base case building archetypes are fully compliant with either NCC2016 or NCC2019 requirements, all base case building archetypes met both the NCC2016 and NCC2019 requirements for building sealing (Part J3) and heated water supply (Part J7).

4.2.2 Building Services

From a technical perspective, most base case mechanical building services either already comply with NCC2016 and NCC2019 Section J, or require only minor adjustments to comply[16]. This finding also extends to artificial lighting and power. Minor adjustments to mechanical building services include changes to the HVAC control settings, installing variable-speed capability for fans and pumps and, for the Darwin retail and multi-storey office archetypes, introduction of demand-controlled ventilation to achieve NCC2019 compliance. To comply with NCC2016 and NCC2019, lighting control upgrades such as installation of motion detector control or timeclocks are required for certain functional spaces.

4.2.3 Building Fabric

None of the building archetypes met NCC2016 or NCC2019 requirements for roof and ceiling, walls and glazing. Hotels and the multi-storey office in Darwin were the only building archetypes with a NCC2016 non-compliant base case floor construction; whilst hotels, single and multi-storey offices in Darwin and Alice Springs had NCC2019 non-compliant base case floor constructions. The non-compliance of base case roof, wall, and floor constructions with NCC2016 and NCC2019 requirements was due to inadequate total system R-values, that is, how well the building fabric can resist heat transfer between conditioned and non-conditioned spaces.

Requirements for external walls and glazing are quite different in NCC2016 and NCC2019. For all building archetypes, the base case external and internal wall construction were non-compliant as the total system R-value was lower than the minimum required by NCC2016. Glazing requirements in NCC2016 vary with numerous factors, including building class, climate zone, shading, orientation and wall construction. While glazing systems on the North and South facades on some buildings were found to be compliant with Section J NCC2016, the glazing system of all base case archetypes on the East and West façade did not comply with Section J NCC2016.

Base case building fabric is largely non-compliant with the NCC2016 and NCC2019 Section J. Most base case mechanical building services and artificial lighting were compliant or only required minor adjustments.

None of the base case buildings complied with the requirements for the wall-glazing construction of Section J NCC2019. Under NCC2019, walls and glazing are assessed together against minimum requirements for total U-values and solar admittance. The wall-glazing U-value is an area-weighted average of the thermal transmittance across both the wall and glazing components of the construction. The solar admittance represents the solar irradiance that adds heat to the building via the glazing component of the wall-glazing construction.

[16] As discussed in Appendix C.2, the code requirements already represent standard industry practice. This is likely because efficient building services equipment in itself is already demonstrably cost-effective and the market availability of such products are widespread without substantial cost uplift.

4.2.4 Energy Monitoring Facilities

Base case hotel, high-rise office and school buildings in both Alice Springs and Darwin are non-compliant with the requirements of Part J8 Facilities for Energy Monitoring in NCC2016 and NCC2019. These building archetypes do not include energy meters to record energy consumption of key systems as specified in Section J. NCC2019 also requires these systems to communicate to a common system that collates time-of-use energy consumption data to a single interface monitoring system where it can be stored, analysed and reviewed. All other building archetypes (single-storey office, retail and hospital ward) are compliant with NCC2016 and NCC2019 because they are smaller than the floor area threshold (2,500m^2) and therefore do not require sub-system energy monitoring.

4.3 Incremental Construction Cost

4.3.1 Differences in Incremental Costs between NCC2016 and NCC2019

As reflected in Figure 4-1, building archetypes that are compliant with NCC2016 cost 1.7% – 2.6% ($59 – $72 per m^2) more than the base case building in Darwin, and 1.3% – 2.1% ($44 – $58 per m^2) more than the base case buildings in Alice Springs.[17] The cost of NCC2019 compliant buildings is 1.4% – 2.4% ($57 – $81 per m^2) and 1.3% – 1.7% ($42 - $76 per m^2) more than the base case in Darwin and Alice Springs, respectively.

The higher end of the observed incremental construction cost range for NCC2016 and NCC2019 correspond to Retail buildings in Darwin. This is at 2.6% (NCC2016) and 2.4% (NCC2019) higher than the base case. The incremental cost of complying with NCC2019 was lower than NCC2016 for three of the modelled archetypes. These are Hotels in Darwin, Schools in Alice Springs, and Retail archetypes in both cities. For the other building archetypes modelled, the construction costs of NCC2019 compliant building forms are on par with, or marginally higher, than that of NCC2016.

Incremental construction cost differences between NCC2016 and NCC2019 compliant building archetypes are, in part, influenced by the cost of building fabric. Generally, where NCC2019 compliant building archetypes depict lower total incremental construction cost compared to NCC2016, this is due to lower building fabric cost. The lower building fabric costs in NCC2019 was primarily due to lower glazing costs, especially since NCC2019 introduces the option for designers to comply using an area-weighted whole-of-façade (and orientation) method instead of orientation-by-orientation basis.

Design and consultancy fees are included within the total construction cost values, and were advised by Sunbuild and industry contacts. This portion of cost scales with construction costs, as described in Appendix D.7 of the report. This portion of cost appears more significant for single-storey offices compared to other building archetypes in Figure 4-1. This is not necessarily unexpected, as design consultancies generally have some amount of fixed mobilisation cost regardless of building size in-built within the fees. In a smaller building, this fixed mobilisation cost may constitute a larger proportion of total cost, due to the lower overall construction cost of the building[18].

[17] Note: The percentages and cost per m^2 specified excludes NCC2016 compliant hospital wards, which had an incremental construction cost that was less than 1% of the base case construction.

[18] For example, a design consultancy fee of fixed mobilisation cost of $3,000 is 0.3% of $1 million incremental cost but 3% of $100,000 incremental cost.

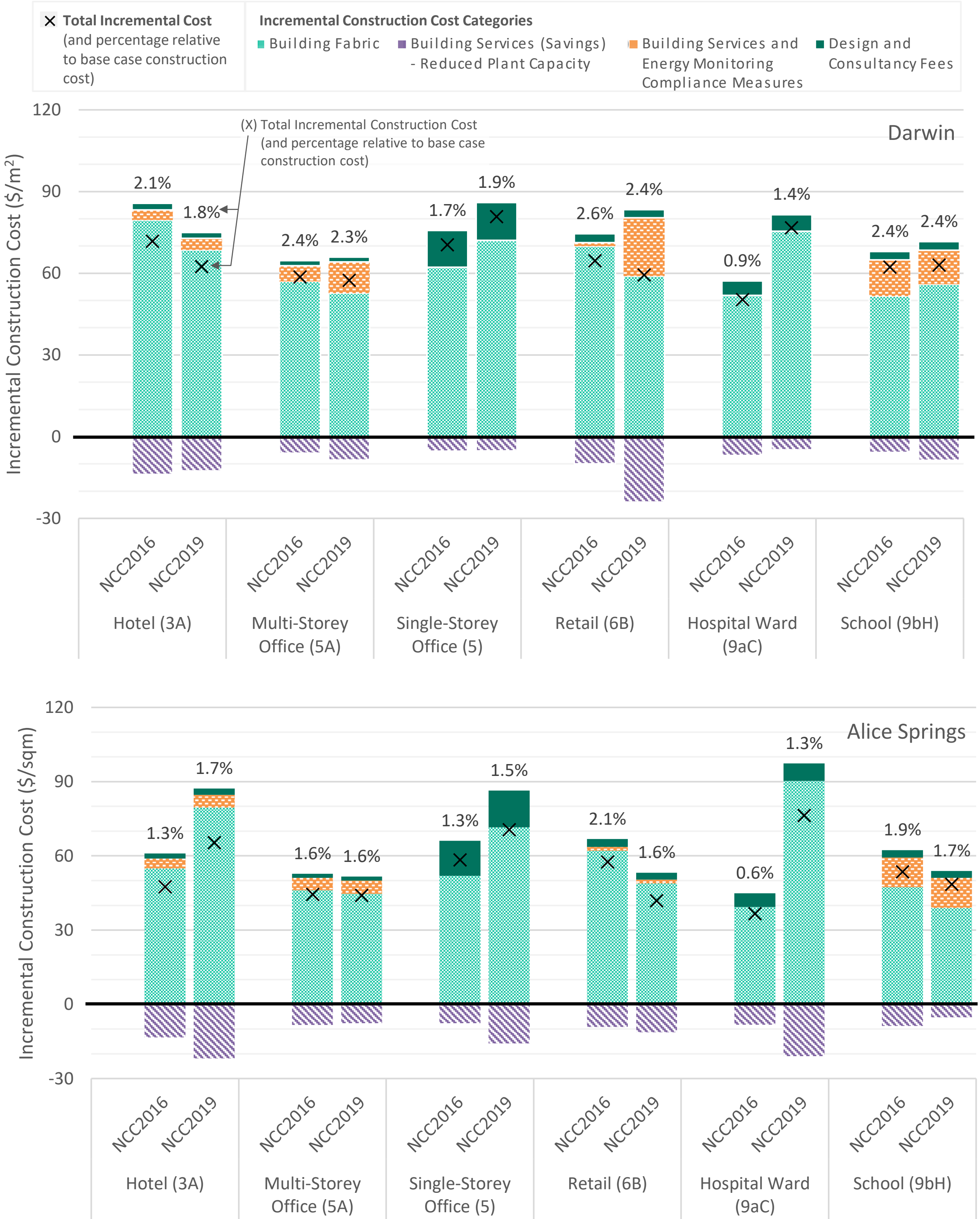

Figure 4-1: Incremental costs of NCC2016 and NCC2019 compliance for each model in Darwin and Alice Springs. Incremental cost is broken down into costs associated with building fabric, building services and design and consultancy fees. Cost savings from reduced plant capacities decreases the total incremental costs. Percentage values shown correspond to the total incremental cost (X-marker) relative to the base case construction costs.

4.3.2 Approach

The cost of making each building form compliant with the NCC2016 and NCC2019 was determined by first considering multiple solutions that address the compliance gaps, then selecting the compliance option with the lowest construction/financial cost ('least-cost'). Appendix C and Appendix D provide details of the various options considered to address compliance gaps between the base case constructions and NCC requirements, and the cost elements considered. Appendix E details how the least-cost compliant solutions were identified, detailed specifications for NCC compliance and the total costs of compliance per archetype. A summary of the changes required to meet Section J requirements for each archetype is also provided in Appendix K.

The difference in cost between a building form that meets the NCC requirements and the cost of the base case archetype is shown in Figure 4-1 for each building form (refer to Appendix E.1 for tabulated construction costings). Costs shown are in dollars per square metre of gross floor area. For building models that were asymmetrical (single-storey office, retail and school), the average cost across two different building orientations is reported here and used in cost benefit analyses. The total incremental construction costs can be divided into the following four categories:

a) ***Incremental Cost of Building Fabric***

This is the cost of achieving compliant building fabric. Wall construction accounts for the largest proportion of incremental building fabric costs, followed by glazing costs. Wall construction costs are mainly associated with using walls that have higher total R-values, which can be realised through using more wall insulation, reflective air gaps and thermal break tapes. Glazing costs arise from the need to use glazing with lower U-values and Solar Heat Gain Coefficients (for example tinted and/or double glazed panes instead of single panes). Costs associated with roof, floor and shading constructions are also included, with cost contributions that are much lower than those of the wall and glazing costs.

b) ***Incremental Cost of Building Services and Energy Monitoring Compliance Measures***

Mechanical plant compliance costs, artificial light and power compliance costs, and facilities for energy monitoring costs are accounted for in this section. The relative contribution of each component to the total incremental cost of building services and energy monitoring varies depending on the building archetypes. The base case building services in small offices and hospitals already meet NCC2016 and NCC2019 requirements, and do not require facilities to monitor their energy usage – they therefore have no incremental cost contribution from this category.

c) ***Cost savings from reductions in plant capacities***

Upgrade of the thermal performance of the building fabric (as required for Section J compliance) reduces the capacity required of the HVAC plant. This will result in reduced capital requirement for HVAC plant and this negative cost impact has been included in the total incremental cost assessment.

d) ***Design and Consultation Fees***

This category includes architectural design and consultancy fees, engineering consultancy fees, and allowances for third-party Section J compliance assessments for each archetype, using the Deemed-To-Satisfy methodology. It should be noted that design and consultation fees apply even if no changes to building construction/ services are required – since compliance of the building still needs to be verified.

5 Building-Level Predicted Energy Use

This section provides information on how much the predicted energy usage, at a building level, can be improved by having NCC2016 and NCC2019 compliant buildings.

5.1 Summary

The change in modelled regulated energy intensity for each building archetype, relative to the base case, is shown in Figure 5-1 (see Appendix F for tabulated energy intensities for each scenario).

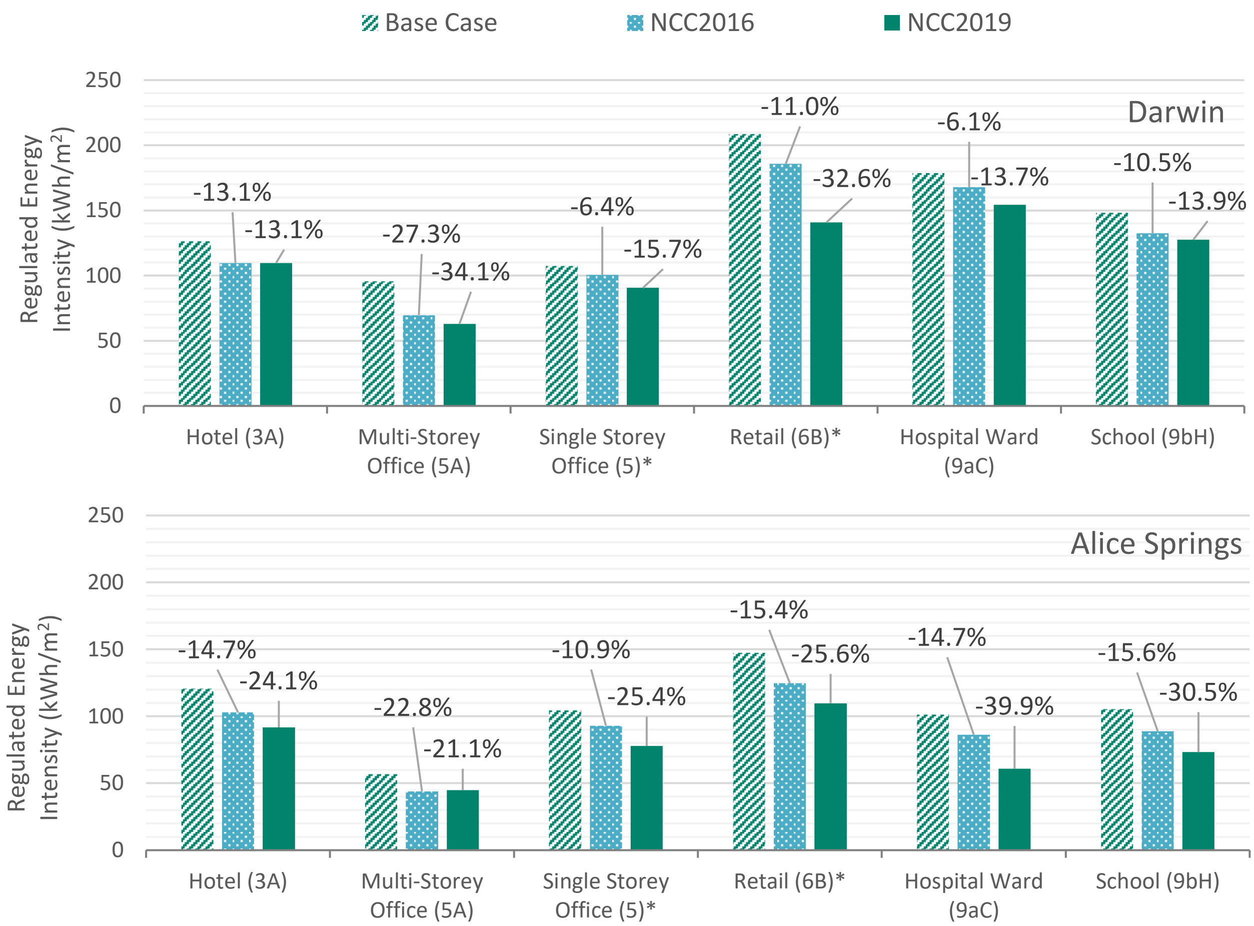

Figure 5-1: Predicted regulated energy intensities of the base case, NCC2016 and NCC2019 compliant building archetypes in Darwin (top) and Alice Springs (bottom). Percentage values shown correspond to change in regulated energy intensity of NCC2016 and NCC2019 compliant building forms, relative to the base case. Values shown include electricity and gas consumption.

As shown in Table 5-1, NCC2019 compliant building archetypes have a weighted average energy intensity[19] that is 23% lower than the base case in Darwin, and 29% lower in Alice Springs. These energy savings are

[19] Weightings, based on the projected building type floor areas to be constructed in the NT in the 2023-2030 period assessed, are applied to the expected energy savings.

larger than NCC2016 compliant building archetypes which, on average, are 12% and 17% less energy intensive than the base case archetype, for Darwin and Alice Springs respectively.

Based on the energy modelling results, the adoption of the NCC2019 Section J is expected to deliver between 13– 34% decrease in energy intensity in Darwin buildings, with the highest percentage of energy saving realised in multi-storey office buildings (34%, 33 kWh/m^2) and retail buildings (33%, 68 kWh/m^2).

Modelled building energy intensities for NCC2019 were up to 40% lower than the base case. The largest energy savings modelled was 68 kWh/m² (33%) for retail buildings in Darwin (NCC2019).

In Alice Springs, the energy intensity of NCC2019 compliant building archetypes decrease by 21 – 40%, relative to the base case, and hospital wards realise the largest percentage energy savings (40%, 40 kWh/m^2). For NCC2016 compliant building models, multi-storey office buildings are modelled to have the largest percentage energy savings in Darwin and Alice Springs (27% and 23%, 26 kWh/m^2 and 13 kWh/m^2)

Two exceptions to NCC2019 compliant buildings being less energy intensive than NCC2016 compliant buildings are:

- The modelled NCC2016 and NCC2019 compliant hotel in Darwin achieve the same energy intensity; and
- The NCC2016 compliant multistorey office building in Alice Springs is marginally less energy intensive than the NCC2019 compliant building form, with a difference of less than 1 kWh per m^2.

On the whole, these results suggest that occupiers of the NCC2019 compliant building form can expect to save more energy than occupants of NCC2016 compliant building forms.

Table 5-1: Summary of Building-Level Energy Savings (gas and electricity) for NCC2016 and NCC2019 compliant buildings (kWh/m^2 and % relative to the base case).

Building Type	NCC2016		NCC2019	
	Darwin	Alice Springs	Darwin	Alice Springs
Hotel (3A)	16.5 (13.1%)	17.8 (14.7%)	16.6 (13.1%)	29.0 (24.1%)
Multi-Storey Office (5A)	26.1 (27.3%)	13.0 (22.8%)	32.5 (34.1%)	12.0 (21.1%)
Single Storey Office (5)*	6.9 (6.4%)	11.4 (10.9%)	16.9 (15.7%)	26.6 (25.4%)
Retail (6B)*	22.9 (11%)	22.7 (15.4%)	68.0 (32.6%)	37.7 (25.6%)
Hospital Ward (9aC)	10.9 (6.1%)	14.9 (14.7%)	24.5 (13.7%)	40.4 (39.9%)
School (9bH)	15.6 (10.5%)	16.4 (15.6%)	20.6 (13.9%)	32.1 (30.5%)
Simple Average Savings:	16.5 (12.4%)	16.0 (15.7%)	29.8 (20.5%)	29.6 (27.8%)
Weighted Average Savings:	**17.7 (11.7%)**	**18.8 (16.7%)**	**34.3 (22.7%)**	**32.4 (28.9%)**

*Averages are weighted based on projected building stock floor area

6 Economy-wide Social Cost Benefit and Impact Analysis

6.1 Social Cost Benefit Analysis

This section presents the economy-wide analysis of the net economic costs or benefits associated with adopting NCC2016 or NCC2019 Section J requirements from a societal or social perspective. In this perspective, costs and benefits may be included even where they are 'unpriced', such as the value of reduced greenhouse gas emissions, or where they are captured by (or fall on) parties not directly involved in a building project, such as reduced peak electrical network loads, where the benefits are shared among all network users.

The minimum benchmark for cost-effectiveness from a social perspective occurs when the total social benefits (including private benefits such as energy cost savings and public benefits such as reducing greenhouse gas emissions and required electrical network investment) are higher than the associated social costs. In such a case, a measure will deliver a Net Present Value (NPV) greater than zero and a Benefit Cost Ratio (BCR) greater than 1. NPV is the discounted present value of benefits *minus* the discounted present value of costs, while the BCR is the discounted present value of benefits *divided by* the discounted present value of costs. Our perspective is that NPV is a better basis for ranking options than BCR, as BCRs are dimensionless and give no indication of the degree to which changes in net social welfare may result from the options. For this reason, BCRs cannot be interpreted using a 'higher is better' rule of thumb. By contrast, NPVs can be interpreted on a 'higher is better' basis – provided all relevant values are captured ('monetised') in the analysis, meaning that options can be unambiguously ranked using NPV.

The CBA findings can be broken down by climate zone[20] and by building control areas (Tier 1 and Tier 2), and this analysis is presented in tables in Appendix H. The analysis is based on an assumed regulatory period of FY2023 to FY2030, during which the Section J requirements are applied to all new non-residential buildings, and a 40-year average economic life for new buildings. If the regulations were to apply for a longer or shorter period, both costs and benefits would change proportionately, without changing the ranking of options or BCRs.

Table 6-1 summarises the different variables used to examine the economic impact of adopting NCC2016 and NCC2019 Section J. As far as possible, the economic analysis has been customised to NT conditions, both costing and energy prices. Furthermore, the analysis uses the Department's own data, as reported to the Australian Bureau of Statistics, for annual construction activity. Further details on the cost benefit analysis methodology and inputs are provided in Appendix G.

[20] Climate zone 1 includes Darwin, and climate zone 3 includes Alice Springs.

Table 6-1: Economic Parameters defining average-, best- and worst-case scenarios, social perspective

Economic Parameters used for CBA - Social	Best Case	Reference Case	Worst Case
Modelled energy savings realised	100%	100%	75%
Real discount rate	3%	7%	10%
Learning rate	5%	2%	0%
Cost of carbon	Low – 3% real discount rate, 9th percentile	Mid - 3% real discount rate	High - 5% real discount rate

6.1.1 Key Findings

Overall, adoption of NCC2019 energy performance requirements from FY2023-FY2030 in both Tier 1 and Tier 2 areas would generate net social benefits for the NT of $276million in present value terms, with a benefit cost ratio (BCR) of 3.6. These values assume default input assumptions including a 7% real discount rate, 2% learning rate, 100% realisation of expected energy savings, and the medium social cost of carbon. That is, on these default assumptions, the present value of benefits would exceed the present value of costs by more than three and a half times. These values are quite high relative to the minimum thresholds for cost effectiveness (an NPV greater than zero and a BCR greater than 1). Other input assumptions are tested in sensitivity analysis below.

Adoption of NCC2019 would generate net social benefits of $276million with BCR of 3.6.

Adoption of NCC2016 energy performance requirements from FY2023-FY2030 in both Tier 1 and Tier 2 areas would generate much lower – but still significant – net social benefits for the NT of $103million at a BCR of 2.0, on the same default input assumptions. The net social benefits associated with adopting NCC2019 are 2.7 times higher than for adopting NCC2016.

These expected values are summarised in Table 6-2.

Table 6-2: Economy-wide Cost Benefit Analysis, Societal Perspective, Default Assumptions

Scenario	Real Discount Rate	Learning Rate	Social Costs of Carbon Scenario	Realisation of Expected Savings	Tier	NPV ('000$2022)	BCR
NCC2016	7%	2%	3% (av.)	100%	1+2	$102,817	2.0
NCC2019	7%	2%	3% (av.)	100%	1+2	$275,517	3.6

6.1.2 Economy-Wide Sensitivity Analysis

While Table 6-2 shows the expected outcomes of the cost benefit analysis from a societal perspective, we also generate a range of scenarios that demonstrate what outcomes would occur if key values used in the analysis deviated from their expected values. This is referred to as sensitivity analysis. The best, expected and worst case values used as inputs for the sensitivity analysis are summarised in Table 6-1 above and discussed further in Appendix G.

Real Discount Rate

Varying the real discount rate has the most significant impact of all the variables considered. The reasons for this are discussed in more detail in Appendix G. In short, higher real discount rates lead to values in the future being discounted more than those that occur in the near term. Conversely, the lower the discount rate, the more evenly values are weighted over time. For example, at a 0% real discount rate, values are exactly the same in real terms (that is, after inflation) regardless of when they occur; whereas with a 10% real discount rate, $100 (whether of cost or benefit) that occurred 25 years into the future would be valued at only $7.18 in present value terms. Since incremental construction costs associated with higher energy performance standards are incurred upfront, while the benefits are spread out over the economic life of the building, the higher the real discount rate, the lower the apparent net social benefit.

For NCC2019:

- a 10% real discount rate reduces the NPV to $160million with a BCR of 2.7
- a 3% real discount rate increases the NPV to $648million with a BCR of 6.2.

For NCC2016:

- a 10% real discount rate reduces the $44.9million with a BCR of 1.5
- a 3% real discount rate increases the NPV to $297million with a BCR of 3.4.

Thus, while the impact of a higher discount rate is severe, both NCC2019 and NCC2016 would remain cost-effective even with a 10% real discount rate. Also, the ranking of options does not change, regardless of the real discount rate selected, with NCC2019 consistently showing higher values than NCC2016.

Realisation of Energy Savings

If only 75% of expected energy savings were realised – for example, if compliance were low, or if simulations under-predicted actual energy consumption, NCC2019 would remain cost effective, with an NPV of $194million and a BCR of 2.8. On the same assumption, NCC2016 would also remain cost effective, with an NPV of $60million and a BCR of 1.6. This indicates that the net benefits associated with both measures would remain robust even if the realisation of energy savings was unexpectedly low.

Cost Learning Rate

Varying the learning rate (that is, the rate at which incremental costs of compliance are expected to fall over time), produces the following results:

For NCC2019:

- with a 0% learning rate (implying that incremental costs of compliance never change over time), the NPV would fall marginally to $269million at a BCR of 3.4
- with a learning rate of 5% (implying that after 20 years, there would be no incremental cost still being incurred as a result of the 2023 performance requirements), the NPV for NCC2019 would increase to $284million at a BCR of 3.9

For NCC2016:

- a 0% learning rate would reduce the NPV to $97million at a BCR of 1.9
- a 5% learning rate would lift the NPV associated with NCC2016 to $111 million with a BCR of 2.2.

Overall, changes in incremental costs over time within the ranges indicated have only a low impact on the social cost benefit analysis.

Social Cost of Carbon

As discussed in Appendix G, the social cost of carbon assumptions are derived from research in the United States that has been used internationally for the Inter-Governmental Panel on Climate Change (IPCC) Assessment Reviews (and which are currently being updated for the 6th Assessment Review). The US analysis considers climate change impacts over a long period (300 years) and therefore, as noted above, the costs are highly sensitive to even small changes in the real discount rate. The reference rate assumes a 3% real discount rate, taking the average of future cost ranges, while the high rate uses the same real discount rate but the 95th percentile of the probability distribution (ie, a 'worst case' – although the research is currently being updated and values are expected to be revised higher). The low case applies a 5% real discount rate.

For NCC2019:

- the low social cost of carbon reduces the NPV to $256million at a BCR of 3.4
- the high social cost of carbon increases the NPV to $336million at a BCR of 4.1.

For NCC2016:

- the low social cost of carbon reduces the NPV to $93million with a BCR of 1.9
- the high social cost of carbon increases the NPV to $134million with a BCR of 2.3.

Thus, varying the social cost of carbon assumption has a larger impact on the social cost benefit analysis results compared to changes in the learning rate. The impact of changing the social cost assumptions is much less than varying the real discount rate.

Summary of Sensitivity Analyses

The sensitivity analyses are summarised in Table 6-3.

Table 6-3: Economy-wide Cost Benefit Analysis, Societal Perspective, Sensitivity Analyses

Scenario	Real Discount Rate	Learning Rate	Social Costs of Carbon Scenario	Realisation of Expected Savings	Tier	NPV ('000$2022)	BCR
NCC2016	10%	2%	3% (av.)	100%	1+2	$44,856	1.5
NCC2019	10%	2%	3% (av.)	100%	1+2	$159,661	2.7
NCC2016	3%	2%	3% (av.)	100%	1+2	$296,576	3.4
NCC2019	3%	2%	3% (av.)	100%	1+2	$648,488	6.2
NCC2016	7%	2%	3% (av.)	75%	1+2	$59,892	1.6
NCC2019	7%	2%	3% (av.)	75%	1+2	$193,960	2.8
NCC2016	7%	0%	3% (av.)	100%	1+2	$96,554	1.9
NCC2019	7%	0%	3% (av.)	100%	1+2	$269,126	3.4
NCC2016	7%	5%	3% (av.)	100%	1+2	$111,356	2.2
NCC2019	7%	5%	3% (av.)	100%	1+2	$284,424	3.9
NCC2016	7%	2%	5%	100%	1+2	$92,519	1.9
NCC2019	7%	2%	5%	100%	1+2	$256,023	3.4
NCC2016	7%	2%	3% (95th)	100%	1+2	$134,492	2.3
NCC2019	7%	2%	3% (95th)	100%	1+2	$335,816	4.1

Stress-Testing

A technique used to explore the outer limits of the cost-effectiveness of potential policy changes is called 'stress-testing'. This technique makes the admittedly rather extreme assumptions, that all of the sensitivity variables turn out either (a) with the *least* favourable outcomes within a plausible range, or (b) with the *most* favourable outcomes with a plausible range, with 'favourable' judged from the perspective of the NPV of the potential policy measures. On this basis, NCC2019 would achieve:

- in the worst case, an NPV of $89million, with a BCR of 1.9
- in the best case, an NPV of $775million, with a BCR of 7.8.

NCC2016 would achieve:

- in the worst case, an NPV of $5million, with a BCR of 1.1
- in the best case, an NPV of $368million, with a BCR of 4.3.

Importantly, this stress-testing reveals that even if extremely unfavourable outcomes were to occur, both measures would remain cost effective – NCC2019, comfortably so, while NCC2016 would be marginally cost-effective in the worst case. The best-case results reveal the upside potential of both measures. Again, it may be noted that the stress-testing does not change the ranking order of the two measures. The stress testing results are summarised in Table 6-4.

Table 6-4: Economy-wide Cost Benefit Analysis, Societal Perspective, Stress Testing Results

Scenario	Stress Test Settings	Real Discount Rate	Learning Rate	Social Costs of Carbon Scenario	Realisation of Expected Savings	Tier	NPV ('000$2022)	BCR
NCC2016	Best	3%	5%	3% (95th)	100%	1+2	$368,084	4.3
	Worst	10%	0%	5%	75%	1+2	$5,466	1.1
NCC2019	Best	3%	5%	3% (95th)	100%	1+2	$775,198	7.8
	Worst	10%	0%	5%	75%	1+2	$89,389	1.9

6.2 Energy and Greenhous Gas Emission Savings

6.2.1 Energy Savings

Energy savings accumulate over the FY2023 – FY2030 period, during which the policy measures are assumed to apply, and then remain at the same level over the balance of economic life of the buildings, as shown in Table 6-5. The savings are predominantly electricity.

Table 6-5: Economy-wide Energy Savings by Fuel and Policy Measure

Policy Case	Unit	Fuel	2023	2024	2025	2026	2027	2028	2029	2030
NCC2016	MWh	Electricity	4,788	9,744	15,496	20,753	26,095	31,523	37,038	42,643
NCC2019	MWh	Electricity	9,104	18,529	29,467	39,463	49,620	59,941	70,429	81,086
NCC2016	GJ	Gas	162	330	525	703	884	1,068	1,255	1,445
NCC2019	GJ	Gas	297	603	960	1,285	1,616	1,952	2,294	2,641
NCC2016	TJ	Both	17	35	56	75	95	115	135	155
NCC2019	TJ	Both	33	67	107	143	180	218	256	295

6.2.2 Energy Cost Savings

The savings shown in Table 6-5 would have a value that reaches $15.0 million for electricity by 2030, if NCC2016 is adopted, or almost double that – $28.6 million – if NCC2019 is adopted (see Table 6-6). The values for gas savings are much lower and relate to the Alice Springs location only. The discounted present values of savings, over the economic life of the 2023 – 2030 new building cohort, are shown in Column 3.

Table 6-6: Value of Economy-wide Energy Cost Savings ($million) by Fuel and Policy Measure

Policy Case	Fuel	Present Values	2023	2024	2025	2026	2027	2028	2029	2030
NCC2016	Electricity	$162.2	$1.7	$3.4	$5.5	$7.3	$9.2	$11.1	$13.1	$15.0
NCC2019	Electricity	$308.5	$3.2	$6.5	$10.4	$13.9	$17.5	$21.1	$24.8	$28.6
NCC2016	Gas	$0.2	$0.00	$0.00	$0.01	$0.01	$0.01	$0.01	$0.02	$0.02
NCC2019	Gas	$0.4	$0.00	$0.01	$0.01	$0.02	$0.02	$0.02	$0.03	$0.03

6.2.3 Greenhouse Gas Emissions Savings

The adoption of NCC2019 generates the largest greenhouse gas savings of 891,000 tonnes of CO_2-e (tCO_2-e) cumulatively over the FY2023 – FY2070 period[21] – see Table 6-7. Under NCC2016, these savings are slightly less than half of those under NCC2019, at 469,000 tCO_2-e. On an annual basis, emissions savings is expected to peak around FY2030, and then decline over time due to the declining greenhouse gas intensity of electricity consumption over time (Table 6-7 and Figure 6-1). Relative to the base case, the emissions savings associated with the adoption of NCC2019 and NCC2016 are 23.3% and 12.3%, respectively. Further details of the GHG emissions savings and energy savings by fuel types are provided in Appendix J.

Adoption of NCC2019 Section J would save more than twice the energy and greenhouse gas emissions than NCC2016.

NCC2019 saves 23.3%

of base case emissions,

891,000tCO_2-e

cumulatively over 50 years.

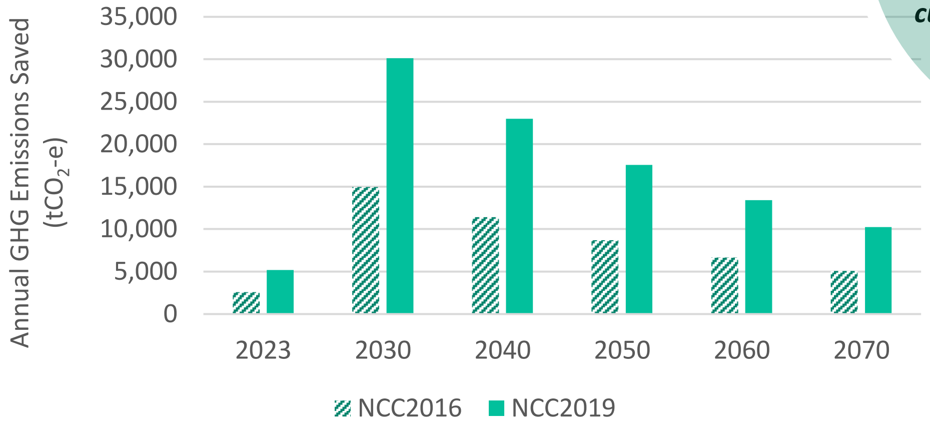

Figure 6-1: Annual greenhouse gas emissions savings, tCO2-e, selected years

Table 6-7: Greenhouse Gas Emissions Savings (tCO_2-e) by Policy Scenario, Selected Years

Policy Case	Cumulative	2023	2030	2040	2050	2060	2070
NCC2016	468,720	2,738	15,852	12,097	9,236	7,055	5,394
NCC2019	891,035	5,205	30,138	22,997	17,556	13,410	10,251

6.3 Limitations of the Analysis

The key limitations of the economy-wide cost benefit analysis from a social perspective are:

- not all building classes have been simulated, and therefore the performance of non-simulated building classes has been estimated. That said, the major building classes are represented, and simulating every building class would add significantly to the cost of the analysis, without necessarily adding significant value

[21] The cumulative emissions savings is determined by summing the annual emissions savings over the stated period of time.

- while NCC2019 is shown to be more cost-effective than NCC2016, and much more cost-effective than the status quo, this does guarantee that all possible building designs would realise the same outcomes – there is an extent to which every building design is unique.

NCC2019 significantly outperforms NCC2016. It generates much higher net economic benefits from a societal perspective, and much larger energy and emissions savings, in all scenarios examined.

6.4 Conclusion

Overall, we find that NCC2019 significantly outperforms NCC2016, generating consistently higher net social benefits and BCRs on all assumptions and sensitivity assumptions examined. This result is not surprising, in that NCC2019 was found to be cost effective at a national level, relative to NCC2016, when subjected to national regulation impact assessment.[22]

[22] The CIE, *Decision Regulation Impact Statement – Energy Efficiency of Commercial Buildings*, November 2018.

7 Economy-wide Owner-Occupier Cost Benefit and Impact Analysis

This chapter presents similar analysis to Section 6, but all results are stated from an owner-occupier's or private perspective. The energy and emissions savings are the same, but benefits or costs that fall on parties other than an owner-occupier are excluded from the analysis. These include:

- the value of avoided greenhouse gas emissions
- costs of government administration
- government costs associated with the energy pricing community service obligation
- avoided (economy-wide) network costs.

The values associated with avoided energy consumption are assessed solely on what is avoidable according to (a typical) owner-occupier's energy bills. We note that some owner-occupiers may be able to generate private value streams from avoided greenhouse emissions, such as reduced loan costs via climate bonds. However, since such benefits are contingent upon factors specific to individual buildings/owners, they are not quantified here.

7.1 Economy-wide Cost Benefit Analysis

Table 7-1 summarises the different variables used to examine the economic impact of adopting NCC2016 and NCC2019 Section J.

Table 7-1: Economic Parameters defining average-, best- and worst-case scenarios, Owner- Occupier

Economic Parameters used for CBA – Owner-Occupier	Best Case	Reference Case	Worst Case
Modelled energy savings realised	100%	100%	75%
Real electricity cost escalation	1%	0.4%	0%
Real discount rate	3.9%	4.7%	6.3%
Learning rate	5%	2%	0%

As noted above, social costs of carbon are not included from an owner-occupier perspective, and different real discount rates from those used in Section 6 are selected. The rationale for the values shown is provided in Appendix H. Broadly, they are based on a range of values for the real cost of capital (for typical commercial construction firms in the NT), which is constructed from a nominal cost of capital, less average NT inflation, plus a pre-tax return on debt. We note that the real cost of capital will vary from firm to firm and that these are intended as indicative values only.

Learning rate assumptions as the same as those used in Section 6, while an additional variable is tested here, which is a real (or after-inflation) escalation of electricity prices – as discussed in Appendix H. The reference case is based on the estimated real escalation rate in commercial electricity prices in the NT since 2010 of 0.4% per year.

NCC2019 would generate net private benefits of $295million – 2.7 times higher than for NCC2016.

7.1.1 Key Findings

Overall, adoption of NCC2019 energy performance requirements from FY2023-FY2030 in both Tier 1 and Tier 2 areas would generate net private benefits in the NT of $295million in present value terms, with a (private) benefit cost ratio (BCR) of 3.8. These values assume default input assumptions including a 4.7% real discount rate, 2% learning rate, 0.4% per year real electricity cost escalation, and 100% realisation of expected energy savings. Other input assumptions are tested in sensitivity analysis below. The NPV and BCR are slightly higher than from the social perspective, despite the non-inclusion of social benefits and the resulting lower level of energy costs, because of the lower real discount rate.

Adoption of NCC2016 energy performance requirements from FY2023-FY2030 in both Tier 1 and Tier 2 areas would generate significantly lower – but still significant – net private benefits in the NT of $108million at a BCR of 2.0 on the same default input assumptions. The net private benefits associated with adopting NCC2019 are 2.7 times higher than for adopting NCC2016, and the benefit cost ratio is almost double.

These expected values are summarised in Table 7-2.

Table 7-2: Economy-wide Cost Benefit Analysis, Owner-Occupier Perspective, Default Assumptions

Scenario	Real Discount Rate	Learning Rate	Electricity Real Cost Escalation	Realisation of Expected Savings	NPV ('000$2022)	BCR
NCC2016	4.7%	2%	0.4%	100%	$108,076	2.0
NCC2019	4.7%	2%	0.4%	100%	$294,846	3.8

The net private benefits and BCRs determined for each building type modelled is summarised in Table 7-3 (Further details in Appendix I.1.2). Adopting NCC2019 was found to be cost effective for each individual building type modelled. This is reflected in the positive net present values and benefit cost ratios greater than 1.0. In contrast, adopting NCC2016 is cost beneficial for buildings modelled, except in the case of the single-storey office building in Darwin, where the incremental construction cost outweighed the private benefits an owner-occupier could experience (negative NPV). At the level of each building type, the net private benefits associated with adopting NCC2019 is up to 6.2 time higher than that for adopting NCC2016.[23]

[23] The only exception to this is the multi-storey office in Alice Springs. For this building type, NCC2016 has a higher NPV than that of NCC2019 because the NCC2016 compliant building is marginally less energy intensive than the NCC2019 compliant building form, with a difference of less than 1 kWh per m^2.

Table 7-3: Building-level Economy-wide Cost Benefit Analysis, Owner-Occupier Perspective, Default Assumptions

Location	Building Archetype	NCC2016		NCC2019	
		NPV ('000$2022)	BCR	NPV ('000$2022)	BCR
Darwin	Hotel (3A)	$7,366	1.6	$9,051	1.8
	Multi-storey Office (5A)	$35,378	3.0	$48,955	3.8
	Single-storey office (5)	-$7,079	0.7	$10,025	1.4
	Retail (6B)	$23,448	2.4	$103,538	7.8
	Hospital Ward (9aC)	$2,463	1.5	$9,260	2.2
	School (9bH)	$19,446	1.7	$34,289	2.2
Alice Springs	Hotel (3A)	$1,033	1.6	$1,847	1.8
	Multi-storey Office (5A)	$2,302	1.9	$1,958	1.8
	Single-storey office (5)	$938	1.3	$5,858	2.5
	Retail (6B)	$4,456	2.6	$9,988	5.9
	Hospital Ward (9aC)	$1,208	2.7	$3,718	3.5
	School (9bH)	$4,569	2.0	$13,711	4.3

7.1.2 Economy-Wide Sensitivity Analysis

While Table 7-2 shows the *expected* (most likely) outcomes of the cost benefit analysis from an owner-occupier perspective, we also generate a range of alternative scenarios as sensitivity analysis. The best, expected and worst case values used as inputs for the sensitivity analysis are summarised in Table 7-1 above, and discussed further in Appendix H.

Real Discount Rate

As for the social cost benefit analysis, varying the real discount rate has the most significant impact of all the variables considered. As noted in Section 6 (and Appendix G), changing the real discount rate changes the weightings of near-term versus future impacts. The higher the real discount rate, the more that present values are weighted towards near-term impacts, such as increased construction costs, and the less weight that is put on impacts that occur over time, such as avoided energy consumption costs. The effect is significant because the assumed discount rate applies every year and accumulates rapidly over time.

For NCC2019:

- a 6.3% real discount rate reduces the NPV to $203million with a BCR of 3.0
- a 3.9% real discount rate increases the NPV to $358million with a BCR of 4.3.

For NCC2016:

- a 6.3% real discount rate reduces the $63million with a BCR of 1.6
- a 3.9% real discount rate increases the NPV to $140million with a BCR of 2.3.

Thus, while the impact of a higher discount rate is significant, both NCC2019 and NCC2016 would remain cost-effective across the range of real discount rates tested. Also, the ranking of options does not change, with NCC2019 consistently showing higher values than NCC2016.

Realisation of Energy Savings

If only 75% of expected energy savings were realised – for example, if compliance were low, or if simulations under-predicted actual energy consumption, NCC2019 would remain cost effective, with an NPV of $195million and a BCR of 2.8. On the same assumption, NCC2016 would also remain cost effective, with an NPV of $56million and a BCR of 1.5. This indicates that the net private benefits associated with both measures would remain robust even if the realisation of energy savings was unexpectedly low.

Cost Learning Rate

Varying the learning rate (that is, the rate at which incremental costs of compliance are expected to fall over time), produces the following results:

- with a 0% learning rate, the NPV associated with implementing NCC2019 would fall marginally to $287million at a BCR of 3.5
- with a learning rate of 5% (implying that after 20 years, there would be no incremental cost still being incurred as a result of the 2023 performance requirements), the NPV for NCC2019 would increase to $305million at a BCR of 4.2
- for NCC2016, a 0% learning rate would reduce the NPV to $101million at a BCR of 1.9
- a 5% learning rate would lift the NPV associated with NCC2016 to $118 million with a BCR of 2.3.

Overall, changes in incremental costs over time within the ranges indicated have only a low impact on the social cost benefit analysis.

Electricity Cost Escalation Rate

Varying the real escalation rate for electricity costs shows the following results:

For NCC2019:

- a 0% real escalation rate for electricity costs reduces the NPV to $262million with a benefit cost ratio of 3.5
- a 1% real escalation rate for electricity costs increases the NPV to $351million with a benefit cost ratio of 4.3.

For NCC2016:

- a 0% real escalation rate for electricity costs reduces the NPV to $91million with a benefit cost ratio of 1.9
- a 1% real escalation rate for electricity costs increases the NPV to $137million with a benefit cost ratio of 2.3.

Thus, impact of real electricity cost escalation is reasonably significant. However, both NCC2019 and NCC2016 remain cost effective even with no cost escalation, and cost escalation rates do not change the ranking order of the two options.

Summary of Sensitivity Analyses

The sensitivity analyses are summarised in Table 7-4.

Table 7-4: Economy-wide Cost Benefit Analysis, Societal Perspective, Sensitivity Analyses

Scenario	Real Discount Rate	Learning Rate	Electricity Real Cost Escalation	Realisation of Expected Savings	NPV ('000$2022)	BCR
NCC2016	6.3%	2%	0.4%	100%	$62,771	1.6
NCC2019	6.3%	2%	0.4%	100%	$203,199	3.0
NCC2016	3.9%	2%	0.4%	100%	$139,881	2.3
NCC2019	3.9%	2%	0.4%	100%	$358,279	4.3
NCC2016	4.7%	2%	0.4%	75%	$55,588	1.5
NCC2019	4.7%	2%	0.4%	75%	$195,008	2.8
NCC2016	4.7%	0%	0.4%	100%	$100,968	1.9
NCC2019	4.7%	0%	0.4%	100%	$287,501	3.5
NCC2016	4.7%	5%	0.4%	100%	$117,749	2.3
NCC2019	4.7%	5%	0.4%	100%	$304,844	4.2
NCC2016	4.7%	2%	0.0%	100%	$91,004	1.9
NCC2019	4.7%	2%	0.0%	100%	$262,373	3.5
NCC2016	4.7%	2%	1.0%	100%	$137,433	2.3
NCC2019	4.7%	2%	1.0%	100%	$350,690	4.3

Stress-Testing

As noted in Section 6, a technique used to explore the outer limits of the cost-effectiveness of potential policy changes is called 'stress-testing'. This technique makes the rather extreme assumptions that all of the sensitivity variables turn out either a) with the *least* favourable outcomes within a plausible range, or b) with the *most* favourable outcomes with a plausible range, with 'favourable' judged from the perspective of the NPV of the potential policy measures. On this basis, from an owner-occupier perspective, NCC2019 would achieve:

- in the worst case, an NPV of $104million, with a BCR of 2.0
- in the best case, an NPV of $438million, with a BCR of 5.4.

NCC2016 would achieve:

- in the worst case, an NPV of $7.8million, with a BCR of 1.1
- in the best case, an NPV of $186million, with a BCR of 2.9.

Importantly, this stress-testing reveals that even if extremely unfavourable outcomes were to occur, from a whole of economy perspective, both measures would remain cost effective – NCC2019, comfortably so, while NCC2016 would be marginally cost-effective in the worst case. The best-case results reveal the upside potential of both measures. Again, it may be noted that the stress-testing does not change the ranking order of the two measures. The stress testing results are summarised in Table 7-5.

Table 7-5: Economy-wide Cost Benefit Analysis, Owner-Occupier Perspective, Stress Testing Results

Scenario	Stress Test Setting	Real Discount Rate	Learning Rate	Electricity Real Cost Escalation	Realisation of Expected Savings	NPV ('000$2022)	BCR
NCC2016	Best Case	3.9%	5%	1.0%	100%	$186,173	2.9
	Worst Case	6.3%	0%	0.0%	75%	$7,841	1.1
NCC2019	Best Case	3.9%	5%	1.0%	100%	$437,551	5.4
	Worst Case	6.3%	0%	0.0%	75%	$104,365	2.0

The economy-wide NPV and BCR results are based on weighting individual building type results by the projected volume of floor area growth for each building type.

Individual building type stress testing results are listed in Appendix I.1.2 It has been found that the most sensitive archetype, from a cost benefit perspective, is the single-storey small office building due to its high envelope surface area to floor area ratio.

Whilst the study core analysis methodology did not allow for some design optimisation options, the window to wall area sensitivity analysis summarised in Section 8.2 demonstrates how varying glazing proportions can improve the cost effectiveness of compliance.

7.2 Energy Savings

This section considers the energy savings that would be expected to follow from the adoption of either NCC2019 or NCC2016 in the NT from an owner-occupier perspective. Note that the quantities of energy and greenhouse gas emissions savings are the same as those reported in Chapter 6, and so are not repeated here. Rather the analysis highlights the absolute and per-square-meter value of savings in the two policy options.

7.2.1 Energy Cost Savings

The energy cost savings for owner-occupiers would have an annual value that reaches $13.2 million for electricity by 2030, if NCC2016 is adopted, or almost double that – $25.1 million – if NCC2019 is adopted – see Table 7-6. The values for gas savings are much lower and relate to the Alice Springs location only. The discounted present values of savings, over the economic life of the 2023 – 2030 new building cohort, are shown in Column 3. It may be noted that the present value of savings for NCC2019 is close to double those for NCC2016.

Table 7-6: Value of Economy-wide Energy Cost Savings ($million) by Fuel and Policy Measure

Policy Case	Fuel	Present Values	2023	2024	2025	2026	2027	2028	2029	2030
NCC2016	Electricity	$217.9	$1.4	$2.9	$4.7	$6.3	$8.0	$9.7	$11.4	$13.2
NCC2019	Electricity	$414.5	$2.7	$5.6	$8.9	$12.0	$15.2	$18.4	$21.7	$25.1
NCC2016	Gas	$0.3	$0.00	$0.00	$0.01	$0.01	$0.01	$0.01	$0.02	$0.02
NCC2019	Gas	$0.6	$0.00	$0.01	$0.01	$0.02	$0.02	$0.02	$0.03	$0.03

Energy Cost Savings per Square Metre

NCC2019 also significantly outperforms NCC2016 from a private cost-effectiveness perspective.

The benefits of adopting NCC2016 and NCC2019 Section J can also be viewed from the perspective of the energy cost savings per square metre ($/m²). An overview of the energy cost savings per square metre from an owner-occupier perspective is provided in Table 7-7. On average across the archetypes in the Darwin, savings increase from 12% in the scenario where NCC2016 Section J is adopted, up to 23% under the NCC2019 scenario – that is, almost double. A similar observation is also made for buildings in Alice Springs, where the energy cost savings per square metre of gross floor area ($/m² savings) under NCC2019 (28%) are much higher than the case of NCC2016 (16%). It should be noted that the value of savings will vary somewhat by energy pricing zone across the NT. Results for individual building archetypes in Darwin and Alice Springs are summarised in provided in Table 7-8, and further detailed in Appendix I.3.

