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Assessment of Draft Green Star Carbon Positive Roadmap Targets

Green Building Council of Australia

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1. Introduction

The Green Building Council of Australia's Carbon Positive Roadmap will set a trajectory toward carbon neutral and positive buildings through implementation of a number of additional requirements forming part of the future Green Star Rating system. The roadmap has been under development by the GBCA with input from a GBCA appointed industry working group and consulting work completed by Ernst and Young.

AECOM were engaged independently of the working group to provide advice on likely changes to building design and operations to achieve potential roadmap targets and assess the capital and operating costs implications. The review focuses on commercial offices and a retail shopping centre. This report summarises the findings of AECOM's investigation into requirements of implementing the potential roadmap targets and associated cost impacts.

1.1 Roadmap Targets Investigated

The following table details the potential roadmap targets requested by the GBCA to be investigated in application across four case study buildings. These targets were taken from a draft version of the Carbon Positive Roadmap (see Appendix B).

Table 1. Potential Carbon Positive Roadmap Targets Investigated

Impact Area	Roadmap Target Description	Assessment Category
Energy Efficiency	• 60% total energy reduction compared to 2016 NCC DTS reference	Energy & Refrigerants
Energy Sourcing	• 100% Green Power electricity • No natural gas usage (electrical energy only)	
Refrigerant Impacts	• Zero GWP refrigerants	
Embodied Carbon	• 10% reduction in embodied carbon compared to reference building (not considering operational energy), as a first step • Additional 10% reduction in embodied carbon compared to reference building (not considering operational energy) • Offset total remaining embodied carbon emissions from construction	Embodied Carbon
Building Operations	• Offset carbon emissions from building operations associated with operational water consumption and waste production (excluding occupant transport)	Building Operations

The potential targets above were nominated in the draft Carbon Positive Roadmap to be applied in combination as the minimum requirements for the Green Star rating levels of 6 Star, 5 Star & 4 Star in the years 2019, 2022 & 2025 respectively. As the assessed targets are from the draft version of the Carbon Positive Roadmap, these targets and the implementation timeline may be subject to change.

As the some of the targets are interdependent and cannot be assessed individually, the targets were grouped into three categories according to influence/impact interdependence for the purposes of assessment as nominated within Table 1.

1.2 Assessment Methodology

The list below describes the outline methodology followed for undertaking assessment of the potential Carbon Positive Roadmap targets in application to each of the case studies:

1. Establish a building design with appropriate attributes and sustainability initiatives to support the Green Star rating target under the current Design & As Built v1.2 rating tool – ***Reference Building***;
2. Identify building design attribute and sustainability initiative adjustments / uplifts to support the potential Carbon Positive Roadmap targets – ***Carbon Roadmap Building***;

Energy & Refrigerants	Embodied Carbon	Building Operations
3. Estimate the additional capital expenditure (CAPEX) required to deliver the adjustments / uplifts of the Carbon Roadmap Building; 4. Estimate the difference in annual energy consumption and energy utility costs due to the adjustments / uplifts of the Carbon Roadmap Building; 5. Assess the investment impact / return due to the adjustments / uplifts for the Carbon Roadmap Building through determination of discounted payback (IRR = discount rate) and Net Present Value (NPV) at 7 and 15 year milestones.	3. Estimate the additional capital expenditure (CAPEX) required to deliver the adjustments / uplifts of the Carbon Roadmap Building; 4. Estimate the additional operational costs for carbon offsets of the Carbon Roadmap Building.	3. Estimate the additional operational costs for carbon offsets of the Carbon Roadmap Building.

1.3 Case Study Scenarios

Four case study scenarios were agreed with the GBCA for assessment that compare a reference new building / building upgrade meeting the minimum requirements of today, for a particular Green Star rating target, to the same new building / building upgrade delivered to achieve the potential Carbon Positive Roadmap targets identified in Table 1.