Table 7-7: Average value of energy cost savings per sqm, all building forms and fuels, Darwin and Alice Springs[24].

Scenario	Location	$/m² consumption[1]	$/ m² savings[2]	% savings[3]
Base Case	Darwin	$43.57	-	-
	Alice Springs	$31.31	-	-
NCC2016	Darwin	$38.47	$5.10	11.7%
	Alice Springs	$26.16	$5.15	16.4%
NCC2019	Darwin	$33.70	$9.87	22.7%
	Alice Springs	$22.45	$8.86	28.3%

Note

1. $/m² consumption – weighted average[25] using the modelled gas and electricity consumption for each building type, and considering energy prices (Appendix G.2.1)
2. $/ m² savings determined – the difference in $/m² consumption between the NCC Compliant scenarios and Base Case
3. % Savings - $/m² savings shown in the table, relative to the base case $/m² consumption.

[24] The value of energy savings relative to the base case (expressed as a percentage) accounts for savings in electricity and gas consumption, which do not have the same value ($) per unit of energy. Only Hotels in Alice Springs are modelled with gas consumption, and hence the % value of energy savings (in $) reflected here differs slightly to the % energy savings (in kWh) presented in Section 5.

[25] Weighted average values - weightings, based on the projected building type floor areas to be constructed in the NT in the 2023-2030 period assessed, are applied to the expected energy savings.

Table 7-8: Building-level value of energy saved in NCC2016 and NCC2019 compliant building archetypes, relative to the base case. Values equate to the decrease in value of energy consumed from the base case. The absolute decrease ($/m²) and percentage (%) decrease are shown.[26]

Location	Building Archetype	NCC2016	NCC2019
Darwin	Hotel (3A) (30% WWR)	$4.77 (13.1%)	$4.77 (13.1%)
	Multi-storey Office (5A) (40% WWR)	$7.51 (27.3%)	$9.38 (34.1%)
	Single-storey office (5) (30% WWR)	$1.98 (6.4%)	$4.86 (15.7%)
	Retail (6B) (30% WWR)	$6.60 (11.0%)	$19.58 (32.6%)
	Hospital Ward (9aC) (30%WWR)	$3.15 (6.1%)	$7.06 (13.7%)
	School (9bH) (30% WWR)	$4.50 (10.5%)	$5.94 (13.9%)
	Weighted Average	**$5.10 (11.7%)**	**$9.87 (22.7%)**
Alice Springs	Hotel (3A) (30% WWR)	$3.41 (12.1%)	$5.23 (18.5%)
	Multi-storey Office (5A) (40% WWR)	$3.74 (22.8%)	$3.45 (21.1%)
	Single-storey office (5) (30% WWR)	$3.29 (10.9%)	$7.65 (25.4%)
	Retail (6B) (30% WWR)	$6.55 (15.4%)	$10.86 (25.6%)
	Hospital Ward (9aC) (30%WWR)	$4.30 (14.7%)	$11.63 (39.9%)
	School (9bH) (30% WWR)	$4.72 (15.6%)	$9.24 (30.5%)
	Weighted Average	**$9.87 (22.7%)**	**$8.86 (28.3%)**

7.3 Limitations of the Analysis

The key limitations of the economy-wide cost benefit analysis from an owner-occupier perspective are:

- the (real) cost of capital will vary from firm to firm, and the sensitivity analysis indicates how much impact this is likely to have.
- not all building classes have been simulated, and therefore the performance of non-simulated building classes has been estimated. That said, the major building classes are represented, and simulating every building class would add significantly to the cost of the analysis, without necessarily adding significant value.
- while NCC2019 is shown to be more cost-effective than NCC2016, and much more cost-effective than the status quo, this does not guarantee that all possible building designs would realise the same outcomes – there is an extent to which every building design is unique.

7.4 Conclusion

Overall, we find that NCC2019 also significantly outperforms NCC2016 from an owner-occupier perspective, generating consistently higher net private benefits and BCRs on all assumptions and sensitivity assumptions examined.

[26] Same as note Footnote 19

8 Sensitivity Analysis Studies – Building Construction Changes

To explore the influence that implementation of NCC2016 or NCC2019 could have on building forms with different construction specifications to those used in the core analysis, sensitivity analyses were performed on three types of variations to the building construction. These are:

- **Variation to the wall construction** of single-storey offices. Walls in the core study were based on single-skin blockwork. In the sensitivity analysis, cladded steel frame walls are considered.

- **Variations in the window-to-wall ratio (WWR)** of hotels and multi-storey offices. In the core study, WWR ratio for hotels and multi-storey offices were 30% and 40%, respectively. In the sensitivity analysis:
  - A base case hotel with 50% WWR is compared with NCC2016 and NCC2019 compliant hotel models with 30% WWR.
  - Multi-storey offices with larger WWR ratios (56%) are considered (for the base case, NCC2016 and NCC2019 compliant models).

- **Replacing wall insulation with external wall shading**. In the core study, wall insulation is added in NCC2016 and NCC2019 compliant models to meet Section J requirements. This sensitivity analysis investigates the effect of substituting wall insulation with external wall shading.

In this section, the incremental construction cost and predicted energy use for each scenario is reported. The total incremental cost for each of these sensitivity analysis are tabulated in Appendix E.4. Further details on the compliance options and incremental cost analysis for individual building elements compliant construction are also available in Appendix E.4. Tabulated forms of the predicted energy intensities are provided in Appendix F, and detailed CBA results are presented in Appendix I.2.

The scenarios related to variation in the WWR and wall construction were also analysed via economic analysis; this was performed from the owner-occupier perspective. NPV and BCR values evaluated for each scenario are presented.

8.1 Wall Construction Variation

This assessment focussed on the sensitivity of the analysis where the base case external wall for the small office building is a cladded steel frame construction rather than single skin blockwork. Incremental construction costs of the small office with steel frame walls are summarised on Figure 8-1, while the predicted energy use is shown in Figure 8-2 (for tabulated incremental costs and energy intensities, see Appendix E.4.1.1 and Appendix F.2). For reference, both figures also show the incremental cost and predicted energy use associated with single-storey office with single skin blockwork, which forms part of the core analysis.

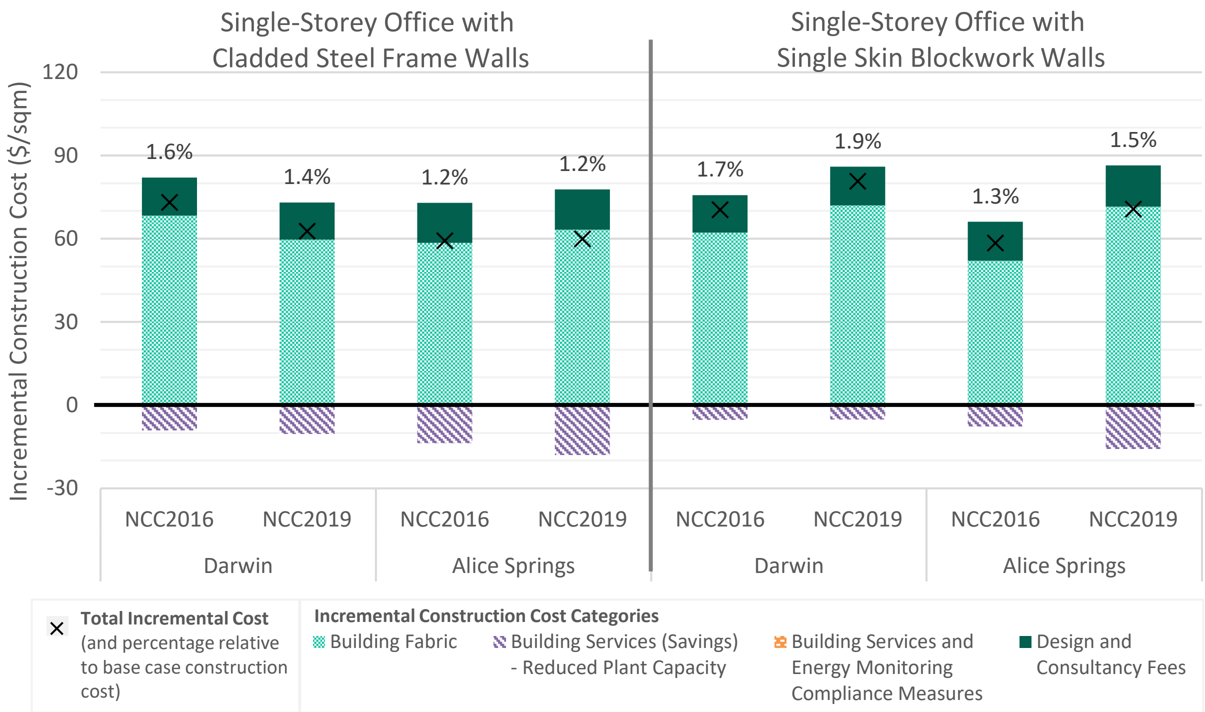

Figure 8-1: Incremental construction costs of NCC2016 and NCC2019 compliance for single-storey office buildings in Darwin and Alice Springs, with cladded steel frame wall (sensitivity case). Costings for models with single skin blockwork (core analysis) included for reference. Percentage values shown correspond to the total incremental cost relative to the base case construction costs.

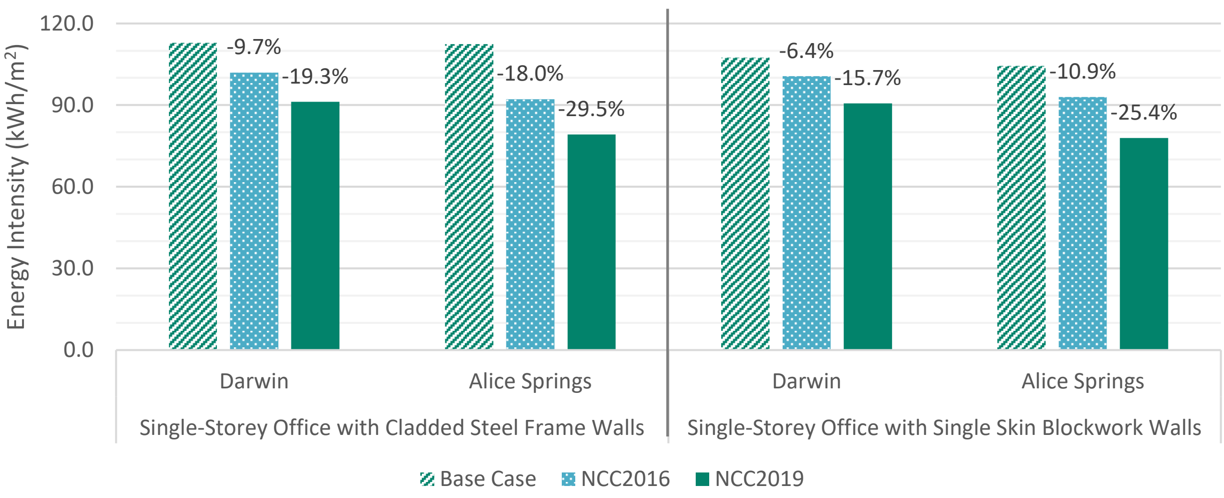

Figure 8-2: Predicted energy intensity of the base case, NCC2016 and NCC2019 compliant single-storey office buildings with cladded steel frame wall (sensitivity case). Costings for models with single skin blockwork (core analysis) included for reference. Energy intensity for models with single skin blockwork (core analysis) has been included for reference.

Changing the wall construction from single skin blockwork to cladded steel frame has an impact on the compliance options, and hence incremental costs. In the context of NCC2016 compliance, the primary impact of the change is on the wall compliance itself. Meanwhile, for NCC2019 compliance, both the wall construction and glazing are affected (since wall and glazing are assessed together). In each of the NCC2016 and NCC2019 compliance assessments, there is also an impact on the reduced plant capacities. These are

Energy savings in buildings with cladded steel frame wall are higher than single skin blockwork when Section J NCC2016 and NCC2019 requirements are implemented.

However, NCC2019 compliant single-storey offices with single skin blockwork are still cost-effective, delivering NPVs of $10million in Darwin, and $6million in Alice Springs.

reflected in differences in the incremental costs for building fabric and savings from reduced plant capacity, between the sensitivity case and the core study. Further notes on the impacts that using a cladded steel frame construction has on compliance options, and details of the compliant construction along with the construction costs are available in Appendix E.4.1.1.

From an energy intensity perspective, NCC2016 and NCC2019 compliant models with the cladded steel frame wall construction had similar energy intensities (+/- 1kWh/m^2) compared to those of the core study (single-storey office with single-skin blockwork walls). However, the energy savings associated with the adoption of Section J NCC2016 and NCC2019 requirements is greater for cladded steel frame walls. This is because the energy intensity of the base case model with cladded steel frame walls is higher than those of the base case with a single skin blockwork wall (6 and 8 kWh/m^2 higher in Darwin and Alice Springs, respectively).

Table 8-1 summarises the economy-wide sensitivity analysis for a small, single storey office building with steel frame walls from an owner-occupier perspective (See Appendix I for detailed CBA results). Benefit cost ratios for the single-storey office archetype with steel-frame walls are greater than 1.0, and larger than those of the archetype with conventional framing (single skin blockwork) in all scenarios. This is because the increase in the value of savings an owner-occupier experiences in the steel-frame variant is larger than the increase in the incremental cost.

NCC2019 again significantly outperforms NCC2016 for this variant. The NCC2019 compliant single-storey office with cladded steel frame is cost-effective in both Darwin and Alice Springs; while NCC2016 would be (marginally) cost-effective in Alice Springs only.

Table 8-1 NPV (‘000$2022) and BCR of NCC2016 and NCC2019 compliant single-storey office with cladded steel frame walls and single skin blockwork walls, performed from an owner-occupier perspective across a 40-year building life cycle.

Scenario	Location	Cladded Steel Frame Walls		Single Skin Blockwork	
		NPV	BCR	NPV	BCR
NCC2016	Darwin	$556	1.0	-$7,079	0.7
	Alice Springs	$4,156	2.2	$938	1.3
NCC2019	Darwin	$25,408	2.4	$10,025	1.4
	Alice Springs	$8,902	3.6	$5,858	2.5

8.2 Window to Wall Ratio Variations

8.2.1 Hotels

This assessment highlights the impact of glazing on construction costs. It also shows that the cost of compliance can be significantly reduced by reducing the proportion of glazing on a building.

Constructing a hotel with less glazing will incur a lower incremental construction cost required to meet NCC Section J compliance.

In this sensitivity analysis, changes to the window-to-wall ratio (WWR) of the hotel model is considered. In the core analysis, WWR for hotels was kept constant at 30% across the base case and NCC compliant cases. Here, the scenario where there is a transition from base case hotel with a higher proportion of glazing (50% WWR) to NCC2016 and NCC2019 compliant hotels with lower WWR of 30% is considered.

The 30% WWR compliance absolute costs and energy intensity for NCC2016 and NCC2019 hotels remain unchanged from the core analysis. However, the incremental cost of compliance and energy savings relative to the 50% WWR base case differed since the base case construction cost and energy intensity of a hotel with 50% WWR is higher than one with a WWR of 30%. The incremental construction costs and predicted energy intensities are shown in Figure 8-3.

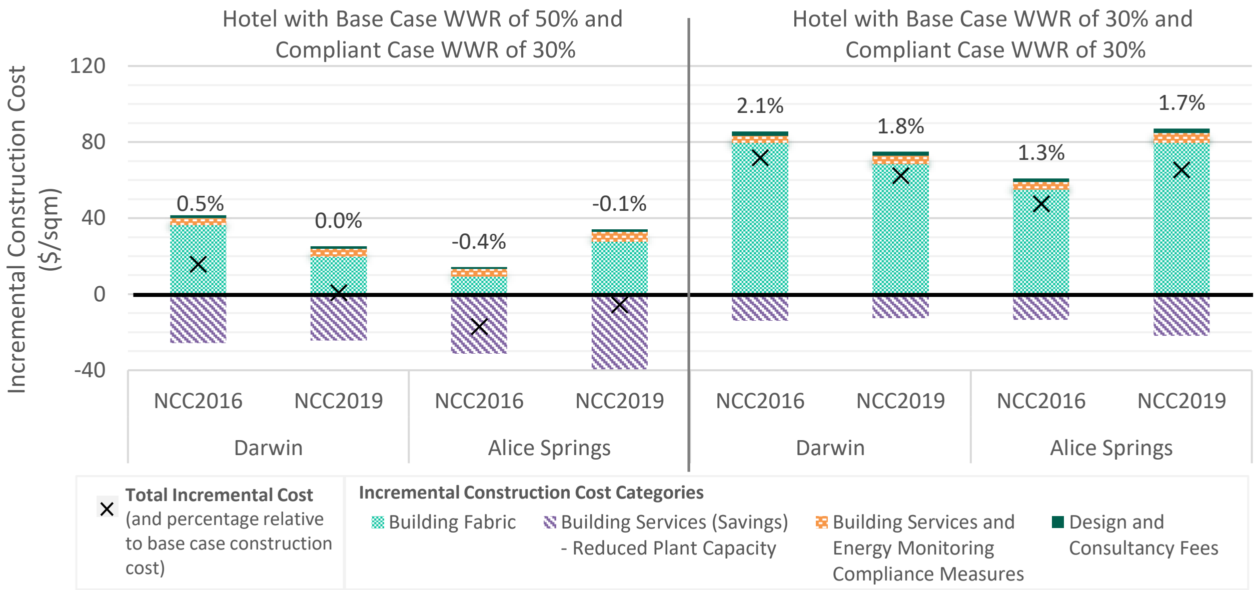

Figure 8-3: Incremental construction costs of NCC2016 and NCC2019 compliance for hotels with WWR of 30%, relative to a base case hotel that has a 50% WWR (left). Incremental costings of compliant hotels relative the base case hotel with a WWR of 30% (core analysis) has been included for reference. Percentage values shown correspond to the total incremental cost relative to the base case construction costs.

Figure 8-3 shows that the incremental construction costs for a base case hotel with more glazing (WWR of 50%) are significantly lower compared to the scenario where the base case hotel has a WWR of 30%. This is because from a thermal performance perspective, glazing is most energy inefficient part of the building fabric and requires substantial (and costly) upgrades. Reducing the amount of glazing[27] and external shading in a

[27] Via decreased WWR.

building, as also has the flow-on benefit of reduced HVAC plant size[28] (hence greater savings from reduced plant capacity). In other words, constructing a hotel with less glazing will incur a lower incremental construction cost to meet NCC Section J requirements.

In this sensitivity analysis, the incremental construction cost of NCC2016 and NCC2019 compliant hotels in Darwin and Alice Springs, when glazing is reduced from 50% WWR to 30% WWR, are within +/- 1% of the base case. This is attributed to the following: the combination of increased cost savings, reduced plant capacity and decreased incremental construction costs associated with the remaining costing components (building fabric, building services, energy monitoring compliance measures, and design and consultancy fees) results in similar construction costs between the compliant models and the base case with 50% WWR. In addition, there is overall cost savings, albeit marginal, for the hotel in Alice Springs (-0.5% and -0.1% for NCC2016 and NCC2019 compliance respectively).

The predicted energy intensities are shown in Figure 8-4 (see Appendix F for tabulated energy intensities).

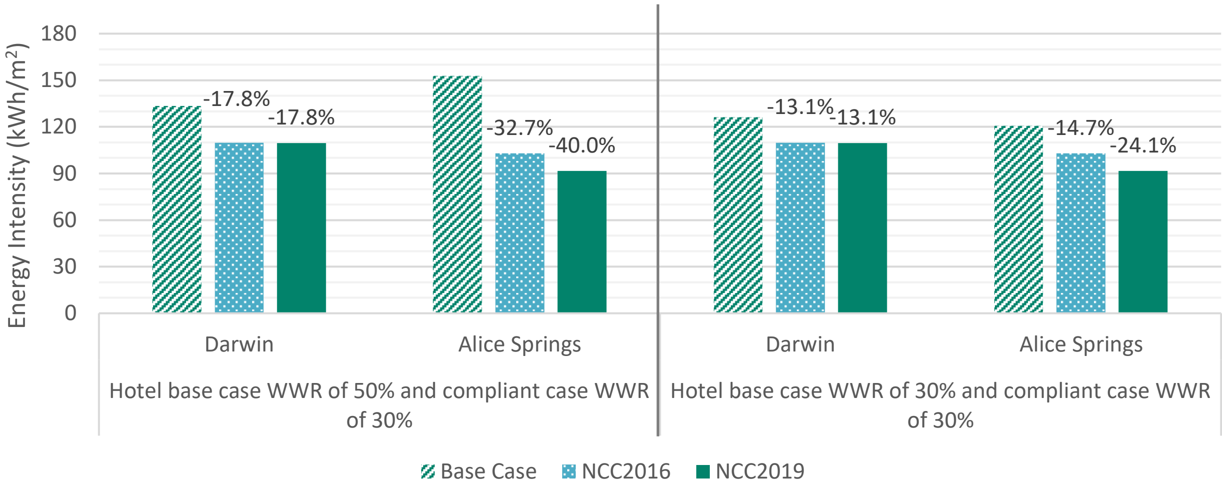

Figure 8-4: Predicted energy intensity (electricity and gas) of the base case, NCC2016 and NCC2019 compliant hotels, where the base case hotel has a WWR of (left) 50% and (right) 30%, and NCC2016 and NCC2019 compliant building forms have a WWR of 30%. Percentage values reflect the difference in energy intensity of the NCC compliant building forms, relative to the base case.

From an energy perspective, the energy intensity of the hotel increases with the proportion of glazing[29]. Consequently, as shown in Figure 8-4, the energy savings realised in the NCC2016 and NCC2019 compliant hotels are larger when the base case hotel has 50% WWR, compared to the base case with 30% WWR. The results clearly show that increasing the WWR of the base case model leads to larger energy savings realised in the NCC2016 and NCC2019 compliant models.

Economy-wide costs benefit analysis was conducted from an owner-occupier perspective. A summary of the results for the sensitivity case (base case of 50% WWR is provided in Table 8-2 (further details in Appendix I). For comparison, results related to the core study, where the base case hotel has a WWR of 30%, are also included in Table 8-2. The conditions considered in both the sensitivity and core study had positive NPVs.

[28] due to less heat entering through the glazing

[29] See earlier explanation regarding glazing being the weakest building fabric element from a thermal performance perspective.

This indicates that the solution is highly cost-effective in all scenarios, although the highest NPVs are for NCC2019. The NPVs for the sensitivity case (50% WWR base case) are larger than those of the core study (30% WWR base case), indicating that a transition from hotels with larger proportion of glazing to one with lower amount of glazing and compliant with NCC2016 and NCC2019, is more cost effective.

Where incremental costs are shown as negative in the Table 8-2 ("-ve cost" in the BCR column), this indicates that there is a net saving in construction costs relative to the base case – this applies to the hotel model in Alice Springs, as discussed earlier.

Table 8-2 NPV ('000$2022) and BCR of NCC2016 and NCC2019 compliant hotel with 30% WWR, where the base case hotel has a WWR of 50% and 30%, performed from an owner-occupier perspective across a 40-year building life cycle.

Scenario	Location	Hotel 50% WWR in Base Case, and 30% WWR compliant model		Hotel 30% WWR in Base Case, and 30% WWR compliant model	
		NPV	BCR	NPV	BCR
NCC2016	Darwin	$26,581	10.2	$7,366	1.6
	Alice Springs	$10,599	NA (-ve cost)	$1,033	1.6
NCC2019	Darwin	$29,385	211.2	$9,051	1.8
	Alice Springs	$11,575	NA (-ve cost)	$1,847	1.8

8.2.2 Multi-Storey Office

This assessment focussed on the case where a multi-storey office building has a window-to-wall ratio of 56% (in both the base case and compliance case). A 56% WWR was selected as it was a scenario tested in national regulatory Impact studies. Total compliance costs are shown in Figure 8-5, while the predicted energy usage is shown in Figure 8-6. For reference, the incremental costs and energy usage of the model with 40% WWR, which was used in the core study, are also shown in the figures.

The total incremental cost for compliance of a multi-storey office with 56% WWR is higher than the case of a 40% WWR, except for the NCC2016 compliant multi-storey building in Alice Springs. Increasing the WWR ratio of a multi-storey office had a direct impact on the compliance and cost of the glazing when considering NCC2016, and of wall and glazing when considering NCC2019 compliance. For NCC2016 and NCC2019 compliance, higher performance glazing is required in the 56% WWR case than the 40% WWR case. Compared to the core study (40% WWR), the combination of higher performance glazing required, and larger glazing areas results in higher incremental construction costs associated with glazing. In contrast, and as expected, the incremental wall construction costs are lower since the wall area is smaller. While buildings with larger WWR require larger mechanical plant capacities, the reduction in plant capacity upon adopting Section J NCC2016 and NCC2019 requirements is also larger; this in turn translates to greater cost savings from the reduced plant capacities.

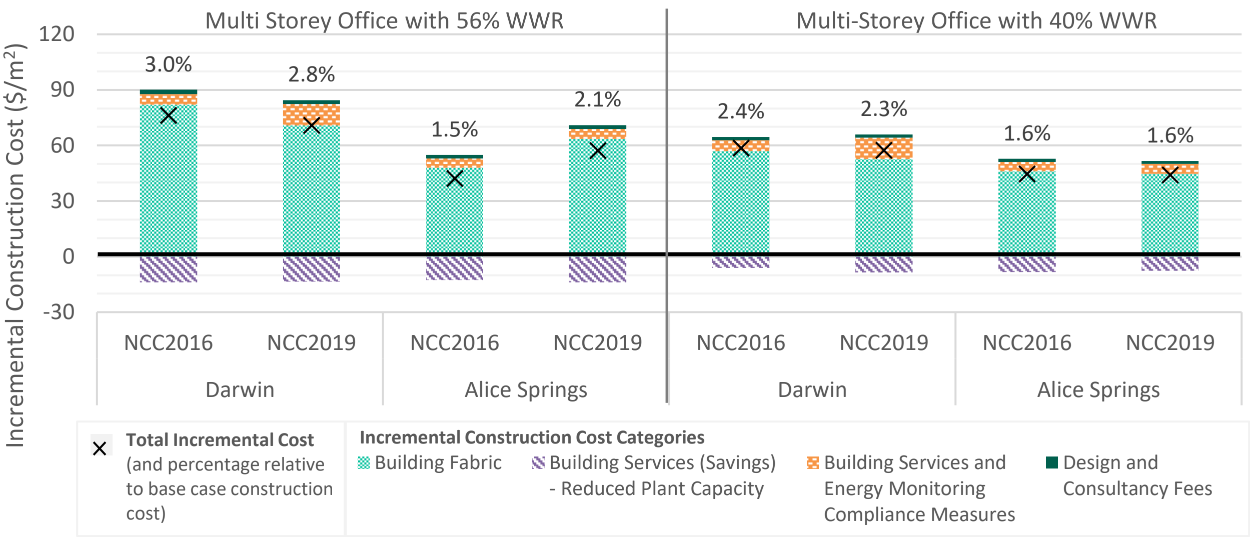

Figure 8-5: Incremental construction costs of NCC2016 and NCC2019 compliance for multi-storey office buildings in Darwin and Alice Springs, with 56% WWR (left). Costings for models with 40% WWR (right, core analysis) included for reference. Percentage values shown correspond to the total incremental cost relative to the base case construction costs.

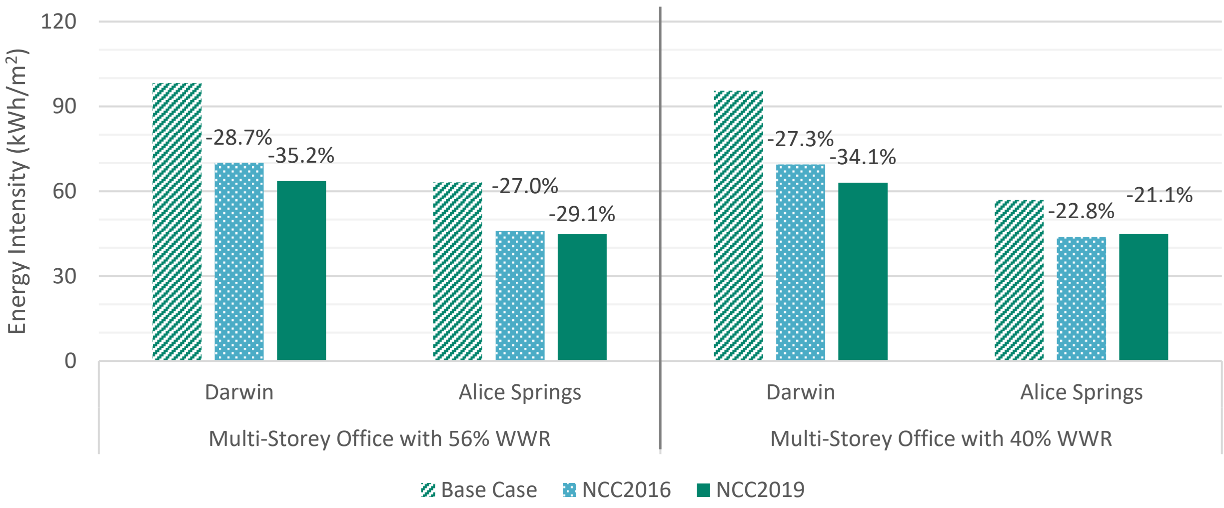

Figure 8-6: Predicted energy intensity of the base case, NCC2016 and NCC2019 compliant multi-storey office buildings with (left) 56% WWR. Energy intensity for models with 40% WWR (right, core analysis) has been included for reference.

The energy intensity of NCC2016 and NCC2019 compliant models with 56% WWR are close to, but slightly higher than, those of the building model with 40% WWR (2.2 kWh/m^2 higher for NCC2016 compliant offices in Alice Springs, and within +/- 1kWh/m^2 for all other cases). Despite this, greater energy savings were realised in multi-storey office building models with larger WWRs. This is attributed to the base case model with 56% WWR being more energy intensive than a building with 40% WWR.

The economy-wide sensitivity analysis from an owner-occupier perspective for a multi-storey office building with 56% WWR is summarised in Table 8-3 (further details in Appendix I). The multi-storey office with a 56% WWR, is cost-effective in both Alice Springs and Darwin. The highest NPVs generally occur for NCC2019 - one exception is that the NPV is a little higher for NCC2016 in Alice Springs, as the incremental costs for this form

Buildings with lower WWR are more favourable, with higher NPV and BCR

are lower than for NCC2019 (net present value incremental cost in '000$2022 for NCC2016 is $3,939, compared to $3,573 in the case of NCC2019), more than offsetting the lower energy savings. However, in total, the NPV for NCC2019 is 54% higher than for NCC2016.

This sensitivity analyses demonstrates that NCC2016 and NCC2019 Section J compliant design variations are cost effective with a higher WWR (56%).

Table 8-3: NPV ('000$2022) and BCR of NCC2016 and NCC2019 compliant multi-storey office with 56% and 40% WWRs, performed from an owner-occupier perspective across a 40-year building life cycle.

Scenario	Location	Multi-Storey Office with 56% WWR		Multi-Storey Office with 40% WWR	
		NPV	BCR	NPV	BCR
NCC2016	Darwin	$34,633	2.5	$35,378	3.0
	Alice Springs	$3,939	2.7	$2,302	1.9
NCC2019	Darwin	$49,234	3.3	$48,955	3.8
	Alice Springs	$3,573	2.1	$1,958	1.8

8.3 Wall Insulation vs External Wall Shading

This assessment focussed on sensitivity of the analysis to the case where external wall shading structures are used in lieu of installing external wall insulation as required by the 2016 and 2019 codes. The aim of this analysis was to investigate if the wall shading can have the same or better effect than wall insulation required by NCC2016 and NCC2019. The energy use of a building model with and without wall insulation and/or external shading was simulated. The single-storey office building with 30% WWR was used in this investigation, with NCC2016 and NCC2019 compliant forms used as the reference point for comparison. The predicted energy use for the building form with insulation, and without external wall shading was compared to predicted energy use of the corresponding model after the removal of wall insulation and addition of external wall shading. Two shading scenarios were considered:

- **Vertical shading** – this can be provided by structures such as louvered horizontal shades. For maximum shading, opaque shading with the same height as the wall, on all external walls without windows, was modelled.
- **Horizontal shading** – this can be provided by structures such as verandas or extended eaves. For maximum shading, the depth of the horizontal shading was modelled as the same height as the wall.

Simulations on the building model **with and without windows** were also performed. Results from the model without windows eliminate the shading effect on the windows (as windows tend to dominate heat transfer through the combined wall/window structure) and therefore provides a better insight into the effect of just replacing wall insulation with external shading. The modelling geometries used are shown in Figure 8-7.

The predicted energy use for a single-storey office with and without wall insulation, external shading and windows are shown in Figure 8-8.

The key result shown in Figure 8-8 is that in all cases without windows, the unshaded insulated wall outperforms the shaded uninsulated wall. An uninsulated building with external shading was found to consume between 1.2 - 1.6% higher energy intensity compared to an insulated building in Darwin, and 2.5 - 9.7% higher energy intensity in Alice Springs. The larger difference in energy intensity for Alice Springs, compared to Darwin is attributed to larger heating energy requirements in Alice Springs (cooler evening temperatures). This indicates that shading is not as effective as wall insulation.

In the scenarios with windows, the results are more ambiguous, with often only small differences in energy intensity between the shaded/uninsulated and unshaded/insulated cases; energy intensities for the vertical shading case are consistently higher than the unshaded/insulated case, while the horizontal shading performs very marginally better than the insulated wall case in three out of four scenarios. Comparison with the windowless scenarios shows however that these results reflect the impact of shading on windows rather than the effect of shading on walls.

Overall, therefore, the analysis demonstrates that there is no evidence to support the inclusion of an NT-specific amendment to Section J Deemed-To-Satisfy requirements permit the substitution of shading as an alternative to wall insulation. This does not, however, prevent projects from electing to implement such design choices, as alternative Verification Methods (such as JV3) provide a compliance pathway for such decisions.

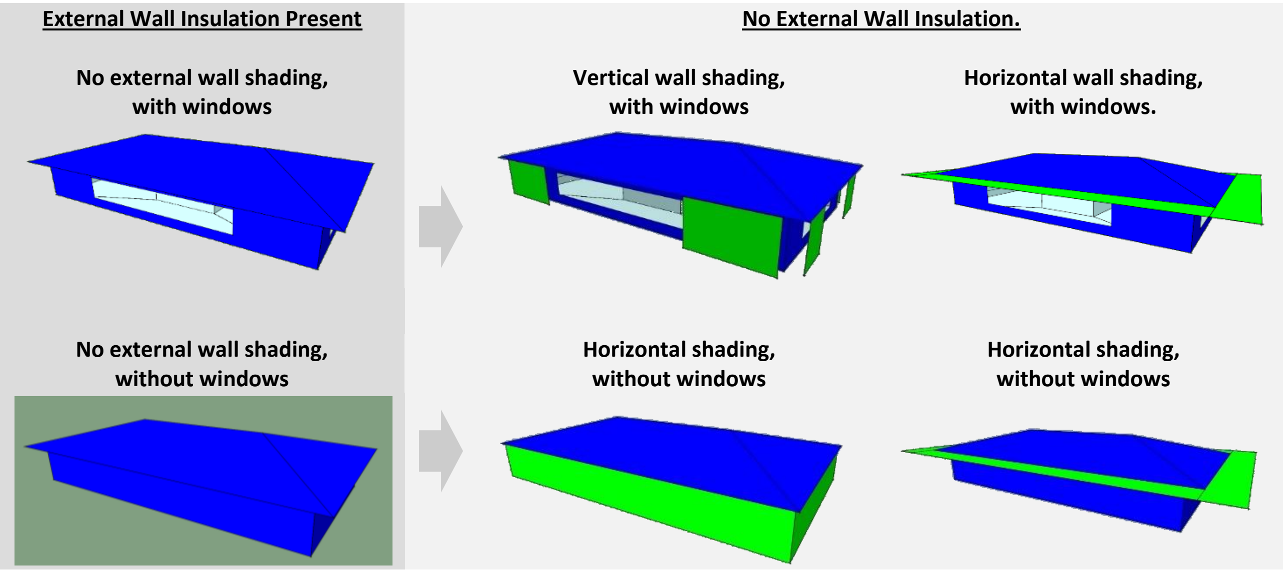

Figure 8-7: Modelled geometry for single-storey office building with and without external wall shading (horizontal and vertical shading, coloured green), and with and without windows. Structures with external wall insulation have no wall shading.

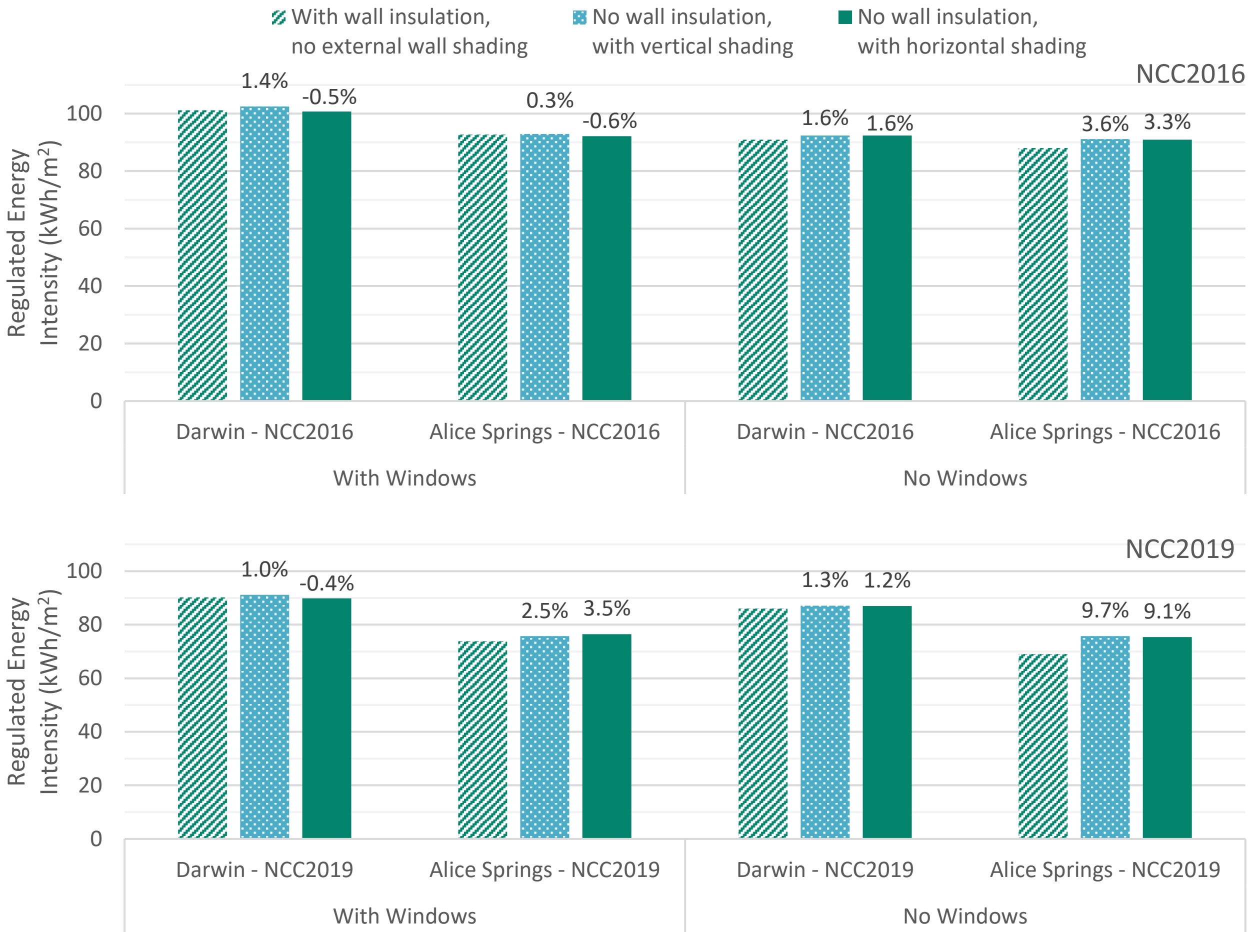

Figure 8-8: Predicted annual energy intensities of a NCC2016 and NCC2019 compliant small office with and without wall insulation and external wall shading. Percentage values shown describe the difference in energy intensity of the model with shading and without wall insulation, relative to the energy intensity of the model with wall insulation and no external wall shading.

9 Impacts of Section J Introduction in the NT

Throughout this report, the cost benefit analysis results have demonstrated a strong positive case for the adoption of minimum energy efficiency standards for non-residential buildings, specifically the NCC2019 Section J, in the NT. In this section, other impacts and practicality of implementing such regulation are discussed and examined.

9.1 Stakeholders Affected

NT building regulations recognise two 'tiers', or regions within declared building control areas. It is expected that Section J, if adopted, would apply in all declared building control areas aligned with the application of the other sections of the NCC - less than 4% of new building floor area is estimated to be outside building control areas. Simply put, the NCC2019 Section J requirements will apply to non-residential building construction projects, with majority of affected buildings anticipated to be in the Tier 1 region, with 67% of the total Tier 1 and Tier 2 floor area falling within the DKIS electricity network area. For more detailed building stock projection, refer to Appendix G.2.5.

Stakeholders in these locations that will be directly affected by the proposed changes include:

- Require familiarity with detail of the Section J requirements
  - Engineers
  - Building certifiers
  - Architects
  - Equipment and building material suppliers
  - Government - Northern Territory
- Require sufficient high-level knowledge to change procurement practices
  - Owner
  - Developers/Builders

The adoption of Section J would largely impact owners and developers of office, education and retail buildings, which comprised 64% of building approvals in FY2020. The predominant stakeholders for these building types are expected to be private, with education and some office buildings likely to be commissioned by the Government.

Many industry stakeholders should already be familiar with the NCC2016 Section J requirements[30], as compliance has recently been required for:

- Large private sector office buildings built for NT Government leasing (for example the Charles Darwin Centre and Manunda Place)
- Selected NT Government owned buildings, such Palmerston Regional Hospital
- The majority of Defence buildings built in the Northern Territory
- All new NT Government buildings over $3 million (or that meet other criteria) designed after 1 May 2021 as part of the Department of Infrastructure, Planning and Logistics Sustainability Minimum Design Standards.

[30] Noting Section J requirements did not change from NCC2010 to NCC2016

The NCC Section J requirements transcend trade and professional boundaries within the construction industry. Specifically, the Section J Part J1 building fabric requirements directly impact designers and architects, Part J3 building sealing requirements affect builders and Parts J5 to J8 affect all practitioners in the building services (electrical, mechanical, hydraulics and building controls) industry. Within the supply chain, equipment manufacturers will need to respond by increasing supply of efficient materials and equipment to the NT, either by creating local distribution partnerships or by local manufacture, due to rising demand – particularly efficient glazing, building materials, chillers or variable-speed drives.

If NCC2019 is adopted, architects and designers will need to learn how to use the ABCB NCC2019 façade calculator or equivalent industry tools. Furthermore, the sensitivity analysis conducted in Section 8 demonstrates that certain architectural design decisions, such as the extent of glazing used, can radically change the balance of cost-effectiveness. In fact, the example of the hotel described in Section 8.2.1 clearly demonstrates that building an energy efficient NCC2019-compliant hotel, with 20% less glass, will be cheaper to construct overall, not to mention the significant operational energy cost savings that could accrue to the hotel owner/operator. All stakeholders, particularly architects, designers and owner-developers, should carefully consider such opportunities in any decisions.

For at least larger projects, local and interstate experience is that specialist Ecologically Sustainable Development (ESD) consultants work with designers to verify Section J compliance. Recent large Section J compliant NT projects have used interstate ESD consultants however, if Section J is adopted in the NT, the creation of local jobs in this area can be expected.

While they have the technical competencies to interpret the requirements, and design accordingly, engineers will also need to be upskilled to provide the compliance reporting.

Building certifiers are critical stakeholders in respect to the achievement of the private and social benefits of Section J implementation. Building certifiers are licensed by the NT Building Practitioners Board to provide building approvals. Given the breadth of topics that building certifiers need to be across to confirm compliance, they are, to a certain extent, dependent on other professionals supplying a design that has been verified to meet Section J compliance in each discipline. It is immensely important that building certifiers are upskilled sufficiently so that they possess the technical competency to interpret design documentation and check that designs do genuinely meet Section J requirements, and review compliance reports.

Last, but not least, government bodies such as the Department of Infrastructure, Planning and Logistics, are the policy lever and enablers for Section J successful implementation.

9.2 Availability of Resources to Assist Stakeholders

DeltaQ recently completed a stocktake of NCC-related information publicly available for the Commonwealth Government. Our research found that most of the information related to NCC training and compliance can be found on the ABCB website, which included detailed documentation such as guidance to the NCC, understanding NCC series factsheets, supporting calculators (particularly those to supplement new building fabric thermal bridging calculations) and many case studies. The ABCB Resource Library should be considered a one-stop shop for all NCC related information and training materials.

For any industry bodies or government seeking to provide training to practitioners, the ABCB NCC Tutor feature on the ABCB website includes training materials that can be used to upskill practitioners. The NCC Tutor feature encompasses 17 learning modules aimed to facilitate progressive learning and systematic understanding of the NCC. Each module consists of a PowerPoint presentation with activities and detailed facilitator notes to help create interesting and interactive lessons. These modules are offered at a Diploma and Certificate IV level, and are mapped to units of competency for Construction, Plumbing and Services, and Property Services.

The Australian Institute of Refrigeration, Air-conditioning and Heating (AIRAH) periodically runs a paid Section J compliance training course, operating as small (typically up to 25 people) in-person classes and during COVID, as-webinars. In FY2020, AIRAH also ran a Section J case study *Streamline* webinar series that were recorded, accompanied by case studies published in their magazine Ecolibrium. However, these case studies and webinar series are only available to members. Topics covered included pumps, fans, ductwork, facades, economy cycle and outside air requirements and how practitioners can use Verification Methods to comply instead of the Deemed-to-Satisfy pathway.

9.3 Options for NT Government Assistance

The following options, could be considered by the NT Government to support the roll-out of new Section J requirements:

a) **Collaborate with industry peak bodies to provide training seminars.** As a first point of call, we recommend that the NT Government liaise with the local industry associations, such as the Australian Institute of Architects, the Building Designers Association of Australia, AIRAH and Master Builders Australia to organise training seminars. While Section J applies to all commercial buildings, particular focus should be placed on implications for offices, education and retail buildings classes, which comprise more than 60% of new building approvals**.**

b) **Develop NT-specific case study materials.** This may include specific illustrations of wall, floor and ceiling constructions suitable for NT conditions. The need for NT-specific case study materials arises because majority of the case studies available in the public domain has focussed on temperate climates, and not NT-specific climate conditions and design/construction practices. Consequently, the development of NT-specific case studies will ensure that resources relevant to Section J compliant requirements in the NT are available. We note that the DIPL Building Sustainable Design Guidelines is an excellent starting point for expansion of these case studies.

c) **Register and train practitioners such as building certifiers.** This may include introducing compulsory Continuing Professional Development (CPD) credits dedicated to NCC-training.

d) **Allocation of budget for government implementation and support.** As the introduction of Section J in the NT will be novel, adequate support and resources will be required to support the roll-out. The cost benefit analysis includes $500,000 per annum (under Appendix G.2.4) for positions for the administration of new aspects of the Code and development of relevant education and training material.

10 Conclusion

To assess the implications of adopting Section J in the NT, changes in construction cost and energy intensity between the base case archetypes and NCC2016 and NC2019 compliant building archetypes have been determined. This process required definition of base case archetypes, completion of a gap analysis to determine areas the base case archetypes are non-compliant in, and performance of analyses to determine the least-cost compliant construction details. The outputs of these analyses were used to the determined incremental construction cost associated with a compliant building archetype and model the changes to building energy intensity.

The incremental construction costs at a building level for adopting NCC2016 and NCC2019 were less than 2.6% and 2.4%, respectively. These figures include changes to the building fabric and services plus associated design consultants' fees. While the incremental construction costs for NCC2019 are similar to those of NCC2016, energy modelling results indicates that NCC2019 leads to significantly larger energy savings. Adoption of NCC2019 energy performance requirements results in energy savings (in kWh/m^2) of 13 – 40% (averages at 23% across all building archetypes in Darwin, and 29% for Alice Springs). Energy savings (kWh/m^2) associated with NCC2016 were present, albeit lower at 6 – 27% (12% for Darwin and 17% for Alice Springs).

Through conducting a cost benefit analysis, we find that NCC2019 significantly outperforms NCC2016. Adopting NCC2019 from FY2023, in both Tier 1 and Tier 2 areas, would generate positive net benefits from both societal and owner-occupier perspectives, on all core scenarios and assumptions examined. If 100% of the modelled energy savings are realised, NCC2019 produces a net social benefit for the NT of $276million (present value), with a BCR of 3.6. This is 2.7 three times the social NPV associated with implementing NCC2016 ($103million at a BCR of 2.0). From an owner-occupier perspective NCC2019 will have a NPV of just under $295million (BCR of 3.8) which is also 2.7 times larger than that of NCC2016 ($108million at a BCR of 2.0). Even when modelling the *least* favourable settings at the same time to, to demonstrate the worst-case scenario, NCC2019 remains cost-effective from both the social and owner-occupier perspectives ($89million and at $104million, and BCRs of 1.9 and 2.0, respectively). Under the same worse-case scenario assumptions the net social and private benefits of NCC2016 would both be positive, but significantly smaller (at $5million and $8million respectively) – both scenarios having a BCR of 1.1.

The cost benefit results indicate a strong case for the adoption of NCC2019 in the NT. We recommend that the NT Government introduce the NCC2019 Section J requirements.

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Appendix B – Base Case – Modelling Parameters and Assumptions

This section contains information on the base case construction and energy modelling parameters.

Appendix B.1 Base Case Parameters

B.1.1 Determination of the Base Case Construction

The determination of a "base case" was conducted in coordination with the following NT-based building industry professionals:

- Sunbuild (Darwin-based builder)
- FRM Refrigeration (Darwin-based air-conditioning and electrical services provider)
- Coldzap (Alice Springs-based air-conditioning and electrical services provider)
- Hoogland Consult (Darwin-based energy efficiency consultancy)

The general approach was to deem the "base case" as the typical construction of a private development for each respective archetype, where the developer has no specific requirements for energy performance. The rationale of this approach was to target the cost benefit analyses at developments that the adoption of Section J would have the greatest regulatory impact on, rather than higher-end commercial or government developments that may already be comparable to Section J. Note however that the base cases were not designed to represent the lowest end of the market either, but rather a "fit-for-purpose" average developments that represent industry contractors' business-as-usual experiences in each location.

In the case of the Hospital Ward building (archetype 9aC), the base case building services design concept was developed with a relatively higher focus on energy efficiency than that of the other archetypes, to better represent the reality that NT buildings in this class are most likely developed by private owner-occupiers or government entities.

> ***Note with respect to multi-storey/high-rise building archetypes in Alice Springs.***
>
> *The scope of this study focussed on six building archetypes in both Alice Springs and Darwin. Two of the archetypes were 10 storeys high. For simplicity of the scope, the general layout of these two buildings were unchanged in the Alice Springs models, despite those buildings being above height restrictions of their jurisdiction. Acknowledging that fact, assumptions regarding the building services of the "high-rise" buildings in Alice Springs were treated as though the buildings were actually only five storeys.*

B.1.2 Building Fabric

Base case building fabric construction in Darwin was generally deemed to be equivalent to that of Alice Springs. Unless specifically noted, the building fabric descriptions below apply to the base case in both Alice Springs and Darwin.

B.1.2.1 External Walls

Two types of external wall construction were identified, as detailed in Table B-1.

Table B-1: Wall types and their applicability to building archetypes.

	Wall A (High rise)	Wall B (Standard)
Applicable to archetypes:	High-rise hotel and high-rise office buildings in Alice Springs and Darwin	All other buildings
Construction layers	• Rendered outer layer (10mm) • Blockwork (190mm) • Battens providing an air gap (25mm) • Plasterboard (13mm)	• Rendered outer layer (10mm) • Blockwork (190mm) • Rendered inner layer (10mm)
Solar absorptance	Light colour (set as 0.45 in the model)	Light colour (set as 0.45 in the model)

B.1.2.2 Roofs

Two types of roof constructions are identified, as detailed in Table B-2.

Table B-2: Roofing types and their applicability to building archetypes.

	Roof A	Roof B
Applicable to archetypes:	High-rise hotel and high-rise office buildings in Darwin & Alice Springs	All other buildings
Construction layers	• Metal sheet roof (0.48mm) • Sarking (0.8mm) • Purlins providing air gap (300mm) • Concrete slab (200mm) • Air gap (300mm) • Suspended plasterboard (13mm)	• Metal sheet roof(0.48mm) • Sarking (0.8mm) • Glasswool insulation (R1.5, 75mm, non-reflective) on the underside of the roof, compressed at steel purlins • Air gap (300mm, measured at wall) • Suspended ceiling tiles
Pitch	Flat	15°C
Overhang	No overhang	1,000mm overhang over external wall
Solar absorptance	Light colour	Light colour

B.1.2.3 Non-External Envelope Walls

Non-external walls which form part of the building envelope (such as walls to fire stairs or lift wells) were treated as single skin 200mm blockwork for all building types, rendered on both sides.

B.1.2.4 Internal Non-Envelope Walls

The parameters in Table B-3 were modelled for buildings in Darwin and Alice Springs.

Table B-3: Additional construction details used for energy modelling.

Building component	Construction Details
Non-Envelope Internal Wall	• 13mm plasterboard • 70mm air cavity • 13mm plasterboard

B.1.2.5 Shading of Walls

No shading of external walls was included in the base case construction, other than that provided by the 1,000mm overhang in the roof construction where is existed.

B.1.2.6 Floors

Table B-4: Floor types and their applicability to building archetypes.

	Floor A (Standard)	Floor B (Hotel)	Floor C (High-rise office)
Applicable to archetypes:	Low-rise buildings, slab on ground	Hotel, slab over carpark	High-rise office, slab over car park
Construction layers	• Vinyl tiles (8mm) • Concrete slab (100mm) • Vapour barrier (plastic membrane) • Sand bedding	• Carpet tiles (8mm) • Suspended concrete slab (150mm) •	• Vinyl tiles (8mm) • Suspended concrete slab (150mm)

B.1.2.7 Glazing

Glazing for all building types in Darwin was determined as single-glazed 6mm grey-tint float glass in a non-thermally broken aluminium frame.

Glazing for all building types in Alice Springs was determined as single-glazed 6mm clear float glass in a non-thermally broken aluminium frame.

As such, the glazing system was modelled in simulation software as follows:

- Darwin - single tinted glazing with total U-Value (including frame) of 6 $W/m^2{\cdot}K$ and SHGC of 0.53.
- Alice Springs – single clear glazing with total U-Value (including frame) of 6.1 $W/m^2{\cdot}K$ and SHGC of 0.75.

B.1.2.8 Shading of Glazing

Table B-5: Shading of glazing types and their applicability to building archetypes.

	Type A	Type B	Type C
Shading description	Horizontal opaque shade (600mm)	Horizontal opaque shade (800mm)	Opaque sun hoods (600mm), declined at 15°
Applicable to	High-rise hotel (class 3) buildings in Alice Springs and Darwin	High-rise office (class 5) buildings in Alice Springs and Darwin	Retail (class 6), school (class 9b) and healthcare (class 9a) buildings in Alice Springs and Darwin

No shading of the single storey office building windows was included other than that provided by the 1,000mm overhang in the roof construction.

B.1.2.9 Ceiling

This is modelled as 13mm plasterboard for buildings in Darwin and Alice Springs.

B.1.3 Building Services

Typical HVAC servicing in Darwin was found to be significantly different from that of Alice Springs and the base case models were built to reflect that.

B.1.3.1 HVAC

B.1.3.1.1 HVAC Configurations

A brief overview of the HVAC specifications for each base case building archetype in Darwin and Alice Springs is provided in Table B-6 – detailed HVAC specifications for Darwin and Alice Springs are presented in Table B-7 and Table B-8, respectively.

> ***Note concerning active dehumidification systems in Darwin***
>
> Note that an active dehumidification system was only included in the base case design for the Hospital archetype. Despite their strong advice that dehumidification should be included for commercial HVAC design in the Top End, FRM noted that in general, for a private low-to-medium range development such as what was targeted as the base case design, active dehumidification would typically not be included.

Table B-6: Brief overview of HVAC specifications for the base case building archetypes in Darwin and Alice Springs.

	Hotel (Class 3A)	Single-Storey Office (Class 5)	Multi-Storey Office (Class 5A)	Retail (Class 6B)	Hospital Ward (Class 9aC)	School (Class 9bH)
HVAC - Darwin	FCU, Air-cooled chilled water system, no heating.	One ducted air-cooled reverse cycle split unit	Constant speed AHU, Air-cooled chilled water system, no heating.	Ducted air-cooled reverse cycle split systems	VAV, AHU, air-cooled chilled water system, dehumidification, no space heating.	FCU, air-cooled chilled water system, no heating.
HVAC – Alice Springs	FCU, Air-cooled chilled water system, condensing boiler.	One ducted air-cooled reverse cycle split unit	Air-cooled reverse cycle VRF system with heat recovery.	Ducted air-cooled reverse cycle split systems	Air-cooled reverse cycle VRF systems	Air-cooled reverse cycle PACs

*FCU – Fan Coiled Unit, AHU – Air Handling Unit, VAV – Variable Air Volume, PAC – Direct expansion package plant

Table B-7: Typical Darwin HVAC configurations for selected building archetypes.

Item	Hotel (10 levels) (Class 3A)	Single-Storey Office (Class 5)	Multi-storey Office (10 levels) (Class 5A)	Retail (3 levels) (Class 6B)	Hospital Ward (1 level) (Class 9aC)	School (3 levels) (Class 9bH)
Cooling	Air-cooled chilled water	One ducted air-cooled reverse cycle split system	Air-cooled chilled water	Two ducted air-cooled reverse cycle split systems per level	Air-cooled chilled water	Air-cooled chilled water
Space Heating	No heating	Split system reverse cycle by default (as above)	No heating	Split systems reverse cycle by default (as above)	No dedicated space heating. Dehumidification reheat achieved via outside-air pre-cooling configuration with a run-around coil	No heating
Air delivery	One 3-speed FCU per guestroom	3-speed indoor unit	Two 3-speed AHUs (commissioned as constant-speed in operation) per floor, serving half the floor each	3-speed indoor unit	One variable volume AHU serving VAV terminals in each room (assuming 10x100m^2 rooms)	One 3-speed FCU per classroom commissioned as constant-speed in operation (assuming 9 classrooms per level)
Outside air ventilation	One variable speed outside air supply fan per floor, ducted to each FCU	Dedicated constant speed outside air supply fan to split unit, interlocked with split unit operation	One variable speed outside air supply fan per floor, ducted to each AHU	One dedicated constant speed outside air supply fan for each respective split unit	Variable volume outside air control integrated with the primary air handler	One dedicated in-line constant speed outside air fan per FCU
Control system	Centralised BMS with user control of FCU temperature setpoint and fan speed in each guest room	Proprietary split system controller within the zone	Centralised BMS with unitary controllers in the zone for each AHU, providing user control of AHU temperature setpoint	One proprietary split system controller within the zone for each system	Centralised BMS for control of all system components	Centralised BMS with push button control for classroom FCUs
Demand controlled ventilation	Not included	Not included	Not included	Not included	Included, driven by CO_2 sensors	Not included
Energy recovery ventilation	Not included	Not included	Not included	Not included	Not included	Not included
Economy cycle	Not included	Not included	Not included	Not included	Not included	Not included

Table B-8: Typical Alice Springs HVAC configurations for selected building archetypes (noting 10 storey designs based on 5 storey concepts given building height limitations in Alice Springs)

Item	Hotel (10 levels) (Class 3A)	Single-Storey Office (Class 5)	Multi-storey Office (10 levels) (Class 5A)	Retail (3 levels) (Class 6B)	Hospital Ward (1 level) (Class 9aC)	School (3 levels) (Class 9bH)
Cooling	Air-cooled chilled water	One reverse cycle ducted air-cooled split system	Air-cooled reverse cycle VRF system	Two ducted air-cooled reverse cycle split systems per level	Air-cooled reverse cycle VRF system	Air-cooled reverse cycle PAC units, three units per floor, each PAC serving four classrooms
Space Heating	Natural gas-fired modular condensing boiler providing a heating hot water	Reverse cycle split system (as above)	Reverse cycle VRF system with heat recovery (as above)	Reverse cycle split systems (as above)	Reverse cycle VRF system with heat recovery (as above)	Reverse cycle PAC units (as above)
Air delivery	One 3-speed chilled & heating hot water FCU per guestroom	3-speed indoor unit	Seven constant speed indoor units per floor	3-speed indoor units	One constant speed indoor unit per room, located in a central plant room (allowing 10x100m^2 rooms)	Variable speed supply air fans commissioned for constant flow operation
Outside air ventilation	One variable speed outside air supply fan per floor, ducted to each FCU	Outside air ducted to indoor unit and drawn under suction from the indoor unit fan, commissioned for constant flow	Two constant speed energy recovery ventilators per floor, ducted to indoor units	Dedicated constant speed energy recovery ventilator for each indoor unit	Two variable speed energy recovery ventilators, ducted to indoor units	Each PAC with dedicated dampers for outside air ventilation
Control system	Centralised BMS with user control of FCU temperature setpoint and fan speed in each guest room	Proprietary controller in zone	Centralised proprietary VRF system control	Third-party centralised BMS system controlling all HVAC	Third-party centralised BMS system controlling all HVAC	Third-party centralised BMS system controlling all HVAC
Demand controlled ventilation	Not included	Not included	Not included	Included, driven by CO_2 sensors	Included, driven by CO_2 sensors	Included, driven by CO_2 sensors
Energy recovery ventilation	Not included	Not included	Included (as noted above)	Included (as noted above)	Included (as noted above)	Not included
Economy cycle	Not included	Not included	Not included	Included, dedicated economy dampers for each indoor unit	Included, dedicated economy dampers for each indoor unit	Included, dedicated economy dampers for each indoor unit

B.1.3.1.2 Methodology

The project team's HVAC contractors provided typical equipment selections and general ductwork/pipework design principles that were used to inform assumptions regarding the efficiency of the base case HVAC systems. Basic designs were built for several of the archetypes in Darwin and Alice Springs based on the contractors' typical practice.

Details for various elements of the base case HVAC systems are provided below and tabulated in Table B-7 and Table B-8.

(a) Fan Systems

Supply air fan systems (FCUs / ducted splits etc.) were nominated by the project team's HVAC contractors for several relevant base case archetypes. Manufacturers were contacted to provide fan performance data and internal static pressure drops for the units.

(b) Pump Systems

The pumping systems for the chilled water network at the school archetype in Darwin and hotel in Alice Springs were assessed using the ABCB Pump System Calculator, with standard pipe sizing designed for 400 Pa/m, flow control configured as constant-speed and typical pump selection advised by the project team's HVAC contractor (and mechanical engineer).

(c) Ductwork and Pipework Insulation

Based on advice from the project team's HVAC contractors, informal consultations with other industry professionals and example documentation from local projects, standard ductwork and pipework insulation practice were applied to the base case.

(d) Heating Systems

The only archetype modelled with a gas-fired heating system is the hotel in Alice Springs. The system proposed by the project team's HVAC contractor as most common for a new installation was a gas-fired, condensing, modulating modular boiler-set with gross thermal efficiency >86%.

(e) Refrigerant Chillers

Air-cooled chillers feature in several of the base case archetypes. The project team's HVAC contractor provided details for selections typical in the Darwin market, which was extrapolated to the Alice Springs hotel.

(f) Unitary Air-Conditioning Equipment

Ducted split units, packaged air-conditioning units and variable refrigerant flow systems feature in several of the base case archetypes. Coefficient of Performance (COP) was acquired for these systems. We note that COP data was not able to be obtained for several of the nominated VRF systems.

B.1.3.2 Lighting

B.1.3.2.1 Methodology

The project team's local resources were able to provide lighting layouts for several recent developments in Alice Springs and Darwin. The project team's electrical contractors were consulted regarding typical lighting control strategies.

B.1.3.2.2 Lighting Hardware

Based on the assessments of recent developments, the lighting hardware in each base case archetype was modelled as LED technology. The maximum illumination power density used in the modelling is listed in Table B-9.

Table B-9: Base case lighting power density.

	Hotel (Class 3)	Single- and Multi-Storey Office (Class 5)	Retail (Class 6)	Hospital Ward (Class 9a)	School (Class 9bH)
Lighting Power Density (W/m^2)	5	4.5	14	2.5	4.5

B.1.3.2.3 Lighting Controls

Based on advice from the project team's electrical contractors, each base case archetype includes manual-only lighting controls for internal spaces, except for hotels which include automated switch-off via a key card system. Exterior lighting for all base case archetypes is controlled via daylight sensor.

It is acknowledged that automated lighting controls for internal spaces are common in Darwin and Alice Springs, however not necessarily by default; manual-only controls are also common for new constructions hence their representation in the base case archetypes.

B.1.4 Domestic Hot Water Heating

Electric storage systems are considered to be the standard domestic hot water (DHW) system for the majority of commercial buildings in both Alice Springs and Darwin. However, for hospitals and hotels, where DHW usage is greater, less energy-cost-intensive systems such as electric heat pumps or gas-fired technology were found to be more common. Heat pumps are assumed for these base case archetypes, with direct-electric storage systems assumed for the offices, retail and school buildings.

B.1.5 Energy Metering

Energy metering requirements for standard new constructions were found to typically be driven by billing requirements between landlords and tenants, rather than for efficiency monitoring purposes. As such, no energy metering other than retail utility meters was included in any of the base case archetypes in Alice Springs or Darwin.

B.1.6 Lifts

Based on informal industry consultation, the minimum standard practice for operating lifts in the base case archetypes match requirements specified in Section J of the 2019 NCC.

Appendix B.2 Base Case Energy Modelling Parameters

B.2.1 Internal Loads

Internal loads and operation profiles assumed for modelling all six building archetypes considered are as follows:

- Occupancy, lighting and equipment power density are modelled as per Table B-10, and operation profiles will be modelled as per Table B-11 to Table B-17.
- Infiltration for hotel rooms and all building archetypes, will be modelled as 0.7 Air Changes per Hour (ACH) throughout all zones when there is no mechanically supplied outdoor air; and 0.35 ACH at all other times.
- For underground carparks, infiltration was modelled as 2 ACH at all times (24/7).

Table B-10: Occupancy, lighting and equipment density for base case modelling.

	Hotel (Class 3)	Single- and Multi-Storey Office (Class 5)	Retail (Class 6)	Hospital Ward (Class 9a)	School (Class 9bH)
Occupancy Density (m^2/person)	15	10	3 (entry level) 5 (other levels)	10	2
Lighting Power Density (W/m^2)	5	4.5	14	2.5	4.5
Equipment Load Density (W/m^2)	6.4	11	5	5	5

Table B-11: Daily occupancy, lighting, equipment and HVAC operation profiles for Class 3 hotel base case modelling.

	Occupancy (Daily)	Lighting (Daily)	Equipment (Daily)	HVAC (Daily)
12:00am to 1:00am	90%	5%	20%	On
1:00am to 2:00am	90%	5%	20%	On
2:00am to 3:00am	90%	5%	15%	On
3:00am to 4:00am	90%	5%	15%	On
4:00am to 5:00am	90%	5%	15%	On
5:00am to 6:00am	80%	25%	15%	On
6:00am to 7:00am	70%	80%	40%	On
7:00am to 8:00am	60%	80%	80%	On
8:00am to 9:00am	60%	50%	50%	On
9:00am to 10:00am	30%	20%	30%	On
10:00am to 11:00am	10%	20%	20%	Off
11:00am to 12:00pm	10%	20%	20%	Off
12:00pm to 1:00pm	10%	20%	20%	Off
1:00pm to 2:00pm	10%	20%	20%	Off
2:00pm to 3:00pm	10%	20%	20%	Off
3:00pm to 4:00pm	10%	20%	20%	Off
4:00pm to 5:00pm	20%	20%	20%	On
5:00pm to 6:00pm	30%	50%	40%	On
6:00pm to 7:00pm	40%	50%	40%	On
7:00pm to 8:00pm	50%	50%	50%	On
8:00pm to 9:00pm	60%	50%	60%	On
9:00pm to 10:00pm	70%	50%	60%	On
10:00pm to 11:00pm	70%	50%	40%	On
11:00pm to 12:00am	90%	50%	20%	On

Table B-12: Weekday occupancy, lighting, equipment and HVAC operation profiles for Class 5 office base case modelling.

	Occupancy (Weekday)	Lighting (Weekday)	Equipment (Weekday)	HVAC (Weekday)
12:00am to 1:00am	0%	30%	25%	Off
1:00am to 2:00am	0%	30%	25%	Off
2:00am to 3:00am	0%	30%	25%	Off
3:00am to 4:00am	0%	30%	25%	Off
4:00am to 5:00am	0%	30%	25%	Off
5:00am to 6:00am	0%	30%	25%	Off
6:00am to 7:00am	0%	30%	25%	Off
7:00am to 8:00am	10%	40%	65%	On
8:00am to 9:00am	20%	90%	80%	On
9:00am to 10:00am	70%	100%	100%	On
10:00am to 11:00am	70%	100%	100%	On
11:00am to 12:00pm	70%	100%	100%	On
12:00pm to 1:00pm	70%	100%	100%	On
1:00pm to 2:00pm	70%	100%	100%	On
2:00pm to 3:00pm	70%	100%	100%	On
3:00pm to 4:00pm	70%	100%	100%	On
4:00pm to 5:00pm	70%	100%	100%	On
5:00pm to 6:00pm	35%	80%	80%	On
6:00pm to 7:00pm	10%	60%	65%	Off
7:00pm to 8:00pm	5%	60%	55%	Off
8:00pm to 9:00pm	5%	50%	25%	Off
9:00pm to 10:00pm	0%	30%	25%	Off
10:00pm to 11:00pm	0%	30%	25%	Off
11:00pm to 12:00am	0%	30%	25%	Off

Table B-13: Weekend occupancy, lighting, equipment and HVAC operation profiles for Class 5 office base case modelling.

	Occupancy (Weekend)	Lighting (Weekend)	Equipment (Weekend)	HVAC (Weekend)
12:00am to 1:00am	0%	30%	25%	Off
1:00am to 2:00am	0%	30%	25%	Off
2:00am to 3:00am	0%	30%	25%	Off
3:00am to 4:00am	0%	30%	25%	Off
4:00am to 5:00am	0%	30%	25%	Off
5:00am to 6:00am	0%	30%	25%	Off
6:00am to 7:00am	0%	30%	25%	Off
7:00am to 8:00am	0%	30%	25%	Off
8:00am to 9:00am	5%	40%	25%	Off
9:00am to 10:00am	5%	40%	25%	Off
10:00am to 11:00am	5%	40%	25%	Off
11:00am to 12:00pm	5%	40%	25%	Off
12:00pm to 1:00pm	5%	40%	25%	Off
1:00pm to 2:00pm	5%	40%	25%	Off
2:00pm to 3:00pm	5%	40%	25%	Off
3:00pm to 4:00pm	5%	40%	25%	Off
4:00pm to 5:00pm	5%	40%	25%	Off
5:00pm to 6:00pm	0%	30%	25%	Off
6:00pm to 7:00pm	0%	30%	25%	Off
7:00pm to 8:00pm	0%	30%	25%	Off
8:00pm to 9:00pm	0%	30%	25%	Off
9:00pm to 10:00pm	0%	30%	25%	Off
10:00pm to 11:00pm	0%	30%	25%	Off
11:00pm to 12:00am	0%	30%	25%	Off

Table B-14: Daily occupancy, lighting, equipment and HVAC operation profiles for Class 6 retail base case modelling.

	Occupancy (Daily)	Lighting (Daily)	Equipment (Daily)	HVAC (Daily)
12:00am to 1:00am	0%	40%	25%	Off
1:00am to 2:00am	0%	40%	25%	Off
2:00am to 3:00am	0%	40%	25%	Off
3:00am to 4:00am	0%	40%	25%	Off
4:00am to 5:00am	0%	40%	25%	Off
5:00am to 6:00am	0%	40%	25%	Off
6:00am to 7:00am	0%	40%	25%	Off
7:00am to 8:00am	10%	100%	70%	On
8:00am to 9:00am	20%	100%	70%	On
9:00am to 10:00am	20%	100%	70%	On
10:00am to 11:00am	15%	100%	70%	On
11:00am to 12:00pm	25%	100%	70%	On
12:00pm to 1:00pm	25%	100%	70%	On
1:00pm to 2:00pm	15%	100%	70%	On
2:00pm to 3:00pm	15%	100%	70%	On
3:00pm to 4:00pm	15%	100%	70%	On
4:00pm to 5:00pm	15%	100%	70%	On
5:00pm to 6:00pm	5%	100%	70%	On
6:00pm to 7:00pm	5%	100%	70%	Off
7:00pm to 8:00pm	0%	25%	10%	Off
8:00pm to 9:00pm	0%	25%	10%	Off
9:00pm to 10:00pm	0%	25%	10%	Off
10:00pm to 11:00pm	0%	25%	10%	Off
11:00pm to 12:00am	0%	25%	10%	Off

Table B-15: Daily occupancy, lighting, equipment and HVAC operation profiles for Class 9a hospital ward base case modelling.

	Occupancy (Daily)	Lighting (Daily)	Equipment (Daily)	HVAC (Daily)
12:00am to 1:00am	70%	5%	100%	On
1:00am to 2:00am	70%	5%	100%	On
2:00am to 3:00am	70%	5%	100%	On
3:00am to 4:00am	70%	5%	100%	On
4:00am to 5:00am	70%	5%	100%	On
5:00am to 6:00am	70%	25%	100%	On
6:00am to 7:00am	70%	80%	100%	On
7:00am to 8:00am	70%	80%	100%	On
8:00am to 9:00am	70%	50%	100%	On
9:00am to 10:00am	70%	20%	100%	On
10:00am to 11:00am	70%	20%	100%	On
11:00am to 12:00pm	70%	20%	100%	On
12:00pm to 1:00pm	70%	20%	100%	On
1:00pm to 2:00pm	70%	20%	100%	On
2:00pm to 3:00pm	70%	20%	100%	On
3:00pm to 4:00pm	70%	20%	100%	On
4:00pm to 5:00pm	70%	20%	100%	On
5:00pm to 6:00pm	70%	50%	100%	On
6:00pm to 7:00pm	70%	50%	100%	On
7:00pm to 8:00pm	70%	50%	100%	On
8:00pm to 9:00pm	70%	50%	100%	On
9:00pm to 10:00pm	70%	50%	100%	On
10:00pm to 11:00pm	70%	50%	100%	On
11:00pm to 12:00am	70%	5%	100%	On

Table B-16: Weekday occupancy, lighting, equipment and HVAC operation profiles for Class 9b school base case modelling.

	Occupancy (Weekday)	Lighting (Weekday)	Equipment (Weekday)	HVAC (Weekday)
12:00am to 1:00am	0%	20%	5%	Off
1:00am to 2:00am	0%	20%	5%	Off
2:00am to 3:00am	0%	20%	5%	Off
3:00am to 4:00am	0%	20%	5%	Off
4:00am to 5:00am	0%	20%	5%	Off
5:00am to 6:00am	0%	20%	5%	Off
6:00am to 7:00am	0%	20%	5%	Off
7:00am to 8:00am	5%	30%	30%	On
8:00am to 9:00am	75%	85%	85%	On
9:00am to 10:00am	90%	95%	95%	On
10:00am to 11:00am	90%	95%	95%	On
11:00am to 12:00pm	90%	95%	95%	On
12:00pm to 1:00pm	50%	80%	70%	On
1:00pm to 2:00pm	50%	80%	70%	On
2:00pm to 3:00pm	90%	95%	95%	On
3:00pm to 4:00pm	70%	90%	80%	On
4:00pm to 5:00pm	50%	70%	60%	On
5:00pm to 6:00pm	20%	35%	20%	Off
6:00pm to 7:00pm	20%	35%	20%	Off
7:00pm to 8:00pm	20%	35%	20%	Off
8:00pm to 9:00pm	10%	25%	10%	Off
9:00pm to 10:00pm	5%	20%	5%	Off
10:00pm to 11:00pm	5%	20%	5%	Off
11:00pm to 12:00am	5%	20%	5%	Off

Table B-17: Weekend occupancy, lighting, equipment and HVAC operation profiles for Class 9b school base case modelling.

	Occupancy (Weekend)	Lighting (Weekend)	Equipment (Weekend)	HVAC (Weekend)
12:00am to 1:00am	0%	20%	5%	Off
1:00am to 2:00am	0%	20%	5%	Off
2:00am to 3:00am	0%	20%	5%	Off
3:00am to 4:00am	0%	20%	5%	Off
4:00am to 5:00am	0%	20%	5%	Off
5:00am to 6:00am	0%	20%	5%	Off
6:00am to 7:00am	0%	20%	5%	Off
7:00am to 8:00am	0%	20%	5%	Off
8:00am to 9:00am	0%	20%	5%	Off
9:00am to 10:00am	0%	20%	5%	Off
10:00am to 11:00am	0%	20%	5%	Off
11:00am to 12:00pm	0%	20%	5%	Off
12:00pm to 1:00pm	0%	20%	5%	Off
1:00pm to 2:00pm	0%	20%	5%	Off
2:00pm to 3:00pm	0%	20%	5%	Off
3:00pm to 4:00pm	0%	20%	5%	Off
4:00pm to 5:00pm	0%	20%	5%	Off
5:00pm to 6:00pm	0%	20%	5%	Off
6:00pm to 7:00pm	0%	20%	5%	Off
7:00pm to 8:00pm	0%	20%	5%	Off
8:00pm to 9:00pm	0%	20%	5%	Off
9:00pm to 10:00pm	0%	20%	5%	Off
10:00pm to 11:00pm	0%	20%	5%	Off
11:00pm to 12:00am	0%	20%	5%	Off

B.2.2 HVAC Control Specifications

HVAC control specifications used for energy modelling differ depending on the building archetype and location. The following subsections detail the HVAC parameters that used in energy modelling.

Where fans ducted to single or multiple FCUs are modelled, the total fan pressure and efficiency used are summarised in Table B-18.

Table B-18: Total fan pressure and efficiency for fans serving FCUs.

	Fans serving single FCUs	Fans serving multiple FCUs
Total Fan Pressure	120Pa	170Pa
Fan Efficiency	14%	23%

B.2.2.1 Building Class 3A: Hotel

B.2.2.1.1 Darwin

- Constant volume FCUs are modelled to deliver the conditioned air to the zones. The FCU fan power used in the simulation is calculated as per Table B-19. Note that these values are used to size the fan motor in the simulation - the fan energy is not determined by directly multiplying these values by the conditioned area.
- The zone temperature range is set between 23°C and 24°C. The maximum and minimum supply air temperatures are set to be 22.5°C and 12°C, respectively. The supply air temperature is proportionally controlled by the zone air temperature.

Table B-19: Maximum fan motor power – supply and return fans.

Air-conditioning sensible load (W/m² of the floor area of the conditioned space)	Maximum fan motor power (W/m² of the conditioned space)
Up to 100	6.8
101 to 150	10.3

- One outside air fan is modelled to supply fresh air to each FCU. The outside air flow rates are calculated based on 7.5 l/s/person.
- Twin air-cooled chillers are modelled, and each has 60% of the chilled water loop capacity. The COP and IPLV of the chiller are modelled as per Table B-20. The impact of the part load, chilled water temperature and ambient conditions on the efficiency was considered in the simulation. Chilled water temperature was modelled to be 7°C.

Table B-20: COP and IPLV of air-cooled chillers.

Chiller Capacity (kW)	COP	IPLV
200 to 528	2.985	4.048
528 to 750	2.985	4.137

- The chilled water pumping system was modelled as a constant flow and constant pressure system. The chilled water pump power is modelled as per Table B-21. Note that these values are used to size the chilled water pump motor in the simulation – these values are not multiplied by the conditioned area to calculate the pump energy directly.

Table B-21: Maximum power of chilled water pumps.

Air-conditioning sensible load (W/m² of the floor area of the conditioned space)	Maximum chilled water pump power (W/m² of the conditioned space)
Up to 100	0.62
101 to 150	0.85

- No demand control, energy recovery or economy cycle is modelled.

B.2.2.1.2 Alice Springs

- Constant volume FCUs are modelled to deliver the conditioned air to the zones. The FCU fan power used in the simulation is calculated as per Table B-19. The zone setpoint is 22.5°C with a 1°C deadband and 1°C proportional band on either side. The maximum and minimum supply air temperatures are 30°C and 12°C, respectively. The supply air temperature is proportionally controlled by the zone air temperature.
- One outside air fan is modelled to supply fresh air to each FCU. The outside air flow rates are calculated based on 7.5 l/s/person.
- Twin air-cooled chillers are modelled, and each has 60% of the chilled water loop capacity. The COP and IPLV of the chiller are modelled as per Table B-20. The impact of the part load, chilled water temperature and ambient conditions on the efficiency is considered in the simulation. Chilled water temperature is modelled as 7°C.
- Chilled water pumping system is modelled as a constant flow and constant pressure system. The chilled water pump power is modelled as per Table B-21.
- Twin condensing boilers with efficiency of 86% is modelled. Each has 60% of the heating hot water loop capacity. The impact of the part load and heating hot water temperature on the efficiency is considered in the simulation. The heating hot water temperature was modelled to be 80°C.
- Primary-secondary heating hot water system is modelled. The heat hot water pumps are modelled as per Table B-22. Note that these values are used to size the heating hot water pump motor in the simulation – they are not multiplied by the conditioned area to calculate the pump energy directly.

Table B-22: Maximum heating hot water pump power.

Air-conditioning sensible load (W/m² of the floor area of the conditioned space)	Maximum heating hot water pump power (W/m² of the floor area of the conditioned space)
Up to 100	0.49
101 to 150	0.57

- No demand control, energy recovery or economy cycle is modelled.

B.2.2.2 Building Class 5 – Single-Storey Office Building

B.2.2.2.1 Darwin

- Constant volume split units are modelled to deliver the conditioned air to the zones. The zone setpoint is 22.5°C with a 1°C deadband and 1°C proportional band on either side. The maximum and minimum supply air temperatures are set to be 30°C and 12°C, respectively. The supply air temperature is proportionally controlled by the zone air temperature.
- Dedicated outside air fan supplies the outside air to the indoor units. One outside air fan per split unit is modelled. The outside air flow rate is calculated based on 7.5 l/s/person.
- The energy efficiency ratio of a split unit with a capacity up to 65 kW is set as per Greenhouse and Energy Minimum Standards (GEMS). For a split unit with a capacity greater than or equal to 65 kW,

the energy efficiency ratio was set to 2.9. The impact of the part load and ambient conditions on the efficiency was considered in the simulation.

- No demand control, energy recovery or economy cycle is modelled.

B.2.2.2.2 Alice Springs

- Constant volume split units are modelled to deliver the conditioned air to the zones. The zone setpoint is 22.5°C with a 1°C deadband and 1°C proportional band on either side. The maximum and minimum supply air temperatures are set to be 30°C and 12°C, respectively. The supply air temperature is proportionally controlled by the zone air temperature.
- Outside air is ducted to the indoor unit and drawn under suction from the indoor unit fan. The outside air flow rate is calculated based on 7.5 l/s/person.
- The energy efficiency ratio of split units with a capacity up to 65 kW is set as per GEMS. For split units with a capacity greater than or equal to 65 kW, the energy efficiency ratio was set to 2.9. The impact of the part load and ambient conditions on the efficiency was considered in the simulation.
- No demand control, energy recovery or economy cycle is modelled.

B.2.2.3 Building Class 5A – Multi-Storey Office Building

B.2.2.3.1 Darwin

- Two constant speed AHUs per floor are modelled to deliver the conditioned air to the zones. The FCU fan power used in the simulation is calculated as per Table B-19. The zone temperature range is set between 23°C and 24°C. The maximum and minimum supply air temperatures are set to be 22.5°C and 12°C, respectively. The supply air temperature is proportionally controlled by the zone air temperature.
- One outside air fan per floor is modelled to supply outside air to each AHU. The outside air flow rates are calculated based on 7.5 l/s/person.
- Twin air-cooled chillers are modelled, and each has 60% of the chilled water loop capacity. The COP and IPLV of the chiller are set as per Table B-20. The impact of the part load, chilled water temperature and ambient conditions on the efficiency was considered in the simulation. Chilled water temperature was modelled to be 7°C.
- Chilled water pumping system was modelled as constant flow and constant pressure system. The chilled water pump powers are modelled as per Table B-21.
- No demand control, energy recovery or economy cycle is modelled.

B.2.2.3.2 Alice Springs

- VRF systems are modelled to deliver the conditioned air to the zones. The zone setpoint is 22.5°C with a 1°C deadband and 1°C proportional band on either side. The maximum and minimum supply air temperatures are set to be 30°C and 12°C respectively. The supply air temperature is proportionally controlled by the zone air temperature.
- The VRF systems are modelled to be one outdoor unit and eight indoor units per floor.[31]

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[31] Note: This is similar to the number of zones modelled in the 2018 Decision RIS for NCC2019 (The Centre for International Economics, *Decision Regulation Impact Statement Energy Efficiency of Commercial Buildings*, 2018, https://ris.pmc.gov.au/sites/default/files/posts/2019/01/02_decision_ris_in_pdf.pdf)

- Two dedicated outside air fans, each with heat exchanger per floor are modelled to supply the outside air to the indoor units. One is to serve perimeter zones and the other is to serve centre zones. The outside air flow rate is calculated based on 7.5 l/s/person.
- The energy efficiency ratio of a VRF with a capacity up to 65 kW is set as per Greenhouse and Energy Minimum Standards (GEMS). For a VRF with a capacity greater than or equal to 65 kW, the energy efficiency ratio was set to 2.9. The impact of the part load and ambient conditions on the efficiency was considered in the simulation.
- No demand control or economy cycle is modelled.

B.2.2.4 Building Class 6B – Retail Building

B.2.2.4.1 Darwin

- Two ducted air-cooled split units per floor (six in total for the building) are modelled to deliver the conditioned air to the zones. One unit serves North and West zones and the other one serves South and East zones. The zone setpoint is 22.5°C with a 1°C deadband and 1°C proportional band on either side. The maximum and minimum supply air temperatures are set to be 30°C and 12°C respectively. The supply air temperature is proportionally controlled by the zone air temperature.
- The supply fans of indoor units are set as constant speed fans.
- Each split unit is modelled to have one outside air fan. The total pressure for the outside air fan is set as 150Pa. The outside air flow rate is calculated based on 7.5 l/s/person.
- The energy efficiency ratio of split units with a capacity up to 65 kW is set as per GEMS. For split units with a capacity greater than or equal to 65 kW, the energy efficiency ratio was set to 2.9. The impact of the part load and ambient conditions on the efficiency is considered in the simulation.
- No demand control or economy cycle is modelled.

B.2.2.4.2 Alice Springs

- Two ducted air-cooled split units are modelled to deliver the conditioned air to the zones. The zone setpoint is 22.5°C with a 1°C deadband and 1°C proportional band on either side. The maximum and minimum supply air temperatures are set to be 30°C and 12°C, respectively. The supply air temperature is proportionally controlled by the zone air temperature.
- The supply fans of the indoor units are set as constant speed fans.
- A dedicated outside air fan with heat exchanger per indoor unit is modelled. The outside air flow rate is calculated based on 7.5 l/s/person and modulated to control the CO_2 between 700ppm to 900ppm.
- The energy efficiency ratio of split units with a capacity up to 65 kW is set as per GEMS. For split units with a capacity greater than or equal to 65 kW, the energy efficiency ratio was set to 2.9.
- Dedicated drybulb economy cycle with dewpoint lockout at 14°C and drybulb lockout at 24°C is modelled for each indoor unit.

B.2.2.5 Building Class 9aC – Hospital Ward

B.2.2.5.1 Darwin

- The zone temperature is controlled by proportionally modulating the VAV damper position from minimum turndown position to 100% open position when the zone temperature increases from 23°C to 24°C. 30% minimum VAV turndown was used for perimeter zones and 50% for centre zones.

- The AHU cooling supply air temperature decreases from 22.5°C to 12°C as the zone temperature increases from 23.5°C to 24°C.
- The cooling supply air temperature will be reduced to 6°C when the relative humidity in the zone exceeds 60%. Then, the sub-cooled supply air is reheated by the outside air via a run-around coil.
- It is assumed that the supply air fan has variable pressure reset control strategy. The fan is modelled to exhibit a power turndown that is proportional to $X^{2.7}$ and the minimum turndown is set to 30%, where '*X*' is the ratio of the actual flow to the design flow.
- It is assumed that the relief air fan has fixed pressure reset control strategy. The fan is modelled to exhibit a power turndown that is proportional to X^2 and the minimum turndown is set to 30%, where '*X*' is the ratio of the actual flow to the design flow.
- The outside air flow rate is calculated based on 7.5 l/s/person and modulated to control the CO_2 between 700ppm to 900ppm.
- We assume the ward modelled is only a small part of the hospital and is served by a large central plant shared across the broader hospital complex. This assumption is consistent with the assumptions employed for the 2018 Decision RIS for the adoption of NCC2019[32]. Twin chillers are modelled, and each has 60% of the chilled water loop capacity. To supply the enough cooling to the broader hospital complex, we assume the capacity of each chiller is over 528 kW. The COP and IPLV of the chiller are modelled as per Table B-20 (p.93). The impact of the part load, chilled water temperature and ambient conditions on the efficiency is considered in the simulation. Chilled water temperature is modelled to be reset from 7°C to 10°C when outside air dewpoint drops from 22°C to 15°C.
- Primary pumping system with VSD control was modelled.

B.2.2.5.2 Alice Springs

- VRF systems are modelled to deliver the conditioned air to the zones. The zone setpoint is 22.5°C with a 1°C deadband and 1°C proportional band on either side. The maximum and minimum supply air temperatures are set to be 30°C and 12°C respectively. The supply air temperature is proportionally controlled by the zone air temperature.
- The VRF system is modelled to be one outdoor unit and eight indoor units. This is in line with the number of zones in the modelling geometry in 2018 RIS project.
- Two dedicated outside air fans with heat exchangers are modelled to supply the outside air to the indoor units. One outside air fan serves the North and West zones, and the other serves the South and East zones. The outside air flow rate is calculated based on 7.5 l/s/person and modulated to control the CO_2 between 700ppm to 900ppm.
- The energy efficiency ratio of a VRF with a capacity up to 65 kW is set as per Greenhouse and Energy Minimum Standards (GEMS). For a VRF with a capacity greater than or equal to 65 kW, the energy efficiency ratio was set to 2.9. The impact of the part load and ambient conditions on the efficiency was considered in the simulation.

[32] Decision Regulation Impact Statement (RIS) - Energy Efficiency of Commercial Buildings, Prepared for Australian Building Codes Board, The CIE, 2018 <https://www.abcb.gov.au/sites/default/files/resources/2020//Final_RIS_Energy_efficiency_of_commercial_buildings_DOC.docx >

- Dedicated drybulb economy cycle with dewpoint lockout at 14°C and drybulb lockout at 24°C is modelled for each indoor unit.

B.2.2.6 Building Class 9bH – School

B.2.2.6.1 Darwin

- Constant volume FCUs are modelled to deliver the conditioned air to the zones. The FCU fan power used in the simulation is calculated as per Table B-19. The zone temperature range is set between 23°C and 24°C. The maximum and minimum supply air temperatures are set to be 22.5°C and 12°C respectively. The supply air temperature is proportionally controlled by the zone air temperature.
- One outside air fan per FCU is modelled. The outside air flow rates are calculated based on 7.5 l/s/person.
- Twin air-cooled chillers are modelled and each has 60% of the chilled water loop capacity. The COP and IPLV of the chiller are set as per Table B-20. The impact of the part load, chilled water temperature and ambient conditions on the efficiency was considered in the simulation. Chilled water temperature was modelled to be 7°C.
- Chilled water pumping system was modelled as constant flow and constant pressure system. The chilled water pump powers are modelled as per Table B-21.
- No demand control, energy recovery or economy cycle is modelled.

B.2.2.6.2 Alice Springs

- Reverse cycle PACs are modelled to deliver conditioned air to the zones. The zone setpoint is 22.5°C with a 1°C deadband and 1°C proportional band on either side. The maximum and minimum supply air temperatures are 30°C and 12°C, respectively. The supply air temperature is proportionally controlled by the zone air temperature.
- The PAC supply fans are set as constant speed fans.
- Each PAC is modelled to have dedicated dampers for outside air ventilation. The outside air flow rate is calculated based on 7.5 l/s/person and modulated to control the CO_2 between 700ppm to 900ppm.
- The energy efficiency ratio of a PAC with a capacity up to 65 kW is set as per Greenhouse and Energy Minimum Standards (GEMS). For a PAC with a capacity greater than or equal to 65 kW, the energy efficiency ratio was set to 2.9. The impact of the part load and ambient conditions on the efficiency was considered in the simulation.
- Dedicated drybulb economy cycle with a dewpoint lockout at 14°C and a drybulb lockout at 24°C is modelled for each PAC.

Appendix C – Construction Gap Analysis

The base case constructions are detailed in Appendix B and are intended to provide a typical sample of low-to-medium grade private commercial developments with no particular focus on energy efficiency. Here we provide a gap analysis of the base case constructions against the energy efficiency requirements of Section J NCC2016 and Section J NCC2019.

Appendix C.1 Construction Gap Analysis

C.1.1 Building Fabric (Section J Parts J1 and J2)

Note concerning the treatment of thermal bridging in R-value calculations

It is a common misconception that thermal bridging is not required to be considered in total system R-value calculations under the requirements of Section J NCC2016. In fact, NCC2016 references AS/NZS 4859.1 which explicitly requires consideration of thermal bridging in R-value calculations. As such we have assessed R-values including the effect of thermal bridging wherever applicable. The perceived ambiguity surrounding this topic was resolved in the NCC2019 with a clear statement specifying the treatment of thermal bridging under clause J1.2 (e).

C.1.1.1 Roof and Ceiling Construction

Base case roof and ceiling constructions of all archetypes in both climate zones were found to be non-compliant with the Section J NCC2016 and Section J NCC2019 requirements. Total system R-values and shortfalls against the Section J requirements are presented in Table C-1 and Table C-2.

Table C-1: Roof and ceiling construction Section J NCC2016 gap analysis

Roof	Archetypes	Description	Total system R-value	Minimum system R-value (NCC2016)	System R-value shortfall (NCC2016)
A	High-rise hotel (3A) and high-rise office buildings (5A) in Darwin & Alice Springs	Flat suspended concrete slab with no insulation	0.43	3.2	2.77
B	All other buildings	Pitched metal roof with R1.5 roof blanket	1.87	3.2	1.14

Table C-2: Roof and ceiling construction Section J NCC2019 gap analysis

Roof	Archetypes	Description	Total system R-value	Minimum system R-value (NCC2019)	System R-value shortfall (NCC2019)
A	High-rise hotel (3A) and high-rise office buildings (5A) in Darwin & Alice Springs	Flat suspended concrete slab with no insulation	0.43	3.7	3.27
B	All other buildings	Pitched metal roof with R1.5 roof blanket	1.87	3.7	1.83

C.1.1.2 Walls (NCC2016 only)

Requirements for external walls and glazing are treated quite differently in NCC2016 and NCC2019 and are thus covered separately here. Refer to Section C.1.1.4 below for the assessment of walls against NCC2019 requirements as part of the wall-glazing construction.

Wall constructions in all base case archetypes are non-compliant with the requirements of Section J 2016. Total system R-values are presented in Table C-3 and compared therein to the minimum requirements applicable to each archetype. Minimum R-value requirements specified in Part J1.5 NCC2016 vary dependent upon a range of parameters such as orientation, shading and construction type. The default requirement for all external walls is R3.3. The following deductions apply to the base case archetypes in both Alice Springs and Darwin:

- Less R0.5 because the wall surface density is over 220 kg/m^3
- Less R0.5 because the solar absorptance of the wall is less than 0.6
- Less R0.5 for all south-facing walls
- For the single-storey office (200m^2), a R0.5 deduction also applies to non-south facing walls because the roof overhang shades the wall by 15-45 degrees (as defined in Figure J1.5 NCC2016) [33]

Part J1.5b NCC2016 also mandates minimum R-values for non-external walls that form part of the building envelope (i.e. walls that border between conditioned space and non-conditioned space). The walls surrounding the building core modelled in each of the base case archetypes meet this definition. Each construction falls below the minimum R-value requirement, for non-external envelope walls, as demonstrated in Table C-4.

[33] NCC2016 Table J1.5a allows for an alternative option for wall requirements "where the only space for insulation is provided by a furring channel, top hat section, batten or the like". In this scenario the required wall R-value is R1.4 and glazing performance requirements are increased to compensate for the lower wall R-value (see NCC2016 Option B of Table J2.4a). This option was considered under the series "E" wall constructions (see Table D-13) but was ultimately discarded as it was found not to be feasible to achieve R1.4 in these constructions when considering thermal bridging across the battens and the reduced performance of insulation compressed to fit within the channel.

Table C-3: External wall construction Section J NCC2016 gap analysis

Archetype	Base case: light coloured external wall description	Total system R-value	Minimum system R-value (NCC2016) for North, East & West facing walls	Minimum system R-value (NCC2016) for South facing walls
Hotel (3A)	Concrete blockwork with rendered outer layer, internal air gap and plasterboard	0.60	2.3	1.8
Single-Storey Office (5)	Concrete blockwork rendered on both sides	0.37	1.8	1.8
Multi-Storey Office (5A)	Concrete blockwork with rendered outer layer, internal air gap and plasterboard	0.60	2.3	1.8
Retail (6B)	Concrete blockwork rendered on both sides	0.37	2.3	1.8
Hospital Ward (9aC)	Concrete blockwork rendered on both sides	0.37	2.3	1.8
School (9bH)	Concrete blockwork rendered on both sides	0.37	2.3	1.8

Table C-4: Non-external envelope wall construction Section J NCC2016 gap analysis

Archetype	Non-external envelope wall description	Total system R-value	Minimum system R-value (NCC2016) for non-external envelope walls
All archetypes	Concrete blockwork rendered on both sides	0.45	2.3

C.1.1.3 Glazing (NCC2016 only)

All of the base case buildings' glazing (refer Appendix A section A.1.2.7) is non-compliant with the glazing requirements of Section J NCC2016. See Section C.1.1.4 for the assessment of glazing against NCC2019 requirements as part of the wall-glazing construction.

Glazing requirements in NCC2016 vary with numerous factors, including building class, climate zone, shading, orientation and wall construction. Glazing systems on some facades on some buildings were found to be compliant with Section J NCC2016. Compliance assessment results are presented per façade for each building in Table C-5, against "Option A" as defined in Table J2.4a Part J2.4 NCC2016.[34]

[34] The options relate to spatial allowance for insulation in the wall construction. Option B is more stringent and against it the only change to the results is that the north façades on the retail and school buildings in Alice Springs would not be compliant.

Table C-5: Glazing Section J NCC2016 gap analysis, per façade per building. Non-compliance is marked by an 'x'.

Location	Archetype	North façade	East façade	South façade	West façade
Alice Springs	Hotel (3A)	x	x	x	x
	Single-Storey Office (5)	x	x	Compliant	x
	Multi-Storey Office (5A)	x	x	Compliant	x
	Retail (6B)	Compliant	x	Compliant	x
	Hospital Ward (9aC)	x	x	Compliant	x
	School (9bH)	Compliant	x	Compliant	x
Darwin	Hotel (3A)	x	x	x	x
	Single-Storey Office (5)	x	x	Compliant	x
	Multi-Storey Office (5A)	x	x	x	x
	Retail (6B)	Compliant	x	Compliant	x
	Hospital Ward (9aC)	x	x	Compliant	x
	School (9bH)	Compliant	x	Compliant	x

C.1.1.4 Wall-Glazing Construction (NCC2019)

All base case buildings did not comply with the requirements for the wall-glazing construction of Section J NCC2019. Under NCC2019, walls and glazing are assessed together against minimum requirements for total U-values and solar admittance. The wall-glazing U-value is an area-weighted average of the thermal transmittance across both the wall and glazing components of the construction. The solar admittance represents the solar irradiance that adds heat to the building via the glazing component of the wall-glazing construction.

Systems can be assessed per orientation/aspect or for all aspects combined, as respectively defined under Method 1 and Method 2 in Specification J1.5a NCC2019. Under Method 2, the solar admittance of all aspects combined is assessed against a maximum *air-conditioning energy value* that represents the air-conditioning energy that would be achieved if all aspects accorded to the reference solar admittance. The orientation of the building impacts the assessment under Method 2 and as such the non-square buildings have been assessed in each orientation. Compliance assessment results are presented in Table C-8.

Irrespective of the wall-glazing combined assessment, minimum R-values apply for the wall components of the construction and are dependent upon building class, climate zone and whether or not they make up 80% of the wall-glazing construction. Minimum R-value requirements as per Part J1.5 (d) NCC2019 as applicable to the base case archetypes are presented in Table C-6. As confirmed in the table, all external walls in the base case archetypes are subject to a minimum R-value requirement of R1.0 under NCC2019. The non-external envelope walls[35] are subject to greater R-value requirements on the basis that the wall component is 100% of the wall-glazing construction (i.e. there are no windows in those constructions). Requirements vary between the base case archetypes based on building class and climate zone, and are demonstrated in Table C-7.

[35] As discussed in Section C.1.1.2, non-external envelope walls are those that border between conditioned and non-conditioned space. An example of this is the wall of a lift shaft. The walls surrounding the building core modelled in each of the base case archetypes meet this definition.

Table C-6: Minimum external wall R-values Section J NCC2019 gap analysis

Archetype	External wall description	Total system R-value	Minimum system R-value (NCC2019) for external walls (all orientations)
Hotel (3A)	Concrete blockwork with rendered outer layer, air gap and internal plasterboard	0.60	1.0
Single-Storey Office (5)	Concrete blockwork rendered on both sides	0.37	1.0
Multi-Storey Office (5A)	Concrete blockwork with rendered outer layer, air gap and internal plasterboard	0.60	1.0
Retail (6B)	Concrete blockwork rendered on both sides	0.37	1.0
Hospital Ward (9aC)	Concrete blockwork rendered on both sides	0.37	1.0
School (9bH)	Concrete blockwork rendered on both sides	0.37	1.0

Table C-7: Non-external envelope wall construction Section J NCC2019 gap analysis

Archetype	Location	Non-external envelope wall description	Total system R-value	Minimum system R-value (NCC2016) for non-external envelope walls
Hotel and hospital	Alice Springs & Darwin	Concrete blockwork rendered on both sides	0.45	3.3
Offices, retail, school	Alice Springs	Concrete blockwork rendered on both sides	0.45	1.4
Offices, retail, school	Darwin	Concrete blockwork rendered on both sides	0.45	2.4

Table C-8: Wall-glazing construction Section J NCC2019 gap analysis. Non-compliant elements are indicated by an "x". For compliance with Section J NCC2019 either all Method 1 U-value and solar admittance elements need to be compliant, or otherwise the Method 2 U-value and AC energy value need to be compliant.

			North façade (Method 1)		East façade (Method 1)		South façade (Method 1)		West façade (Method 1)		Multiple aspects (Method 2)	
Location	**Model**	**Orientation (long façade)**	**Wall-glazing U-value**	**Solar admittance**	**Wall-glazing U-value**	**Solar admittance**	**Wall-glazing U-value**	**Solar admittance**	**Wall-glazing U-value**	**Solar admittance**	**Wall-glazing U-value**	**AC energy value**
Alice Springs	Hotel (3A)	NA	x	x	x	x	x	x	x	x	x	x
	Single-Storey Office (5)	North/South	x	x	x	x	x	x	x	x	x	x
		West/East	x	x	x	x	x	x	x	x	x	x
	Multi-Storey Office (5A)	NA	x	x	x	x	x	x	x	x	x	x
	Retail (6B)	North/South	x	x	x	x	x	x	x	x	x	x
		West/East	x	x	x	x	x	x	x	x	x	x
	Hospital Ward (9aC)	NA	x	x	x	x	x	x	x	x	x	x
	School (9bH)	North/South	x	Compliant	x	Compliant	x	x	x	Compliant	x	x
		West/East	x	Compliant	x	Compliant	x	x	x	Compliant	x	x
Darwin	Hotel (3A)	NA	x	x	x	x	x	x	x	x	x	x
	Single-Storey Office (5)	North/South	x	x	x	x	x	x	x	x	x	x
		West/East	x	x	x	x	x	x	x	x	x	x
	Multi-Storey Office (5A)	NA	x	x	x	x	x	x	x	x	x	x
	Retail (6B)	North/South	x	Compliant	x	Compliant	x	x	x	Compliant	x	Compliant
		West/East	x	Compliant	x	Compliant	x	x	x	Compliant	x	Compliant
	Hospital Ward (9aC)	NA	x	x	x	x	x	x	x	x	x	x
	School (9bH)	North/South	x	Compliant	x	Compliant	x	x	x	Compliant	x	Compliant
		West/East	x	Compliant	x	Compliant	x	x	x	Compliant	x	Compliant

C.1.1.5 Floors

Several of the floor constructions in the base case archetypes are compliant with Section J NCC2016 and/or NCC2019. The requirements of NCC2016 and NCC2019 differ significantly in their treatment of floor system R-value calculations and minimum R-value requirements. The requirements differ as NCC2019 has been updated to reflect developments in the scientific understanding of thermal transmittance through floor constructions. As such both the calculation of the base case R-values and the minimum compliance requirements are different between NCC2016 and NCC2019. Results of the gap analyses against NCC2016 is presented in Table C-9 and the gap analysis against NCC2019 in Table C-10.

Table C-9: Floors Section J NCC2016 gap analysis

Floor type	Building	Total system R-value (NCC2016)	Minimum system R-value (NCC2016)	System R-value shortfall (NCC2016)
BC1 – Vinyl floor on slab on ground	All buildings not noted below	0.19	Nil	Compliant
BC2– Carpet tiles on suspended slab over car park	Hotel in Alice Springs	0.42	Nil	Compliant
BC2 – Carpet tiles on suspended slab over car park	Hotel in Darwin	0.42	1.00	0.58
BC3 – Vinyl floor on suspended slab over carpark	Multi-Storey Office in Alice Springs	0.33	Nil	Compliant
BC3 – Vinyl floor on suspended slab over carpark	Multi-Storey Office in Darwin	0.33	1.00	0.67

Table C-10: Floors Section J NCC2019 gap analysis

Floor type	Building	Total system R-value (NCC2019)	Minimum system R-value (NCC2019)	System R-value shortfall (NCC2019)
BC1 – Vinyl floor on slab on ground	Single-Storey Office 200m^2	1.59	2.00	0.41
	Retail	2.59	2.00	Compliant
	Hospital	2.89	2.00	Compliant
	School	2.39	2.00	Compliant
BC2 – Carpet tiles on suspended slab over a car park	Hotel	1.12	2.00	0.88
BC3 – Vinyl floor on suspended slab over car park	Multi-Storey Office	1.03	2.00	0.97

C.1.2 Building Sealing (Section J Part J3)

Each of the base case archetypes in both Alice Springs and Darwin is deemed to be compliant with Part J3 Building Sealing of NCC2016 and NCC2019. Part J3 largely refers to construction quality.

C.1.3 Building Services (Section J Parts J5, J6 and J7)

C.1.3.1 Air Conditioning and Ventilation Systems

The majority of base case archetypes are compliant with Part J5 Air-Conditioning and Ventilation Systems of NCC2016 and NCC2019. Instances of non-compliance are noted below.

Part J5 NCC2016 Non-Compliances

The following base case elements are not compliant with Part J5 NCC2016:

I. Clause J5.2 (c) NCC2016 - Chilled water pumping systems for the hotel, high-rise office and school buildings in Darwin are non-compliant on the basis that they have constant speed pump motors that are over 3 kW and need variable speed pumps to comply
II. Clause J5.2 (c) NCC2016 - Chilled water pumping systems for the hotel in Alice Springs are also non-compliant on the basis that they have constant speed pump motors that are over 3 kW and need variable speed pumps to comply

Part J5 NCC2019 Non-Compliances

The following base case elements are non-compliant with Part J5 NCC2019:

I. Clause J5.2 (viii) NCC2019 – Air-conditioning systems in each archetype in Alice Springs are non-compliant on the basis that they do not feature a zone control dead band between heating and cooling of at least 2°C.
II. Clause J5.2 (xi) NCC2019 – Chilled water systems in the hotel, high-rise office and school buildings in Darwin are non-compliant on the basis that they do not feature automatic variable control of the chilled water supply temperature setpoint.
III. Clause J5.2 (xi) NCC2019 – Chilled water and heating hot water systems in the hotel in Alice Springs are also non-compliant on the basis they are do not feature automatic variable control of the leaving water temperature setpoints.
IV. Clause J5.3 (a) (ii) (A) NCC2019 – Fresh air ventilation systems in the high-rise office, retail and school buildings in Darwin are non-compliant on the basis that they are over 500 l/s and do not feature demand-controlled ventilation.
V. Part J5.7 NCC2019 – Chilled water pumping systems for the hotel in both Alice Springs and Darwin are non-compliant on the basis that they operate >5,000 hours/year, have pipework pressure losses greater than 170 Pa/m and do not have variable-speed pumps.

C.1.3.2 Artificial Lighting and Power

The majority of base case archetypes are compliant with Part J6 Artificial Lighting and Power of NCC2016 and NCC2019. Instances of non-compliance are noted below.

Part J6 NCC2016 Non-compliances

The following base case elements are non-compliant with Part J6 NCC2016:

I. Clause J6.3 (d) NCC2016 – Lighting control systems in the high-rise office, retail and school buildings in both Alice Springs and Darwin are non-compliant on the basis that 95% of the light fittings are not controlled by a time switch or occupancy sensing device.

II. Clause J6.3 (e) NCC2016 – Lighting control systems in the high-rise office building in both Alice Springs and Darwin are non-compliant on the basis that lights in a natural lighting zone are not separately switched (from lights not within a natural lighting zone).

Part J6 NCC2019 Non-compliances

The following base case elements are non-compliant with Part J6 NCC2019:

I. Clause J6.3 (d) NCC2019 – Lighting control systems in the high-rise office, retail and school buildings in both Alice Springs and Darwin are non-compliant on the basis that 95% of the light fitting are not controlled by a time switch or occupancy sensing device (identical requirement to NCC2016).

II. Clause J6.3 (e) NCC2019 – Lighting control systems in the high-rise office building in both Alice Springs and Darwin are non-compliant on the basis that lights in a natural lighting zone are not separately switched (from lights not within a natural lighting zone) (identical requirement to NCC2016).

Note concerning lighting control in fire-isolated stairways, fire-isolated passageways and fire-isolated ramps.

Clause J6.3 (f) NCC2019 specifies that lighting in fire-isolated stairways, fire-isolated passageways and fire-isolated ramps need to be controlled by motion detectors. This requirement is not further considered in this report, since fire-isolated stairways, passageways and ramps are not modelled as part of this study. However, it is expected that most building in Darwin and Alice Springs do not comply with Clause J6.3 (f) NCC2019, on the basis that lighting in fire-isolated stairways, fire-isolated passageways and fire-isolated ramps are not controlled by motion detectors.

C.1.3.3 Heated Water Supply

The domestic hot water (DHW) systems in each of the base case archetypes (direct electric storage systems and electric heat pumps for hotels and hospitals) in both Alice Springs and Darwin were deemed to be compliant with Part J7.2 of NCC2016 and NCC2019.

C.1.4 Facilities for Energy Monitoring (Section J Part J8)

The hotel, high-rise office and school buildings in both Alice Springs and Darwin are non-compliant with the requirements of Part J8 Facilities for Energy Monitoring of NCC2016 and NCC2019, as follows:

I. Clauses J8.3 (b) & (c) NCC2016 & NCC2019 – These building archetypes in Alice Springs and Darwin are over 2,500 m^2 and do not include energy meters to record energy consumption of key systems as specified. NCC2019 also requires these systems to communicate to a common system that collates time-of-use energy consumption data to a single interface monitoring system where it can be stored, analysed and reviewed.

All other building archetypes (single-storey office, retail and hospital ward) are compliant with NCC2016 and NCC2019 because they are smaller than the floor area threshold (2,500m^2) and therefore do not require sub-system energy monitoring.

Appendix C.2 – Additional Notes Concerning NCC2019 Section J Compliance

C.2.1 Building Services HVAC

Basic designs for the base case HVAC systems were built for several of the archetypes in Darwin and Alice Springs based on the contractors' typical practice. These were tested for 2019 Section J compliance utilising the ABCB calculators for fan and pump systems.

C.2.1.1 Fan Systems

Fan performance data and internal static pressure drops for the units, provided by manufacturer, were assessed against Section J requirements. The data obtained allowed assessment of a fan coil unit for the hotel archetype, a ducted split system for the retail archetype and a packaged air-conditioner for the school archetype in Alice Springs. In each case, the individual fan component did not meet the efficiency requirements of Section J 2019. However, when assessed as a whole system (as per clause J5.4 (a) (ii), NCC2019), and employing standard practice assumptions for pressure drops of ductwork and components, each system did meet compliance requirements for Section J 2019 (using the ABCB Fan System Calculator).

This finding is consistent with general industry advice that the ductwork system requirements of Section J 2019 (J5.4 NCC2019) generally represent standard industry practice. The results were taken as typical and as such all base case archetypes are modelled with fan systems that meet Section J 2019 requirements (J5.4).

C.2.1.2 Pump Systems

The pumping system for the chilled water network at the school archetype in Darwin was assessed using the ABCB Pump System Calculator, with standard pipe sizing designed for 400 Pa/m, flow control configured as constant-speed and typical pump selection advised by the project team's HVAC contractor (and mechanical engineer). Similar to the case with the fan systems, the nominated pump did not meet the individual pump component efficiency requirements of Section J 2019. However, when assessed as a whole system operating less than 5,000 hrs per year (as per clause J5.7 (a) (ii) NCC2019), the system did meet compliance requirements for Section J 2019.

This finding is also consistent with general industry advice that the pipework system requirements of Section J 2019 (J5.7 NCC2019) represent standard industry practice. As such, the pumping systems of all relevant base case archetypes operating less than 5,000 hours per year are modelled as compliant with Section J 2019 requirements. The Section J 2019 requirements for pumping systems operating more than 5,000 hours are more stringent. Therefore, any base case building archetypes with constant speed pumps (namely, the hotel, multi-storey office and school archetypes in Darwin, as well as the hotel in Alice Springs) were found to be non-compliant with Section J 2019 requirements.

C.2.1.3 Ductwork and Pipework Insulation

Standard ductwork and pipework insulation practice were generally found to be consistent with Section J 2019 requirements. As such, all base case archetypes include ductwork and pipework insulation compliant with Section J 2019 requirements (J5.5 & J5.8 NCC2019).

C.2.1.4 Heating Systems

The systems proposed by the project team's Alice Springs HVAC contractor as most common for a new installation have a gross thermal efficiency >86%, which is consistent with Section J 2019 requirements (J5.9 (d) NCC2019).

C.2.1.5 Refrigerant Chillers

Air-cooled chillers were each shown to be compliant with Section J 2019 requirements (J5.10 NCC2019). Chillers in the base case archetypes have thus been modelled consistent with the minimum performance requirements specified in Table J5.10a. J5.10 NCC2019.

We note that during informal industry consultation it was identified by a Darwin-based mechanical engineer that it has been difficult to source Section J 2019 compliant air-cooled chillers in the capacity range 50-100 kWr. This finding is not relevant to the base case buildings in this study as air-cooled chillers are not typically selected to serve systems in this capacity range.

C.2.1.6 Unitary Air-Conditioning Equipment

Where Coefficient of Performance (COP) data was available (ducted split units, packaged air-conditioning units and variable refrigerant flow systems), the standard selections nominated by the project team's HVAC contractors were able to be proven compliant with the efficiency requirements of Section J 2019. As such, all base case archetype unitary air-conditioning equipment is modelled as compliant with Section J 2019 (J5.11 NCC2019).

C.2.2 Lifts

It is assumed that all lifts in the base case archetypes are compliant with Part J6.7 NCC2019. This assumption is made on the basis of discussions with engineers and suppliers from the vertical transport industry who have indicated that the Section J NCC2019 requirements for lifts are generally representative of minimum standard of equipment available via the industry's dominant suppliers.

Appendix D - Section J Compliance Options and Costings

This section provides details of the various options considered to address compliance gaps between the base case constructions and NCC requirements. The cost elements considered, and detailed specifications for NCC compliance are also provided here.

Building construction options are broken down into the following building elements:

- wall (Appendix D.1),
- roof (Appendix D.1),
- floor (Appendix D.4),
- glazing and shading (Appendix D.3).

Other cost elements considered and detailed in this section include:

- building services (Appendix D.5)
- facilities for energy monitoring (Appendix D.6)
- incremental design and consultancy fees (Appendix D.7), and
- decremental mechanical plant costs (Appendix D.8)

Details of the least-cost compliant option and incremental construction cost for each building archetype are detailed in Appendix E.

Appendix D.1 Roof Construction

All base case roof constructions require additional insulation to achieve Section J compliance. Options considered include various combinations of the following:

- Increasing the thickness and/or performance grade of base case roof blanket insulation
- Use of foil-faced insulation blankets to create reflective air gaps
- Application of rigid board insulation to the underside of roof slabs
- Use of roof-raising framing systems to reduce thermal bridging through roof blanket insulation

A summary of roof constructions, R-values and cost rates is provided in Table D-1. Detailed layer by layer descriptions are provided in Table D-2 to Table D-12. Note the following with respect to roof R-value calculations:

- Thermal performance of typical roofing materials are derived from Specification J1.3 NCC2016
- Thermal performance of reflective air gaps are derived from Specification J1.2 NCC2019
- The effective R-value of the insulation layer in each construction is calculated allowing for compromised performance due to compression of the insulation between purlins and the sheet metal roof, using Anderson Energy's *Roof Insulation Compression Calculator* available at https://andersonenergy.com.au/roof-insulation-compression-calculator (accessed April to August 2021)
- The high-rise roof system includes a suspended ceiling which hangs from the underside of the suspended slab. The ceiling space is assumed to be used as a return air plenum and therefore the plenum and ceiling tiles are not treated as part of the building envelope and thus not included in the system R-value calculations
- Where reflective layers are included in the construction, outer emittance is treated as <0.9 where the layer will face upward (and thus be visible to the public during construction) and <0.2 where the layer will face downward

Table D-1: Description and costing of compliance options for roof construction.

Roof type	Roof ID	Description	R-value	NCC2016 Compliant?	NCC2019 Compliant?	Darwin cost/m²	Alice Springs cost/ m²	Darwin incremental cost/ m²	Alice Springs incremental cost/ m²
High-rise slab roof	HR-BC1	Base case - Metal sheet roof over a concrete slab	0.43	No	No	$412	$454	n/a	n/a
	HR-A1	Metal sheet roof over a concrete slab with underslab R2.85 board insulation	3.28	Yes	No	$502	$553	$90	$99
	HR-B1	Metal sheet roof over a concrete slab with underslab R2.15 board insulation and a reflective air gap	3.42	Yes	No	$507	$558	$95	$104
	HR-B2	Metal sheet roof over a concrete slab with underslab R2.85 board insulation and a reflective air gap	4.12	Yes	Yes	$522	$575	$110	$121
	HR-C1	Metal sheet roof over a concrete slab with foil-faced R1.8 roof blanket insulation under roof and R0.2 foam insulation underslab	3.23	Yes	No	$450	$495	$38	$41
	HR-D1	Metal sheet roof over a concrete slab with foil-faced R2.5 roof blanket insulation under roof with a roof-raiser framing system	3.96	Yes	Yes	$460	$506	$48	$52
Low-rise metal roof	LR-BC1	Base case - Pitched metal roof with R1.5 roof blanket	1.87	No	No	$165	$182	n/a	n/a
	LR-A1	Pitched metal roof with R3.0 roof blanket and roof-raiser framing system	3.47	Yes	No	$178	$196	$13	$14
	LR-B1	Pitched metal roof with R1.8 reflective roof blanket and roof-raiser framing system	3.20	Yes	No	$177	$195	$12	$13
	LR-A2	Pitched metal roof with R3.3 roof blanket and roof-raiser framing system	3.76	Yes	Yes	$183	$202	$18	$20
	LR-B2	Pitched metal roof with R2.3 reflective roof blanket and roof-raiser framing system	3.70	Yes	Yes	$185	$204	$20	$22

Table D-2: Roof HR-BC1 detailed construction

Roof HR-BC1	Metal sheet roof over a concrete slab	
Layer	**Layer Description**	**R-value**
1	Outside air film	0.04
2	Metal sheet roof	0.00
3	Sarking	0.00
4	Air gap (300mm)	0.22
5	Concrete slab (200mm)	0.14
6	Air film (moving air)	0.03
Total		**0.43**

Table D-3: Roof HR-A1 detailed construction

Roof HR-A1	Metal sheet roof over a concrete slab with underslab R2.85 board insulation	
Layer	**Layer Description**	**R-value**
1	Outside air film	0.04
2	Metal sheet roof	0.00
3	Sarking	0.00
4	Air gap (300mm)	0.22
5	Concrete slab (200mm)	0.14
6	Underslab PIR board insulation (60mm)	2.85
7	Indoor air film	0.03
Total		**0.43**

Table D-4: Roof HR-B1 detailed construction

Roof HR-B1	Metal sheet roof over a concrete slab with underslab R2.15 board insulation and a reflective air gap	
Layer	**Layer Description**	**R-value**
1	Outside air film	0.04
2	Metal sheet roof	0.00
3	Sarking with a reflective underside surface facing the air gap and anti-glare outer surface	0.00
4	Reflective air gap (outer emittance <0.9, inner emittance <0.05)	1.06
5	Concrete slab (200mm)	0.14
6	Underslab PIR board insulation (45mm)	2.15
7	Inside air film	0.03
Total		**3.42**

Table D-5: Roof HR-B2 detailed construction

Roof HR-B2	Metal sheet roof over a concrete slab with underslab R2.85 board insulation and a reflective air gap	
Layer	**Layer Description**	**R-value**
1	Outside air film	0.04
2	Metal sheet roof	0.00
3	Sarking with a reflective underside surface facing the air gap and anti-glare outer surface	0.00
4	Reflective air gap (outer emittance <0.9, inner emittance <0.05)	1.06
5	Concrete slab (200mm)	0.14
6	Underslab PIR board insulation (60mm)	2.85
7	Inside air film	0.03
Total		**4.12**

Table D-6: Roof HR-C1 detailed construction

Roof HR-C1	Metal sheet roof over a concrete slab with foil-faced R1.8 roof blanket insulation under roof and R0.2 foam insulation underslab	
Layer	**Layer Description**	**R-value**
1	Outside air film	0.04
2	Metal sheet roof	0.00
3	Sarking	0.00
4	R1.8 insulation roof blanket (75mm) with bonded perforated foil facing down	1.54
5	Reflective air gap (outer emittance <0.2, inner emittance <0.05)	1.28
6	Concrete slab (200mm)	0.14
7	7mm foam insulation	0.20
8	Indoor air film	0.03
Total		**3.23**

Table D-7: Roof HR-D1 detailed construction

Roof HR-D1	Metal sheet roof over a concrete slab with foil-faced R2.5 roof blanket insulation under roof with a roof-raiser framing system	
Layer	**Layer Description**	**R-value**
1	Outside air film	0.04
2	Metal sheet roof	0.00
3	Sarking	0.00
4	R2.5 insulation roof blanket with roof raiser framing system (110mm) with bonded perforated foil facing down	2.47
5	Reflective air gap (outer emittance <0.2, inner emittance <0.05)	1.28
6	Concrete slab (200mm)	0.14
7	Indoor air film	0.03
Total		**3.96**

Table D-8: Roof LR-BC1 detailed construction

Roof LR-BC1	Pitched metal roof with R1.5 roof blanket	
Layer	**Layer Description**	**R-value**
1	Outside air film	0.04
2	Metal sheet roof	0.00
3	Sarking	0.00
4	R1.5 roof blanket insulation (75mm)	1.31
5	Air gap (300mm)	0.28
6	Suspended ceiling tiles	0.08
7	Internal air film	0.16
Total		**1.87**

Table D-9: Roof LR-A1 detailed construction

Roof LR-A1	Pitched metal roof with R3.0 roof blanket and roof-raiser framing system	
Layer	**Layer Description**	**R-value**
1	Outside air film	0.04
2	Metal sheet roof	0.00
3	Sarking	0.00
4	R3.0 roof blanket insulation (130mm)	2.91
5	Air gap (300mm)	0.28
6	Suspended ceiling tiles	0.08
7	Internal air film	0.16
Total		**3.47**

Table D-10: Roof LR-A2 detailed construction

Roof LR-A2	Pitched metal roof with R3.3 roof blanket and roof-raiser framing system	
Layer	**Layer Description**	**R-value**
1	Outside air film	0.04
2	Metal sheet roof	0.00
3	Sarking	0.00
4	R3.3 roof blanket insulation in roof-raiser framing system (140mm)	3.20
5	Air gap (300mm)	0.28
6	Suspended ceiling tiles	0.08
7	Internal air film	0.16
Total		**3.76**

Table D-11: Roof LR-B1 detailed construction

Roof LR-B1	Pitched metal roof with R1.8 reflective roof blanket and roof-raiser framing system	
Layer	**Layer Description**	**R-value**
1	Outside air film	0.04
2	Metal sheet roof	0.00
3	Sarking	0.00
4	R1.8 insulation roof blanket in roof-raiser framing system (75mm) with bonded perforated foil facing down	1.80
5	Reflective air gap (outer emittance <0.2, inner emittance <0.05)	1.12
6	Suspended ceiling tiles	0.08
7	Internal air film	0.16
Total		**3.20**

Table D-12: Roof LR-B2 detailed construction

Roof LR-B2	Pitched metal roof with R2.3 reflective roof blanket and roof-raiser framing system	
Layer	**Layer Description**	**R-value**
1	Outside air film	0.04
2	Metal sheet roof	0.00
3	Sarking	0.00
4	R2.3 insulation roof blanket in roof-raiser framing system (100mm) with bonded perforated foil facing down	2.30
5	Reflective air gap (outer emittance <0.2, inner emittance <0.05)	1.12
6	Suspended ceiling tiles	0.08
7	Internal air film	0.16
Total		**3.70**

Appendix D.2 Wall Construction

All base case wall constructions require additional R-value to achieve Section J compliance. Over 40 different wall constructions were assessed, summarised as follows:

- Blockwork wall construction with reflective air gaps and no insulation
- Blockwork wall construction with bulk insulation in a thermally broken steel frame
- Blockwork wall construction with a reflective air gap and bulk insulation in a thermally broken steel frame
- Blockwork wall construction with insulation blankets laid between thermally broken top hat spacers

Note the following with respect to least-cost compliance analysis of wall constructions:

- For the archetypes that do not have multiple floors, rigid board insulation could also be considered for application in the blockwork wall construction (these insulation products are typically not available as options in multi-storey constructions due to the requirements of NCC Section C - Fire Resistance).
- Application of insulation to the external surface of the blockwork was discussed with Sunbuild and eliminated in the early stages of analysis due to the relatively higher construction cost (compared to insulating on the internal surface).
- In the unique case of the NCC2019-compliant constructions for non-external envelope walls (around lift wells) in the hotel archetypes in Darwin and Alice Springs, an unusual construction was required to achieve the minimum R-value of R3.3. This was modelled as a dual blockwork cavity wall with blow-in insulation.
- In all cases, the Section J compliant walls are incrementally thicker than the base case wall constructions. In order to account for this from a capital cost perspective, the total incremental costs for each building include allowance to increase the building footprint such that the occupied floor area of the compliant model is equal to that of the base case construction.

Details and costs of all wall constructions considered are provided in the following sections.

D.2.1 Wall Construction Options and Cost Summary

All wall constructions considered in the analysis are summarised in Table D-13. A number of options considered were not eventually employed in the models. Detailed layer by layer descriptions are provided in Appendix D.2.3 for those walls that were used in either the base case or Section J compliance models. The R-values for all constructions were calculated using the NCC2019 Façade Calculator Volume One which includes calculation of the significant thermal bridging that occurs in layers that include insulation and steel members such as steel frames and top hat battens.

Table D-13: Description and costing of options reviewed for walls. Walls that are only applicable to ground floor buildings, due to fire code, have a star (*) after the Wall IDs (Column 1). (Prices provided are in dollars per sqm of wall surface area).

Wall ID	Description	Total thickness (mm)	Total R-value	Darwin cost/m² surface area	Alice Springs cost/ m² surface area
BC1	Base case high rise external wall - rendered single skin blockwork with plasterboard	238	0.58	$234	$258
BC2	Base case low rise external wall - rendered single skin blockwork	210	0.35	$215	$237
BC3	Base case non-external envelope wall - rendered single skin blockwork	210	0.46	$215	$237
BC4	Steel frame construction base case - sensitivity analysis (R2.0 bulk insulation in 75mm frame with no thermal break)	89	0.59	$262	$289
BC5	Steel frame construction base case non-external envelope wall - sensitivity analysis (R2.0 bulk insulation in 75mm frame with no thermal break)	101	0.78	$262	$289
A1*	One reflective air gap created by spacers and foil bonded foam	241	1.10	$267	$294
B1*	Two reflective air gaps created by spacers and foil bonded foam	315	1.57	$314	$346
B2	Two reflective air gaps created by battens and double-sided reflective wrap	309	1.37	$312	$343
C1*	Direct stick insulation onto blockwork - 35mm PIR insulation board with integrated plasterboard	235	1.74	$254	$280
C2*	Direct stick insulation onto blockwork - 50mm PIR insulation board with integrated plasterboard	250	2.34	$255	$281
C3*	Direct stick insulation onto blockwork - 60mm PIR insulation board with integrated plasterboard	260	2.94	$257	$283
C4*	Direct stick insulation onto blockwork - 80mm PIR insulation board with integrated plasterboard	280	3.84	$259	$285
C5*	Direct stick insulation onto blockwork - 90mm PIR insulation board with integrated plasterboard	290	4.34	$260	$286
D1*	Blockwork wall with reflective air gap, R2.0 bulk insulation in a 75mm frame and foil-bonded foam	315	2.16	$322	$355
D2*	Blockwork wall with reflective air gap, R2.5 bulk insulation in a 92mm frame and foil-bonded foam	332	2.18	$326	$359
D3*	Blockwork wall with reflective air gap, R2.7 bulk insulation in a 92mm frame and foil-bonded foam	332	2.21	$330	$363
D4*	Blockwork wall with reflective air gap, R4.0 bulk insulation in a 150mm frame and foil-bonded foam	390	2.50	$341	$375
D5	Blockwork wall with reflective air gap, R2.0 bulk insulation in a 75mm frame and thermal break tape	318	1.86	$310	$341
D6	Blockwork wall with reflective air gap, R2.5 bulk insulation in a 92mm frame and thermal break tape	335	1.98	$314	$345
D7	Blockwork wall with reflective air gap, R2.7 bulk insulation in a 92mm frame and thermal break tape	335	2.01	$318	$350
D8	Blockwork wall with reflective air gap, R4.0 bulk insulation in a 150mm frame and thermal break tape	393	2.30	$329	$362
D9	Blockwork wall with reflective air gap, R4.0 bulk insulation in a 150mm frame and thermal break tape on both sides of steel frame	403	2.81	$340	$374
E1*	Blockwork wall with 50mm deep top hat spacers and R2.0 blanket insulation and foil-bonded foam ^	273	0.89	$285	$314
E2*	Blockwork wall with 50mm deep top hat spacers and R2.5 blanket insulation and foil-bonded foam ^	273	0.98	$289	$318

Wall ID	Description	Total thickness (mm)	Total R-value	Darwin cost/m^2 surface area	Alice Springs cost/ m^2 surface area
E3*	Blockwork wall with 50mm deep top hat spacers and R4.0 blanket insulation and foil-bonded foam ^	273	1.16	$293	$323
E4	Blockwork wall with 50mm deep top hat spacers and R2.0 blanket insulation and thermal break tape ^	273	0.73	$273	$300
E5	Blockwork wall with top hat spacers and R2.5 blanket insulation and thermal break tape ^	273	0.85	$277	$305
F1*	Steel frame construction with R2.0 bulk insulation in a 75mm frame and foil-bonded foam	99	1.39	$285	$314
F2*	Steel frame construction with R2.5 bulk insulation in a 92mm frame and foil-bonded foam	116	1.51	$289	$318
F3*	Steel frame construction with R2.7 bulk insulation in a 92mm frame and foil-bonded foam	116	1.54	$293	$323
F4*	Steel frame construction with R4.0 bulk insulation in a 150mm frame and foil-bonded foam	174	1.83	$304	$334
F5	Steel frame construction with R2.0 bulk insulation in a 75mm frame and thermal break tape	99	1.19	$273	$300
F6	Steel frame construction with R2.5 bulk insulation in a 92mm frame and thermal break tape	116	1.31	$277	$305
F7	Steel frame construction with R2.7 bulk insulation in a 92mm frame and thermal break tape	116	1.34	$281	$309
F8	Steel frame construction with R4.0 bulk insulation in a 150mm frame and thermal break tape	174	1.63	$292	$321
F-INT	Steel frame construction with R2.5 bulk insulation in a 92mm frame and thermal break tape - internal envelope wall	128	1.50	$277	$305
G1*	Steel frame construction with reflective air gap, foil-bonded foam and R2.0 bulk insulation in a 75mm frame	119	2.22	$307	$338
G2*	Steel frame construction with reflective air gap, foil-bonded foam and R2.5 bulk insulation in a 92mm frame	136	2.44	$311	$342
G3*	Steel frame construction with reflective air gap, foil-bonded foam and R2.7 bulk insulation in a 92mm frame	136	2.52	$315	$347
G4*	Steel frame construction with reflective air gap, foil-bonded foam and R4.0 bulk insulation in a 150mm frame	194	3.00	$326	$359

Wall ID	Description	Total thickness (mm)	Total R-value	Darwin cost/m^2 surface area	Alice Springs cost/ m^2 surface area
G5	Steel frame construction with reflective air gap, thermal break tape and R2.0 bulk insulation in a 75mm frame	119	2.02	$295	$325
G6	Steel frame construction with reflective air gap, thermal break tape and R2.5 bulk insulation in a 92mm frame	136	2.24	$299	$329
G7	Steel frame construction with reflective air gap, thermal break tape and R2.7 bulk insulation in a 92mm frame	136	2.32	$303	$333
G8	Steel frame construction with reflective air gap, thermal break tape and R4.0 bulk insulation in a 150mm frame	194	2.80	$314	$345
G-INT	Steel frame construction with reflective air gap, thermal break tape and R2.5 bulk insulation in a 92mm frame - internal envelope wall	148	2.43	$299	$329
H1*	Direct stick insulation onto blockwork - PIR 25mm insulation board plus separate plasterboard	238	1.51	$245	$270
H2*	Direct stick insulation onto blockwork - PIR 40mm insulation board plus separate plasterboard	253	2.16	$246	$271
J1	Double blockwork wall with 90mm cavity filled with blow-in insulation	440	3.41	$382	$420

Note (^): Wall constructions labelled with ^ were considered theoretically to test the potential for application of Option B of Table J1.5a whereby required wall R-value is reduced considering the only space available for insulation is provided by “a furring channel, top hat section, batten or the like”. Allowing for thermal bridging across the spacer, and for compression of the insulation, it was found that the required R-value of R1.4 could not be achieved. Consequently, the constructions were discarded on that basis irrespective of whether or not it is practical to compress insulation to this thickness. Performance of insulation was derated at 50% of the compression ratio as per Kenna et al *Thermal Bridging – Calculations and Impacts* 2017 which references Appendix 2 NZS 4214.

D.2.2 Cost Impact of Increased Wall Thickness

In all cases, the Section J compliant walls are incrementally thicker than the base case wall constructions. In order to account for this from a capital cost perspective, the total incremental costs for each building include allowance to increase the building footprint such that the occupied floor area of the compliant model is equal to that of the base case construction.

Incremental costs for increased building footprint allow for:

- Increased area of slabs between floors in multi-storey buildings:
    - $300 per m^2 in Darwin
    - $330 per m^2 in Alice Springs
- Increased area of roofs:
    - Application of sqm cost rates for corresponding Section J least cost compliant roof selection
- Increased area of floors:
    - Application of sqm cost rates for corresponding Section J least cost compliant floor selection

D.2.3 Detailed Wall Constructions for Least Cost Compliant Options

Detailed layer by layer descriptions of walls that were used in either the base case or Section J compliance models are provided here.

Table D-14: Wall BC1 detailed construction

Wall BC1	Base case high rise external wall - rendered single skin blockwork with plasterboard		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	External surface resistance (moving air, more than 3m/s and not more than 7m/s wind speed)	-	0.03
2	Cement render	10	0.02
3	Concrete blockwork	190	0.17
4	Non-reflective air gap provided by 25mm spacers	25	0.17
5	Gypsum plasterboard	13	0.08
6	Internal surface resistance	-	0.12
Total		238	0.59

Table D-15: Wall BC2 detailed construction

Wall BC2	Base case low rise external wall - rendered single skin blockwork		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	External surface resistance (moving air, more than 3m/s and not more than 7m/s wind speed)	-	0.03
2	Cement render	10	0.02
3	Concrete blockwork	190	0.17
4	Cement render	10	0.02
5	Internal surface resistance	-	0.12
Total		210	0.36

Table D-16: Wall BC3 detailed construction

Wall BC3	Base case non-external envelope wall - rendered single skin blockwork		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	Internal surface resistance (still air)	-	0.14
2	Cement render	10	0.02
3	Concrete blockwork	190	0.17
4	Cement render	10	0.08
5	Internal surface resistance	-	0.12
Total		210	0.53

Table D-17: Wall BC4 detailed construction

Wall BC4	Steel frame construction base case external wall - sensitivity analysis (R2.0 bulk insulation in 75mm frame with no thermal break)		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	External surface resistance (moving air, more than 3m/s and not more than 7m/s wind speed)	-	0.03
2	Steel cladding	1	<0.01
3	Reflective sarking (AS4200.1 heavy duty Class 1 vapour and water barrier)	<1	0.00
4	75mm R2.0 bulk insulation in a 75mm frame with no thermal break (frame modelled as 16% of cross-sectional area, 50mm flange width and 1.15 Base Metal Thickness (BMT))	75	0.36
5	Gypsum plasterboard	13	0.08
6	Internal surface resistance	-	0.12
Total		89	0.59

Table D-18: Wall BC5 detailed construction

Wall BC5	Steel frame construction base case non-external envelope wall - sensitivity analysis (R2.0 bulk insulation in 75mm frame with no thermal break)		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	Internal surface resistance (still air)	-	0.14
2	Gypsum plasterboard	13	0.08
3	75mm R2.0 bulk insulation in a 75mm frame with no thermal break (frame modelled as 16% of cross-sectional area, 50mm flange width and 1.15 BMT)	75	0.36
4	Gypsum plasterboard	13	0.08
5	Internal surface resistance	-	0.12
Total		101	0.78

Table D-19: Wall C2 detailed construction

Wall C2	Direct stick insulation onto blockwork - 50mm PIR insulation board with integrated plasterboard		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	External surface resistance (moving air, more than 3m/s and not more than 7 m/s wind speed)	-	0.03
2	Cement render	10	0.02
3	Concrete blockwork	190	0.17
4	50mm PIR board insulation with integrated plasterboard	50	2.00
5	Internal surface resistance	-	0.12
Total		250	2.34

Table D-20: Wall C4 detailed construction

Wall C4	Direct stick insulation onto blockwork - 80mm PIR insulation board with integrated plasterboard		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	External surface resistance (moving air, more than 3m/s and not more than 7 m/s wind speed)	-	0.03
2	Cement render	10	0.02
3	Concrete blockwork	190	0.17
4	80mm PIR board insulation with integrated plasterboard	80	3.50
5	Internal surface resistance	-	0.12
Total		280	3.84

Table D-21: Wall D5 detailed construction

Wall D5	Blockwork wall with reflective air gap, R2.0 bulk insulation in a 75mm frame and thermal break tape		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	External surface resistance (moving air, more than 3m/s and not more than 7m/s wind speed)	-	0.03
2	Cement render	10	0.02
3	Concrete blockwork	190	0.17
4	Reflective air gap with inner surface emittance of 0.05 provided by 20mm spacers	20	0.48
5	Reflective sarking (AS4200.1 heavy duty Class 1 vapour and water barrier)	<1	0.00
6	75mm R2.0 bulk insulation in a 75mm frame with 10mm R0.2 thermal break tape applied to the edge of the frame (frame modelled as 16% of cross-sectional area, 50mm flange width and 1.15 BMT)	85	0.96
7	Gypsum plasterboard	13	0.08
8	Internal surface resistance	-	0.12
Total		318	1.86

Table D-22: Wall D8 detailed construction

Wall D8	Blockwork wall with reflective air gap, R4.0 bulk insulation in a 150mm frame and thermal break tape		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	External surface resistance (moving air, more than 3m/s and not more than 7m/s wind speed)	-	0.03
2	Cement render	10	0.02
3	Concrete blockwork	190	0.65
4	Reflective air gap with inner surface emittance of 0.05 provided by 20mm spacers (resistance included in concrete blockwork layer above)	20	0.00
5	Reflective sarking (AS4200.1 heavy duty Class 1 vapour and water barrier)	<1	0.00
6	140mm R4.0 bulk insulation in a 150mm frame with 10mm R0.2 thermal break tape applied to the edge of the frame (frame modelled as 16% of cross-sectional area, 50mm flange width and 1.15 BMT)	160	1.41
7	Gypsum plasterboard	13	0.08
8	Internal surface resistance	-	0.12
Total		393	2.31

Table D-23: Wall F5 detailed construction

Wall F5	Steel frame construction with R2.0 bulk insulation in a 75mm frame and thermal break tape		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	External surface resistance (moving air, more than 3m/s and not more than 7m/s wind speed)	-	0.03
2	Steel cladding	1	0.00
3	Reflective sarking (AS4200.1 heavy duty Class 1 vapour and water barrier)	<1	0.00
4	75mm R2.0 bulk insulation in a 75mm frame with 10mm R0.2 thermal break tape applied to the edge of the frame (frame modelled as 16% of cross-sectional area, 50mm flange width and 1.15 BMT)	85	0.97
5	Gypsum plasterboard	13	0.08
6	Internal surface resistance	-	0.12
Total		99	1.20

Table D-24: Wall G7 detailed construction

Wall G7	Steel frame construction with reflective air gap, thermal break tape and R2.7 bulk insulation in a 92mm frame		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	External surface resistance (moving air, more than 3m/s and not more than 7m/s wind speed)	-	0.03
2	Steel cladding	1	0.00
3	Reflective sarking (AS4200.1 heavy duty Class 1 vapour and water barrier)	<1	0.00
4	Reflective air gap with inner surface emittance of 0.05 provided by 20mm spacers (resistance included in insulation layer below)	20	0.00
5	90mm R2.7 bulk insulation in a 92mm frame with 10mm R0.2 thermal break tape applied to the edge of the frame (frame modelled as 16% of cross-sectional area, 50mm flange width and 1.15 BMT)	102	2.09
6	Gypsum plasterboard	13	0.08
7	Internal surface resistance	-	0.12
Total		136	2.32

Table D-25: Wall G-INT detailed construction

Wall G-INT	Steel frame construction with reflective air gap, thermal break tape and R2.5 bulk insulation in a 92mm frame - internal envelope wall		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	Internal surface resistance (still air)	-	0.14
2	Gypsum plasterboard	13	0.08
3	Reflective sarking (AS4200.1 heavy duty Class 1 vapour and water barrier)	<1	0.00
4	Reflective air gap with inner surface emittance of 0.05 provided by 20mm spacers (resistance included in insulation layer below)	20	0.00
5	90mm R2.5 bulk insulation in a 92mm frame with 10mm R0.2 thermal break tape applied to the edge of the frame (frame modelled as 16% of cross-sectional area, 50mm flange width and 1.15 BMT)	102	2.02
6	Gypsum plasterboard	13	0.08
7	Internal surface resistance	-	0.12
Total		148	2.44

Table D-26: Wall H1 detailed construction

Wall H1	Direct stick insulation onto blockwork - PIR 25mm insulation board plus separate plasterboard		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	External surface resistance (moving air, more than 3m/s and not more than 7m/s wind speed)	-	0.03
2	Cement render	10	0.02
3	Concrete blockwork	190	0.17
4	25mm PIR board insulation	25	1.09
5	Gypsum plasterboard	13	0.08
6	Internal surface resistance	-	0.12
Total		238	1.51

Table D-27: Wall H2 detailed construction

Wall H2	Direct stick insulation onto blockwork - PIR 40mm insulation board plus separate plasterboard		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	External surface resistance (moving air, more than 3m/s and not more than 7m/s wind speed)	-	0.03
2	Cement render	10	0.02
3	Concrete blockwork	190	0.17
4	40mm PIR board insulation	40	1.74
5	Gypsum plasterboard	13	0.08
6	Internal surface resistance	-	0.12
Total		253	2.16

Table D-28: Wall J1 detailed construction

Wall J1	Double blockwork wall with 90mm cavity filled with blow-in insulation		
Layer	**Layer Description**	**Thickness (mm)**	**R-value**
1	Internal surface resistance (still air)	-	0.14
2	Cement render	10	0.02
3	Concrete blockwork	190	0.17
4	Blow-in insulation in 90mm cavity	90	2.73
5	Concrete blockwork (140mm lightweight)	140	0.21
6	Cement render	10	0.02
7	Internal surface resistance	-	0.12
Total		440	3.41

Appendix D.3 Glazing and Shading

Options for glazing and shading upgrades were considered where required to reduce either or both the conduction of heat through windows, and/or the admittance of solar irradiance through windows. Glazing options considered are shown in Table D-29 - costings for these were provided by a local glazing distributor (Elements Glass). Shading options considered are shown in Table D-30. Sunbuild provided cost rates for horizontal shades in various widths, as well as louvered vertical shades (both external).

Table D-29: Description and costing of compliance options for glazing

Glazing ID	Description	U-value	SHGC	Darwin rate cost/ m^2 surface area	Alice Springs rate cost/ m^2 surface area
GL1	Clear single pane glazing (Alice Springs base case)	6.1	0.75	$80	$88
GL2	Grey tint single pane glazing (Darwin base case)	6	0.53	$85	$94
GL3	Single glazed HC low-E clear	4.1	0.64	$190	$209
GL4	Single glazed HC Low-E neutral	4.2	0.49	$205	$226
GL5	Single glazed HC low-E grey	4.2	0.43	$225	$248
GL6	Double glazed clear	3.5	0.64	$180	$198
GL7	Double glazed tint	3.5	0.42	$185	$204
GL8	Double glazed SC low-E clear	2.5	0.53	$290	$319
GL9	Double glazed SC low-E - neutral	2.4	0.25	$305	$336
GL10	Double glazed SC low-E - grey	2.4	0.21	$325	$358
GL11	Double glazed clear in thermally broken frame	2.9	0.64	$330	$363
GL12	Double glazed tint in thermally broken frame	2.9	0.42	$335	$369
GL13	Doubled glazed SC low-E clear in thermally broken frame	1.9	0.53	$440	$484
GL14	Double glazed SC low-E neutral in thermally broken frame	1.8	0.25	$455	$501
GL15	Double glazed SC low-E grey in thermally broken frame	1.8	0.21	$475	$523
HC = Hard Coat, SC = Soft/Sputter Coat					

Table D-30: Description and costings of compliance options for shading.

Shading ID	Description	Darwin rate cost/ m	Alice Springs rate cost/m
A1	600mm horizontal shade	$320	$352
B1	800mm horizontal shade	$410	$451
C1	1000mm horizontal shade	$500	$550
D1	1200mm horizontal shade	n/a	$700
E1	800mm projection with 300mm vertical hanging louvres that block >80% of solar radiation	$750	$825
E2	800mm projection with 500mm vertical hanging louvres that block >80% of solar radiation	$850	$935
E3	800mm projection with 700mm vertical hanging louvres that block >80% of solar radiation	$950	$1,045
E4	800mm projection with 900mm vertical hanging louvres that block >80% of solar radiation	$1,050	$1,155
E5	800mm projection with 1100mm vertical hanging louvres that block >80% of solar radiation	$1,150	$1,265
E6	800mm projection with 1300mm vertical hanging louvres that block >80% of solar radiation	$1,250	$1,375
E7	800mm projection with 1500mm vertical hanging louvres that block >80% of solar radiation	$1,350	$1,485
E8	800mm projection with 1700mm vertical hanging louvres that block >80% of solar radiation	$1,450	$1,595
E9	800mm projection with 1900mm vertical hanging louvres that block >80% of solar radiation	$1,550	$1,705
E10	800mm projection with 2100mm vertical hanging louvres that block >80% of solar radiation	$1,650	$1,815
F1	Exclude shading	$0	$0
G1	Single-storey office base case shading	$0	$0

Appendix D.4 Floor Construction

Floor constructions in several of the archetypes required R-value for compliance. Options for compliance are relatively limited in the case of floor constructions. For the constructions above suspended car parks, application of rigid board insulation underneath the slab was the only option identified. For slab on ground constructions, two options were considered:

- Application of extruded polystyrene insulation board underneath the slab
- Application of extruded polystyrene insulation board around the perimeter of the slab, in-between the slab and the slab wall

Table D-31 details and costs of all floor constructions considered.

Table D-31: Description and costings of compliance options for floor construction

Floor type	Description	Darwin cost/ m^2	Alice Springs cost/ m^2	Darwin cost/perimeter m	Alice Springs cost/perimeter m
BC1	Base case low-rise buildings concrete slab on ground with vinyl floor	$195	$215	NA	NA
BC2	Base case hotel suspended slab over car park with carpet tiles	$370	$407	NA	NA
BC3	Base case office suspended slab over car park with vinyl floor	$370	$407	NA	NA
CP-A	Suspended slab over car park with vinyl floor and 25mm R1.1 underslab PIR board insulation	$495	$545	NA	NA
CP-B	Suspended slab over car park with carpet tiles and 25mm R1.1 underslab PIR board insulation	$495	$545	NA	NA
GND-A	Slab on ground with 25mm R1.0 XPS board under slab	$218	$240	NA	NA
GND-B	Slab on ground with 25mm (thick) R1.0 XPS board with a vertical height of 750mm applied around perimeter of slab	NA	NA	$18	$20

Appendix D.5 Building Services Compliance Cost Rates

The compliance options to meet Section J requirements for building services follow straightforwardly from the gap analysis (see Section C.1.3). Advice on practicality and costing of the various compliance measures were provided by FRM and Coldzap. In most cases there was only one "option" to resolve compliance gaps. The only exceptions were:

- In the case of the hotel in Alice Springs and Darwin, upgrading pipe sizing to reduce pressure losses was discarded in favour of installation of a VSD for chilled water pumps to address the requirement of Part J5.7 NCC2019, on the basis of cost and consistency with current industry practice
- In the case of lighting control systems in the high-rise office, retail and school buildings in both Alice Springs and Darwin, occupancy sensors were discarded in favour of timeclocks to address the requirement of Clause J6.3 (d) NCC2016 and Clause J6.3 (e) NCC2019, on the basis of cost

Cost rates for building services compliance measures were determined in consultation with FRM and Coldzap and reconciled against the project team's internal experience in implementing these measures. The rates are presented in Table D-32.

Table D-32: Cost rates for building services compliance measures

Compliance measure	Cost unit	Darwin cost	Alice Springs cost
Increase the dead band between heating and cooling zone controls from 1°C to 2°C	$/zone	Nil	Nil
Apply an automatic variable chilled water leaving water temperature set point controlled via the Building Management System	$/plantroom	$4,100	$4,500
Apply an automatic variable heating hot water leaving water temperature set point controlled via the Building Management System	$/plantroom	n/a	$4,700
Apply demand-controlled ventilation for the high-rise office building, with CO_2 sensors installed for each AHU and variable speed outside air fans controlled via the Building Management System in response to CO_2 levels	$/building	$50,000	n/a
Apply demand-controlled ventilation for the retail building, with CO_2 sensors installed for each indoor unit, substitution of constant speed outside air fans for variable speed outside air fans, and addition of a dedicated controller installed for control of the fans in response to CO_2	$/building	$40,000	n/a
Include a variable speed drive for a 7.5 kW chilled water pump motor	$/pump	$6,000	$6,600
Include a variable speed drive for a 3.0 kW chilled water pump motor	$/pump	$3,500	n/a
Include a timeclock for a lighting circuit	$/timeclock	$460	$506
For the high-rise office building, include one additional lighting circuit for each perimeter on each floor, to allow perimeter lighting to be switched separately to internal lighting	$/floor	$1,280	$1,408

Appendix D.6 Facilities for Energy Monitoring Compliance Cost Rates

Several options for energy monitoring systems were considered to resolve compliance gaps with Part J8 NCC2016 & NCC2019, summarised as follows:

- Stand-alone hard-wired electricity sub-meters
- Hard-wired electricity sub-meters connected to a Building Management System (BMS) for remote reading (where the base case building already included a BMS)
- Hard-wired electricity sub-meters connected to a dedicated Energy Management System (EMS) for remote reading (allowing for the cost of installing a dedicated EMS)
- Wireless electricity sub-meters reporting to a cloud-based system for remote reading

The hard-wired systems are more traditional than the wireless options and were discussed with and priced by FRM and Coldzap. The wireless options were discussed and costed in consultation with Seeitek, the Australian distributor of Panoramic Power.

D.6.1 Energy Monitoring Costs

Cost rates for energy monitoring compliance measures were determined in consultation with FRM and Coldzap and reconciled against the project team's internal experience in implementing these measures. Costs for wireless energy monitoring options were determined in consultation with *Seeitek*, the Australian distributor for *Panoramic Power* metering systems. Rates are presented in Table D-33.

Table D-33: Cost rates for energy monitoring compliance measures

Energy monitoring compliance measure	Cost unit	Darwin cost	Alice Springs cost
Supply, install and commission an electricity meter (allowing for a 3ph, 100A unit)	$/meter	$1,170	$1,287
Connect an electricity meter to an existing Building Management System for remote reading capability	$/meter	$1,140	$1,254
Install a dedicated energy monitoring system to remotely read up to 20 meters	$/building	$26,800	$29,480
Supply and install a wireless metering system with cloud reporting for 21 metering points (assuming 3ph 100A per point)	$/building	$26,838	$29,522
Supply and install a wireless metering system with cloud reporting for 20 metering points (assuming 3ph 100A per point)	$/building	$26,467	$29,113
Supply and install a wireless metering system with cloud reporting for 8 metering points (assuming 3ph 100A per point)	$/building	$9,762	$10,738

D.6.2 Energy Monitoring System Design Assumptions

Energy monitoring systems were required for Section J compliance at each of the school, hotel and high-rise office archetypes. The following assumptions were made in determining the number of metering points required for each building:

- Hotel, total of 21 meters including:
  - 1 meter per floor on the light and power board, capturing power exclusively

- 2 parent meters on 2 light and power risers, providing lighting consumption via virtual meter
- 1 meter for lifts
- 1 meter for domestic hot water
- 1 meter for a floor-by-floor mechanical riser
- 2 meters for the rooftop plantroom
- 2 meters for the carpark
- 2 meters contingency

- High-rise office, total of 20 meters including:
  - 1 meter per floor on the light and power board, capturing power exclusively
  - 2 parent meters on 2 light and power risers, providing lighting consumption via virtual meter
  - 1 meter for lifts
  - 1 meter for a floor-by-floor mechanical riser
  - 2 meters for the rooftop plantroom
  - 2 meters for the carpark
  - 2 meters contingency
- School, total of 8 meters including:
  - 1 meter per floor on the light and power board, capturing power exclusively
  - 1 parent meter for 1 light and power riser, providing lighting consumption via virtual meter
  - 2 meters for the rooftop plantroom
  - 1 meter for floor-by-floor mechanical riser
  - 1 meter contingency

Appendix D.7 Incremental Design and Consultancy Fees

Incremental costs of Section J compliance associated with design and consultancy fees were assessed and added to the total incremental costs. Design and consultancy fees were considered in consultation with Sunbuild and various informal consultations with industry professionals. The incremental cost allowances are based on the following assumptions:

- ***Architectural design and consultancy fees.*** General industry feedback indicated that no increase in architectural fees would be expected specifically in relation to Section J compliance requirements. However, acknowledging that building fabric construction costs will increase, we have conservatively assumed that architectural fees will also increase in the same proportion.
- ***Mechanical engineering fees*.** Base case mechanical systems are generally compliant with Section J and industry advice was that designs are generally conducted in reference to Section J benchmarks irrespective of compliance requirements. We have made incremental allowances for mechanical engineering consultancy based on internal estimates of hours required for assessment of pump systems and fan systems using NCC Calculators.
- ***Electrical engineering fees.*** Base case lighting systems are generally compliant with Section J requirements. We have made incremental allowances for electrical engineering consultancy based on internal estimates of hours required for assessment lighting power densities. Where metering systems are required for compliance, we have also allowed for incremental engineering fees for meter system design.

- ***Third-party Section J compliance assessment fees.*** Allowances for third-party Section J compliance assessments have been included for each archetype, using the Deemed-To-Satisfy methodology. Indicative costs for these assessments were provided by an interstate-based consultancy and scaled up to allow for the conditions of the local market.

D.7.1 Architectural Design and Consultancy Fees

Assumptions for architectural design and consultancy fees were made in consultation with Sunbuild and their industry contacts, who advised typical allowances for total base case fees based on total construction cost, provided in Table D-34.

Table D-34: Architectural design and consultancy fees as a percentage of total construction cost

Building Model	Standard architectural fees (% of construction cost)
Hotel (3A)	2.0%
Multi-Storey Office (5A)	2.0%
Single-Storey Office (5)	4.0%
Retail (6B)	2.5%
Hospital Ward (9aC)	3.0%
School (9bH)	2.5%

Based on industry advice, no specific allowance is made for incremental architectural design and consultancy fees in relation to Section J compliance. Rather, incremental architectural fees have been assumed to increase in linear proportion to the impact on the total incremental cost on building fabric construction.

D.7.2 Engineering Consultancy Fees

Incremental engineering consultancy fees were estimated internally by the project team, allowing for:

- Incremental time required for mechanical engineering consultancy for assessment of pump systems and fan systems using NCC Calculators
- Incremental time required for electrical engineering consultancy for assessment of lighting power densities against Section J benchmarks
- Incremental time required for electrical engineering consultancy for metering system design
- Assuming a rate of $200 per hour
- Note that incremental design fees associated with the building services compliance measures (other than energy monitoring) are included in the rates specific to building services measures (see Section Appendix D.4)

Hours estimates for each of the above were based on the size of the buildings and number of relevant fan and pump systems. Results are detailed in Table D-35.

Table D-35: Incremental building services design and consultancy fees for both NCC2016 and NCC2019 compliance

Archetype / model	Mechanical engineering hours estimate	Electrical engineering hours estimate	Total building services engineering fee estimate
Hotel (3A) – Darwin	5	12	$3,400
Hotel (3A)– Alice Springs	6	12	$3,600
Multi-Storey Office– Darwin	4	12	$3,200
Multi-Storey Office– Alice Springs	4	12	$3,200
Single-Storey Office– Darwin	1	1	$400
Single -Storey Office– Alice Springs	1	1	$400
Retail (6B) – Darwin	4	1	$1,000
Retail (6B)– Alice Springs	4	1	$1,000
Hospital Ward (9aC) – Darwin	3	1	$800
Hospital Ward (9aC)– Alice Springs	4	1	$1,000
School (9bH)– Darwin	5	8	$2,600
School (9bH)– Alice Springs	4	8	$2,400

D.7.3 Third party Section J Compliance Assessment

Allowances for third-party Section J compliance assessments have been included for each archetype, using the Deemed-To-Satisfy methodology. Indicative costs for these assessments were provided by an interstate-based consultancy and scaled up to allow for the conditions of the local market. Allowances are detailed in Table D-36.

Table D-36: Third party Deemed-To-Satisfy Section J Compliance assessment fee for both NCC2016 and NCC2019.

Building	Deemed-To-Satisfy Section J Compliance Assessment Fee
Hotel (3A)	$4,800
Multi-Storey Office (5A)	$4,200
Single-Storey Office (5)	$1,800
Retail (6B)	$2,000
Hospital Ward (9aC)	$3,000
School (9bH)	$2,550

Appendix D.8 Decremental Mechanical Plant Costs Due to Reduced Capacity

Upgrade of the thermal performance of the building fabric (as required for Section J compliance) has the impact of reducing the capacity required of the HVAC plant. This will result in reduced capital requirement for HVAC plant and this negative cost impact has been included in the total incremental cost assessment.

Decremental plant costs were assessed in consultation with FRM and Coldzap, based on supply costs per unit of capacity of chillers, boilers, fan coil units and direct expansion cooling (DX) systems. Cost rates are provided in Table D-37.

Table D-37: Cost rates per unit of capacity for reduction in mechanical plant capacity

Decremental plant capacity costs	Unit	Rate
Air-cooled chiller	$ per kW_r	$272
Heating hot water boiler	$ per kW_{th}	$105
Fan coil unit / Air handling unit	$ per l/s	$4.28
DX plant (VRV / ducted split / PAC)	$ per kW_r	$374

Appendix E – Incremental Construction Costs and Least-Cost Compliant Construction

Appendix E.1 Incremental Construction Cost

E.1.1 Total Base Case Construction Cost

Total cost estimates for the base case buildings were developed. The purpose of these absolute construction cost estimates is solely to allow the incremental costs of Section J compliance to be contextualised as a percentage of the total cost of new development. **The total construction costs estimate only apply to the modelled building forms and are only intended for this study. They are not suitable for any other purposes and should not be used for the actual assessment of a construction project budget**.

The base case constructions are detailed in Appendix B, and the total construction cost estimates provided by Sunbuild are inclusive of building structure, services and standard internal fit-outs. The total cost estimates exclude allowance for site preparation and external works. All figures exclude GST.

Cost estimates have been developed by Sunbuild for the Darwin market and based on their advice, an additional 10% has been applied to the Alice Springs constructions to allow for incremental labour costs, transportation costs and market factors.

Table E-1: Base case total construction cost estimate

	Hotel (3A)	Single-Storey Office (5)	Multi-storey Office (5A)	Retail (6B)	Hospital Ward (9aC)	School (9bH)
Structure	$7,208,000	$230,000	$6,362,000	$1,340,000	$893,000	$1,688,000
Internal fitout & building services	$17,317,000	$275,000	$11,000,000	$1,620,000	$2,964,000	$3,446,000
Transportation systems	$600,000	$0	$600,000	$450,000	$0	$200,000
External services	$370,000	$110,000	$370,000	$220,000	$225,000	$220,000
Contingency (10%)	$2,549,000	$61,000	$1,833,000	$363,000	$408,000	$555,000
Prelims, overhead and margin (20%)	$5,609,000	$135,000	$4,033,000	$799,000	$898,000	$1,222,000
Design and consultancy	$673,000	$32,000	$484,000	$120,000	$162,000	$220,000
Total cost estimate (Darwin)	$34,326,000	$843,000	$24,682,000	$4,912,000	$5,550,000	$7,551,000
Total cost estimate (Alice Springs)	$37,759,000	$927,000	$27,150,000	$5,403,000	$6,105,000	$8,306,000

E.1.2 Section J NCC2016 and NCC2019 Compliance Costs

Total incremental costs of Section J NCC2016 and NCC2019 compliance for each model are presented in Table E-2 and Table E-3 respectively.

Table E-2: Incremental costs of NCC2016 compliance for each model in Darwin (DRW) and Alice Springs (ASP). For non-square buildings "N-S" denotes the orientation of the building with the longer façade facing North/South, and similarly for "W-E".

NCC2016-Compliant Building Model	Incremental building fabric costs	Incremental building services plant capacity costs	Incremental building services and energy monitoring compliance measures costs	Incremental design and consultancy fees	Total incremental cost	Incremental cost as % of total construction cost
Hotel (3A)- DRW	$795,719	-$139,018	$36,570	$24,114	$717,385	2.09%
Hotel (3A)- ASP	$549,150	-$133,900	$40,227	$19,883	$475,360	1.26%
Multi-Storey Office (5A) - DRW	$570,002	-$60,340	$57,400	$18,800	$585,863	2.37%
Multi-Storey Office (5A) - ASP	$461,029	-$83,028	$49,940	$17,021	$444,962	1.64%
Single-Storey Office (5) - DRW N-S	$11,667	-$1,234	$0	$2,667	$13,100	1.55%
Single-Storey Office (5) - DRW W-E	$13,222	-$898	$0	$2,729	$15,054	1.79%
Single-Storey Office (5) - ASP N-S	$9,891	-$1,122	$0	$2,796	$11,565	1.25%
Single-Storey Office (5) - ASP W-E	$10,907	-$1,945	$0	$2,836	$11,798	1.27%
Retail (6B)- DRW N-S	$128,119	-$18,700	$2,760	$6,203	$118,382	2.41%
Retail (6B) - DRW W-E	$151,520	-$21,318	$2,760	$6,788	$139,750	2.85%
Retail (6B) - ASP N-S	$118,329	-$16,082	$3,036	$6,158	$111,441	2.06%
Retail (6B) - ASP W-E	$130,059	-$20,570	$3,036	$6,451	$118,977	2.20%
Hospital (9aC) - DRW	$51,825	-$6,870	$0	$5,355	$50,309	0.91%
Hospital (9aC) - ASP	$39,380	-$8,228	$0	$5,481	$36,633	0.60%
School (9bH)- DRW N-S	$141,463	-$18,281	$38,440	$8,687	$170,308	2.26%
School (9bH)- DRW W-E	$155,554	-$15,233	$38,440	$9,039	$187,799	2.49%
School (9bH)- ASP N-S	$138,661	-$24,310	$34,584	$8,667	$157,602	1.90%
School (9bH)- ASP W-E	$134,036	-$26,180	$34,584	$8,551	$150,991	1.82%

Table E-3: Incremental costs of NCC2019 compliance for each model in Darwin (DRW) and Alice Springs (AS). For non-square buildings "N-S" denotes the orientation of the building with the longer façade facing North/South, and similarly for "W-E".

NCC2019-Compliant Building Model	Incremental building fabric costs	Incremental building services plant capacity costs	Incremental building services and energy monitoring compliance measures costs	Incremental design and consultancy fees	Total incremental cost	Incremental cost as % of total construction cost
Hotel (3A)- DRW	$685,005	-$125,427	$42,938	$21,900	$624,416	1.82%
Hotel (3A)- ASP	$794,955	-$218,284	$51,922	$24,799	$653,392	1.73%
Multi-Storey Office (5A) - DRW	$527,061	-$85,812	$114,567	$17,941	$573,757	2.32%
Multi-Storey Office (5A) - ASP	$446,205	-$75,922	$53,313	$16,724	$440,321	1.62%
Single-Storey Office (5) - DRW N-S	$14,411	-$1,346	$0	$2,776	$15,841	1.88%
Single-Storey Office (5) - DRW W-E	$14,411	-$748	$0	$2,776	$16,439	1.95%
Single-Storey Office (5) - ASP N-S	$14,303	-$4,114	$0	$2,972	$13,161	1.42%
Single-Storey Office (5) - ASP W-E	$14,303	-$2,207	$0	$2,972	$15,069	1.63%
Retail (6B)- DRW N-S	$117,978	-$47,498	$42,760	$5,949	$119,189	2.43%
Retail (6B) - DRW W-E	$117,978	-$48,620	$42,760	$5,949	$118,067	2.40%
Retail (6B) - ASP N-S	$97,767	-$20,944	$3,036	$5,644	$85,503	1.58%
Retail (6B) - ASP W-E	$97,767	-$24,310	$3,036	$5,644	$82,137	1.52%
Hospital (9aC) - DRW	$75,472	-$4,887	$0	$6,064	$76,649	1.38%
Hospital (9aC) - ASP	$90,322	-$20,944	$0	$7,010	$76,388	1.25%
School (9bH)- DRW N-S	$158,585	-$25,575	$35,942	$9,115	$178,066	2.36%
School (9bH)- DRW W-E	$163,548	-$24,139	$35,942	$9,239	$184,590	2.44%
School (9bH)- ASP N-S	$112,087	-$17,578	$35,026	$8,002	$137,537	1.66%
School (9bH)- ASP W-E	$112,087	-$12,716	$35,026	$8,002	$142,399	1.71%

Appendix E.2 Least-Cost Compliance Options Analysis Methodology

The building fabric and building services compliance options were each respectively costed by Sunbuild, FRM and Coldzap, and in most cases the least cost option for each construction element was straightforwardly selected from the schedule of rates. However, in the following cases identification of the least cost options were more complex:

- ***Walls for NCC2016 compliance***. Restrictions on rigid board insulation and foil-bonded foam insulation in NCC Section C - Fire Resistance, meant that wall constructions using either of these materials could only be considered for the ground-floor-only archetypes (i.e., the hospital and small office).
- ***Glazing and shading for NCC2016 compliance***. NCC2016 compliance analysis for glazing systems incorporates external shading of the glazing. Compliance is assessed independently on each aspect and is a factor of the U-value of the glazing system, the Solar Heat Gain Co-efficient (SHGC) of the glazing system, the dimensions of the glazing system and the dimensions of the shading element. In order to identify the least cost compliance option for each façade of each archetype, various permutations of shading types and glazing types were tested for compliance using the *NCC Volume One Glazing Calculator (first issued with NCC 2014)*. Numerous compliant options were identified, and the least cost scenario was selected.
- ***Walls, glazing and shading for NCC2019 compliance***. NCC2019 compliance analysis for wall-glazing systems incorporates glazing, shading and walls together in the same analysis. Compliance is a factor of glazing and shading parameters as per NCC2016, with wall U-value also considered, allowing increased glazing performance to be traded off against decreased wall performance and vice-versa. NCC2019 also allows for assessment of each aspect either in aggregate or independently, allowing increased performance on one façade to offset decreased performance on another. To identify the least compliance option for each archetype as a whole, various permutations of shading types, glazing types and wall constructions were tested for compliance using the *NCC Façade Calculator Volume One 2019*. Numerous compliant options were identified, and the least cost scenario was selected.

Floors for NCC2019 compliance. Part J1.6 NCC2019 allows for the assessment of R-value of floor constructions using the methodology prescribed in Section 3.5 of CIBSE Guide A, which allows for the consideration of insulation to be applied around the perimeter of the slab edge (as opposed to beneath the slab). Assessment of the NCC2019 least cost compliance option for floor construction in the small office building thus included calculation of the total cost of these two options.

Appendix E.3 Section J NCC2016 and NCC2019 Compliance Specification

E.3.1 Building Fabric

NCC2016 and NCC2019 building fabric compliance specifications are detailed in this section. The specifications are the result of extensive analysis of the various options available to resolve compliance gaps between the base case constructions and NCC requirements for roof, wall, glazing and floor constructions, of which the least-cost compliant solutions were selected for each.

The upgrade specifications generally include:

- Increased insulation and introduction of reflective air gaps in roof constructions
- Addition of insulation and reflective air gaps in wall constructions
- Higher glazing specification for reduced Solar Heat Gain Co-Efficient and increased U-Value
- Exclusion of shading where upgrade of glazing was identified as the least-cost solution
- Addition of insulation to floor constructions, where required

Detailed descriptions and figures are provided in Appendix C.

Based on the incremental costs for various construction options provided in Appendix D, the building fabric options that were found to offer the least cost compliant path to achieve NCC2016 Section J compliance are presented in Table E-4. The incremental building fabric construction cost for each NCC2016 Section J least cost compliant construction is presented in Table E-5. Similarly, building fabric options found to offer the least cost compliant path to achieve NCC2019 Section J compliance are presented in Table E-6; the associated incremental building fabric construction costs for each NCC2019 Section J least cost compliant construction is presented in Table E-7.

Table E-4: NCC2016 building fabric compliance specifications for various building archetypes in Darwin (DRW) and Alice Springs (ASP). For non-square buildings, "N-S" denotes orientation with the longer façade on the North/South, and "W-E" the longer façade on West/East. Reference to the specific construction acronyms can be found in Appendix D.

2016 Compliance Specification	Wall constructions					Roof construction	Floor construction	Glazing				Shading			
Model	**North**	**East**	**South**	**West**	**Non-external envelope walls**	**Roof**	**Floor**	**North**	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Hotel (3A)- DRW	D8	D8	D5	D8	D8	HR-C1	CP-B	GL10	GL9	GL9	GL15	F1	A1	F1	F1
Hotel (3A)- ASP	D8	D8	D5	D8	D8	HR-C1	BC2	GL2	GL9	GL2	GL9	B1	F1	F1	F1
Multi-Storey Office (5A) - DRW	D8	D8	D5	D8	D8	HR-C1	CP-A	GL9	GL9	GL4	GL9	F1	F1	F1	F1
Multi-Storey Office (5A) - ASP	D8	D8	D5	D8	D8	HR-C1	BC3	GL9	GL9	GL1	GL9	F1	F1	F1	F1
Single-Storey Office (5) - DRW N-S	H2	H2	H2	H2	BC3	LR-B1	BC1	GL4	GL7	GL2	GL5	G1	G1	G1	G1
Single-Storey Office (5) - DRW W-E	H2	H2	H2	H2	BC3	LR-B1	BC1	GL4	GL7	GL2	GL5	G1	G1	G1	G1
Single-Storey Office (5) - ASP N-S	H2	H2	H2	H2	BC3	LR-B1	BC1	GL2	GL4	GL1	GL2	G1	G1	G1	G1
Single-Storey Office (5) - ASP W-E	H2	H2	H2	H2	BC3	LR-B1	BC1	GL2	GL4	GL1	GL2	G1	G1	G1	G1
Retail (6B)- DRW N-S	D8	D8	D5	D8	D8	LR-B1	BC1	GL7	GL9	GL2	GL9	F1	F1	F1	F1
Retail (6B) - DRW W-E	D8	D8	D5	D8	D8	LR-B1	BC1	GL7	GL9	GL2	GL9	F1	F1	F1	F1
Retail (6B) - ASP N-S	D8	D8	D5	D8	D8	LR-B1	BC1	GL4	GL4	GL1	GL4	F1	F1	F1	F1
Retail (6B) - ASP W-E	D8	D8	D5	D8	D8	LR-B1	BC1	GL4	GL4	GL1	GL4	F1	F1	F1	F1
Hospital (9aC) - DRW	C2	C2	H2	C2	C2	LR-B1	BC1	GL5	GL9	GL2	GL9	F1	F1	F1	F1
Hospital (9aC) - ASP	C2	C2	H2	C2	C2	LR-B1	BC1	GL4	GL4	GL1	GL4	F1	F1	F1	F1
School (9bH)- DRW N-S	D8	D8	D5	D8	D8	LR-B1	BC1	GL5	GL4	GL2	GL4	F1	F1	F1	F1
School (9bH)- DRW W-E	D8	D8	D5	D8	D8	LR-B1	BC1	GL5	GL4	GL2	GL4	F1	F1	F1	F1
School (9bH)- ASP N-S	D8	D8	D5	D8	D8	LR-B1	BC1	GL4	GL2	GL1	GL2	F1	F1	F1	F1
School (9bH)- ASP W-E	D8	D8	D5	D8	D8	LR-B1	BC1	GL4	GL2	GL1	GL2	F1	F1	F1	F1

Table E-5: Incremental building fabric construction costs of NCC2016 compliant options for various building archetypes in Darwin (DRW) and Alice Springs (ASP) (additional cost to achieve compliance compared to base case building costs). For non-square buildings, "N-S" denotes orientation with the longer façade on the North/South, and "W-E" the longer façade on West/East.

Model (2016)	Wall constructions	Roof construction	Floor construction	Glazing	Shading	Incremental cost of increased building footprint	Total incremental building fabric cost
Hotel (3A)- DRW	$389,333	$37,945	$125,000	$372,678	-$192,011	$62,774	$795,719
Hotel (3A)- ASP	$425,712	$40,941	$0	$207,225	-$191,411	$66,684	$549,150
Multi-Storey Office (5A) - DRW	$348,265	$37,945	$125,000	$374,498	-$378,481	$62,774	$570,002
Multi-Storey Office (5A) - ASP	$380,811	$40,941	$0	$388,923	-$416,329	$66,684	$461,029
Single-Storey Office (5) - DRW N-S	$3,515	$3,280	$0	$3,912	$0	$960	$11,667
Single-Storey Office (5) - DRW W-E	$3,515	$3,280	$0	$5,468	$0	$960	$13,222
Single-Storey Office (5) - ASP N-S	$3,810	$3,553	$0	$1,470	$0	$1,058	$9,891
Single-Storey Office (5) - ASP W-E	$3,810	$3,553	$0	$2,486	$0	$1,058	$10,907
Retail (6B)- DRW N-S	$121,211	$9,709	$0	$46,909	-$66,544	$16,834	$128,119
Retail (6B) - DRW W-E	$123,825	$9,709	$0	$66,369	-$66,544	$18,161	$151,520
Retail (6B) - ASP N-S	$132,777	$10,519	$0	$29,700	-$73,199	$18,532	$118,329
Retail (6B) - ASP W-E	$135,653	$10,519	$0	$37,095	-$73,199	$19,992	$130,059
Hospital (9aC) - DRW	$25,444	$14,025	$0	$35,209	-$24,769	$1,916	$51,825
Hospital (9aC) - ASP	$27,922	$15,194	$0	$21,398	-$27,246	$2,112	$39,380
School (9bH)- DRW N-S	$167,963	$14,523	$0	$39,089	-$101,745	$21,633	$141,463
School (9bH)- DRW W-E	$173,650	$14,523	$0	$46,855	-$101,745	$22,271	$155,554
School (9bH)- ASP N-S	$183,978	$15,733	$0	$27,055	-$111,919	$23,814	$138,661
School (9bH)- ASP W-E	$190,234	$15,733	$0	$15,472	-$111,919	$24,516	$134,036

Table E-6: NCC2019 building fabric compliance specifications for various building archetypes in Darwin (DRW) and Alice Springs (ASP). For non-square buildings, "N-S" denotes orientation with the longer façade on the North/South, and "W-E" the longer façade on West/East. Reference to the specific construction acronyms can be found in Appendix D.

2019 Compliance Specification	Wall constructions					Roof construction	Floor construction	Glazing				Shading			
Model	**North**	**East**	**South**	**West**	**Non-external envelope walls**	**Roof**	**Floor**	**North**	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Hotel (3A)- DRW	D5	D5	D5	D5	J1	HR-D1	CP-B	GL9	GL9	GL9	GL9	F1	F1	F1	F1
Hotel (3A)- ASP	D5	D5	D5	D5	J1	HR-D1	CP-B	GL10	GL9	GL9	GL10	F1	F1	F1	F1
Multi-Storey Office (5A) - DRW	D5	D5	D5	D5	D9	HR-D1	CP-A	GL9	GL9	GL4	GL9	F1	F1	F1	F1
Multi-Storey Office (5A) - ASP	D5	D5	D5	D5	D5	HR-D1	CP-A	GL9	GL4	GL1	GL9	F1	F1	F1	F1
Single-Storey Office (5) - DRW N-S	H1	H1	H1	H1	BC3	LR-A2	GND-B	GL5	GL5	GL2	GL5	G1	G1	G1	G1
Single-Storey Office (5) - DRW W-E	H1	H1	H1	H1	BC3	LR-A2	GND-B	GL5	GL2	GL5	GL5	G1	G1	G1	G1
Single-Storey Office (5) - ASP N-S	C4	C4	C4	C4	BC3	LR-A2	GND-B	GL2	GL1	GL1	GL2	G1	G1	G1	G1
Single-Storey Office (5) - ASP W-E	C4	C4	C4	C4	BC3	LR-A2	GND-B	GL2	GL1	GL1	GL2	G1	G1	G1	G1
Retail (6B)- DRW N-S	D5	D5	D5	D5	D9	LR-A2	BC1	GL9	GL2	GL5	GL2	F1	F1	F1	F1
Retail (6B) - DRW W-E	D5	D5	D5	D5	D9	LR-A2	BC1	GL2	GL5	GL2	GL9	F1	F1	F1	F1
Retail (6B) - ASP N-S	D5	D5	D5	D5	D5	LR-A2	BC1	GL7	GL2	GL2	GL2	F1	F1	F1	F1
Retail (6B) - ASP W-E	D5	D5	D5	D5	D5	LR-A2	BC1	GL2	GL2	GL2	GL7	F1	F1	F1	F1
Hospital (9aC) - DRW	H1	H2	H2	H2	C4	LR-A2	BC1	GL9	GL9	GL9	GL9	F1	F1	F1	F1
Hospital (9aC) - ASP	H2	H2	H2	H1	C4	LR-A2	BC1	GL9	GL10	GL9	GL10	F1	F1	F1	F1
School (9bH)- DRW N-S	D5	D5	D5	D5	D9	LR-A2	BC1	GL7	GL5	GL5	GL7	F1	F1	F1	F1
School (9bH)- DRW W-E	D5	D5	D5	D5	D9	LR-A2	BC1	GL7	GL7	GL7	GL7	F1	F1	F1	F1
School (9bH)- ASP N-S	D5	D7	D5	D5	D5	LR-A2	BC1	GL2	GL2	GL2	GL6	F1	F1	F1	F1
School (9bH)- ASP W-E	D5	D5	D7	D5	D5	LR-A2	BC1	GL6	GL2	GL2	GL2	F1	F1	F1	F1

Table E-7: Incremental building fabric construction costs of NCC2019 compliant options for various building archetypes in Darwin (DRW) and Alice Springs (ASP) (additional cost to achieve compliance compared to base case building costs). For non-square buildings, “N-S” denotes orientation with the longer façade on the North/South, and “W-E” the longer façade on West/East.

Model (2019)	Wall constructions	Roof construction	Floor construction	Glazing	Shading	Incremental cost of increased building footprint	Total incremental building fabric cost
Hotel (3A)- DRW	$400,770	$47,931	$125,000	$330,359	-$256,015	$36,959	$685,005
Hotel (3A)- ASP	$438,293	$51,925	$138,000	$407,693	-$281,617	$40,660	$794,955
Multi-Storey Office (5A) - DRW	$321,154	$47,931	$125,000	$374,498	-$378,481	$36,959	$527,061
Multi-Storey Office (5A) - ASP	$315,605	$51,925	$138,000	$316,344	-$416,329	$40,660	$446,205
Single-Storey Office (5) - DRW N-S	$3,402	$4,920	$1,080	$4,374	$0	$635	$14,411
Single-Storey Office (5) - DRW W-E	$3,402	$4,920	$1,080	$4,374	$0	$635	$14,411
Single-Storey Office (5) - ASP N-S	$5,443	$5,466	$1,188	$454	$0	$1,751	$14,303
Single-Storey Office (5) - ASP W-E	$5,443	$5,466	$1,188	$454	$0	$1,751	$14,303
Retail (6B)- DRW N-S	$113,798	$14,564	$0	$44,584	-$66,544	$11,576	$117,978
Retail (6B) - DRW W-E	$113,798	$14,564	$0	$44,584	-$66,544	$11,576	$117,978
Retail (6B) - ASP N-S	$115,361	$16,182	$0	$26,674	-$73,199	$12,748	$97,767
Retail (6B) - ASP W-E	$115,361	$16,182	$0	$26,674	-$73,199	$12,748	$97,767
Hospital (9aC) - DRW	$22,268	$21,038	$0	$55,060	-$24,769	$1,875	$75,472
Hospital (9aC) - ASP	$24,175	$23,376	$0	$67,949	-$27,246	$2,069	$90,322
School (9bH)- DRW N-S	$148,528	$21,784	$0	$75,494	-$101,745	$14,523	$158,585
School (9bH)- DRW W-E	$148,528	$21,784	$0	$80,457	-$101,745	$14,523	$163,548
School (9bH)- ASP N-S	$164,721	$24,205	$0	$18,537	-$111,919	$16,543	$112,087
School (9bH)- ASP W-E	$164,721	$24,205	$0	$18,537	-$111,919	$16,543	$112,087

E.3.2 Building Services

Upgrades to the base case building services required to achieve NCC2016 and NCC2019 compliance provided in this section.

- Air-conditioning and ventilation systems upgrades are summarised in Table E-8
- Artificial light and power upgrades to the base case required are tabulated in Table E-9.
- Energy monitoring services upgrades to the base case are tabulated in Table E-10.
- Building services compliance costs are provided in Table E-11 (NCC2016) and Table E-12 (NCC2019). For details of costing rates, refer to Appendix D.5 and Appendix D.6.

Table E-8: Air-conditioning and ventilation systems upgrade scope for Section J NCC2016 and NCC2019 compliance

Location	Building	Upgrade scope for NCC2016 compliance	Upgrade scope for NCC2019 compliance
Alice Springs	Hotel (3A)	• Replace constant speed CHW pumps with variable speed pumps	• Replace constant speed CHW pumps with variable speed pumps • Incorporate a variable chilled water supply temperature setpoint to the CHW system • Incorporate a variable heating hot water supply temperature setpoint to the HHW system • Increase the control dead band between heating and cooling from 1°C to 2°C
	Single-storey office (5)	• No change to base case	• Increase the control dead band between heating and cooling from 1°C to 2°C
	Multi-storey office (5A)	• No change to base case	• Increase the control dead band between heating and cooling from 1°C to 2°C
	Retail (6B)	• No change to base case	• Increase the control dead band between heating and cooling from 1°C to 2°C
	Hospital Ward (9aC)	• No change to base case	• Increase the control dead band between heating and cooling from 1°C to 2°C
	School (9bH)	• No change to base case	• Increase the control dead band between heating and cooling from 1°C to 2°C
Darwin	Hotel (3A)	• Replace constant speed CHW pumps with variable speed pumps	• Replace constant speed CHW pumps with variable speed pumps • Incorporate a variable chilled water supply temperature setpoint to the CHW system
	Single-storey office (5)	• No change to base case	• Increase the control dead band between heating and cooling from 1°C to 2°C
	Multi-storey office (5A)	• Replace constant speed CHW pumps with variable speed pumps	• Replace constant speed CHW pumps with variable speed pumps • Incorporate a variable chilled water supply temperature setpoint to the CHW system • Incorporate demand-controlled ventilation on each respective floor whereby the outside air ventilation rate is modulated via the variable speed fan from the base case design rate down to a minimum rate (based on 0.35 l/s/m² as per AS 1668.2) as the zone CO_2 level reduces from 800ppm to 700ppm
	Retail (6B)	• No change to base case	• Increase the control dead band between heating and cooling from 1°C to 2°C • Incorporate demand-controlled ventilation on each respective split system whereby the outside air ventilation rate is modulated via the variable speed fan from the base case design rate down to a minimum rate (based on 0.35 l/s/m² as per AS 1668.2) as the zone CO_2 level reduces from 800ppm to 700ppm
	Hospital Ward (9aC)	• No change to base case	• No change to base case
	School (9bH)	• Replace constant speed CHW pumps with variable speed pumps	• Incorporate a variable chilled water supply temperature setpoint to the CHW system

Table E-9: Artificial light and power upgrade scope for Section J NCC2016 and NCC2019 compliance

Location	Building	Upgrade scope for NCC2016 compliance	Upgrade scope for NCC2019 compliance
Alice Springs & Darwin	Hotel (3A)	• No change to base case	• No change to base case
	Single-storey office (5)	• No change to base case	• No change to base case
	Multi-storey office (5A)	• Incorporate time clock control for lighting allowing for two zones per floor • Incorporate additional lighting control circuits on each perimeter of each floor, to allow lighting to be manually switched off during time scheduled operation	• Incorporate time clock control for lighting allowing for two zones per floor • Incorporate additional lighting control circuits on each perimeter of each floor, to allow lighting to be manually switched off during time scheduled operation
	Retail (6B)	• Incorporate time clock control for lighting allowing for two zones per floor	• Incorporate time clock control for lighting allowing for two zones per floor
	Hospital Ward (9aC)	• No change to base case	• No change to base case
	School (9bH)	• Incorporate time clock control for lighting allowing for one zone per classroom	• Incorporate time clock control for lighting allowing for one zone per classroom

Table E-10: Energy monitoring services upgrade scope for Section J NCC2016 and NCC2019 compliance

Location	Building	Upgrade scope for NCC2016 compliance	Upgrade scope for NCC2019 compliance
Alice Springs & Darwin	Hotel (3A)	• Incorporate an energy metering system to individually record the consumption of air-conditioning, lighting, appliance power, central hot water, lifts and other ancillary plants (allow for 21 hard-wired meters).	• Incorporate an energy metering system to record individually the consumption of air-conditioning, lighting, appliance power, central hot water, lifts and other ancillary plants (allow for 21 cloud-based CT meters) • Connect all above meters to a common cloud-based system that collates time-of-use energy consumption data to a single interface monitoring system where it can be stored, analysed and reviewed.
	Single-Storey Office (5)	• No change to base case	• No change to base case
	Multi-Storey Office (5A)	• Incorporate an energy metering system to record individually the consumption of air-conditioning, lighting, appliance power, central hot water, lifts and other ancillary plant (allow for 20 hard-wired meters)	• Incorporate an energy metering system to record individually the consumption of air-conditioning, lighting, appliance power, central hot water, lifts and other ancillary plant (allow for 20 cloud-based CT meters) • Connect all above meters to a common cloud-based system that collates time-of-use energy consumption data to a single interface monitoring system where it can be stored, analysed and reviewed.
	Retail (6B)	• No change to the base case	• No change to the base case
	Hospital Ward (9aC)	• No change to the base case	• No change to the base case
	School (9bH)	• Incorporate an energy metering system to record individually the consumption of air-conditioning, lighting, appliance power and other ancillary plants (allow for 8 hard-wired meters)	• Incorporate an energy metering system to record individually the consumption of air-conditioning, lighting, appliance power and other ancillary plants (allow for 8 cloud-based CT meters) • Connect all above meters to a common cloud-based system that collates time-of-use energy consumption data to a single interface monitoring system where it can be stored, analysed and reviewed.

Table E-11: Incremental cost for building services and energy monitoring measures of NCC2016 compliant options for various building archetypes in Darwin (DRW) and Alice Springs (ASP) (additional cost to achieve compliance compared to base case building costs). For non-square buildings, "N-S" denotes orientation with the longer façade on the North/South, and "W-E" the longer façade on West/East.

Model (2019)	Air conditioning and Ventilation	Artificial Light and Power	Facilities for Energy Monitoring	(Total) Incremental building services and energy monitoring compliance measures costs
Hotel (3A)- DRW	$12,000	$0	$24,570	$36,570
Hotel (3A)- ASP	$13,200	$0	$27,027	$40,227
Multi-Storey Office (5A) - DRW	$12,000	$22,000	$23,400	$57,400
Multi-Storey Office (5A) - ASP	$0	$24,200	$25,740	$49,940
Single-Storey Office (5) - DRW N-S	$0	$0	$0	$0
Single-Storey Office (5) - DRW W-E	$0	$0	$0	$0
Single-Storey Office (5) - ASP N-S	$0	$0	$0	$0
Single-Storey Office (5) - ASP W-E	$0	$0	$0	$0
Retail (6B)- DRW N-S	$0	$2,760	$0	$2,760
Retail (6B) - DRW W-E	$0	$2,760	$0	$2,760
Retail (6B) - ASP N-S	$0	$3,036	$0	$3,036
Retail (6B) - ASP W-E	$0	$3,036	$0	$3,036
Hospital (9aC) - DRW	$0	$0	$0	$0
Hospital (9aC) - ASP	$0	$0	$0	$0
School (9bH)- DRW N-S	$7,000	$22,080	$9,360	$38,440
School (9bH)- DRW W-E	$7,000	$22,080	$9,360	$38,440
School (9bH)- ASP N-S	$0	$24,288	$10,296	$34,584
School (9bH)- ASP W-E	$0	$24,288	$10,296	$34,584

Table E-12: Incremental cost for building services and energy monitoring measures of NCC2019 compliant options for various building archetypes in Darwin (DRW) and Alice Springs (ASP) (additional cost to achieve compliance compared to base case building costs). For non-square buildings, "N-S" denotes orientation with the longer façade on the North/South, and "W-E" the longer façade on West/East.

Model (2019)	Air conditioning and Ventilation	Artificial Light and Power	Facilities for Energy Monitoring	(Total) Incremental building services and energy monitoring compliance measures costs
Hotel (3A)- DRW	$16,100	$0	$26,838	$42,938
Hotel (3A)- ASP	$22,400	$0	$29,522	$51,922
Multi-Storey Office (5A) - DRW	$66,100	$22,000	$26,467	$114,567
Multi-Storey Office (5A) - ASP	$0	$24,200	$29,113	$53,313
Single-Storey Office (5) - DRW N-S	$0	$0	$0	$0
Single-Storey Office (5) - DRW W-E	$0	$0	$0	$0
Single-Storey Office (5) - ASP N-S	$0	$0	$0	$0
Single-Storey Office (5) - ASP W-E	$0	$0	$0	$0
Retail (6B)- DRW N-S	$40,000	$2,760	$0	$42,760
Retail (6B) - DRW W-E	$40,000	$2,760	$0	$42,760
Retail (6B) - ASP N-S	$0	$3,036	$0	$3,036
Retail (6B) - ASP W-E	$0	$3,036	$0	$3,036
Hospital (9aC) - DRW	$0	$0	$0	$0
Hospital (9aC) - ASP	$0	$0	$0	$0
School (9bH)- DRW N-S	$4,100	$22,080	$9,762	$35,942
School (9bH)- DRW W-E	$4,100	$22,080	$9,762	$35,942
School (9bH)- ASP N-S	$0	$24,288	$10,738	$35,026
School (9bH)- ASP W-E	$0	$24,288	$10,738	$35,026

Appendix E.4 Sensitivity Analysis – Compliance Specifications and Incremental Construction Costs

E.4.1.1 Cladded Steel Frame Wall

This assessment focussed on the sensitivity of the analysis to the case where the base case external wall for the small office building is a cladded steel frame construction rather than single skin blockwork. This had the following impacts on compliance options and incremental costs:

- Sunbuild advised on the details of and cost rates for a typical cladded steel frame construction that was assumed as the base case
- The base case construction included R2.0 bulk insulation in the steel frame, with no air gap and no thermal break across the frame, which results in a total system R-value of R0.59
- Compliance options for increased R-value were discussed with and costed by Sunbuild, and included variations of the base case construction with the following:
    - Increased insulation thickness and/or,
    - Inclusion of a reflective air gap (achieved with either reflective sarking or foil-bonded foam) and/or,
    - Application of a thermal break in the form of a continuous layer of foil-bonded foam or,
    - Application of a thermal break in the form of tape applied to the edge of the frame
- For NCC2016 compliance, the only primary impact of the changed wall construction is on the wall construction itself. All other least cost compliance selections are identical to the core analysis case
- For NCC2019 compliance, the changed wall construction also has implications for the glazing as these are assessed together under Part J1.5 NCC2019. All other least cost compliance selections are identical to the core analysis case
- In each of the NCC2016 and NCC2019 compliance assessments, there is also a secondary order impact on the assessment of decremental mechanical plant capacity costs

The total base case construction cost is presented in Table E-13. The least cost building fabric specifications for Section J 2016 and 2019 compliance for the steel frame construction of the ground floor office building are presented in Table E-14 and Table E-15 respectively. Incremental costs are presented in Table E-16 and Table E-17. Total compliance cost figures are presented in Table E-18 and Table E-19.

Table E-13: Total base case construction cost estimate for the small office cladded steel frame construction sensitivity case

	Darwin	Alice Springs
Base case total construction cost for small office with cladded steel frame construction	$907,000	$998,000

Table E-14: NCC2016 least cost building fabric compliance specification for single-storey office steel-frame construction sensitivity case.

2016 Compliance Specification	Wall constructions					Roof construction	Floor construction	Glazing				Shading			
Model	North	East	South	West	Non-external envelope walls	Roof	Floor	North	East	South	West	North	East	South	West
Steel-Frame Single-Storey Office (5) Darwin N-S	G7	G7	G7	G7	BC5	LR-B1	BC1	GL4	GL7	GL2	GL5	G1	G1	G1	G1
Steel-Frame Single-Storey Office (5) Darwin W-E	G7	G7	G7	G7	BC5	LR-B1	BC1	GL4	GL7	GL2	GL5	G1	G1	G1	G1
Sensitivity - Single-Storey Office (5) Alice Springs N-S	G7	G7	G7	G7	BC5	LR-B1	BC1	GL2	GL4	GL1	GL2	G1	G1	G1	G1
Sensitivity - Single-Storey Office (5) Alice Springs W-E	G7	G7	G7	G7	BC5	LR-B1	BC1	GL2	GL4	GL1	GL2	G1	G1	G1	G1

Table E-15: NCC2019 least cost building fabric compliance specification for small office steel-frame construction sensitivity case

2019 Compliance Specification	Wall constructions					Roof construction	Floor construction	Glazing				Shading			
Model	North	East	South	West	Non-external envelope walls	Roof	Floor	North	East	South	West	North	East	South	West
Steel-Frame Single-Storey Office (5) Darwin N-S	F5	F5	F5	F5	BC5	LR-A2	GND-B	GL7	GL2	GL2	GL9	G1	G1	G1	G1
Steel-Frame Single-Storey Office (5) Darwin W-E	F5	F5	F5	F5	BC5	LR-A2	GND-B	GL9	GL2	GL2	GL7	G1	G1	G1	G1
Steel-Frame Single-Storey Office (5) Alice Springs N-S	F5	F5	F5	F5	BC5	LR-A2	GND-B	GL3	GL3	GL3	GL2	G1	G1	G1	G1
Steel-Frame Single-Storey Office (5) Alice Springs W-E	F5	F5	F5	F5	BC5	LR-A2	GND-B	GL2	GL3	GL3	GL3	G1	G1	G1	G1

Table E-16: Incremental cost of building fabric for NCC2016 compliance for the small office steel-frame construction sensitivity case

NCC2016-Compliant Building Model	Wall constructions	Roof construction	Floor construction	Glazing	Shading	Incremental cost of increased building footprint	Total incremental cost
Steel-Frame Single-Storey Office (5) Darwin N-S	$4,649	$3,280	$0	$3,912	$0	$1,049	$12,890
Steel-Frame Single-Storey Office (5) Darwin W-E	$4,649	$3,280	$0	$5,468	$0	$1,049	$14,446
Steel-Frame Single-Storey Office (5) Alice Springs N-S	$5,024	$3,553	$0	$1,470	$0	$1,156	$11,203
Steel-Frame Single-Storey Office (5) Alice Springs W-E	$5,024	$3,553	$0	$2,486	$0	$1,156	$12,219

Table E-17: Incremental cost of building fabric for NCC2019 compliance for the small office steel-frame construction sensitivity case

NCC2019-Compliant Building Model	Wall constructions	Roof construction	Floor construction	Glazing	Shading	Incremental cost of increased building footprint	Total incremental cost
Steel-Frame Single-Storey Office (5) Darwin N-S	$1,247	$4,920	$1,080	$4,455	$0	$227	$11,929
Steel-Frame Single-Storey Office (5) Darwin W-E	$1,247	$4,920	$1,080	$4,455	$0	$227	$11,929
Steel-Frame Single-Storey Office (5) Alice Springs N-S	$1,281	$5,466	$1,188	$4,473	$0	$250	$12,659
Steel-Frame Single-Storey Office (5) Alice Springs W-E	$1,281	$5,466	$1,188	$4,473	$0	$250	$12,659

Table E-18: Incremental costs of NCC2016 compliance for the cladded steel frame wall sensitivity case applied to the small office building in Darwin and Alice Springs. "N-S" denotes the orientation of the building with the longer façade facing North/South, and similarly for "W-E".

NCC2016-Compliant Building Model	Incremental building fabric costs	Incremental building services plant capacity costs	Incremental building services and energy monitoring compliance measures costs	Incremental design and consultancy fees	Total incremental cost	Incremental cost as % of total construction cost
Steel-Frame Single-Storey Office (5) Darwin N-S	$12,890	-$2,207	$0	$2,716	$13,399	1.48%
Steel-Frame Single-Storey Office (5) Darwin W-E	$14,446	-$1,421	$0	$2,778	$15,802	1.74%
Steel-Frame Single-Storey Office (5) Alice Springs N-S	$11,203	-$3,590	$0	$2,848	$10,461	1.05%
Steel-Frame Single-Storey Office (5) Alice Springs W-E	$12,219	-$1,907	$0	$2,889	$13,200	1.32%

Table E-19: Incremental costs of NCC2019 compliance for the cladded steel frame wall sensitivity case applied to the small office building in Darwin and Alice Springs. "N-S" denotes the orientation of the building with the longer façade facing North/South, and similarly for "W-E".

NCC2019-Compliant Building Model	Incremental building fabric costs	Incremental building services plant capacity costs	Incremental building services and energy monitoring compliance measures costs	Incremental design and consultancy fees	Total incremental cost	Incremental cost as % of total construction cost
Steel-Frame Single-Storey Office (5) Darwin N-S	$11,929	-$2,618	$0	$2,677	$11,988	1.32%
Steel-Frame Single-Storey Office (5) Darwin W-E	$11,929	-$1,533	$0	$2,677	$13,073	1.44%
Steel-Frame Single-Storey Office (5) Alice Springs N-S	$12,659	-$5,161	$0	$2,906	$10,404	1.04%
Steel-Frame Single-Storey Office (5) Alice Springs W-E	$12,659	-$2,020	$0	$2,906	$13,545	1.36%

E.4.1.2 WWR Variation

E.4.1.3 Hotels

This assessment focussed on sensitivity of the analysis to the case where the window-to-wall ratio of the hotel is 50% in the base case and reduced to 30% in the compliance case. In this case there is no impact on compliance measures as the compliant case is unchanged from the core analysis case. There is an impact however on the base case construction cost and incremental cost of compliance. The impacts were assessed as follows:

- Using $/m² rates provided by Sunbuild, the impact on the base case construction cost was assessed to allow for:
  - Increased area of glazing using the base case glazing specification
  - Increased linear length of shading using the base case shading specification
  - Reduced area of external walls using the base case wall specification
- With those points re-established as the base case, the incremental cost of compliance was assessed to allow for:
  - Reduced area of glazing using the NCC2016 and NCC2019 glazing compliance specifications
  - Reduced linear length (or exclusion) of shading as per the NCC2016 and NCC2019 shading compliance specifications
  - Increased area of external walls using the NCC2016 and NCC2019 wall compliance specifications
- In each of the NCC2016 and NCC2019 compliance assessments, there was also a secondary order impact on the assessment of decremental mechanical plant capacity costs

The hotel WWR sensitivity case represents the hotel with a 50% WWR in the base case and 30% WWR in the compliance case. The least cost Section J compliance specifications are identical to the core analysis cases because the compliant model is identical to the core analysis case. The base case construction costs and the incremental costs of compliance are however different to the core analysis cases. Changes to the total construction cost due to increased WWR are calculated in accordance with cost rates for walls, glazing and shading for the base case archetypes and are detailed in Table E-20. The incremental costs of Section J compliance are calculated with respect to these adjusted base case construction costs and are detailed in Table E-21 and Table E-22. The compliance specification and costs associated with building services and energy monitoring measures (Table E-23 and Table E-24) are identical to hotels in the core study (See Appendix E.3.2). The total compliance costs are provided in Table E-25 and Table E-26.

Table E-20: Changes to total construction cost for the hotel WWR sensitivity case for the hotel WWR sensitivity case (base case WWR of 50% and compliant case WWR of 30%).

	Darwin	Alice Springs
Original base case total construction cost	$34,326,000	$37,759,000
Incremental cost of external walls for 50% WWR	-$212,959	-$234,801
Incremental cost of glazing for 50% WWR	$468,691	$498,542
Incremental cost of shading for 50% WWR	$74,250	$81,675
Total adjusted base case construction cost for 50% WWR	$34,655,982	$38,104,416

Table E-21: Incremental cost of building fabric for NCC2016 compliance for the hotel WWR sensitivity case (base case WWR of 50% and compliant case WWR of 30%).

NCC2016-Compliant Building Model	Wall constructions	Roof construction	Floor construction	Glazing	Shading	Incremental cost of increased building footprint	Total incremental building fabric cost
Hotel (3A) Darwin 30%WWR (relative to 50% WWR base case)	$500,430	$37,945	$125,000	-$96,013	-$266,261	$62,774	$363,875
Hotel (3A) Alice Springs 30%WWR (relative to 50% WWR base case)	$549,108	$40,941	$0	-$291,317	-$273,086	$66,684	$92,330

Table E-22: Incremental cost of building fabric for NCC2019 compliance for the hotel WWR sensitivity case (base case WWR of 50% and compliant case WWR of 30%).

NCC2019-Compliant Building Model	Wall constructions	Roof construction	Floor construction	Glazing	Shading	Incremental cost of increased building footprint	Total incremental building fabric cost
Hotel (3A) Darwin 30%WWR (relative to 50% WWR base case)	$455,040	$47,931	$125,000	-$138,332	-$330,265	$36,959	$196,333
Hotel (3A) Alice Springs 30%WWR (relative to 50% WWR base case)	$499,179	$51,925	$138,000	-$90,849	-$363,291	$40,660	$275,624

Table E-23: Incremental cost for building services and energy monitoring measures of NCC2016 compliant options for the hotel WWR sensitivity case (base case WWR of 50% and compliant case WWR of 30%).

NCC2016-Compliant Building Model	Air conditioning and Ventilation	Artificial Light and Power	Facilities for Energy Monitoring	(Total) Incremental building services and energy monitoring compliance measures costs
Hotel (3A) Darwin 30%WWR (relative to 50% WWR base case)	$12,000	$0	$24,570	$36,570
Hotel (3A) Alice Springs 30%WWR (relative to 50% WWR base case)	$13,200	$0	$27,027	$40,227

Table E-24: Incremental cost for building services and energy monitoring measures of NCC2019 compliant options for the hotel WWR sensitivity case (base case WWR of 50% and compliant case WWR of 30%).

NCC2019-Compliant Building Model	Air conditioning and Ventilation	Artificial Light and Power	Facilities for Energy Monitoring	(Total) Incremental building services and energy monitoring compliance measures costs
Hotel (3A) Darwin 30%WWR (relative to 50% WWR base case)	$16,100	$0	$26,838	$42,938
Hotel (3A) Alice Springs 30%WWR (relative to 50% WWR base case)	$22,400	$0	$29,522	$51,922

Table E-25: Incremental costs of NCC2016 compliance for the hotel WWR sensitivity case (base case WWR of 50% and compliant case WWR of 30%).

Model (2016)	Incremental building fabric costs	Incremental building services plant capacity costs	Incremental building services and energy monitoring compliance measures costs	Incremental design and consultancy fees	Total incremental cost	Incremental cost as % of total construction cost
Hotel (3A) Darwin 30%WWR (relative to 50% WWR base case)	$363,875	-$257,312	$36,570	$15,478	$158,611	0.46%
Hotel (3A) Alice Springs 30%WWR (relative to 50% WWR base case)	$92,330	-$313,056	$40,227	$10,747	-$169,753	-0.45%

Table E-26: Incremental costs of NCC2019 compliance for the hotel WWR sensitivity case (base case WWR of 50% and compliant case WWR of 30%).

Model (2019)	Incremental building fabric costs	Incremental building services plant capacity costs	Incremental building services and energy monitoring compliance measures costs	Incremental design and consultancy fees	Total incremental cost	Incremental cost as % of total construction cost
Hotel (3A) Darwin 30%WWR (relative to 50% WWR base case)	$196,333	-$243,721	$42,938	$12,127	$7,677	0.02%
Hotel (3A) Alice Springs 30%WWR (relative to 50% WWR base case)	$275,624	-$397,440	$51,922	$14,412	-$55,481	-0.15%

E.4.1.4 Multi-Storey Offices

This assessment focussed on sensitivity of the analysis to the case where the multi-storey office building has a window-to-wall ratio of 56% (in both the base case and compliance case). This had the following impacts on the assessment of compliance options and incremental costs:

- The base case construction cost was assessed by Sunbuild, allowing for increased glazing, increased shading and reduced external wall area (compared to the 40% WWR core analysis case)
- All options for compliance and cost rates per sqm are identical to the core analysis
- For NCC2016 compliance, the least cost compliance option for glazing requires a relatively higher performance glazing than does the 40% WWR case. Shading is included in the glazing analysis, but the result of the analysis is the same, that the least cost compliance option is to exclude shading. All other least cost compliance selections are unaffected by the WWR.
- For NCC2019 compliance, the least cost compliance option for glazing also requires a relatively higher performance glazing than does the 40% WWR case. Shading and wall construction is included in the wall-glazing analysis, but the least cost compliance selections for these are identical to the 40% WWR case. All other least cost compliance selections are unaffected by the WWR.
- In each of the NCC2016 and NCC2019 compliance assessments, there is also a secondary order impact on the assessment of decremental mechanical plant capacity costs

The multi-storey office WWR sensitivity case represents the multi-storey office with a 56% WWR in both the base case and compliance case constructions. There are resulting changes to the base case construction cost, least cost compliance specification and incremental compliance costs. The base case construction cost was advised by Sunbuild at $25,099,000 for Darwin, with a 10% incremental allowance for construction in Alice Springs. The base case construction cost is provided in Table E-27. The least compliance specifications are detailed in Table E-28 and Table E-29, with incremental costs for the revised total construction cost presented in Table E-30 and Table E-31. The compliance specification and costs associated with building services and energy monitoring measures (Table E-32 and Table E-33) are identical to multi-storey office buildings in the core study (See Appendix E.3.2). Total compliance costs are provided in Table E-34 and Table E-35.

Table E-27: Base case total construction cost for multi-storey office building with 56% WWR.

	Darwin	Alice Springs
Base case total construction cost for high rise office with 56% WWR	$25,099,000	$27,609,000

Table E-28: NCC2016 least cost building fabric compliance specification for the multi-storey office 56% WWR sensitivity case (base case and compliance case WWR of 56%).

2016 Compliance Specification	Wall constructions					Roof construction	Floor construction	Glazing				Shading			
Model	North	East	South	West	Non-external envelope walls	Roof	Floor	North	East	South	West	North	East	South	West
Multi-Storey Office (5) 56% WWR - Darwin	D8	D8	D5	D8	D8	HR-C1	CP-A	GL10	GL15	GL9	GL15	F1	F1	F1	F1
Multi-Storey Office (5) 56% WWR - Alice Springs	D8	D8	D5	D8	D8	HR-C1	BC3	GL9	GL9	GL2	GL9	F1	F1	F1	F1

Table E-29: NCC2019 least cost building fabric compliance specification for the multi-storey office 56% WWR sensitivity case (base case and compliance case WWR of 56%).

2019 Compliance Specification	Wall constructions					Roof construction	Floor construction	Glazing				Shading			
Model	North	East	South	West	Non-external envelope walls	Roof	Floor	North	East	South	West	North	East	South	West
Multi-Storey Office (5) 56% WWR - Darwin	D5	D5	D5	D5	D9	HR-D1	CP-A	GL10	GL10	GL10	GL10	F1	F1	F1	F1
Multi-Storey Office (5) 56% WWR - Alice Springs	D5	D5	D5	D5	D5	HR-D1	CP-A	GL10	GL9	GL4	GL9	F1	F1	F1	F1

Table E-30: Incremental cost of building fabric for NCC2016 compliance for the multi-storey office 56% WWR sensitivity case (base case and compliance case WWR of 56%).

Model	Wall constructions	Roof construction	Floor construction	Glazing	Shading	Incremental cost of increased building footprint	Total incremental building fabric cost
Multi-Storey Office (5) 56% WWR - Darwin	$282,558	$37,945	$125,000	$758,734	-$447,800	$62,774	$819,211
Multi-Storey Office (5) 56% WWR - Alice Springs	$308,969	$40,941	$0	$556,405	-$492,580	$66,684	$480,418

Table E-31: Incremental cost of building fabric for NCC2019 compliance for the multi-storey office 56% WWR sensitivity case (base case and compliance case WWR of 56%).

Model	Wall constructions	Roof construction	Floor construction	Glazing	Shading	Incremental cost of increased building footprint	Total incremental building fabric cost
Multi-Storey Office (5) 56% WWR - Darwin	$265,821	$47,931	$125,000	$680,376	-$447,800	$36,959	$708,287
Multi-Storey Office (5) 56% WWR - Alice Springs	$255,175	$51,925	$138,000	$641,898	-$492,580	$40,660	$635,078

Table E-32: Incremental cost for building services and energy monitoring measures of NCC2016 compliant options for the multi-storey office 56% WWR sensitivity case (base case and compliance case WWR of 56%).

NCC2016-Compliant Building Model	Air conditioning and Ventilation	Artificial Light and Power	Facilities for Energy Monitoring	(Total) Incremental building services and energy monitoring compliance measures costs
Multi-Storey Office (5) 56% WWR - Darwin	$12,000	$22,000	$23,400	$57,400
Multi-Storey Office (5) 56% WWR - Alice Springs	$0	$24,200	$25,740	$49,940

Table E-33: Incremental cost for building services and energy monitoring measures of NCC2019 compliant options for the multi-storey office 56% WWR sensitivity case (base case and compliance case WWR of 56%).

NCC2019-Compliant Building Model	Air conditioning and Ventilation	Artificial Light and Power	Facilities for Energy Monitoring	(Total) Incremental building services and energy monitoring compliance measures costs
Multi-Storey Office (5) 56% WWR - Darwin	$66,100	$22,000	$26,467	$114,567
Multi-Storey Office (5) 56% WWR - Alice Springs	$0	$24,200	$29,113	$53,313

Table E-34: Incremental costs of NCC2016 compliance for the multi-storey office 56% WWR sensitivity case (base case and compliance case WWR of 56%).

NCC2016-Compliant Building Model	Incremental building fabric costs	Incremental building services plant capacity costs	Incremental building services and energy monitoring compliance measures costs	Incremental design and consultancy fees	Total incremental cost	Incremental cost as % of total construction cost
Multi-Storey Office (5) 56% WWR - Darwin	$819,211	-$139,219	$57,400	$23,784	$761,176	3.03%
Multi-Storey Office (5) 56% WWR - Alice Springs	$480,418	-$127,160	$49,940	$17,808	$421,006	1.52%

Table E-35: Incremental costs of NCC2019 compliance for the multi-storey office 56% WWR sensitivity case (base case and compliance case WWR of 56%).

NCC2019-Compliant Building Model	Incremental building fabric costs	Incremental building services plant capacity costs	Incremental building services and energy monitoring compliance measures costs	Incremental design and consultancy fees	Total incremental cost	Incremental cost as % of total construction cost
Multi-Storey Office (5) 56% WWR - Darwin	$708,287	-$136,243	$114,567	$21,566	$708,176	2.82%
Multi-Storey Office (5) 56% WWR - Alice Springs	$635,078	-$138,006	$53,313	$20,902	$571,287	2.07%

Appendix F – Predicted Energy Usage

Predicted energy intensities were based on simulations performed using dynamic thermal and energy simulation software IES<VE>. Modelled equipment control sequences, applied to the simulation, were confirmed by local consultants and services contractors to be representative of a building in Darwin or Alice Springs. As the simulation is an idealised model, the simulation results were adjusted to account for energy savings associated with using VSD pumps and energy monitoring systems. For cases where VSDs are used, a 10% energy saving was applied to the simulated pump energy consumption.[36] For archetypes where the energy monitoring systems to comply with NCC2016 and NCC2019, a 5% energy savings was applied to the modelled energy intensity to reflect improved energy management.[37]

[36] The simulation does not include losses due to oversized pumps. In practical applications, VSDs will provide energy savings because they will be used in commissioning to set a maximum speed for the pump that is less than 100% of the pump's maximum design speed. From experience, this practice provides approximately 10% energy savings to pump energy consumption.

[37] Energy savings resulting from the introduction of energy monitoring systems have been widely studied. Savings that are 10 - 36% of the whole building energy intensity have been reported in multiple studies. These savings are realised through a various means including changes to occupant behaviour, and optimisation of operations and maintenance in commercial buildings.
Zhai, Z.J. and Salazar, A., 2020. Assessing the implications of submetering with energy analytics to building energy savings. *Energy and Built Environment*, 1(1), pp.27-35.

Appendix F.1 Core Analysis

Table F-1: Annual regulated electricity intensities (kWh/m²) of base case, NCC2016 and NCC2019 compliant buildings. (*) Starred building forms were simulated in two different orientations – the average values are presented. ** Hotels in Alice Springs also consume gas – the energy intensity associated with gas consumption is reported separately.

	Building Archetype	Base Case	NCC2016	NCC2019
Darwin	Hotel (3A)	126.2	109.7	109.7
	Multi-Storey Office (5A)	95.6	69.5	63.0
	Single-Storey Office (5) - N-S	108.6	101.1	90.2
	Single-Storey Office (5) – W-E	106.3	100.1	91.0
	Single-Storey Office (5) – Average*	107.5	100.6	90.6
	Retail (6B) – N-S	207.0	183.4	139.4
	Retail (6B) – W-E	210.5	188.1	142.1
	Retail (6B) – Average*	208.7	185.8	140.8
	Hospital Ward (9aC)	178.8	167.8	154.3
	School (9bH) - N-S	147.7	132.5	127.5
	School (9bH) - W-E	148.6	132.5	127.5
	School (9bH) – Average**	148.1	132.5	127.5
Alice Springs	Hotel (3A)**	93.2	82.5	77.1
	Multi-Storey Office (5A)	56.9	43.9	44.9
	Single-Storey Office (5) - N-S	103.8	92.7	73.9
	Single-Storey Office (5) – W-E	105.1	93.4	81.9
	Single-Storey Office (5) – Average*	104.4	93.0	77.9
	Retail (6B) – N-S	145.7	124.6	108.9
	Retail (6B) – W-E	149.2	124.8	110.5
	Retail (6B) – Average*	147.4	124.7	109.7
	Hospital Ward (9aC)	101.2	86.3	60.8
	School (9bH) - N-S	104.5	88.9	73.2
	School (9bH) - W-E	106.0	88.9	73.2
	School (9bH) – Average**	105.3	88.9	73.2

Table F-2: Annual gas intensities (MJ/m²) of base case, NCC2016 and NCC2019 compliant buildings. All other building archetypes do not have gas consumption.

	Building Archetype	Base Case	NCC2016	NCC2019
Darwin	All Archetypes	N/A	N/A	N/A
Alice Springs	Hotel (3A)	98.9	73.4	52.5
	All Other Archetypes	N/A	N/A	N/A

Table F-3: Peak electricity load (kW) of base case, NCC2016 and NCC2019 compliant buildings. (*) Starred building forms were simulated in two different orientations – the average values are presented. ** Hotels in Alice Springs also consume gas – the energy intensity associated with gas consumption is reported separately.

	Building Archetype	Base Case	NCC2016	NCC2019
Darwin	Hotel (3A)	407.6	338.7	342.3
	Multi-Storey Office (5A)	410.5	315.3	289.7
	Single-Storey Office (5) - N-S	10.2	9.2	9.1
	Single-Storey Office (5) – W-E	9.9	9.2	9.3
	Single-Storey Office (5) – Average*	10.0	9.2	9.2
	Retail (6B) – N-S	136.2	118.2	86.2
	Retail (6B) – W-E	139.3	120.3	86
	Retail (6B) – Average*	137.7	119.2	86.1
	Hospital Ward (9aC)	37.4	34.6	36.1
	School (9bH) - N-S	240	229.7	227.4
	School (9bH) - W-E	243.4	236.2	231.8
	School (9bH) – Average**	241.7	233.0	229.6
Alice Springs	Hotel (3A)**	451.9	375.7	291.8
	Multi-Storey Office (5A)	379.5	321.6	319
	Single-Storey Office (5) - N-S	10.6	9.8	9.3
	Single-Storey Office (5) – W-E	11.3	9.9	9.9
	Single-Storey Office (5) – Average*	10.9	9.9	9.6
	Retail (6B) – N-S	95.6	82	79.3
	Retail (6B) – W-E	97.8	80.4	79.5
	Retail (6B) – Average*	96.7	81.2	79.4
	Hospital Ward (9aC)	35.4	29.6	22.7
	School (9bH) - N-S	199.3	168.4	167.7
	School (9bH) - W-E	203.7	167.7	173.3
	School (9bH) – Average**	201.5	168	170.5

Appendix F.2 Single-Storey Office with Steel Frame Construction

Table F-4: Electricity intensities (kWh/m²) and peak electricity loads (kW) of Base case, NCC2016 and NCC2019 compliant Single-Storey Office with cladded steel frame walls. This building archetype was modelled with no gas consumption.

Model and Scenario		Regulated Electricity Intensity (kWh/m²)		Peak Electricity Load (kW)	
		Darwin	Alice Springs	Darwin	Alice Springs
Base Case	Orientation 1 - North/South	115.2	112.9	11.1	11.7
	Orientation 2 West/East	110.6	111.9	10.7	11.2
	Average	112.9	112.4	10.9	11.5
NCC2016 Compliant Model	Orientation 1 - North/South	102.1	89.4	9.3	9.4
	Orientation 2 West/East	101.8	94.9	9.6	10
	Average	102	92.2	9.5	9.7
NCC2019 Compliant Model	Orientation 1 - North/South	90.2	74.4	8.9	9.2
	Orientation 2 West/East	92.2	84.2	9.5	10
	Average	91.2	79.3	9.2	9.6

Appendix F.3 Hotel with 50% WWR

The regulated and whole building energy intensities for the hotel base case with 50% WWR, NCC2016 compliant model and NCC2019 compliant model are presented in Table F-5.

Note that NCC2016 and NCC2019 compliant models still have 30% WWR.

Table F-5: Regulated Electricity intensities (kWh/m²), regulated gas intensity (MJ/m²), and peak electricity loads (kW) of base case hotel model with 50% WWR, NCC2016 compliant model and NCC2019 compliant model.

Model and Scenario	Regulated Electricity Intensity (kWh/m²)		Regulated Gas Intensity (MJ/m²)		Peak Electricity Load (kW)	
	Darwin	Alice Springs	Darwin	Alice Springs	Darwin	Alice Springs
Base Case Hotel (3A) (50% WWR)	133.5	125.6	0	98.1	466.2	598.3
NCC2016 Compliant Hotel (3A) Model (30% WWR)	109.7	82.5	0	73.4	338.7	375.7
NCC2019 Compliant Hotel (3A) Model (30% WWR)	109.7	77.1	0	52.5	342.3	291.8

Appendix F.4 Office (5A) with 56% WWR

The regulated and whole building energy intensities for the office (5A) base case with 56% WWR, NCC2016 compliant model with 56% WWR and NCC2019 compliant model with 56WWR are presented below.

Table F-6: Regulated electricity intensities (kWh/m²) and peak electricity load (kW) of base case multi-storey office (5A) model with 56% WWR, NCC2016 compliant model and NCC2019 compliant model. This building archetype was modelled with no gas consumption

Model and Scenario	Regulated Electricity Intensity (kWh/m²)		Peak Electricity Load (kW)	
	Darwin	Alice Springs	Darwin	Alice Springs
Base Case Multi-Storey Office (5A) (56% WWR)	98.3	63.1	419.8	411.3
NCC2016 Compliant Model Multi-Storey Office (5A) (56% WWR)	70.0	46.1	317.6	337.9
NCC2016 Compliant Model Multi-Storey Office (5A) (56% WWR)	63.6	44.8	292.1	324.8

Appendix F.5 External Shading vs Wall Insulation

Table F-7: Regulated Electricity Intensity(kWh/m²) of NCC2016 and NCC2019 modelling for wall shading analysis

Model	Energy Intensity (kWh/m²) NCC2016 models		Energy Intensity (kWh/m²) NCC2019 models	
	Darwin	Alice Springs	Darwin	Alice Springs
NCC2016/2019 compliant model with windows. (With wall insulation, no shading)	101.2	92.7	90.17	73.9
Model with vertical wall shading but without wall insulation	102.5	93.0	91.11	75.7
Model with horizontal shading but without wall insulation	100.7	92.2	89.80	76.5
NCC2016/2019 compliant model without windows (With wall insulation, no shading)	90.9	88.0	86.20	67.6
Model with vertical wall shading but without windows and wall insulation	92.4	89.8	86.62	73.1
Model with horizontal shading but without windows and wall insulation	92.3	89.8	86.37	72.9

Appendix G – Cost Benefit Analysis Methodology and Inputs

Appendix G.1 Methodology

G.1.1 Overview

The CBA methodology used for this report is the same as that used by SPR in recent years for the COAG Energy Council Code Trajectory for new commercial buildings (with Energy Action Pty Ltd), for the COAG Existing Buildings Trajectory (with Ernst & Young Pty Ltd), and for the Consultation and Decision Regulatory Impact Statements (RISs) prepared for the Australian Building Codes Board (regarding separate heating and cooling load limits for residential buildings). The methodology complies with the Australian Government's Office of Best Practice Regulation's (OBPR) RIS and cost benefit analysis Guidance Notes. However, all values used in the analysis reflect local NT conditions and pricings, as set out in earlier chapters[38].

Our approach is to construct a stock turnover model for the building classes that could be covered by Section J, and for an assumed regulatory period of FY2023 to FY2030. A base case projection of fuel use by new buildings is made, by building type, climate zone and building control area. We assume a 40-year average economic life for new buildings, so we model the energy consumption of the new building cohort out to FY2070 (FY2030 + 40 years). However, no *new* building work is modelled after FY2030, as this period may be covered by different energy performance standards. In any case, the assumed regulatory period is long enough to demonstrate the net benefits or costs – if, in fact, a longer regulatory period applied, NPVs and BCRs would improve marginally in all scenarios where a learning rate is assumed, as this implies falling incremental costs over time, and therefore rising net benefits.

The analysis is first conducted for each individual building archetype, as if each policy scenario applied to this building type alone. While this is not a realistic scenario, it serves to highlight the potentially different impacts by building type. Second, we estimate the impact of each scenario applying to all new non-residential building work at the same time, which we call the 'composite' scenario.

Appendix G.2 Cost Benefit Analysis Inputs - Overview

For the stock turnover model, we resolve the floor area by non-residential building type, year, and Tier 1/Tier 2 region (relevant to the application of building regulations – see below) and also by electricity network region, to allow for different resource costs of energy by region. The Department has supplied historical building approvals data, by building class and region (able to be related to Tier 1 and Tier 2), for FY2012 – FY2020. Net stock growth in the projections period has been found to correlate best with Gross State Product (GSP). Stock modelling is further detailed in Section G.2.5 below.

[38] This includes the building-level construction cost and energy use differences between the Section J compliant and base case building archetypes - specifically, incremental construction cost, change in energy consumption and change in peak electrical load.

Energy savings[39] are valued[40] using annual real price assumptions for electricity and for gas, and these differ depending upon whether a social or a private (owner-occupier) perspective is adopted. The social perspective includes the value of community service obligations, along with social costs of carbon.

Additional benefits modelled included avoided network costs associated with reduced peak energy demand in the policy cases, as compared to the base case. The quantum of peak demand reduction (in kW) has been estimated for each archetype, and a weighted average of these values is used for the composite scenario. The value of this peak demand reduction is estimated using an avoidable network cost ($kW). The latter values differ depending upon whether a social or an owner-occupier perspective is adopted.

Further details on each of these steps are provided below.

G.2.1 Energy Pricing and Resource Costs

Energy prices are an important indicator of the benefits associated with adopting Section J. We value only the *avoidable* costs of energy use, and these vary for the social and private perspectives. From a private perspective, avoidable energy costs are determined by the structure of pricing that applies to building owners and users. In the NT, for electricity, this varies by location and also by customer type and size. For this study, we examine both private and social perspectives.

From a private or owner-occupier perspective, energy is valued at its avoidable cost. This excludes daily charges, whether for retail or network services, as these do not vary as a function of energy consumption, and therefore cannot be avoided when energy consumption is saved. Private costs are determined by the relevant energy tariffs (or market pricing, for larger customers) that apply. Retail tariffs for 2020-21 that apply to non-residential customers are shown in Table G-1. Where environmental charges are levied per unit energy consumption – such as under the business unregulated tariff in the Darwin to Katherine Interconnected System (DKIS) – these are also avoidable on a private cost basis and are therefore included. Power and Water Corporation – the network services provider – also retails power to remote regions, and in this case, the 'commercial standard' tariff is an energy charge of 30.32 c/kWh and a daily charge of 0.82 c/day.[41] For unregulated customers – such as the approximately 200 customers in the NT that consume more than 750 MWh/year – pricing is negotiated and contractual, although peak and off-peak tariffs for those that consume 750 – 2,000 MWh/year are published by Jacana Energy (the major retailer), as per Table G-1, and these are used as reference values.

For network tariffs, generally from a private perspective, charges for regulated customers are bundled into the tariffs noted in Table G-1. Only customers above the 750 MWh/year threshold in the DKIS are exposed to additional network tariffs, levied by Power and Water Corporation. Three tariff types may be relevant to non-residential building owners and users: Tariff 3 (Low Voltage Smart Meter); Tariff 5 (Low Voltage Majors) and Tariff 7 (High Voltage Majors). While the volume of energy priced through each tariff is not clear, we estimate a weighted average based on an assumption of 70% tariff 5, 20% tariff 7 and 10% tariff 3. This

[39] This accounts for the differences in volume of energy used and peak electrical loads, between the Section J compliant model and the base case, for each building archetype modelled.
[40] The value is referred to as 'energy cost savings' in this report. This is differentiated from 'energy savings' which refers to the savings in energy consumption in kWh.
[41] Power and Water Corporation, Power Pricing Tariffs, accessed on 21 September 2021, https://www.powerwater.com.au/customers/remote/power-pricing-and-tariffs

generates a weighted average cost of $12.03/kVA/month for these larger customers. In addition, these customers face 'anytime [network] energy charges' that vary slightly by tariff and which have a weighted average value of 2.1 c/kWh in FY2021.

Table G-1: Current Electricity Pricing Structures in the NT. [42]

Charge Type	Scope	Tariff Type	Load Type	Charge (excl. GST)	Unit
Energy charge	All	Business regulated, less than 750 MWh/y, excl. GST		27.56	c/kWh
Energy charge	DKIS	Business unregulated, 750 MWh to 2000 MWh	Peak	21.09	c/kWh
Energy charge	DKIS	Business unregulated, 750 MWh to 2000 MWh	Off peak	16.89	c/kWh
Env. Charge	DKIS	Business unregulated, 750 MWh to 2000 MWh		1.99	c/kWh
Energy charge	Alice Springs	Business unregulated, 750 MWh to 2000 MWh	Peak	28.00	c/kWh
Energy charge	Tennant Creek	Business unregulated, 750 MWh to 2000 MWh	Peak	35.00	c/kWh

However, market prices do not carry the full avoidable social costs of energy consumption. Social costs can include costs associated with network infrastructure, community service obligations, greenhouse gas emissions, and potentially other factors (e.g., air pollution). This need to be included in the social cost benefit analysis perspective.

For avoidable social costs associated with network services, we consider two different kinds of cost – network augmentation capital expenditure (or 'augex') and avoidable operational expenditure ('opex'). Values for both are derived from Regulation Information Notice (RIN) reports submitted by Power and Water Corporation (PWC) to the Australian Energy Regulator. Note that the most recent reports available relate to

Note with respect to opex and augex

In this study, values for operating expenditure (opex) and augmented capital expenditure (augex) are drawn from the Power and Water Corporation's Regulatory Information Notice (RIN) reports to the Australian Energy Regulator.

The opex includes operating expenditure for network services, which has been divided into six categories - employee benefits expenses, repairs and maintenance expenditures, inter-group sales, external service agreements (contractors), and energy and materials, and other expenses.

In this study, augex is considered from the commercial/industrial perspective - distribution sub-stations, high voltage augmentation and low voltage augmentation are included. Augex relating to residential, subdivisions, or embedded generation are not included.

[42] Derived from Jacana Energy Pricing and Tariffs, accessed on 15 June 2021, https://www.jacanaenergy.com.au/residential/pricing#commercialtariffs

FY2020, and we escalate these to current (FY2022) prices. For augex, we calculate a value of $167/kW in $2020 ($173.75 in $2022). This is based on PWC's declaration of FY2020 expenditure of $1,085,000 relating to commercial/industrial connections and augmentation, and its declared resulting capacity increase of 7 kVA. Assuming a power factor close to 100%, this generates the value of $167/kW. For opex, PWC RIN reports note that opex for network services (only – excluding metering, connection and other services) was $90,501,000, and this is divided by the 'Non–coincident Summated Weather Adjusted System Annual Maximum Demand 10% POE' capacity value of 501 MW, generating a value (in $2020) of $179.57/kW, or $186.82 in $2022. As the latter is an annual cost, it can be avoided each year when peak demand is avoided, while the augex cost is capital in nature, so any avoided augex costs are avoided only once in the year that peak demand savings occur.

Note that original network costs in Australian Energy Regulator (AER) RIN reports are stated in units of $/MVA, and so a power factor needs to be applied to convert these to $/MW. PWC's RIN reports note that they use a power factor of 1 for reporting purposes, although we would expect values more in the 0.9 – 0.95 range to apply in reality. This difference is not considered material to the analysis and has been ignored.

For the community service obligation, we estimate an average annual cost of $55.5 per MWh in 2019-20. This is based on Jacana Energy's reported CSO revenue in that year of $91.9million, grossed up marginally (by 0.63%) for non-Jacana retailers,[43] divided by total consumption reported by Power and Water Corporation for the same year of 1.66 million MWh.[44] We note that if real generation costs decline over time, on average, this could lead to a reduction in the real cost of the CSO. However, as a default, we assume the *real* (that is, inflation-adjusted) energy and network costs do not change over time.

For gas pricing, there appears to be limited transparency as to what prices are offered to commercial customers in the Northern Territory. Cost estimates were based on data from the Australian Energy Markets Operator's Gas Statement of Opportunities, 2021, although this does not report actual pricing in the NT. The average price from other markets was used a proxy. This equates to $10.69/GJ in FY2020-21, rising to $12.07/GJ ($real 2021).

G.2.2 Social Costs of Carbon

For shadow carbon prices – or the social cost of carbon – used in the social cost benefit analysis, we use values sourced from the latest major global review of the social cost of carbon, which was conducted by the United States (US) Government's Interagency Working Group (IWG) on Social Cost of Greenhouse Gases in 2016.[45] These values were also used in The CIE's Decision RIS for NCC2019.[46] The low scenario discounts the average estimate of the future costs of climate change using a 5% real discount rate. The medium scenario

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[43] Based on the difference between CSO revenue reported by Jacana Energy for 2017-18, cf reported *total* CSO cost for the same year in https://utilicom.nt.gov.au/__data/assets/pdf_file/0003/742782/Northern-Territory-Electricity-Retail-Review-2017-18.pdf, accessed on 15 June 2021.

[44] Australian Energy Regulator RIN data, accessed on 15 June 2021, https://www.aer.gov.au/networks-pipelines/performance-reporting/power-and-water-corporation-rin-responses

[45] Interagency Working Group on Social Cost of Carbon, *Technical Support Document: - Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 1286*, US Government, July 2015, Table A1: Annual SSC Values: 2010-2050 (2007$/metric ton CO2).

[46] Decision Regulation Impact Statement (RIS) - Energy Efficiency of Commercial Buildings, Prepared for Australian Building Codes Board, The CIE, 2018 (Section H.6) <https://www.abcb.gov.au/sites/default/files/resources/2020//Final_RIS_Energy_efficiency_of_commercial_buildings_DOC.docx >

discounts the average estimate of the future costs of climate change using a 3% real discount rate. The high scenario corresponds to the 95th percentile of the frequency distribution of the future costs of climate change using a 3% real discount rate. Values are converted from USD at an assumed exchange rate of 0.7 AUD = 1.0 USD and rebased from 2007 values to FY2022 assuming average inflation of 2% per year. Values are projected beyond 2050 at the same average rate of change experienced during the 2010 – 2050 period covered by the original US data.

We note that the IWG is currently reviewing the social costs of carbon, and there is an expectation that these values may be revised upwards substantially, but these results will not be available until sometime in 2022. In the meantime, the 'high' sensitivity analysis may be taken as a proxy for the impact of higher social costs of carbon.

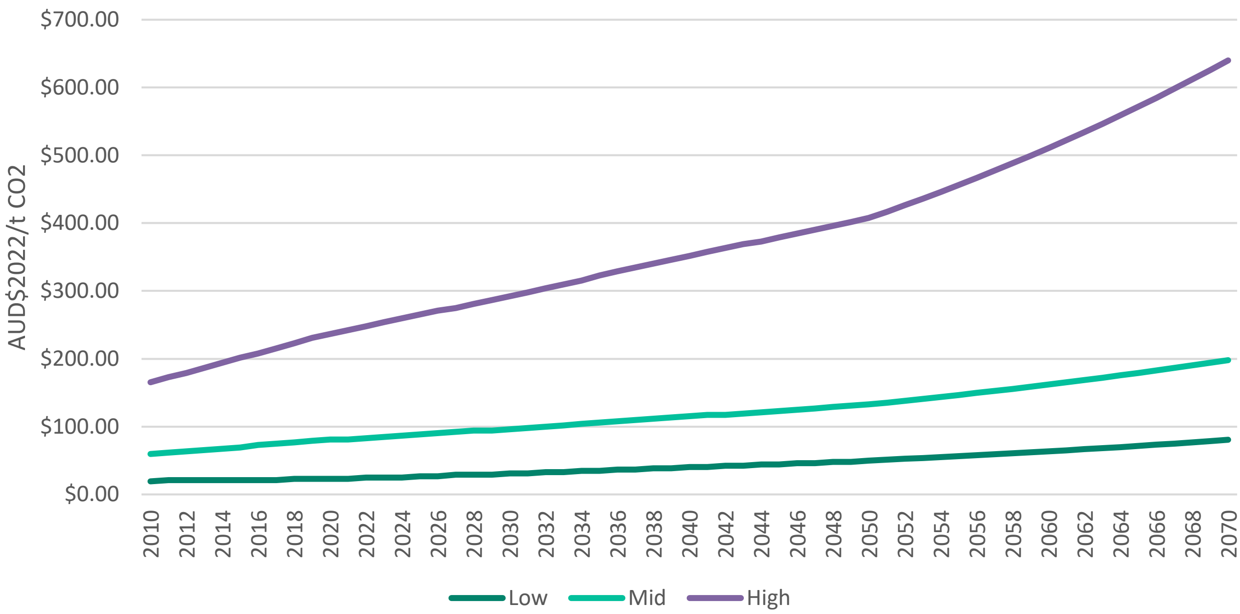


Figure G-1: Social cost of carbon estimates

G.2.3 Greenhouse Gas Intensity of Electricity Consumption

For the emissions intensity of electricity consumption in the NT, we source values as follows:

- For 2020 from Table 46: Scope 2 and 3 emissions factors – consumption of purchased electricity by end users, NGA Factors Workbook
- For 2020 - 2030 from Appendix C, Australia's Emissions Projections, 2020
- For post 2030, we assume the same average annual rate of change in emissions intensity as projected for the 2020 – 2030 period.

Note that the use of a different source for 2020 may explain the discontinuity between 2020 – 2021.

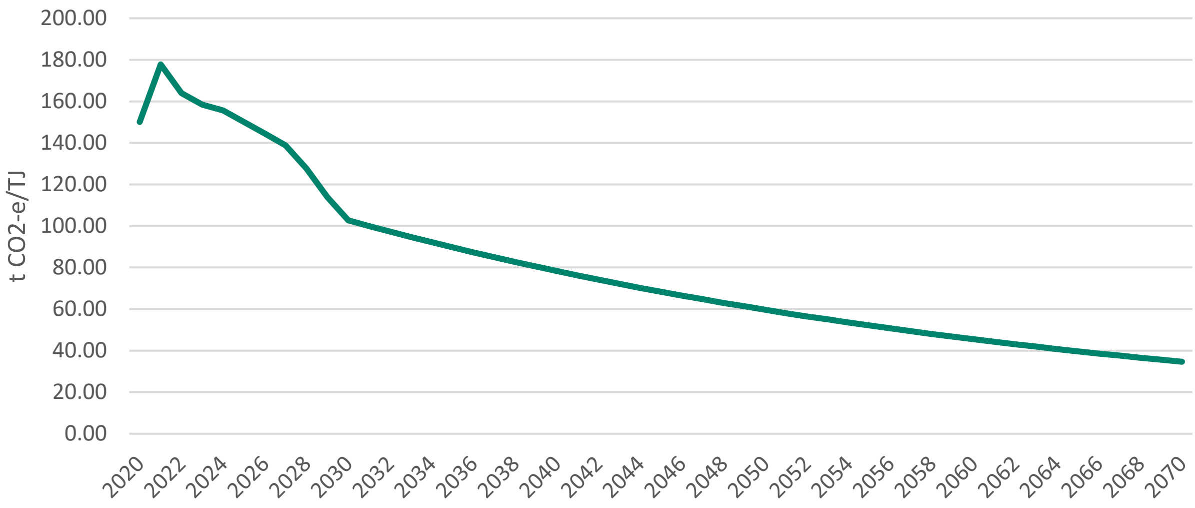


Figure G-2: Scope 2 and 3 Electricity Emissions Projection [tonnes CO_2-e /TJ]

The emissions intensity of pipeline delivered gas is assumed, in the Australian Government's Accounts Factors Workbook, to be a constant at 51.53 kg CO_2-e/GJ.

G.2.4 Incremental Construction / Plant Costs

Incremental costs of construction[47] (including plant) in the policy case have been estimated for each building form, as described in Appendix E. As with all elements of the cost benefit analysis, prices are treated as 'real' or after-inflation, and thus are not escalated for general inflation. As noted below, a discount or 'learning rate' of 2% annually will be applied to incremental construction costs.

A reference 'learning rate' (rate of reduction over time in the incremental costs of construction, due to learning processes by industry) of 2% annually has been applied, with 0% and 5% applied in sensitivity analyses. Learning rates cover several factors that are expected to lead to declining incremental costs of compliance over time, including:

- changed designs and/or specifications
- changed construction materials
- economies of scale for higher-performance building components.

We note that a 2% reference learning rate is very conservative, as it implies that incremental costs associated with the introduction of Section J would still be being felt 50 years later. The 2% reference rate is recommended by Houston Kemp (2017).[48] While this report relates to residential building code changes, learning is not confined to residential buildings. It is possible that higher rates could apply in the non-residential buildings sector, given greater budgets for design and optimisation. However, changes in real construction costs are not well documented, as they are generally considered confidential, and so we propose to use the residential value referenced. The 5% sensitivity case implicitly assumes that such incremental costs are not discernible after 20 years.

[47] The is the change on construction costs associated with a Section J compliant building and the base case. See Appendix C, Appendix D, and Appendix E for details on the incremental construction costs.
[48] Houston Kemp, Residential Buildings Regulatory Impact Statement Methodology, April 2017, p.22.

In the social cost benefit analysis, to the incremental construction costs are added incremental cost allowances for:

- positions for administration of new aspects of the Code, including administration of outreach to and enabling training for industry professionals.
- incremental education and training material costs.

As incremental adjustment/training costs to any new performance requirements would be expected to be temporary, we make allowances for three years the above costs – in total, $500,000 per year for each of FY2023 – FY2025. These are applied for the economy-wide or 'composite' scenario only, as it is unclear how such costs might be broken down by archetype.

G.2.5 Stock Projections

Figure G-3 provides an overview of the estimated historical and projected floor area of non-residential buildings in the Northern Territory by building type.

Historical stock is taken from the current update to the 2012 Commercial Building Baseline Study. This observation is ultimately sourced from Geoscape,[49] where the primary data source is satellite imagery, and estimates derived from that imagery. We estimate the total gross floor area for non-residential buildings in the NT to have been around 7.6 million sqm at the end of FY2020.

Gross construction rates in the historical period have been sourced from DIPL, and is the same data provided to the Australian Bureau of Statistics for its building activity data series. NT building regulations recognise two 'tiers', or regions within declared building control areas, where different provisions may apply. It is expected that Section J, if adopted, would apply in all declared Building Control Areas aligned with the application of the other sections of the NCC. It is anticipated that the majority of building in the projected timeframe will be in Tier 1 regions, but the analysis also examines the application in Tier 2 areas – see Table G-2.

[49] Geoscape, accessed on 15 September 2021, https://geoscape.com.au/

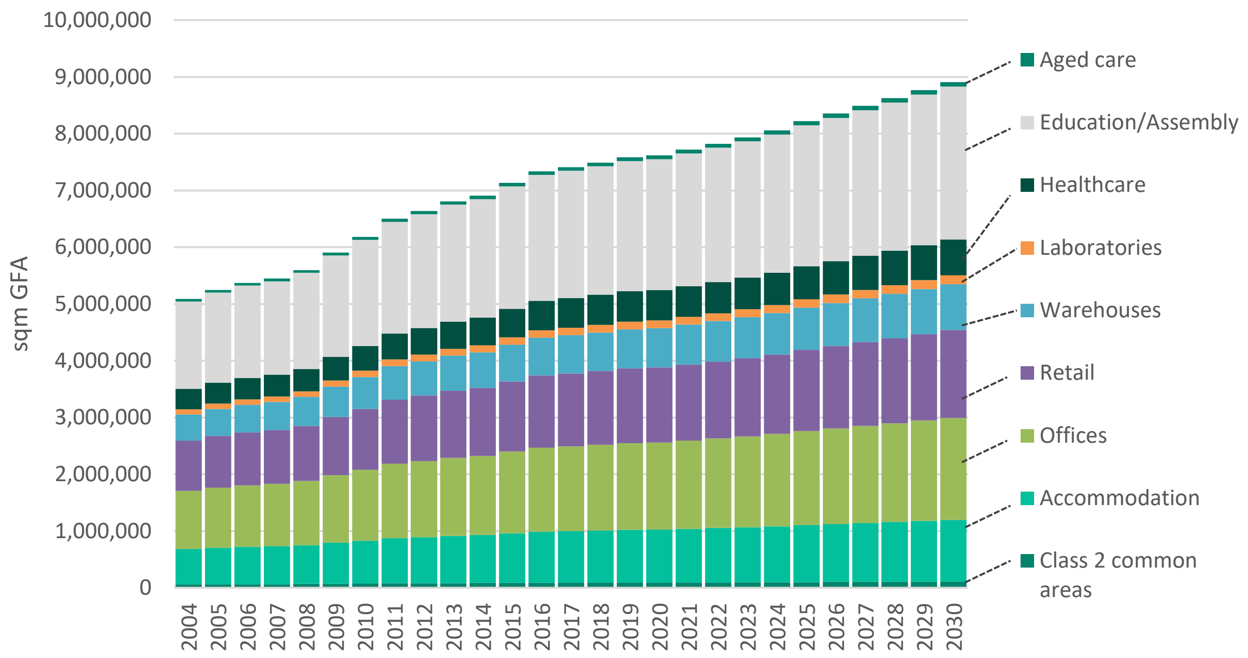


Figure G-3: Northern Territory: Non-Residential Stock by Building Type

Table G-2: Building regulation Tier 1 and Tier 2 regions.

Tier 1	Tier 2	Tier 2
Darwin	Adelaide River	Kings Canyon
Alice Springs	Batchelor	Larrimah
Lake Bennett	Borroloola	Mataranka
	Brewer Estate	Namarada
	Elliott	Pine Creek
	Jabiru	Tennant Creek
	Katherine	Timber Creek
	Katherine Gorge	Ti Tree

For the stock model, we estimate the split between floor area in Tier 1 and 2 regions by allocating the floor area – which is modelled in its original source by local government area (LGA) – to the two Tiers. This process may not be precise, as Tier boundaries and LGA boundaries may not be the same. Overall, this process indicates that in FY2016, some 68% of all non-residential floor area in the NT was in Tier 1 areas, with just over 28% in Tier 2 areas, with just under 4% of floor area estimated to be outside either Tier.

However, building approval data indicates that new construction activity is even more heavily weighted in favour of Tier 1 areas: in total over the FY2012 – FY2020 period, just over 90% of new floor area in the NT was added in Tier 1 areas – see Table G-3 and Table G-4 below.

Table G-3: New construction floor area (approvals, sqm), by financial year, Tier 1 zones.

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Class 2 common areas	4,165	16,003	11,122	17,790	5,969	876	1,007	1,638	725
Accommodation	73,719	61,750	40,207	5,055	14,110	4,713	7,581	137,923	1,088
Offices	75,664	104,123	144,782	231,695	81,525	31,014	69,405	45,231	34,091
Retail	20,077	26,404	18,968	49,383	40,148	37,389	159,432	45,530	11,573
Warehouses	39,800	13,266	15,066	38,488	17,561	13,706	48,453	20,152	33,917
Laboratories	13,432	21,164	3,606	6,931	2,251	3,610	5,669	3,338	2,332
Healthcare	4,586	468	2,898	3,551	10,223	2,218	4,892	1,353	1,688
Education/Assembly	15,370	12,965	17,676	17,206	18,060	46,236	18,306	29,051	16,449
Aged care	0	0	0	1,168	0	3,225	0	18	96
Totals	**246,813**	**256,143**	**254,325**	**371,267**	**189,847**	**142,987**	**314,745**	**284,234**	**101,959**

Table G-4: New construction floor area (approvals, sqm), by financial year, Tier 2 zones

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Class 2 common areas	0	0	266	15	16	0	0	0	0
Accommodation	1,580	816	1,893	939	1,162	7,446	7,217	45,524	0
Offices	3,079	7,446	5,948	10,851	2,519	2,404	4,568	1,439	5,440
Retail	330	2,773	1,430	2,553	750	80	941	13,017	116
Warehouses	364	219	12,713	8,642	3,225	7,480	1,747	77	461
Laboratories	1,012	495	7,599	2,777	12,862	2,496	391	0	710
Healthcare	0	213	106	286	9	1,737	222	0	450
Education/Assembly	2,349	4,031	2,594	3,736	3,872	1,549	828	3,246	5,766
Aged care	0	0	0	0	0	0	0	0	0
Totals	**8,714**	**15,993**	**32,549**	**29,799**	**24,415**	**23,192**	**15,914**	**63,303**	**12,943**

The future rate of growth in the non-residential building stock is uncertain and will vary as a function of the strength as well as the sectoral composition of economic growth over time. For the historical period (in this case, FY2012 to FY2020, we were supplied with gross construction data by DIPL. This, along with an allowance for demolitions (see below), enabled us to relate the rate of net stock growth to growth in the real value of Gross State Product over this period. We then use a value of 2.3% expected annual growth in real GSP – as advised by DIPL and in line with Treasury 4-year projections – to model expected future stock growth to FY2030. Based on the trends since FY2012, this implies an average annual growth in the net stock of around 0.9% per year.

The rate of demolition of existing floor area is generally not well documented in Australia, as we apply an assumption that, on average, 2% of the stock is demolished annually. This assumption is consistent with an average economic life of 50 years for non-residential buildings.

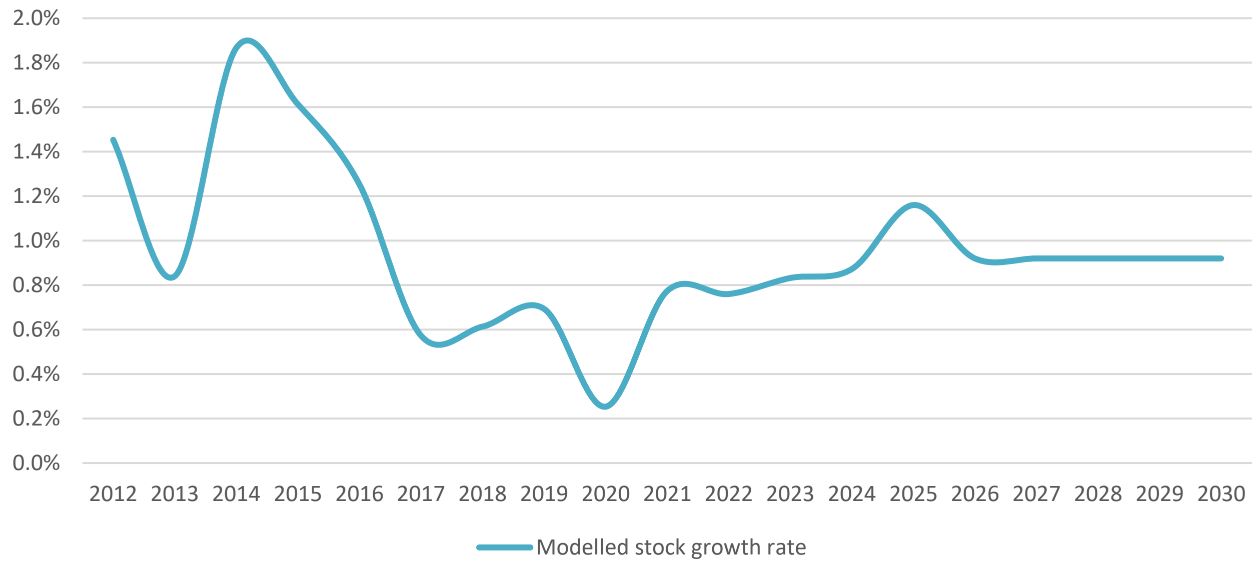


Figure G-4: Historical and Expected Future Net Annual Growth in Non-Residential Floor Area

Given that electricity pricing and underlying resource costs vary by region, as noted above, we also need to understand the distribution of the stock, and stock growth, by network regions. For this purpose, we also allocate the stock into the three main networks (Darwin to Katherine Interconnected System (DKIS), Alice Springs and Tennant Creek) and then the unregulated areas. We estimate these stock shares by comparison with the building stock data by LGA. As above, this may not be precise, as the boundaries between the different network regions do not precisely align with LGA boundaries.

Table G-5 indicates the floor area shares by LGA (included floor area in unincorporated areas[50] of the NT), along with our mapping to building regulation Tiers and electricity network areas.

[50] Areas of land that are not covered by a LGA are referred to as 'Unincorporated'. This definition is as per the Australian Statistical Geography Standard (ASGS) (1270.0.55.003).

Table G-5: Non-residential floor area shares, by LGA, tier and Network area.
(Cities (C), Municipalities (M), Regions (R), Shires (S) and Towns (T)). Unincorporated NT refers to areas that are not covered by a LGA.

Stock % by LGA (2016)	Floor Area Shares	Tier	Network
Alice Springs (T)	9.5%	Tier 1	Alice Springs
Barkly (R)	2.5%	Tier 2	Tennant Creek
Belyuen (S)	0.0%	Tier 1	Remote
Central Desert (R)	1.1%	Tier 2	Alice Springs
Coomalie (S)	0.9%	Tier 2	DKIS
Darwin (C)	33.8%	Tier 1	DKIS
East Arnhem (R)	3.3%	Outside Building Control	Remote
Katherine (T)	4.2%	Tier 2	DKIS
Litchfield (M)	14.1%	Tier 1	DKIS
MacDonnell (R)	2.7%	Tier 2	Alice Springs
Palmerston (C)	10.3%	Tier 1	DKIS
Roper Gulf (R)	1.8%	Tier 2	DKIS
Tiwi Islands (R)	0.2%	Outside Building Control	Remote
Unincorporated NT	11.7%	Tier 2	Remote
Victoria Daly (R)	1.9%	Tier 2	DKIS
Wagait (S)	0.0%	Tier 1	Remote
West Arnhem (R)	1.7%	Tier 2	Remote
West Daly (R)	0.3%	Outside Building Control	Remote
Total	100.0%		

The matrix of estimated non-residential floor divisions by Tier and network region are shown in Table G-6. This table sums to 96.2%, as we estimate just under 4% of non-residential floor area is outside either Tier 1 or Tier 2 building control areas.

Table G-6: Estimated non-residential floor area shares by tier and network region.

Stock Shares	Tier 1	Tier 2	Totals
DKIS	58.2%	8.8%	67.0%
Alice Springs	9.5%	3.8%	13.3%
Tennant Creek	0.0%	2.5%	2.5%
Unregulated	0.0%	13.4%	13.4%
Totals	67.7%	28.5%	96.2%

Since the Department was able to provide the project team with detailed historical data on building approvals (including project numbers and floor area by building class, year and geography – allocated to Tiers), we use this data to estimate gross construction volumes (floor area) by year from FY2012 – FY2020, making allowances for 2% of the annual stock being demolished. However, annual building approvals do not provide any indication of the *total* floor area by building type, nor of the floor area demolished annually. For this, it was necessary to refer to (not yet published) data being compiled for the Commercial Building Baseline Study 2021 Update.

The modelled stock turnover implies gross construction activity that is volatile in the historical period but varying around a mean of some 265,000 sqm per annum in total across the NT over FY2012 – FY2020 (established via building approval data). This is forecast to rise to around 350,000 sqm per annum on average by FY2030, in line with rising GSP – see Figure G-5. These values are critical to the cost benefit analysis, as they set the volume of impact that Section J could potentially have each year. This impact will be modelled on the assumption that new energy performance requirements could apply over the period from FY2023 to FY2030. After that it is likely that another standard may apply and, in any case, this period is long enough to determine the net costs and benefits.

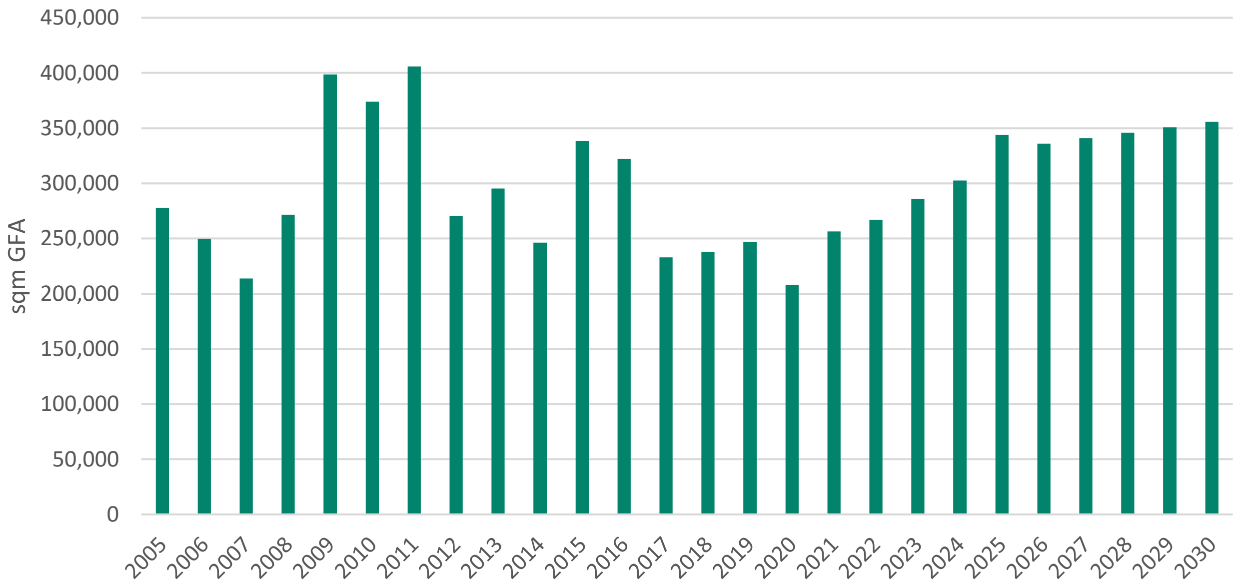


Figure G-5: Modelled gross construction activity in NT.

Appendix H – Owner-Occupier Perspective Cost Benefit Analysis Parameters

During the delivery of this project, the question was raised as to whether there might be different key assumptions that should be used for analyses from an owner-occupier perspective, rather than from a societal or social perspective, beyond the factors noted in Appendix F. It was noted that the applicable real discount rate could be different, and that there is a history of real electricity cost escalation. Consequently, SPR conducted further research leading to a proposed setting for analysing the cost-effectiveness of the potential adoption of NCC2016 or NCC2019 in the Northern Territory, from an owner-occupier perspective. This section sets out the research results and covers recommendations for:

- Real discount rates from an owner-occupier perspective
- Real electricity cost escalation
- Other sensitivity analysis parameters.

Appendix H.1 Real Discount Rate

The societal cost benefit analysis uses a reference real discount rate of 7%, as this reflects advice from the Australian Government's Office of Best Practice Regulation (OBPR).[51] The same *Guidance Note* recommends sensitivity analysis is undertaken at 3% real and 10% real. However, different rates may be appropriate when considering cost effectiveness from an owner-occupier perspective.

Why Discount?

By way of background, discounting of cashflows (both costs and benefits) over time is done to allow different options to be compared and evaluated on a consistent basis when cashflows may be spread out over time, and potentially also irregular over time. For example, one option may have some costs upfront and then others that occur at regular intervals over time (eg, reinvestment in capital goods, or maintenance expenditures) while benefits mostly occur in the short term; but another option may have all the costs occurring in year 1, but benefits spread out evenly over 50 years. Comparing and ranking these two options is difficult unless they can both be brought to a common base.

This is done by discounting the future cashflows annually using a real (that is, after-inflation) percentage (more on this below), and then summing that discounted cashflow to a present value. This is done separately for costs and for benefits, using the same real discount rate for both. The present value of benefits *minus* the present value of costs is called the 'net present value' (NPV), while the present value of benefit *divided by* the present value of costs is called the 'benefit cost ratio' (BCR).

SPR argues that NPV is a better metric for ranking options than BCR, as BCR is dimensionless (no units), and it is often incorrectly assumed that a 'higher is better' rule of thumb can be applied to BCRs. But this is not the case. A high BCR may be associated with low value of net social welfare and vice versa. Generally high BCRs occur when the option in question differs very little from 'business as usual' and, if implemented, would have little impact. By contrast, NPV is measured in dollars, and a 'higher is better' rule of thumb can be applied – provided all the relevant impacts are 'monetised' (valued in monetary terms). This rule of thumb provides a consistent basis for ranking options, which BCR does not.

Discounting means that the further into a future a value (cost or benefit) occurs, the lower is its contribution to the present value (the value in today's terms). The degree to which this occurs is *highly* sensitive to the

[51] Australian Government Office of Best Practice Regulation, *Cost Benefit Analysis – Guidance Note*, December 2020.

real discount rate selected, because the discounts accumulate year on year. A lower real discount rate gives a more even weighting to impacts in all years, while a higher discount rate weights impacts that occur in the near future more strongly than those that occur in the more distant future. To illustrate, the NPV in FY2022 (this year) of $100 of cost or benefit that arises in 2089 is $100 at a 0% real discount rate, $13.40 at 3% real, $1.00 at 7% real, and just $0.15 at 10% real.

Given this, the choice of real discount rate has a very material impact on both the absolute net present values of different options, and how they might rank, depending upon how their costs and benefits are distributed over time. So, on what basis should a real discount rate be selected, and what differences might be made for an owner-occupier perspective vs a societal perspective?

In the economic literature, there are two rationales offered for discounting:

- time preference (or the observation that people tend to place a higher value on consumption today than in the future, and may require compensation to put off consumption to a future period)
- the opportunity cost of capital (or the observation that the returns on the investment or project in question should not be less than those available on (equivalent) investments elsewhere, or else capital will not be used efficiently across the economy).

These two approaches can align, at least broadly, where the values involved are monetary, as the real (after-inflation) interest rate on capital (adjusted for risk) also defines the value of 'waiting' to consume or spend a dollar, under the time value perspective. That is, a dollar not spent today can be invested and earn *at least* the real risk-free interest rate (normally defined by the interest rate on 10-year or longer-term Treasury bonds). Also, the economic literature suggest that the private rate of time preference can vary widely from individual to individual, and it can be hard to agree what an appropriate 'social' rate of time preference might be. For these reasons, an opportunity cost of capital is generally taken as the more practical basis for defining real interest rates. This also provides a rationale for applying different discount rates for private and social investments. The cost of capital is likely to be different in the two cases, broadly reflecting the size the risk premium that is added to the risk-free cost of capital (Treasury bond rate).

In principle, this implies that that social real discount rate might be lower than the private real discount rate, as it extremely rare for governments to default on debt, and they can raise funds through taxes, whereas private businesses present greater risks and do not have access to tax revenue. However, in current Australian practice, at least, the opposite is true. As noted, the OBPR requires a 7% real discount rate be applied for public investments, even though this is far above the 10-year bond rate (currently 1.67%, and potentially zero or negative in real terms, if an allowance of, say, 2% is made for inflation – this would imply the risk-free real cost of capital in Australia is currently negative (1.67% – 2% = -0.33%). Why then does OBPR continue to insist that 7% real is an appropriate rate of discount for public investments? A recent paper by Synergies Economic Consulting suggests that it reflects past interest rates, which were much higher.[52] However, another explanation is that the Australian Government effectively uses what is perceived (including in the Synergies report) to be a very high real discount rate to ration public expenditure. That is, proposals for public investment that achieved less than a 7% real rate of return are likely to be set aside, reducing the overall call on the Budget. This also ensures that the set of investments that do proceed have relatively high

[52] Synergies Economic Consulting, *Discount rates for use in cost benefit analysis of AEMO's 2022 Integrated System Plan*, July 2021. This source notes that OBPR advice on real discount rates has not changed since 1989, despite very significant changes in capital markets since that time.

societal value – at least where values can be readily monetised. This is seen by many as problematic for investments – for example, to avoid future climate damage – where the rate of monetary return may be low and where many benefits (avoided loss of species, for example) are difficult or impossible to monetise.

Turning to the private – or owner-occupier – perspective, the opportunity cost of capital will be *at least* the real cost of capital to the borrower, and that varies according to the perceived riskiness of the borrower/investment. In reality, investors may well seek higher returns from their investment portfolios, but if capital is available at a given real rate, then investments that are expected to earn at least this rate could proceed.[53] More realistically, a rate of return on debt is likely to be required, in return for the risk accepted by the construction firm in undertaking the investment. The Synergies reference above suggests (p. 28) that pre-tax return on debt values of between 3.0% (low case) and 3.2% (mid and high cases) be used. This is based on electricity sector investments rather than building construction sector investments. A high case of 3.5% is used to reflect the uncertainty about risk perceptions between the two asset classes.

A survey of business loan rates available as at 1 December 2021 indicates as follows (Table H-1):

Table H-1: Commercial Loan Rates (Nominal)

Lender	Loan Type	Nominal Interest Rate
Westpac	Business Development Base Rate	4.77% (*less* negotiated customer margin)
Westpac	Small Business Loan Rate	3.66%
Westpac	Market linked debit interest rates	0.06% + negotiated customer margin
NAB	Business Options Prime	3.60%
Commonwealth	Market rate finance (linked to daily Bank Bill Swap Bid rate)	0.14% (mid, 6-month rollover) + negotiated customer margin
Commonwealth	Bank Guarantee (ongoing, no expiry date)	3.0%
IMB Bank	Fully drawn business loan (commercial security, > $1million)	2.99%
IMB Bank	Fixed business loan rate (5 years, commercial security)	4.19%
BOQ	3-year fixed rate (commercial security)	2.99%

The negotiated customer margins that might apply for NT-based construction firms is not clear, although the Synergies reference above associates a risk premium of 1.45% with a BBB commercial risk rating. This suggest that it might be possible for some customers to access finance at interest rates less than 2% nominal at present – albeit that they would be exposed to daily changes in market rates. Taking a more conservative approach, Table H-1 suggests that central nominal (pre-inflation) interest rates are likely to be in the 3 – 4% range at present (say, 3.5%). As the Synergies reference notes (p. 16), interest rates have, of course, been higher in past, and may well be higher in future. The 10-year Treasury bond rate averaged around 3.5% (but falling over time) throughout the 2010s, and a little under 6% through the 2000s. We propose to test 6% nominal as the high assumption.

For inflation, the average quarterly change in the national consumer price index over the 5 years to September 2021 has been 0.5%, or 2% on an annualised basis.[54] This is similar to the current 'trimmed mean

[53] This is particularly the case in the current global economy, where capital is effectively unconstrained.

[54] Australian Bureau of Statistics, *6401.0 Consumer Price Index, Australia - TABLES 1 and 2. CPI: All Groups, Index Numbers and Percentage Changes*, September 2021.

inflation' rate (which excludes large, one-off impacts on prices) of 2.1%.[55] The average quarterly change in CPI in Darwin over this same period was slightly below the national average, at 0.4% per quarter or 1.6% on an annualised basis. Over a longer period, from the March 2011 quarter to September 2021, the Darwin quarterly average was 0.5%, or 2.0% on an annualised basis.

This implies that real interest rates in the NT at present would be between 1.4% and 2.4% (3% - 1.6% = 1.4%; and 4% - 1.6% = 2.4%), with 1.9% as a central value (3.5% - 1.6% = 1.9%). For a 'worst case' assumption, it might be assumed that nominal interest rates returned to around the 2000s average of 6%, although such a scenario would likely be associated with higher inflation as well. For example, the ABS reference above notes that the average quarterly CPI between March quarter 2000 and December quarter 2010 was 0.8%, or 3.2% on an annualised basis. This would imply a real interest rate of around 2.8% (6% - 3.2% = 2.8%).

If we add back the range of return on debt values noted above, then a plausible range of real discount rates from an owner-occupier perspective may be from 3.9% (low), to 4.7% (central) to 6.3% (high) as per Table H-2.

Table H-2: Derivation of Low, Mid and High Real Discount Rates, Owner-Occupier Perspective, NT

Component		Low	Mid	High
1)	Nominal cost of capital	2.5%	3.5%	6%
2)	Inflation (CPI)	1.6%	2.0%	3.2%
3)	Real cost of capital (1 *minus* 2)	0.9%	1.5%	2.8%
4)	Pre-tax return on debt	3.0%	3.2%	3.5%
5)	**Proposed real discount rates, owner-occupier perspective (3 + 4)**	**3.9%**	**4.7%**	**6.3%**

Appendix H.2 Real Electricity Cost Escalation

DIPL provided Power and Water Corporation commercial tariff data, which indicates that nominal electricity prices rose by 2.4% per year on average over the July 2010 – July 2021 period. However, as noted above, inflation averaged 2% per year over this period, which means that real electricity price inflation was only 0.4% on average. If a base year of 2013 is chosen both nominal and real price changes would be negative over the period to 2021. The nominal and real price data is shown in Figure H-1 below.

[55] See https://www.abs.gov.au/statistics/economy/price-indexes-and-inflation/consumer-price-index-australia/latest-release

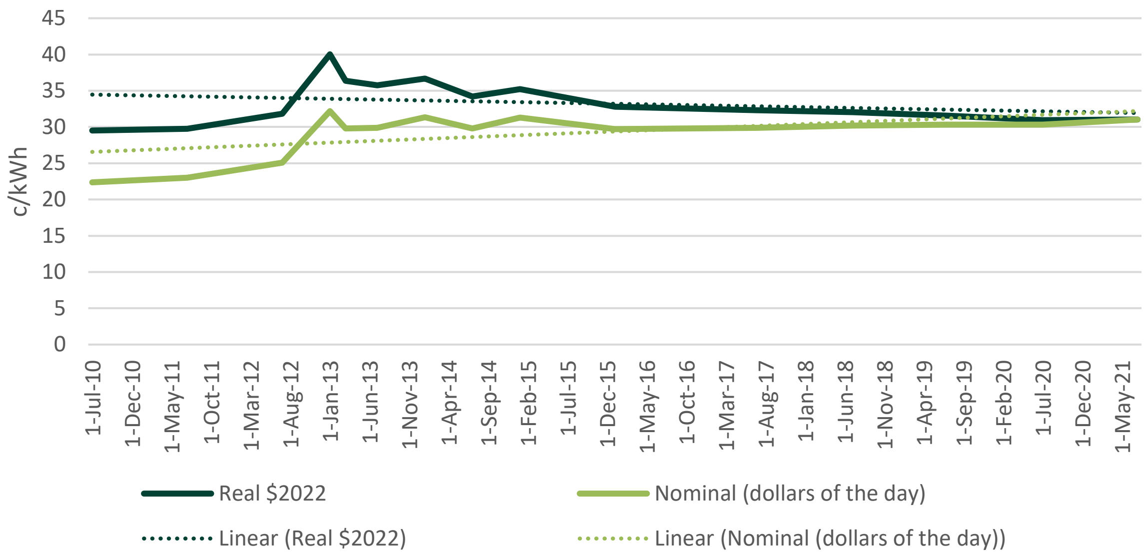


Figure H-1: Nominal and Real Commercial Tariffs, NT (Power & Water Corporation)

However, Figure H-1 also shows that over some periods shown, and also earlier in the 2000s, there have been periods of rapid price rises for electricity, and this cannot be ruled out for the future. We therefore propose to undertake sensitivity analysis with a central assumption of 0.4% per year increase in *real* electricity prices, low at 0% per year (as per the current analysis), and high at 1% per year.

Appendix H.3 Other Sensitivity Analysis Parameters

For the other sensitivity analysis parameters, we propose the factors shown in Table H-3. For completeness, the real discount rate and real electricity cost escalation factors are also included. Note that for the owner-occupier perspective, the social costs of carbon and the social costs of network provision are not included – even though there may be private value obtainable by building owners in carbon offsets markets – and the analysis is conducted territory-wide; that is, for both building control zones 1 and 2.

Table H-3: Summary of Sensitivity Analysis Parameters, Owner-Occupier Perspective

Parameter	Worst	Expected	Best
Real discount rate	6.3%	4.7%	3.9%
Real electricity cost escalation	0%	0.4%	1%
Realisation of expected energy savings	75%	100%	100%
Cost learning rates	0%	2%	5%

Appendix I – Cost Benefit Analysis – Detailed Results by Scenario and Archetype

The detailed results of the economy-wide cost benefit analysis by building type are set out in this Appendix, assuming ‘default’ settings, as summarised below:

Table I-1: Default Cost Benefit Analysis Parameters by Perspective

Parameter	Value in Owner-Occupier Perspective	Value in Social Perspective
Real discount rate	4.7%	7.0%
Realisation of savings	100%	100%
Learning rate	2%	2%
Tier	1+2	1+2
Real annual electricity price escalation rate	0.4%	-
Social costs of carbon	-	3% (av.)

Appendix I.1 Cost Benefit Analysis – Detailed Results by Scenario and Archetype

The key results of the cost benefit analysis for the economy-wide or ‘composite’ scenario – that is, if new requirements are implemented for all new non-residential buildings from FY2023 – are summarised in Section 6 and Section 7. This section provides background to that by showing the separate results for each building archetype and (relevant) scenario. To minimise the length of tables, we show these results for default settings, as per Table I-1.

I.1.1 Cost Benefit Analysis – Social Perspective

Reference/Expected Case

Table I-2: NCC2016 – Detailed Results – Social Perspective (Darwin – CZ1, Alice Springs – CZ3), Reference Case

Building Archetype	CZ	PV of Energy Savings	PV of Carbon Savings	PV of Avoided Network Augex	PV of Avoided Network Opex	PV of Total Benefits	PV of Incremental Costs	NPV	BCR
Hotel (3A)	1	$15,083	$1,482	$212	$3,319	$20,096	$11,925	$8,172	1.7
Multi-Storey Office (5A)	1	$39,126	$3,844	$483	$7,544	$50,997	$16,036	$34,961	3.2
Single-Storey Office (5)	1	$10,319	$1,014	$212	$3,313	$14,858	$19,265	-$4,407	0.8
Retail (6B)	1	$29,611	$2,909	$404	$6,315	$39,239	$15,198	$24,042	2.6
Hospital (9aC)	1	$5,724	$562	$49	$767	$7,102	$4,808	$2,294	1.5
School (9bH)	1	$19,004	$1,867	$231	$3,613	$24,716	$25,517	-$801	1.0
Hotel (3A)	3	$1,968	$252	$44	$690	$2,954	$1,486	$1,468	2.0
Multi-Storey Office (5A)	3	$3,593	$360	$55	$862	$4,870	$2,291	$2,580	2.1
Single-Storey Office (5)	3	$3,160	$317	$51	$803	$4,331	$3,007	$1,324	1.4
Retail (6B)	3	$5,414	$543	$64	$993	$7,013	$2,552	$4,462	2.7
Hospital (9aC)	3	$1,441	$145	$20	$307	$1,912	$659	$1,253	2.9
School (9bH)	3	$4,853	$487	$166	$2,599	$8,105	$4,136	$3,969	2.0

Table I-3: NCC2019 – Detailed Results – Social Perspective (Darwin – CZ1, Alice Springs – CZ3), Reference Case

Building Archetype	CZ	PV of Energy Savings	PV of Carbon Savings	PV of Avoided Network Augex	PV of Avoided Network Opex	PV of Total Benefits	PV of Incremental Costs	NPV	BCR
Hotel (3A)	1	$15,083	$1,482	$201	$3,148	$19,914	$10,379	$9,535	1.9
Multi-Storey Office (5A)	1	$48,886	$4,803	$613	$9,580	$63,882	$15,705	$48,177	4.1
Single-Storey Office (5)	1	$25,341	$2,490	$213	$3,337	$31,381	$22,089	$9,292	1.4
Retail (6B)	1	$87,800	$8,627	$1,127	$17,615	$115,168	$13,969	$101,200	8.2
Hospital (9aC)	1	$12,844	$1,262	$22	$343	$14,471	$7,326	$7,145	2.0
School (9bH)	1	$46,389	$4,558	$320	$5,001	$56,268	$25,841	$30,427	2.2
Hotel (3A)	3	$3,016	$402	$93	$1,449	$4,960	$2,043	$2,918	2.4
Multi-Storey Office (5A)	3	$3,316	$333	$58	$902	$4,608	$2,267	$2,341	2.0
Single-Storey Office (5)	3	$7,346	$737	$65	$1,015	$9,163	$3,633	$5,529	2.5
Retail (6B)	3	$8,976	$900	$71	$1,110	$11,058	$1,856	$9,201	6.0
Hospital (9aC)	3	$3,899	$391	$43	$665	$4,998	$1,373	$3,625	3.6
School (9bH)	3	$13,307	$1,335	$154	$2,408	$17,203	$3,752	$13,452	4.6

Best Case

Table I-4: NCC2016 – Detailed Results – Social Perspective (Darwin – CZ1, Alice Springs – CZ3), Best Case

Building Archetype	CZ	PV of Energy Savings	PV of Carbon Savings	PV of Avoided Network Augex	PV of Avoided Network Opex	PV of Total Benefits	PV of Incremental Costs	NPV	BCR
Hotel (3A)	1	$30,742	$8,642	$251	$6,766	$46,400	$12,665	$33,735	3.7
Multi-Storey Office (5A)	1	$79,747	$22,419	$569	$15,376	$118,111	$17,031	$101,080	6.9
Single-Storey Office (5)	1	$21,033	$5,913	$250	$6,753	$33,949	$20,461	$13,488	1.7
Retail (6B)	1	$60,353	$16,967	$477	$12,872	$90,668	$16,141	$74,527	5.6
Hospital (9aC)	1	$11,667	$3,280	$58	$1,563	$16,568	$5,107	$11,461	3.2
School (9bH)	1	$71,605	$20,130	$273	$7,365	$99,372	$27,100	$72,272	3.7
Hotel (3A)	3	$4,020	$1,550	$52	$1,406	$7,028	$1,578	$5,449	4.5
Multi-Storey Office (5A)	3	$7,323	$2,102	$65	$1,757	$11,247	$2,433	$8,814	4.6
Single-Storey Office (5)	3	$6,440	$1,848	$61	$1,637	$9,986	$3,194	$6,792	3.1
Retail (6B)	3	$11,035	$3,167	$75	$2,024	$16,300	$2,710	$13,590	6.0
Hospital (9aC)	3	$2,936	$843	$23	$625	$4,428	$699	$3,728	6.3
School (9bH)	3	$13,848	$3,974	$196	$5,297	$23,316	$4,393	$18,923	5.3

Table I-5: NCC2019 – Detailed Results – Social Perspective (Darwin – CZ1, Alice Springs – CZ3), Best Case

Building Archetype	CZ	PV of Energy Savings	PV of Carbon Savings	PV of Avoided Network Augex	PV of Avoided Network Opex	PV of Total Benefits	PV of Incremental Costs	NPV	BCR
Hotel (3A)	1	$30,742	$8,642	$238	$6,416	$46,038	$11,024	$35,014	4.2
Multi-Storey Office (5A)	1	$99,640	$28,011	$723	$19,525	$147,900	$16,679	$131,220	8.9
Single-Storey Office (5)	1	$51,650	$14,520	$252	$6,802	$73,223	$23,460	$49,763	3.1
Retail (6B)	1	$178,956	$50,308	$1,329	$35,903	$266,496	$14,836	$251,660	18.0
Hospital (9aC)	1	$26,179	$7,360	$26	$699	$34,264	$7,780	$26,483	4.4
School (9bH)	1	$94,550	$26,580	$377	$10,194	$131,702	$27,445	$104,257	4.8
Hotel (3A)	3	$6,162	$2,490	$109	$2,954	$11,715	$2,170	$9,546	5.4
Multi-Storey Office (5A)	3	$6,759	$1,940	$68	$1,838	$10,604	$2,408	$8,196	4.4
Single-Storey Office (5)	3	$14,972	$4,297	$77	$2,069	$21,415	$3,859	$17,556	5.5
Retail (6B)	3	$18,295	$5,251	$84	$2,263	$25,893	$1,972	$23,921	13.1
Hospital (9aC)	3	$7,948	$2,281	$50	$1,355	$11,634	$1,458	$10,176	8.0
School (9bH)	3	$27,122	$7,784	$182	$4,908	$39,995	$3,985	$36,011	10.0

Worse Case

Table I-6: NCC2016 – Detailed Results – Social Perspective (Darwin – CZ1, Alice Springs – CZ3), Worst Case

Building Archetype	CZ	PV of Energy Savings	PV of Carbon Savings	PV of Avoided Network Augex	PV of Avoided Network Opex	PV of Total Benefits	PV of Incremental Costs	NPV	BCR
Hotel (3A)	1	$7,519	$252	$189	$2,206	$10,167	$11,333	-$1,166	0.9
Multi-Storey Office (5A)	1	$19,505	$654	$430	$5,014	$25,604	$15,240	$10,363	1.7
Single-Storey Office (5)	1	$5,144	$172	$189	$2,202	$7,708	$18,309	-$10,601	0.4
Retail (6B)	1	$14,762	$495	$360	$4,198	$19,815	$14,444	$5,371	1.4
Hospital (9aC)	1	$2,854	$96	$44	$510	$3,503	$4,570	-$1,067	0.8
School (9bH)	1	$17,514	$587	$206	$2,402	$20,709	$24,251	-$3,542	0.9
Hotel (3A)	3	$980	$42	$39	$458	$1,520	$1,412	$107	1.1
Multi-Storey Office (5A)	3	$1,791	$61	$49	$573	$2,475	$2,177	$297	1.1
Single-Storey Office (5)	3	$1,575	$54	$46	$534	$2,209	$2,858	-$649	0.8
Retail (6B)	3	$2,699	$92	$57	$660	$3,508	$2,425	$1,083	1.4
Hospital (9aC)	3	$718	$25	$17	$204	$964	$626	$338	1.5
School (9bH)	3	$3,387	$116	$148	$1,728	$5,379	$3,931	$1,448	1.4

Table I-7: NCC2019 – Detailed Results – Social Perspective (Darwin – CZ1, Alice Springs – CZ3), Worst Case

Building Archetype	CZ	PV of Energy Savings	PV of Carbon Savings	PV of Avoided Network Augex	PV of Avoided Network Opex	PV of Total Benefits	PV of Incremental Costs	NPV	BCR
Hotel (3A)	1	$7,519	$252	$179	$2,092	$10,043	$9,864	$179	1.0
Multi-Storey Office (5A)	1	$24,371	$817	$546	$6,368	$32,102	$14,925	$17,176	2.2
Single-Storey Office (5)	1	$12,633	$423	$190	$2,218	$15,465	$20,993	-$5,528	0.7
Retail (6B)	1	$43,771	$1,467	$1,004	$11,709	$57,951	$13,276	$44,675	4.4
Hospital (9aC)	1	$6,403	$215	$20	$228	$6,865	$6,962	-$97	1.0
School (9bH)	1	$23,126	$775	$285	$3,325	$27,511	$24,559	$2,952	1.1
Hotel (3A)	3	$1,501	$67	$83	$963	$2,614	$1,941	$673	1.3
Multi-Storey Office (5A)	3	$1,653	$57	$51	$599	$2,360	$2,154	$206	1.1
Single-Storey Office (5)	3	$3,662	$125	$58	$675	$4,520	$3,453	$1,067	1.3
Retail (6B)	3	$4,475	$153	$63	$738	$5,429	$1,764	$3,665	3.1
Hospital (9aC)	3	$1,944	$67	$38	$442	$2,490	$1,305	$1,185	1.9
School (9bH)	3	$6,634	$227	$137	$1,600	$8,599	$3,566	$5,033	2.4

I.1.2 Cost Benefit Analysis – Owner-Occupier Perspective

Reference Case

Table I-8: NCC2016 – Detailed CBA Results ('000$2022) – Owner-Occupier Perspective (Darwin – CZ1, Alice Springs – CZ3), Reference Case

Building Archetype	CZ	PV of Energy Savings	PV of Avoided Network Opex	PV of Total Benefits	PV of Incremental Construction Costs	NPV	BCR
Hotel (3A)	1	$20,278	$150	$20,428	$13,062	$7,366	1.6
Multi-Storey Office (5A)	1	$52,604	$340	$52,944	$17,566	$35,378	3.0
Single-Storey Office (5)	1	$13,874	$149	$14,023	$21,103	-$7,079	0.7
Retail (6B)	1	$39,811	$285	$40,096	$16,647	$23,448	2.4
Hospital (9aC)	1	$7,696	$35	$7,730	$5,267	$2,463	1.5
School (9bH)	1	$47,234	$163	$47,396	$27,951	$19,446	1.7
Hotel (3A)	3	$2,661	$0	$2,661	$1,628	$1,033	1.6
Multi-Storey Office (5A)	3	$4,811	$0	$4,811	$2,509	$2,302	1.9
Single-Storey Office (5)	3	$4,232	$0	$4,232	$3,294	$938	1.3
Retail (6B)	3	$7,251	$0	$7,251	$2,795	$4,456	2.6
Hospital (9aC)	3	$1,929	$0	$1,929	$721	$1,208	2.7
School (9bH)	3	$9,099	$0	$9,099	$4,530	$4,569	2.0

Table I-9: NCC2019 – Detailed CBA Results ('000$2022) – Owner-Occupier Perspective (Darwin – CZ1, Alice Springs – CZ3) , Reference Case

Building Archetype	CZ	PV of Energy Savings	PV of Avoided Network Opex	PV of Total Benefits	PV of Incremental Construction Costs	NPV	BCR
Hotel (3A)	1	$20,278	$142	$20,420	$11,369	$9,051	1.8
Multi-Storey Office (5A)	1	$65,726	$432	$66,158	$17,203	$48,955	3.8
Single-Storey Office (5)	1	$34,070	$150	$34,220	$24,196	$10,025	1.4
Retail (6B)	1	$118,046	$794	$118,839	$15,301	$103,538	7.8
Hospital (9aC)	1	$17,269	$15	$17,284	$8,025	$9,260	2.2
School (9bH)	1	$62,369	$225	$62,594	$28,306	$34,289	2.2
Hotel (3A)	3	$4,084	$0	$4,084	$2,238	$1,847	1.8
Multi-Storey Office (5A)	3	$4,441	$0	$4,441	$2,483	$1,958	1.8
Single-Storey Office (5)	3	$9,838	$0	$9,838	$3,980	$5,858	2.5
Retail (6B)	3	$12,021	$0	$12,021	$2,034	$9,988	5.9
Hospital (9aC)	3	$5,222	$0	$5,222	$1,504	$3,718	3.5
School (9bH)	3	$17,821	$0	$17,821	$4,110	$13,711	4.3

Best Case

Table I-10: NCC2016 – Detailed CBA Results ('000$2022) – Owner-Occupier Perspective (Darwin – CZ1, Alice Springs – CZ3), Best Case

Building Archetype	CZ	PV of Energy Savings	PV of Avoided Network Opex	PV of Total Benefits	PV of Incremental Construction Costs	NPV	BCR
Hotel (3A)	1	$27,162	$174	$27,336	$12,216	$15,121	2.2
Multi-Storey Office (5A)	1	$70,462	$395	$70,857	$16,427	$54,429	4.3
Single-Storey Office (5)	1	$18,584	$173	$18,757	$19,735	-$978	1.0
Retail (6B)	1	$53,326	$331	$53,657	$15,568	$38,088	3.4
Hospital (9aC)	1	$10,308	$40	$10,348	$4,926	$5,423	2.1
School (9bH)	1	$63,268	$189	$63,457	$26,139	$37,318	2.4
Hotel (3A)	3	$3,520	$0	$3,520	$1,522	$1,998	2.3
Multi-Storey Office (5A)	3	$6,445	$0	$6,445	$2,347	$4,098	2.7
Single-Storey Office (5)	3	$5,668	$0	$5,668	$3,080	$2,588	1.8
Retail (6B)	3	$9,712	$0	$9,712	$2,614	$7,098	3.7
Hospital (9aC)	3	$2,584	$0	$2,584	$675	$1,910	3.8
School (9bH)	3	$12,188	$0	$12,188	$4,237	$7,951	2.9

Table I-11: NCC2019 – Detailed CBA Results ('000$2022) – Owner-Occupier Perspective (Darwin – CZ1, Alice Springs – CZ3), Best Case

Building Archetype	CZ	PV of Energy Savings	PV of Avoided Network Opex	PV of Total Benefits	PV of Incremental Construction Costs	NPV	BCR
Hotel (3A)	1	$27,162	$165	$27,327	$10,633	$16,695	2.6
Multi-Storey Office (5A)	1	$88,038	$501	$88,540	$16,088	$72,452	5.5
Single-Storey Office (5)	1	$45,636	$175	$45,810	$22,627	$23,183	2.0
Retail (6B)	1	$158,119	$922	$159,041	$14,309	$144,731	11.1
Hospital (9aC)	1	$23,131	$18	$23,149	$7,504	$15,644	3.1
School (9bH)	1	$83,541	$262	$83,803	$26,471	$57,332	3.2
Hotel (3A)	3	$5,391	$0	$5,391	$2,093	$3,298	2.6
Multi-Storey Office (5A)	3	$5,949	$0	$5,949	$2,322	$3,626	2.6
Single-Storey Office (5)	3	$13,178	$0	$13,178	$3,722	$9,455	3.5
Retail (6B)	3	$16,102	$0	$16,102	$1,902	$14,200	8.5
Hospital (9aC)	3	$6,995	$0	$6,995	$1,407	$5,588	5.0
School (9bH)	3	$23,871	$0	$23,871	$3,843	$20,028	6.2

Worst Case

Table I-12: NCC2016 – Detailed CBA Results ('000$2022) – Owner-Occupier Perspective (Darwin – CZ1, Alice Springs – CZ3), Worst Case

Building Archetype	CZ	PV of Energy Savings	PV of Avoided Network Opex	PV of Total Benefits	PV of Incremental Construction Costs	NPV	BCR
Hotel (3A)	1	$10,636	$114	$10,750	$13,079	-$2,328	0.8
Multi-Storey Office (5A)	1	$27,592	$259	$27,851	$17,588	$10,263	1.6
Single-Storey Office (5)	1	$7,277	$114	$7,391	$21,129	-$13,738	0.3
Retail (6B)	1	$20,882	$217	$21,098	$16,668	$4,430	1.3
Hospital (9aC)	1	$4,037	$26	$4,063	$5,274	-$1,211	0.8
School (9bH)	1	$24,775	$124	$24,899	$27,986	-$3,087	0.9
Hotel (3A)	3	$1,406	$0	$1,406	$1,630	-$224	0.9
Multi-Storey Office (5A)	3	$2,524	$0	$2,524	$2,512	$11	1.0
Single-Storey Office (5)	3	$2,220	$0	$2,220	$3,298	-$1,078	0.7
Retail (6B)	3	$3,803	$0	$3,803	$2,799	$1,005	1.4
Hospital (9aC)	3	$1,012	$0	$1,012	$722	$290	1.4
School (9bH)	3	$4,773	$0	$4,773	$4,536	$237	1.1

Table I-13: NCC2019 – Detailed CBA Results ('000$2022) – Owner-Occupier Perspective (Darwin – CZ1, Alice Springs – CZ3), Worst Case

Building Archetype	CZ	PV of Energy Savings	PV of Avoided Network Opex	PV of Total Benefits	PV of Incremental Construction Costs	NPV	BCR
Hotel (3A)	1	$10,636	$108	$10,744	$11,384	-$639	0.9
Multi-Storey Office (5A)	1	$34,475	$329	$34,803	$17,224	$17,579	2.0
Single-Storey Office (5)	1	$17,870	$114	$17,985	$24,226	-$6,241	0.7
Retail (6B)	1	$61,917	$604	$62,521	$15,320	$47,201	4.1
Hospital (9aC)	1	$9,058	$12	$9,070	$8,035	$1,035	1.1
School (9bH)	1	$32,714	$172	$32,885	$28,341	$4,544	1.2
Hotel (3A)	3	$2,161	$0	$2,161	$2,241	-$79	1.0
Multi-Storey Office (5A)	3	$2,329	$0	$2,329	$2,486	-$157	0.9
Single-Storey Office (5)	3	$5,160	$0	$5,160	$3,985	$1,175	1.3
Retail (6B)	3	$6,305	$0	$6,305	$2,036	$4,269	3.1
Hospital (9aC)	3	$2,739	$0	$2,739	$1,506	$1,233	1.8
School (9bH)	3	$9,348	$0	$9,348	$4,115	$5,233	2.3

Appendix I.2 Cost Benefit Analysis – Sensitivity Analyses – Building Construction Changes

Table I-14: Economy-wide analysis (owner-occupier perspective) of single-storey office with cladded steel frame walls in Darwin (CZ 1), and Alice Springs (CZ 3). Present values (PV) ('000$2022) are determined across a 40-year building life cycle.

Scenario		CZ	PV of Energy Savings	PV of Avoided Opex	PV of Total Benefits	PV of Incremental Construction Costs	NPV	BCR
Default Case	NCC2016	1	$22,185	$259	$22,444	$21,889	$556	1.0
	NCC2016	3	$7,492	$0	$7,492	$3,336	$4,156	2.2
	NCC2019	1	$43,891	$301	$44,192	$18,784	$25,408	2.4
	NCC2019	3	$12,278	$0	$12,278	$3,376	$8,902	3.6
Best Case	NCC2016	1	$29,716	$301	$30,017	$20,470	$9,548	1.5
	NCC2016	3	$10,036	$0	$10,036	$3,120	$6,916	3.2
	NCC2019	1	$58,791	$349	$59,140	$17,567	$41,574	3.4
	NCC2019	3	$16,446	$0	$16,446	$3,158	$13,289	5.2
Worst Case	NCC2016	1	$11,636	$198	$11,834	$21,916	-$10,082	0.5
	NCC2016	3	$3,930	$0	$3,930	$3,340	$590	1.2
	NCC2019	1	$23,022	$229	$23,251	$18,808	$4,443	1.2
	NCC2019	3	$6,440	$0	$6,440	$3,381	$3,059	1.9

Table I-15: Economy-wide sensitivity analysis of hotel with 30% WWR, relative to a base case with 50% WWR, in Darwin (CZ 1), and Alice Springs (CZ3). Present values (PV) ('000$2022) are determined across a 40-year building life cycle.

Scenario		CZ	PV of Energy Savings	PV of Avoided Opex	PV of Total Benefits	PV of Incremental Construction Costs	NPV	BCR
Default Case	NCC2016	1	$29,142	$327	$29,469	$2,888	$26,581	10.2
	NCC2016	3	$9,934	$0	$9,934	-$665	$10,599	-ve cost
	NCC2019	1	$29,142	$383	$29,525	$140	$29,385	211.2
	NCC2019	3	$11,358	$0	$11,358	-$217	$11,575	-ve cost
Best Case	NCC2016	1	$39,034	$380	$39,414	$2,701	$36,714	14.6
	NCC2016	3	$13,264	$0	$13,264	-$763	$14,027	-ve cost
	NCC2019	1	$39,034	$445	$39,479	$131	$39,348	302.0
	NCC2019	3	$15,135	$0	$15,135	-$249	$15,384	-ve cost
Worst Case	NCC2016	1	$15,285	$249	$15,534	$2,892	$12,643	5.4
	NCC2016	3	$5,221	$0	$5,221	-$582	$5,803	-ve cost
	NCC2019	1	$15,285	$292	$15,577	$140	$15,437	111.3
	NCC2019	3	$5,976	$0	$5,976	-$190	$6,166	-ve cost

Table I-16: Economy-wide sensitivity analysis of multi-storey office with 56% WWR in Darwin (CZ 1), and Alice Springs (CZ3). Present values (PV) ('000$2022) are determined across a 40-year building life cycle.

Scenario		CZ	PV of Energy Savings	PV of Avoided Opex	PV of Total Benefits	PV of Incremental Construction Costs	NPV	BCR
Default Case	NCC2016	1	$57,091	$365	$57,455	$22,822	$34,633	2.5
	NCC2016	3	$6,313	$0	$6,313	$2,374	$3,939	2.7
	NCC2019	1	$70,011	$456	$70,467	$21,233	$49,234	3.3
	NCC2019	3	$6,795	$0	$6,795	$3,222	$3,573	2.1
Best Case	NCC2016	1	$76,471	$424	$76,895	$21,343	$55,552	3.6
	NCC2016	3	$8,457	$0	$8,457	$2,220	$6,236	3.8
	NCC2019	1	$93,777	$530	$94,307	$19,857	$74,451	4.7
	NCC2019	3	$9,102	$0	$9,102	$3,013	$6,089	3.0
Worst Case	NCC2016	1	$29,945	$277.73	$30,223	$22,851	$7,372	1.3
	NCC2016	3	$3,311	$0.00	$3,311	$2,377	$934	1.4
	NCC2019	1	$36,722	$347.30	$37,069	$21,260	$15,810	1.7
	NCC2019	3	$3,564	$0.00	$3,564	$3,226	$338	1.1

Appendix I.3 Energy Cost Savings Per Square Meter

Table I-17: Energy cost savings per square meter ($/m²) in FY2023 for base case and NCC2016, and NCC2019-compliant building archetypes in Darwin and Alice Springs. The total energy cost savings for all scenarios are derived from electricity consumption, except for hotels (3A) in Alice Springs, where both energy is consumed is derived from both electricity and gas.

Location	Building Archetype	Base Case	NCC2016	NCC2019
Darwin	Hotel (3A) (30% WWR)	$42.67	$38.17	$36.73
	Multi-storey Office (5A) (40% WWR)	$27.53	$20.02	$18.15
	Single-storey office (5) (30% WWR)	$30.97	$28.99	$26.10
	Retail (6B) (30% WWR)	$60.13	$53.53	$40.55
	Hospital Ward (9aC) (30%WWR)	$51.50	$48.36	$44.44
	School (9bH) (30% WWR)	$42.67	$38.17	$36.73
Alice Springs	Hotel (3A) – Total (30% WWR)	$28.12	$24.71	$22.88
	Hotel (3A) - Electricity	$26.85	$23.77	$22.21
	Hotel (3A) - Gas	$1.27	$0.94	$0.67
	Multi-storey Office (5A) (40% WWR)	$16.39	$12.65	$12.94
	Single-storey office (5) (30% WWR)	$30.09	$26.80	$22.44
	Retail (6B) (30% WWR)	$42.47	$35.92	$31.61
	Hospital Ward (9aC) (30%WWR)	$29.15	$24.84	$17.52
	School (9bH) (30% WWR)	$30.33	$25.61	$21.09

Table I-18: Energy costs saved in NCC2016 and NCC2019 compliant building archetypes, relative to the base case. Values equate to the decrease in value of energy consumed from the base case. The absolute decrease ($/m²) and percentage (%) decrease are shown.

Location	Building Archetype	NCC2016	NCC2019
Darwin	Hotel (3A) (30% WWR)	$4.77 (13.1%)	$4.77 (13.1%)
	Multi-storey Office (5A) (40% WWR)	$7.51 (27.3%)	$9.38 (34.1%)
	Single-storey office (5) (30% WWR)	$1.98 (6.4%)	$4.86 (15.7%)
	Retail (6B) (30% WWR)	$6.60 (11.0%)	$19.58 (32.6%)
	Hospital Ward (9aC) (30%WWR)	$3.15 (6.1%)	$7.06 (13.7%)
	School (9bH) (30% WWR)	$4.50 (10.5%)	$5.94 (13.9%)
Alice Springs	Hotel (3A) (30% WWR)	$3.41 (12.1%)	$5.23 (18.5%)
	Multi-storey Office (5A) (40% WWR)	$3.74 (22.8%)	$3.45 (21.1%)
	Single-storey office (5) (30% WWR)	$3.29 (10.9%)	$7.65 (25.4%)
	Retail (6B) (30% WWR)	$6.55 (15.4%)	$10.86 (25.6%)
	Hospital Ward (9aC) (30%WWR)	$4.30 (14.7%)	$11.63 (39.9%)
	School (9bH) (30% WWR)	$4.72 (15.6%)	$9.24 (30.5%)

Appendix J – Greenhouse Gas Emissions Savings and Energy Saving by Fuel

Appendix J.1 Greenhouse Gas Emissions Savings

Greenhouse gas emissions savings were determined using greenhouse gas intensity input specified in Appendix G.2.3. In terms of greenhouse gas savings by scenario, the economy-wide results are summarised in Table J-1. NCC2019 generates the largest greenhouse gas savings of 891,000 tCO_2-e cumulatively over the FY2023 – FY2070 period. Under NCC2016, these savings are around half of those under NCC2019, at 469,000 tCO_2-e. Note that the *quantities* of greenhouse gas emissions and energy savings noted below do not change as a function of whether an owner-occupier or social perspective is taken. These values are however used to calculate social cost of carbon for the social cost benefit analyses.

Table J-1: Cumulative greenhouse gas emissions savings, tCO_2-e, FY2023 – FY2070, by scenario.

Scenario	Cumulative Emissions Savings, FY2023 – FY2070 (tCO_2-e)
Base Case	0
NCC2016	468,720
NCC2019	891,035

On an annualised basis, greenhouse gas emissions savings peak in FY2030 at 30,138 tCO_2-e under NCC2019, as this is the assumed final year of application of new standards, and cumulative energy savings have reached their peak by this time. Emissions then fall over time due to the declining greenhouse gas intensity of electricity consumption over time (Table J-2).

Table J-2: Annual greenhouse gas emissions savings, tCO_2-e, selected years.

Policy Case/Core Study	2023	2030	2040	2050	2060	2070
Base Case	0.0	0.0	0.0	0.0	0.0	0.0
NCC2016	2,738	15,852	12,097	9,236	7,055	5,394
NCC2019	5,205	30,138	22,997	17,556	13,410	10,251

In percentage terms, the emissions savings by scenario, relative to the base case, are set out in Table J-3. The same percentages apply regardless of whether emissions savings are expressed in annual or cumulative terms.

Table J-3: Greenhouse gas emissions savings by scenario, % relative to base case.

Policy Case/Core Study	% emissions savings
NCC2016	12.3%
NCC2019	23.4%

J.1.1 Energy Savings by Fuel

The greenhouse gas emissions savings above are based on the realisation of economy-wide electricity and gas savings, that vary by policy scenario. These are shown for electricity in Table J-4 and for gas in Table J-5.

Also, these tables make clear that energy savings only accumulate during the FY2023 – FY2030 years when new policy is assumed to apply, and those savings are retained for the balance of the economic life of the new building cohort. Some equipment and systems will have significantly shorter lives than the 50 years assumed for new buildings. We do not model future reinvestment in equipment due to uncertainty about future incremental costs and technology change. In particular, where a given level of technical performance has been selected consistently for new buildings for many years (due to building regulations, for example), other lower-specification options can lose market share while the newer specification tends to be become the new norm. This means that there may be no incremental costs to be paid when that equipment comes dues for renewal at the end of its economic life.

Economy wide energy savings by scenario, when expressed as percentages (Table J-6), are very similar to greenhouse gas emissions savings percentages.

Table J-4: Economy-wide annual electricity savings by scenario, MWh, selected years.

Policy Case /Core Study	2023	2024	2025	2026	2027	2028	2029	2030
NCC2016	4,788	9,744	15,496	20,753	26,095	31,523	37,038	42,643
NCC2019	9,104	18,529	29,467	39,463	49,620	59,941	70,429	81,086

Table J-5: Economy-wide annual gas consumption savings, GJ, selected years.

Policy Case /Core Study	2023	2024	2025	2026	2027	2028	2029	2030
NCC2016	162	330	525	703	884	1,068	1,255	1,445
NCC2019	297	603	960	1,285	1,616	1,952	2,294	2,641

Table J-6: Energy savings (electricity and gas) by scenario, % relative to base case.

Policy Case/Core Study	% energy savings
NCC2016	12.3%
NCC2019	23.4%

J.1.2 Peak Network Electrical Load

Table J-7 indicates that under the base case, the cohort of new buildings built between FY2023 and FY2030 would be expected to add almost 132 MW of peak demand to the NT electricity grid – noting that there would also be some building retirements over this period that would offset this growth to some degree. By contrast, if NCC2016 were adopted from FY2023, then by FY2030, the growth in peak demand would be reduced to just under 115 MW, a 13% reduction. If NCC2019 were adopted from FY2023, the growth in peak demand would fall to 104.5 MW, almost 21% less than in the base case. The table also shows these results broken down by energy pricing zone – as the extent to which the avoided peak loads flow through to owner-occupiers varies as a function of electricity pricing arrangements in each zone.

Table J-7: Peak demand (MW) from new commercial buildings by scenario and energy pricing zones, selected years.

Climate Zone	Energy Pricing Zone	Scenario	2023	2024	2025	2026	2027	2028	2029	2030
1	DKIS	Base Case	10.1	20.6	32.7	43.8	55.0	66.5	78.1	89.9
		NCC2016	8.9	18.0	28.7	38.4	48.3	58.3	68.5	78.9
		NCC2019	8.0	16.3	26.0	34.8	43.7	52.8	62.1	71.4
3	Alice Springs	Base Case	1.8	3.6	5.8	7.7	9.7	11.7	13.8	15.9
		NCC2016	1.5	3.0	4.8	6.4	8.0	9.7	11.4	13.1
		NCC2019	1.4	2.8	4.5	6.0	7.6	9.2	10.8	12.4
3	Tennant Creek	Base Case	0.3	0.7	1.1	1.5	1.8	2.2	2.6	3.0
		NCC2016	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.5
		NCC2019	0.3	0.5	0.8	1.1	1.4	1.7	2.0	2.3
1	Unregulated	Base Case	2.6	5.3	8.4	11.2	14.1	17.0	20.0	23.1
		NCC2016	2.3	4.6	7.3	9.8	12.4	14.9	17.6	20.2
		NCC2019	2.1	4.2	6.7	8.9	11.2	13.5	15.9	18.3
Total		**Base Case**	**14.8**	**30.1**	**47.9**	**64.2**	**80.7**	**97.5**	**114.5**	**131.9**
		NCC2016	**12.9**	**26.2**	**41.7**	**55.8**	**70.2**	**84.8**	**99.6**	**114.7**
		NCC2019	**11.7**	**23.9**	**38.0**	**50.9**	**64.0**	**77.3**	**90.8**	**104.5**

These results underpin the cost benefit analysis [above], since networks must incur considerable cost to cover expected growth in peak demands, and these costs can be reduced when the growth is reduced. The results follow directly from the modelling of the peak loads under different policy scenarios at the building archetype level, aggregated up to the whole-of-NT (or whole of energy pricing zone) level.

Figure J-1 (on the next page) presents the same information as Table J-7 in graphical form. We note that both the table and figure show values only to FY2030, as the policy cases are only modelled over this timeframe, so no further increases in avoided peak demand are assumed. If, in reality, the policy cases were to operate over a longer period, the benefits of avoided peak demand would also grow. Similarly, the benefits of lowered peak demand are assumed to persist over the whole of the economic life of this building cohort.

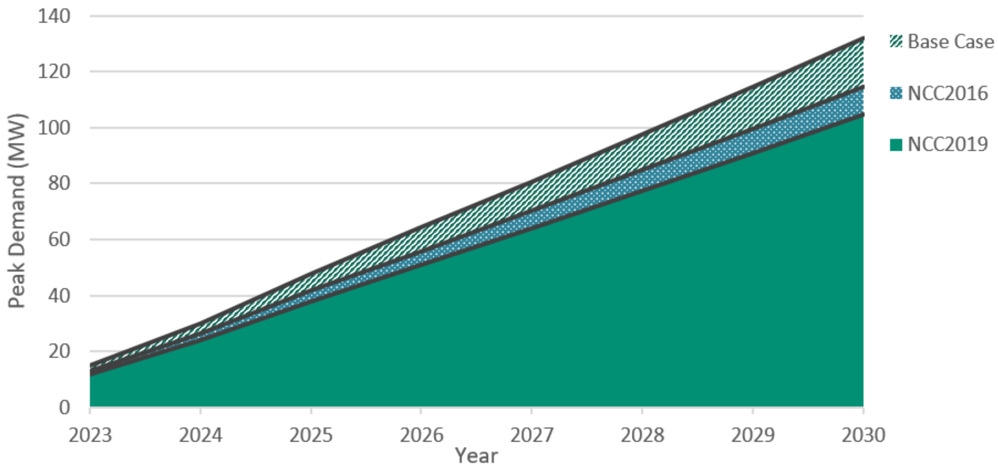
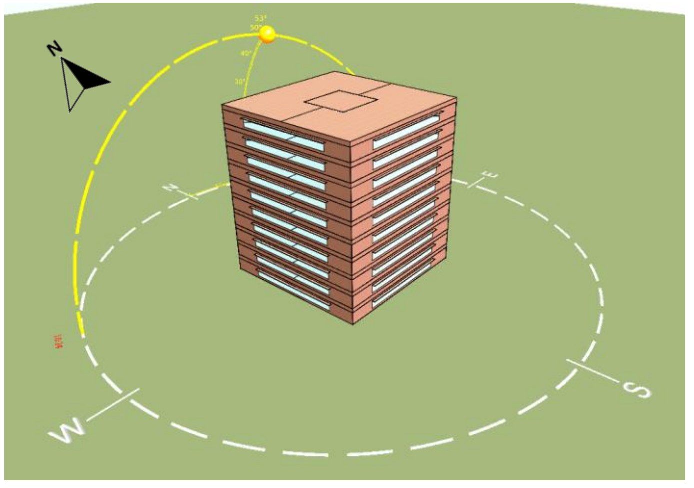


Figure J-1: Northern Territory peak demand (MW), new commercial buildings by scenario.

Appendix K – Summary of Base Case and NCC Compliance Specification - by Building Archetype

Appendix K.1 Hotels

Hotel (3A) Model and Floor Layout



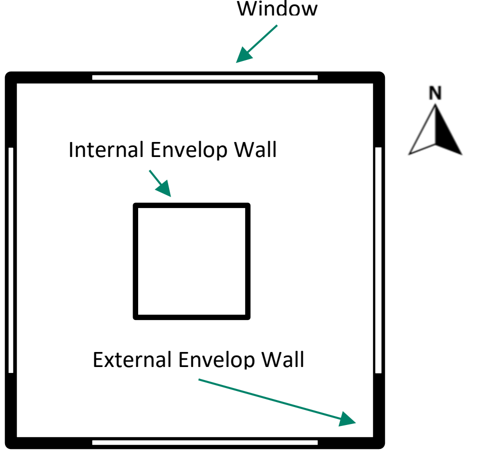


Figure K-1: Hotel (3A) model and floor layout - showing the position of the windows, external and internal envelop walls[56].

[56] External envelope walls are walls that separate a conditioned space or habitable room from the exterior of the building. The internal envelop walls separate a conditioned space or habitable room from a non-conditioned space (e.g. the wall surrounding the lift wells).

Table K-1: Hotels (3A) – Darwin, summary of building fabric and services changes

Darwin	Base Case	NCC2016	NCC2019
Roof (Metal sheet roof over a concrete slab)	• HR-BC1: Uninsulated (total R-value of 0.43)	• HR-C1: Foil-faced R1.8 (75mm) blanket insulation under roof, and R0.2 (7mm) foam insulation underslab (total R-value 3.23).	• HR-D1: Foil-faced R2.5 (110mm) blanket insulation under roof with a roof-raiser framing system (total R-Value 3.96).
Walls (insulation to be added inside external blockwork walls)	• BC1: Rendered single skin blockwork with plasterboard (total R-Value 0.58) (external wall, all façades) • BC3: Rendered single skin blockwork (total R-Value 0.46) (internal envelop walls)	• D5: 75mm frame, R2.0 insulation batts, 20mm reflective air gap, and thermal break tape (total R-Value 1.86) (south) • D8: 150mm frame, R4.0 insulation batts, 20mm reflective air gap and thermal break tape (total R-Value 2.30) (remaining 3 façades and internal envelop wall)	• D5: 75mm frame, R2.0 insulation batts, 20mm reflective air gap, and thermal break tape (total R-Value 1.86) (all façades – external wall) • J1: Double blockwork wall with 90mm cavity filled with blow-in insulation (total R-value 3.41) (internal envelop wall).
Window glazing (single pane unless otherwise stated)	• GL2: Grey tint (all façades)	• GL10: Double glazed low-E grey (north) • GL9: Double glazed low-E neutral (south and east) • GL15: Double glazed low-E grey in thermally broken frame (west)	• GL9: Double glazed low-E neutral (all façades)
Window Shading[57]	• 600mm sun hoods over windows on all façades	• 600mm sun hood over windows on the eastern façade. No window shading on all other windows	• No Shading
Floor	• Uninsulated slab	• R1.1 (25mm) underslab board insulation.	• R1.1 (25mm) underslab board insulation.
Air-Conditioning and Ventilation System	• Cooling via air-cooled chilled water, Fan Coil Units (FCUs) used for air delivery. No space heating. • No demand-controlled ventilation, energy recovery ventilation and economy cycle.	• Replace constant speed CHW pumps with variable speed pumps	• Replace constant speed CHW pumps with variable speed pumps • Incorporate a variable chilled water supply temperature set point to the CHW system
Lighting and Power	• Internal lighting control includes automated-off via a key card system	• No change to base case	• No change to base case
Energy Monitoring	• Retail utility meters, no energy metering for energy efficiency monitoring purposes[58]	• Incorporate an energy metering system to record individually the consumption of various building services.	• Incorporate an energy metering system to record individually the consumption of various building services, plus collating and storage of time of use energy consumption data.

Table K-2: Hotels (3A)– Alice Springs, summary of building fabric and services changes

Alice Springs	Base Case	NCC2016	NCC2019
Roof	• Same as Darwin (HR-BC1)	• Same as Darwin (HR-C1)	• Same as Darwin (HR-D1)
Walls	• Same as Darwin (BC1, BC3)	• Same as Darwin (D5, D8)	• Same as Darwin (D5, J1)
Window Glazing (single pane unless otherwise stated)	• GL1: Clear (all façades)	• GL2: Grey tint (north and south) • GL9: Double glazed low-E neutral (east and west)	• GL10: Double glazed low-E grey (north and west) • GL9: Double glazed low-E neutral (east and south)
Window Shading	• 600mm sun hoods (all façades)	• 800mm sun hood over windows (north). • No shading on all other windows	• No Shading
Floor	• Uninsulated slab	• No change to base case	• R1.1 (25mm) under slab board insulation.
Air-Conditioning and Ventilation System	• Cooling via air-cooled chilled water, and space heating via hot water from gas-fired condensing boilers. FCUs used for air delivery. • No demand-controlled ventilation, energy recovery ventilation and economy cycle.	• Same as Darwin	• Changes as per Darwin NCC2019, plus: • Incorporate a variable heating hot water supply temperature set point to the HHW system • Increase the control dead band between heating and cooling from 1°C to 2°C
Lighting and Power	• Same as Darwin[59]	• No change to base case	• No change to base case
Energy Monitoring	• Same as Darwin	• Same as Darwin	• Same as Darwin

[57] Note that in some instances, high performance glazing was found to be a lower cost means to meet Section J requirements compared to shading. Internal glare management benefits of shading are not existing considerations under Section J (though this may be subject to review in future code iterations). Design decisions to use shading will in many cases reduce the required performance specification of the glazing, but was not the least cost option amongst those assessed.

[58] Energy metering requirements for standard new constructions were found to typically be driven by billing requirements between landlords and tenants, rather than for efficiency monitoring purposes.

[59] It is acknowledged that automated lighting controls for internal spaces are common in Darwin and Alice Springs, however not necessarily by default.

Appendix K.2 Multi-Storey Office Building

Multi-Storey Office (5A) Model and Floor Layout

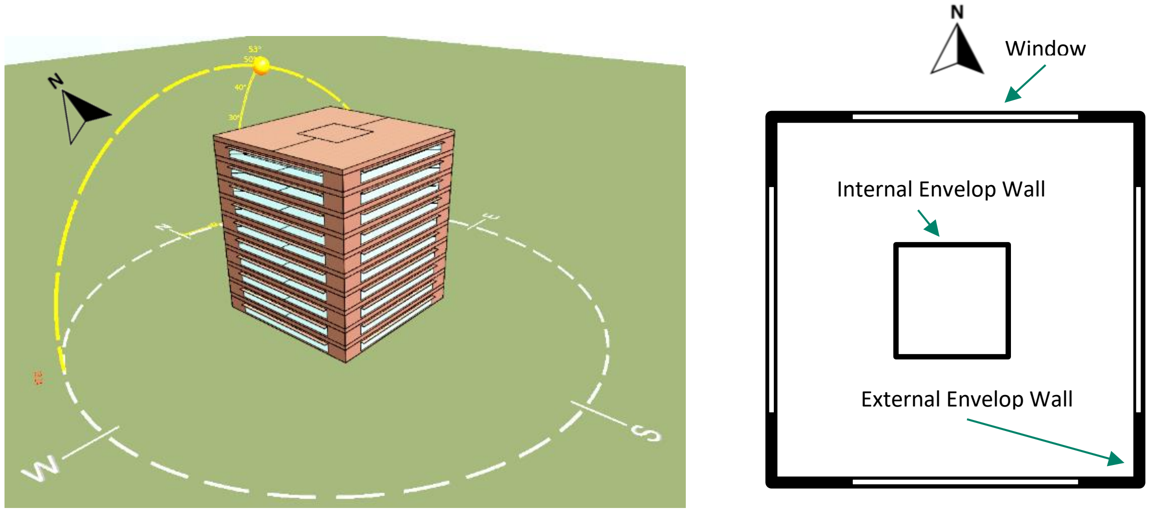


Figure K-2: Multi-storey office (5A) (left) model and (right) floor layout - showing the position of the windows, external and internal envelop walls. [60]

Table K-3: Multi-Storey Office Building (5A) – Darwin, summary of building fabric and services changes (specifications are the same for 40% and 56% WWR, unless otherwise stated).

Darwin	Base Case	NCC2016	NCC2019
Roof (Metal sheet roof over a concrete slab)	• HR-BC1: uninsulated (total R-value of 0.43)	• HR-C1: Foil-faced R1.8 (75mm) blanket insulation under roof, and R0.2 (7mm) foam insulation underslab (total R-value 3.23)	• HR-D1: Foil-faced R2.5 (110mm) blanket insulation under roof with a roof-raiser framing system (total R-Value 3.96)

[60] External envelope walls are walls that separate a conditioned space or habitable room from the exterior of the building. The internal envelop walls separate a conditioned space or habitable room from a non-conditioned space (e.g. the wall surrounding the lift wells).

<table>
<tr><th>Darwin</th><th>Base Case</th><th colspan="2">NCC2016</th><th colspan="2">NCC2019</th></tr>
<tr><td>Walls
(insulation to be added inside external blockwork walls)</td><td>• BC1: Rendered single skin blockwork with plasterboard (total R-Value 0.58) (external wall, all façades)
• BC3: Rendered single skin blockwork (total R-Value 0.46) (internal envelop walls)</td><td colspan="2">• D5: 75mm frame, R2.0 insulation batts, 20mm reflective air gap, and thermal break tape (total R-Value 1.86) (south façade)
• D8: 150mm frame, R4.0 insulation batts, 20mm reflective air gap and thermal break tape (total R-Value 2.30) (remaining 3 façades and internal envelop wall)</td><td colspan="2">• D5: 75mm frame, R2.0 insulation batts, 20mm reflective air gap, and thermal break tape (total R-Value 1.86) (all façades – external wall)
• D9: 150mm steel frame with thermal break tape on both sides, R4.0 batts, 20mm reflective air gap and (total R-value 2.81) (internal envelop wall)</td></tr>
<tr><td>Window Glazing
(single pane unless otherwise stated)</td><td>GL2: Grey tint (all façades)</td><td>For 40%WWR buildings
• GL9: Double glazed low-E neutral (north, east and west)
• GL4: Low-E neutral (south)</td><td>For 56%WWR buildings
• GL10: Double glazed low-E grey (north)
• GL9: Double glazed low-E neutral (south)
• GL15: Double glazed SC low-E grey in thermally broken frame (east and west)</td><td>For 40%WWR buildings
• Same as Darwin NCC2016, 40%WWR</td><td>For 56%WWR buildings
• GL10: Double glazed low-E grey (all façades)</td></tr>
<tr><td>Window Shading</td><td>• 800mm sun hoods (all façades)</td><td colspan="2">• No Shading</td><td colspan="2">• No Shading</td></tr>
<tr><td>Floor</td><td>• Uninsulated slab</td><td colspan="2">• R1.1 (25mm) under slab board insulation.</td><td colspan="2">• R1.1 (25mm) underslab board insulation.</td></tr>
<tr><td>Air-Conditioning and Ventilation System</td><td>• Cooling via an air-cooled chilled water system, with constant-speed air handling units for air delivery[61]. No space heating.
• No demand-controlled ventilation, energy recovery ventilation and economy cycle.</td><td colspan="2">• Replace constant speed CHW pumps with variable speed pumps</td><td colspan="2">• Replace constant speed CHW pumps with variable speed pumps
• Incorporate a variable chilled water supply temperature set point to the CHW system
• Incorporate demand-controlled ventilation</td></tr>
<tr><td>Lighting and Power</td><td>• Internal lighting controlled by manual on/off switches</td><td colspan="2">• Incorporate time clock control for lighting, and additional lighting control circuits on each perimeter of each floor, to allow lighting to be manually switched off when daylight levels are sufficient</td><td colspan="2">• Same as Darwin NCC2016</td></tr>
<tr><td>Energy Monitoring</td><td>• Retail utility meters, no energy metering for energy efficiency monitoring purposes[62]</td><td colspan="2">• Incorporate an energy metering system to record individually the consumption of various building services.</td><td colspan="2">• Incorporate an energy metering system to record individually the consumption of various building services, plus collating and storage of time of use energy consumption data.</td></tr>
</table>

[61] Installed as 3-speed AHUs but commissioned as constant-speed in operation

[62] Energy metering requirements for standard new constructions were found to typically be driven by billing requirements between landlords and tenants, rather than for efficiency monitoring purposes.

Table K-4: Multi-Storey Office Building (5A) – Alice Springs, summary of building fabric and services changes (specifications are the same for 40% and 56% WWR, unless otherwise stated).

<table>
<tr><th>Alice Springs</th><th>Base Case</th><th colspan="2">NCC2016</th><th colspan="2">NCC2019</th></tr>
<tr><td>Roof</td><td>• Same as Darwin (HR-BC1)</td><td colspan="2">• Same as Darwin (HR-C1)</td><td colspan="2">• Same as Darwin (HR-D1)</td></tr>
<tr><td>Walls
(insulation to be added inside external blockwork walls)</td><td>• Same as Darwin</td><td colspan="2">• Same as Darwin</td><td colspan="2">• D5: 75mm frame, R2.0 insulation batts, 20mm reflective air gap, and thermal break tape (total R-Value 1.86) (all external and internal envelop walls)</td></tr>
<tr><td>Window Glazing
(single pane unless otherwise stated)</td><td>• GL1: clear (all façades)</td><td>For 40%WWR buildings
• GL9: Double glazed low-E neutral (north, east and west)
• GL1: clear (south)</td><td>For 56%WWR buildings
• GL9: Double glazed low-E neutral (north, east and west)
• GL2: Grey tint (south)</td><td>For 40%WWR buildings
• GL9: Double glazed low-E neutral (north and west)
• GL1: Clear (south)
• GL4: Low-E neutral (east)</td><td>For 56%WWR buildings
• GL10: Double glazed low-E grey (north)
• GL4: Low-E neutral (south)
• GL9: Double glazed low-E neutral (east and west)</td></tr>
<tr><td>Window Shading</td><td>• 800mm sun hoods (all façades)</td><td colspan="2">• No Shading</td><td colspan="2">• No Shading</td></tr>
<tr><td>Floor</td><td>• Uninsulated slab</td><td colspan="2">• No change to base case</td><td colspan="2">• R1.1 (25mm) underslab board insulation.</td></tr>
<tr><td>Air-Conditioning and Ventilation System</td><td>• Air-cooled reverse variable refrigerant flow system with heat recovery used for cooling and space heating.
• No demand-controlled ventilation, energy recovery ventilation and economy cycle.</td><td colspan="2">• No changes to base case</td><td colspan="2">• Increase the control dead band between heating and cooling from 1°C to 2°C</td></tr>
<tr><td>Lighting and Power</td><td>• Same as Darwin</td><td colspan="2">• Same as Darwin</td><td colspan="2">• Same as Darwin</td></tr>
<tr><td>Energy Monitoring</td><td>• Same as Darwin</td><td colspan="2">• Same as Darwin</td><td colspan="2">• Same as Darwin</td></tr>
</table>

Appendix K.3 Single-Storey Office – Cladded Blockwork Walls

Single-Storey Office (5) Model and Floor Layout

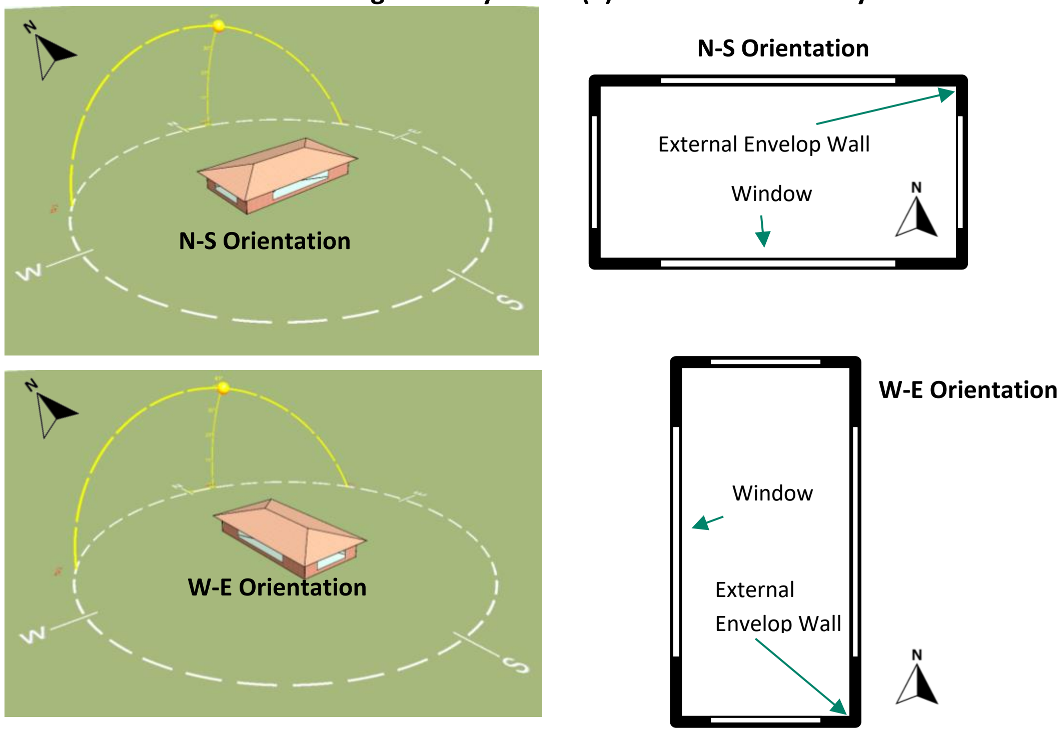


Figure K-3: Single-storey office (5) model and floor layout - showing the position of the windows, external and internal envelop walls. The building was modelled in 2 orientations – N-S Orientation and W-E orientation.

Table K-5: Single-Storey Office Building (5) – Darwin, summary of building fabric and services changes. Specification are the same for both building orientations unless otherwise stated.

Darwin	Base Case	NCC2016	NCC2019 – Core study
Roof (Pitched metal roof)	• LR-BC1: R1.5 (75mm) blanket	• LR-B1: R1.8 (75mm) blanket, foil underneath and spacing system	• LR-A2: R3.3 (140mm) blanket (no foil underneath)[63] and spacing system
Walls (insulation to be added inside external blockwork walls)	• BC2: Rendered single skin blockwork (total R-value 0.36) (all façades)	• H2: 40mm insulation board directly stuck onto blockwork plus separate 13mm plasterboard (total R-Value 2.16) (all façades)	• H1: 25mm insulation board directly stuck onto blockwork plus separate 13mm plasterboard (total R-Value 1.51) (all façades)
Window Glazing (single pane unless otherwise stated)	• GL2: Grey tint (all façades)	• GL4: Low-E neutral (north) • GL2: Grey tint (south) • GL7: Double glazed tint (east) • GL5: Low-E grey (west)	• GL2: Grey tint (1 façade - south for N-S orientation and east for W-E orientation) • GL5: Low-E grey (remaining 3 façades)
Window Shading	• No shading (1,000mm roof overhang)	• No change to base case	• No change to base case
Floor[64]	• Uninsulated slab	• No change to base case	• Insulated slab - extruded polystyrene board applied around perimeter of slab (GND-B)
Air-Conditioning and Ventilation System	• Ducted air-cooled reverse cycle split system for space heating and cooling. • No demand-controlled ventilation, energy recovery ventilation and economy cycle.	• No change to base case	• Increase the control dead band between heating and cooling from 1°C to 2°C
Lighting and Power	• Internal lighting controlled by manual on/off switches	• No change to base case	• No change to base case
Energy Monitoring	• Retail utility meters, no energy metering for energy efficiency monitoring purposes[65]	• No change to base case	• No change to base case

[63] Note 100mm R2.5 blanket with perforated foil underneath is called up by the DIPL Sustainability MDS for buildings under the Section J Compliance Threshold as DIPL officers have suggested there are benefits of keeping fibre contained between foil layers over the lives of buildings
[64] The draft NCC2022 code (public comment version, Section J4D7 (2)) specifies that a slab-on-ground without in-slab heating or cooling system is considered to achieve a total R-Value of 2.0. Under this provision, the base case, floor for this model, would not require additional insulation for NCC2022. (NCC 2022 Volume One - Version 20210906.pdf, accessed on 20 February 2021)
[65] Energy metering requirements for standard new constructions were found to typically be driven by billing requirements between landlords and tenants, rather than for efficiency monitoring purposes.

Table K-6: Single-Storey Office Building (5) – Alice Springs, summary of building fabric and services changes. Specification are the same for both building orientations unless otherwise stated.

Alice Springs	Base Case	NCC2016	NCC2019 – Core study
Roof	• Same as Darwin (LR-BC1)	• Same as Darwin (LR-B1)	• Same as Darwin (LR-A2)
Walls (insulation to be added inside external blockwork walls)	• Same as Darwin (BC2)	• Same as Darwin (H2)	• C4: 80mm insulation board with integrated plasterboard directly stuck onto blockwork (total R-Value 3.84) (all façades)
Window Glazing (single pane unless otherwise stated)	• GL1: Clear (all façades)	• GL4: Low-E neutral (east) • GL1: Clear (south) • GL2: Grey tint (north and west)	• GL1: Clear (south and east) • GL2: Grey tint (north and west)
Window Shading	• Same as Darwin (No shading)	• No change to base case	• No change to base case
Floor[66]	• Uninsulated slab	• No change to base case	• Insulated slab - extruded polystyrene board applied around perimeter of slab (GND-B)
Air-Conditioning and Ventilation System	• Ducted air-cooled reverse cycle split system for space heating and cooling. • No demand-controlled ventilation, energy recovery ventilation and economy cycle.	• No change to base case	• Same as Darwin
Lighting and Power	• Same as Darwin	• No change to base case	• No change to base case
Energy Monitoring	• Same as Darwin	• Same as Darwin	• No change to base case

[66] The draft NCC2022 code (public comment version, Section J4D7 (2)) specifies that a slab-on-ground without in-slab heating or cooling system is considered to achieve a total R-Value of 2.0. Under this provision, the base case, floor for this model, would not require additional insulation for NCC2022. (NCC 2022 Volume One - Version 20210906.pdf, accessed on 20 February 2021)

Appendix K.4 Single-storey office - Cladded Steel-Frame Walls (Sensitivity)

Table K-7: Cladded Steel-Frame Single-Storey Office Building (5) – Darwin, summary of building fabric and services changes. Specification are the same for both building orientations unless otherwise stated.

Darwin	Base Case	NCC2016	NCC2019 – Core study
Walls (insulation to be added inside external blockwork walls)	• BC4: 75mm steel frame construction base case - sensitivity analysis (R2.0 bulk insulation with no thermal break) (total R-Value 0.59)	• G7: 92mm steel frame construction with reflective air gap, thermal break tape and R2.7 bulk insulation (total R-Value 2.32)	• F5: 75mm steel frame construction with R2.0 bulk insulation and thermal break tape (total R-Value 1.34)
Window Glazing (single pane unless otherwise stated)	• GL2: Grey tint (all façades)	• GL4: Low-E neutral (north) • GL2: Grey tint (south) • GL7: Double glazed tint (east) • GL5: Low-E grey (west)	• GL2: Grey tint (east and south) • GL7: Double glazed tint (1 façade - north for N-S orientation, west for W-E orientation) • GL9: Double glazed low-E neutral (1 façade - west for N-S orientation, north for W-E orientation)
Roof, Shading, Flooring, Building Services	• Same as blockwork single-storey offices (Table K-5).		

Table K-8: Cladded Steel-Frame Single-Storey Office Building (5) – Alice Springs, summary of building fabric and services changes. Specification are the same for both building orientations unless otherwise stated.

Alice Springs	Base Case	NCC2016	NCC2019 – Core study
Walls	• Same as Darwin (BC4)	• Same as Darwin (G7)	• Same as Darwin (F5)
Window Glazing (single pane unless otherwise stated)	• GL1: Clear (all façades)	• GL2: Grey tint (north, west) • GL1: Clear (south) • GL4: Low-E neutral (east)	• GL2: Grey tint (1 façade – west for N-S orientation, north for W-E orientation) • GL3: Low-E clear (remaining 3 façades)
Roof, Shading, Flooring, Building Services	• Same as blockwork single-storey offices (Table K-6).		

Appendix K.5 Retail Building

Retail Building (6B) Model and Floor Layout

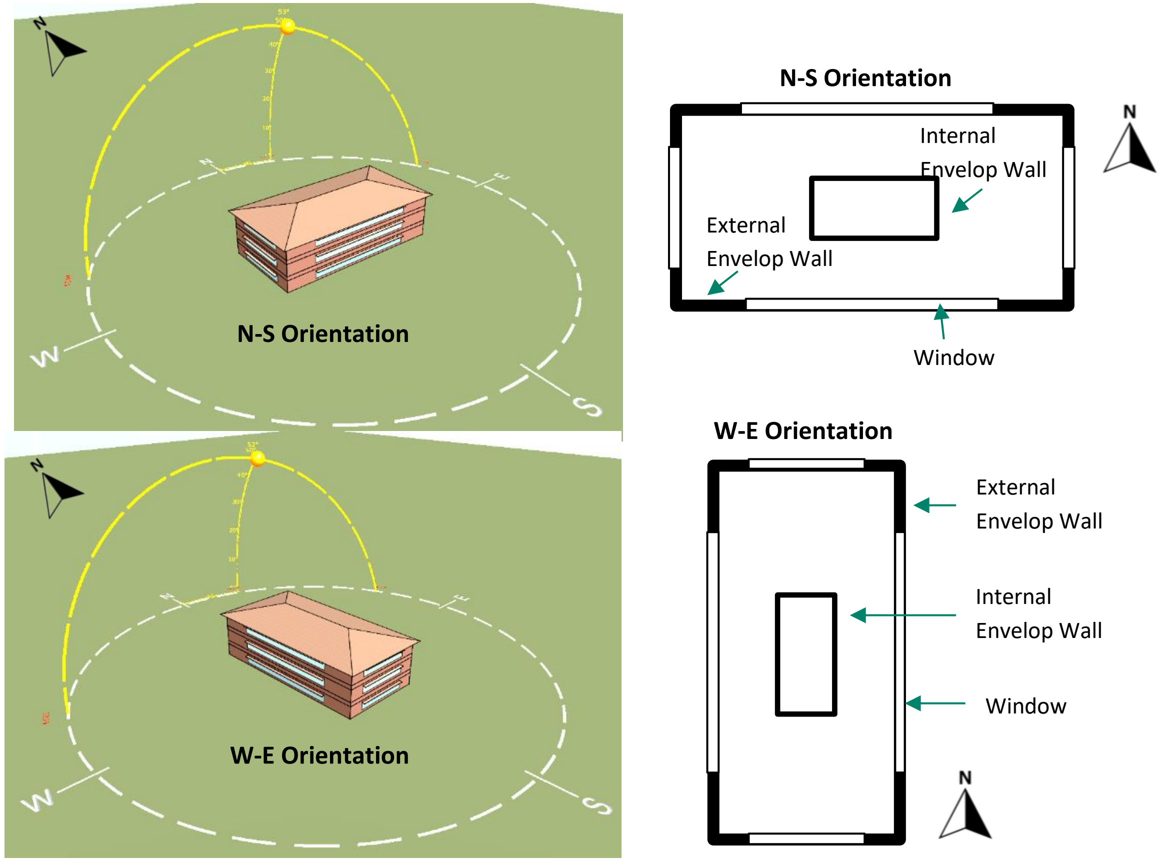


Figure K-4: Retail (6B) model and floor layout - showing the position of the windows, external and internal envelop walls.[67] The building was modelled in 2 orientations – N-S Orientation and W-E orientation.

[67] External envelope walls are walls that separate a conditioned space or habitable room from the exterior of the building. The internal envelop walls separate a conditioned space or habitable room from a non-conditioned space (e.g. the wall surrounding the lift wells).

Table K-9: Retail (6B) – Darwin, summary of building fabric and services changes. Specification are the same for both building orientations unless otherwise stated.

Darwin	Base Case	NCC2016	NCC2019 – Core study
Roof (Pitched metal roof)	• LR-BC1: R1.5 (75mm) blanket	• LR-B1: R1.8 (75mm) blanket, foil underneath and spacing system	• LR-A2: R3.3 (140mm) blanket (no foil underneath)[68] and spacing system
Walls (insulation to be added inside external blockwork walls)	• BC1: Rendered single skin blockwork with plasterboard (total R-Value 0.58) (external wall, all façades) • BC3: Rendered single skin blockwork (total R-Value 0.46) (Internal envelop walls)	• D5: 75mm frame, R2.0 insulation batts, 20mm reflective air gap, and thermal break tape (total R-Value 1.86) (south façade) • D8: 150mm frame, R4.0 insulation batts, 20mm reflective air gap and thermal break tape (total R-Value 2.30) (remaining 3 façades and internal envelop wall)	• D5: 75mm frame, R2.0 insulation batts, 20mm reflective air gap, and thermal break tape (total R-Value 1.86) (all façades – external wall) • D9: 150mm steel frame with thermal break tape on both sides, R4.0 batts, 20mm reflective air gap and (total R-value 2.81) (internal envelop wall)
Window Glazing (single pane unless otherwise stated)	• GL2: Grey tint (all façades/ both building orientations)	Same for both N-S and W-E orientations • GL7: Double glazed tint (north) • GL2: Grey tint (south) • GL9: Double glazed low-E neutral (east, west)	N-S orientation • GL9: Double glazed low-E neutral (north) • GL5: Low-E grey (south) • GL2: Grey tint (east and west) W-E orientation • GL2: Grey tint (north and south) • GL5: Low-E grey (east) • GL9: Double glazed low-E neutral (west)
Window Shading	• 600mm sun hood (all façades)	• No shading	• No shading
Floor[69]	• Uninsulated slab	• No change to base case	• No change to base case
Air-Conditioning and Ventilation System	• Ducted air-cooled reverse cycle split system for space heating and cooling. • No demand-controlled ventilation, energy recovery ventilation and economy cycle.	• No change to base case	• Increase the control dead band between heating and cooling from 1°C to 2°C • Incorporate demand-controlled ventilation
Lighting and Power	• Internal lighting controlled by manual on/off switches	• Incorporate time clock control for lighting allowing for 2 zones per floor	• Same as Darwin NCC2016
Energy Monitoring	• Retail utility meters, no energy metering for energy efficiency monitoring purposes[70]	• No change to base case	• No change to base case

[68] Note 100mm R2.5 blanket with perforated foil underneath is called up by the DIPL Sustainability MDS for buildings under the Section J Compliance Threshold as DIPL officers have suggested there are benefits of keeping fibre contained between foil layers over the lives of buildings.

Table K-10: Retail (6B) – Alice Springs, summary of building fabric and services changes.
Specification are the same for both building orientations unless otherwise stated.

Alice Springs	Base Case	NCC2016	NCC2019 – Core study
Roof	• Same as Darwin (LR-BC1)	• Same as Darwin (LR-B1)	• Same as Darwin (LR-A2)
Walls (insulation to be added inside external blockwork walls)	• Same as Darwin (BC1 and BC3)	• Same as Darwin (D5 and D8)	• D5: 75mm frame, R2.0 insulation batts, 20mm reflective air gap, and thermal break tape (total R-Value 1.86) (all external and internal envelop walls)
Window Glazing (single pane unless otherwise stated)	• GL1: Clear (all façades)	• GL1: Clear (south) • GL4: Low-E neutral (remaining 3 façades)	• GL7: Double glazed tint (1 façade – north for N-S orientation, west for W-E orientation) • GL2: Grey tint (remaining 3 façades)
Window Shading	• 600mm sun hood (all façades)	• No shading	• No shading
Floor[71]	• Uninsulated slab	• No change to base case	• No change to base case
Air-Conditioning and Ventilation System	• Ducted air-cooled reverse cycle split system for space heating and cooling. • Includes demand-controlled ventilation, energy recovery ventilation [72] driven and economy cycle.	• No change to base case	• Increase the control dead band between heating and cooling from 1°C to 2°C
Lighting and Power	• Same as Darwin	• Same as Darwin	• Same as Darwin
Energy Monitoring	• Same as Darwin	• Same as Darwin	• No change to base case

[69] The draft NCC2022 code (public comment version, Section J4D7 (2)) specifies that a slab-on-ground without in-slab heating or cooling system is considered to achieve a total R-Value of 2.0. Under this provision, the base case, floor for this model, would not require additional insulation for NCC2022. (NCC 2022 Volume One - Version 20210906.pdf, accessed on 20 February 2021)
[70] Energy metering requirements for standard new constructions were found to typically be driven by billing requirements between landlords and tenants, rather than for efficiency monitoring purposes.
[71] See footnote 63.
[72] Demand-control ventilation and energy recovery driven by CO_2 sensors

Appendix K.6 Hospital Ward

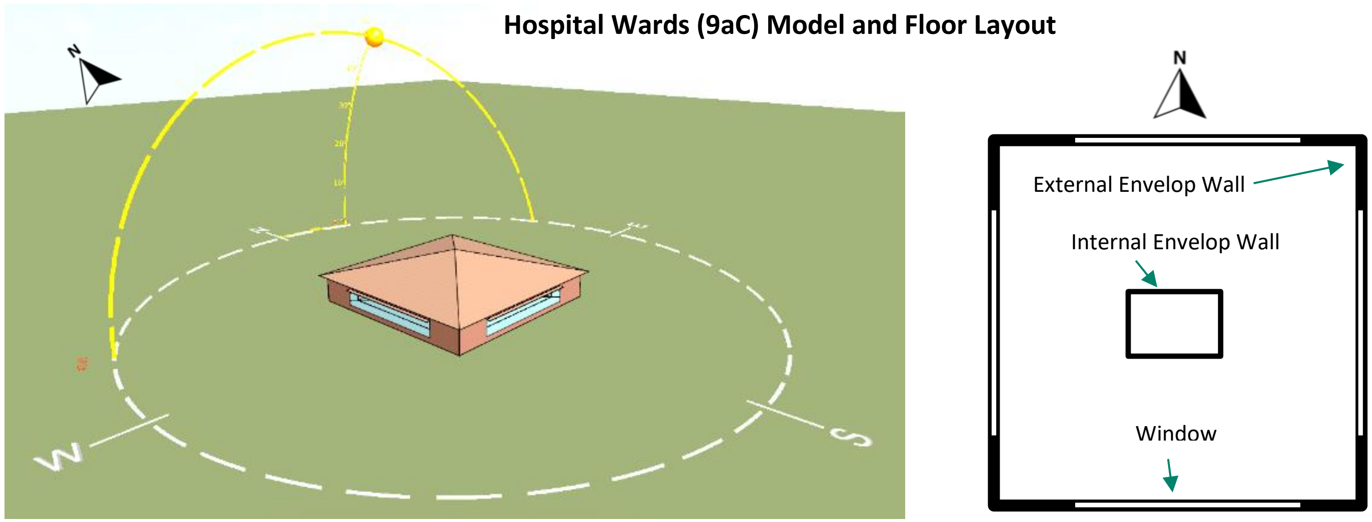


Figure K-5: Hospital Ward (9aC) model and floor layout - showing the position of the windows, external and internal envelop walls.[73] The building was modelled in 1 orientation.

[73] External envelope walls are walls that separate a conditioned space or habitable room from the exterior of the building. The internal envelop walls separate a conditioned space or habitable room from a non-conditioned space.

Table K-11: Hospital Ward (9aC) – Darwin, summary of building fabric and services changes

Darwin	Base Case	NCC2016	NCC2019 – Core study
Roof (Pitched metal roof)	• LR-BC1: R1.5 (75mm) blanket	• LR-B1: R1.8 (75mm) blanket, foil underneath and spacing system	• LR-A2: R3.3 (140mm) blanket (no foil underneath)[74] and spacing system
Walls (insulation to be added inside external blockwork walls)	• BC2: Rendered single skin blockwork (total R-Value 0.36) (external wall, all façades) • BC3: Rendered single skin blockwork (total R-Value 0.46) (internal envelop walls)	• H2: 40mm insulation board directly stuck onto blockwork plus separate 13mm plasterboard (total R-Value 2.16) (south) • C2: 50mm insulation board with integrated plasterboard directly stuck onto blockwork (total R-Value 2.34) (remaining 3 façades and internal envelop walls)	• H1: 25mm insulation board directly stuck onto blockwork plus separate 13mm plasterboard (total R-Value 1.51) (north) • H2: 40mm insulation board directly stuck onto blockwork plus separate 13mm plasterboard (total R-Value 2.16) (remaining 3 external wall façades) • C4: 80mm insulation board with integrated plasterboard directly stuck onto blockwork (total R-Value 3.84) (internal envelop walls)
Window Glazing (single pane unless otherwise stated)	• GL2: Grey tint (all façades)	• GL5: Low-E grey (north) • GL2: Grey tint (south) • GL9: Double glazed low-E neutral (east and west)	• GL9: Double glazed low-E neutral (all façades)
Window Shading	• 600mm sun hood (all façades)	• No shading	• No shading
Floor[75]	• Uninsulated slab	• No change to base case	• No change to base case
Air-Conditioning and Ventilation System	• Cooling via air-cooled chilled water. Has a dehumidification system but no dedicated space heating. Air delivery using air-handling units and variable air volume terminals. • Demand-controlled ventilation driven by CO_2 sensors. No energy recovery ventilation and economy cycle.	• No change to base case	• No change to base case
Lighting and Power	• Internal lighting controlled by manual on/off switches	• No change to base case	• No change to base case
Energy Monitoring	• Retail utility meters, no energy metering for energy efficiency monitoring purposes[76]	• No change to base case	• No change to base case

[74] Note 100mm R2.5 blanket with perforated foil underneath is called up by the DIPL Sustainability MDS for buildings under the Section J Compliance Threshold as DIPL officers have suggested there are benefits of keeping fibre contained between foil layers over the lives of buildings

[75] The draft NCC2022 code (public comment version, Section J4D7 (2)) specifies that a slab-on-ground without in-slab heating or cooling system is considered to achieve a total R-Value of 2.0. Under this provision, the base case, floor for this model, would not require additional insulation for NCC2022. (NCC 2022 Volume One - Version 20210906.pdf, accessed on 20 February 2021)

Table K-12: Hospital Ward (9aC) – Alice Springs, summary of building fabric and services changes

Alice Springs	Base Case	NCC2016	NCC2019 – Core study
Roof	• Same as Darwin (LR-BC1)	• Same as Darwin (LR-B1)	• Same as Darwin (LR-A2)
Walls (insulation to be added inside external blockwork walls)	• Same as Darwin (BC2 and BC3)	• Same as Darwin (H2 and C2)	• H1: 25mm insulation board directly stuck onto blockwork plus separate 13mm plasterboard (total R-Value 1.51) (west) • H2: 40mm insulation board directly stuck onto blockwork plus separate 13mm plasterboard (total R-Value 2.16) (remaining 3 external wall façades) • C4: 80mm insulation board with integrated plasterboard directly stuck onto blockwork (total R-Value 3.84) (internal envelop walls)
Window Glazing (single pane unless otherwise stated)	• Gl1: Clear (all façades)	• GL4: Low-E neutral (north, east and west) • GL1: Clear (south)	• GL9: Double glazed low-E neutral (north and south) • GL10: Double glazed low-E grey (east and west)
Window Shading	• 600mm sun hood (all façades)	• No shading	• No shading
Floor[77]	• Uninsulated slab	• No change to base case	• No change to base case
Air-Conditioning and Ventilation System	• Air-cooled reverse variable refrigerant flow system with heat recovery used for cooling and space heating. • Has demand-controlled ventilation, energy recovery ventilation[78] driven and economy cycle.	• No change to base case	• Increase the control dead band between heating and cooling from 1°C to 2°C
Lighting and Power	• Same as Darwin	• No change to base case	• No change to base case
Energy Monitoring	• Same as Darwin	• Same as Darwin	• No change to base case

[76] Energy metering requirements for standard new constructions were found to typically be driven by billing requirements between landlords and tenants, rather than for efficiency monitoring purposes.
[77] The draft NCC2022 code (public comment version, Section J4D7 (2)) specifies that a slab-on-ground without in-slab heating or cooling system is considered to achieve a total R-Value of 2.0. Under this provision, the base case, floor for this model, would not require additional insulation for NCC2022. (NCC 2022 Volume One - Version 20210906.pdf, accessed on 20 February 2021)
[78] Demand-control ventilation and energy recovery driven by CO_2 sensors

Appendix K.7 Schools

School (9bH) Model and Floor Layout

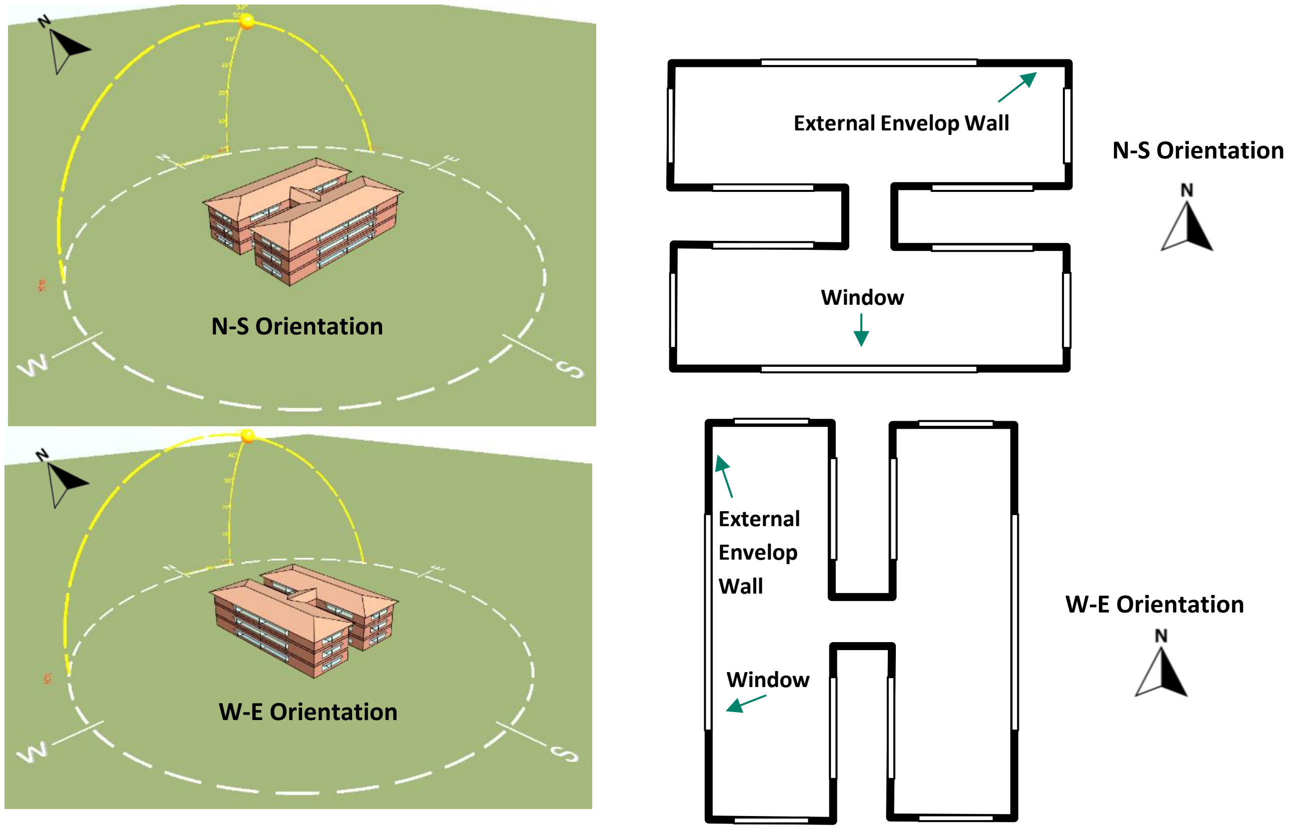


Figure K-6: School (9bH) model and floor layout - showing the position of the windows, external and internal envelop walls (internal partition walls are not shown). The building was modelled in 2 orientations – N-S Orientation and W-E orientation.

Table K-13: School (9bH) – Darwin, summary of building fabric and services changes.
Specification are the same for both building orientations unless otherwise stated.

Darwin	Base Case	NCC2016	NCC2019 – Core study
Roof (Pitched metal roof)	• LR-BC1: R1.5 (75mm) blanket	• LR-B1: R1.8 (75mm) blanket, foil underneath and spacing system	• LR-A2: R3.3 (140mm) blanket (no foil underneath) and spacing system
Walls (insulation to be added inside external blockwork walls)	• BC2: rendered single skin blockwork (total R-value 0.36) (all façades)	• D5: 75mm frame, R2.0 insulation batts, 20mm reflective air gap, and thermal break tape (total R-Value 1.86) (south) • D8: 150mm frame, R4.0 insulation batts, 20mm reflective air gap and thermal break tape (total R-Value 2.30) (remaining 3 façades and Internal envelop wall)	• D5: 75mm frame and R2.0 batts plus 20mm reflective air gap (all façades) • D9: 150mm steel frame with thermal break tape on both sides, R4.0 batts, 20mm reflective air gap and (total R-value 2.81) (internal envelop wall)
Window Glazing (single pane unless otherwise stated)	• GL2: Grey tint (all façades)	• GL5: Low-E grey (north) • GL2: Grey tint (south) • GL4: Low-E neutral (east and west)	• GL5: Low-E grey (east and south for N-S orientation) • GL7: Double glazed tint (all other scenarios/façades)
Window Shading	• 600mm sun hoods	• No window shading	• No window shading
Floor[79]	• Uninsulated slab	• No change to base case	• No change to base case
Air-Conditioning and Ventilation System	• Cooling via air-cooled chilled water, and no space heating. Fan-coiled units used for air delivery. • No demand-controlled ventilation, energy recovery ventilation and economy cycle.	• Replace constant speed CHW pumps with variable speed pumps	• Incorporate a variable chilled water supply temperature setpoint to the CHW system
Lighting and Power	• Internal lighting controlled by manual on/off switches	• Incorporate time clock control for lighting allowing for 1 zone per classroom.	• Same as Darwin NCC2016
Energy Monitoring	• Retail utility meters, no energy metering for energy efficiency monitoring purposes[80]	• Incorporate an energy metering system to record individually the consumption of various building services.	• Incorporate an energy metering system to record individually the consumption of various building services, plus collating and storage of time of use energy consumption data.

[79] The draft NCC2022 code (public comment version, Section J4D7 (2)) specifies that a slab-on-ground without in-slab heating or cooling system is considered to achieve a total R-Value of 2.0. Under this provision, the base case, floor for this model, would not require additional insulation for NCC2022. (NCC 2022 Volume One - Version 20210906.pdf, accessed on 20 February 2021)

[80] Energy metering requirements for standard new constructions were found to typically be driven by billing requirements between landlords and tenants, rather than for efficiency monitoring purposes.

Table K-14: School (9bH) – Alice Springs, summary of building fabric and services changes. Specification are the same for both building orientations unless otherwise stated.

Alice Springs	Base Case	NCC2016	NCC2019 – Core study
Roof	• Same as Darwin (LR-BC1)	• Same as Darwin (LR-B1)	• Same as Darwin (LR-A2)
Walls (insulation to be added inside external blockwork walls)	• Same as Darwin	• Same as Darwin	• D7: 92mm steel frame with thermal break tape on both sides, R2.7 batts, reflective air gap and (total R-value 2.01) (1 façade – east for N-S orientation, and south for W-E orientation) • D5: 75mm frame and R2.0 batts plus 20mm reflective air gap (total R-Value 1.86) (Remaining 3 façades and internal envelop wall)
Window Glazing (single pane unless otherwise stated)	• GL1: Clear (all façades)	• GL4: Low-E neutral (north) • GL1: Clear (south) • GL2: Grey tint (east and west)	• GL6: Double glazed clear (west for N-S orientation, north for W-E orientation) • GL2: Grey tint (remaining 3 façades)
Window Shading	• 600mm sun hoods	• No window shading	• No window shading
Floor[81]	• Uninsulated slab	• No change to base case	• No change to base case
Air-Conditioning and Ventilation System	• Air-cooled reverse cycle package air conditioning systems for cooling and space heating. • Includes demand-controlled ventilation, energy recovery ventilation driven and economy cycle.	• No change to base case	• Increase the control dead band between heating and cooling from 1°C to 2°C
Lighting and Power	• Same as Darwin	• Same as Darwin	• Same as Darwin
Energy Monitoring	• Same as Darwin	• Same as Darwin	• Same as Darwin

[81] The draft NCC2022 code (public comment version, Section J4D7 (2)) specifies that a slab-on-ground without in-slab heating or cooling system is considered to achieve a total R-Value of 2.0. Under this provision, the base case, floor for this model, would not require additional insulation for NCC2022. (NCC 2022 Volume One - Version 20210906.pdf, accessed on 20 February 2021)

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