The following table details a description of the four case studies including the associated Green Star rating target and the year nominated for enforcement of the potential roadmap targets (per the draft version) according to the star rating.

Table 2. Case Study Scenarios General Description

Scenario	Description	Green Star Rating	Year of Roadmap Targets Enforcement
Case 1A	New Office Building Sydney	6 Star	2019
Case 1B	New Office Building in Melbourne	6 Star	2019
Case 2	Existing Office Building Upgrade in Melbourne	4 Star	2025
Case 3	Retail Centre Extension in Melbourne	5 Star	2022

The following table details description of the general attributes for each of the case study reference buildings and performance across the impact areas for which new targets are being defined in the Carbon Positive Roadmap.

Table 3. Attributes of Reference Buildings for each Case Study Scenario

Item / Impact Area	Case 1A/1B	Case 2	Case 3
General Attributes	• New high rise commercial office building • Designed for a 6 Star rating under Design & As Built v1.2 • PCA A Grade plus • CBD location • NLA of 40,000m^2	• Upgrade of an existing PCA B Grade office building • Upgrade designed for a 4 Star rating under Design & As Built v1.2 • Upgrade to PCA A Grade • Suburban business park location • NLA of 12,000m^2	• New Retail shopping centre building extension • Designed for a 5 Star rating under Design & As Built v1.2 • CBD location • Fully air-conditioned • GLAR of 13,000m^2
Energy Efficiency	• 6 Points achieved under credit 15E for GHG emissions reduction (current D+AB v1.2 6 Star minimum) • Equates to 37.5% GHG emissions reduction compared	• Upgrade from a 4 Star NABERS Energy performance to 5 Star NABERS Energy • Upgrade equates to approximately 4.3 points under credit 15D (D+AB v1.2)	• 3 Points achieved under credit 15E for GHG emissions reduction (current D+AB v1.2 5 Star minimum) • Equates to 18.75% GHG emissions reduction compared

Item / Impact Area	Case 1A/1B	Case 2	Case 3
	to a Benchmark Building (10% improvement on 2016 NCC Section J DTS)		to a Benchmark Building (10% improvement on 2016 NCC Section J DTS)
Energy Sourcing	• Electricity from grid (no Green Power) • Gas energy used for heating, potable hot water and cooking (where applicable)		
Refrigerant Impacts	• Standard use refrigerants of today (e.g. R134A, R410A etc.)		
Embodied Carbon	• Minimum embodied carbon reduction to obtain sufficient points in support of a 6 Star D+AB v1.2 rating • No carbon offsets	• Upgrade achieves embodied carbon reduction using prescriptive materials credits to obtain sufficient points in support of a 4 Star D+AB v1.2 rating • No carbon offsets for the upgrade	• Minimum embodied carbon reduction to obtain sufficient points in support of a 5 Star D+AB v1.2 rating • No carbon offsets
Building Operations	• No carbon offsets for building operations		

1.4 Assessment Assumptions

1.4.1 Energy & Refrigerants Assumptions

The following assumptions apply to the assessments undertaken for the Energy & Refrigerants targets:

- Past projects of AECOM have been used as the basis for establishing the case study buildings.
- Adjustments have been made to the design performance and efficiency of past projects in order to meet the potential roadmap targets.
- Significant alterations of the design strategies to support targets were outside the scope of this assessment.
- All assessment of annual energy performance for the case study buildings was undertaken in accordance with the requirements of the GBCA Energy Consumption and Greenhouse Gas Emission Calculation Guide.

1.4.2 Embodied Carbon Assumptions

The following assumptions apply to the assessments undertaken for the Embodied Carbon targets:

- Embodied carbon assessed in accordance with EN 15804
- Estimations of waste generation for building operations in accordance with Combined Sydney Councils Draft Waste Management Guidelines
- Estimations of water consumption for commercial office based on Green Star Potable Water Calculator
- Estimations of water consumption for retail shopping centre based on https://www.sydneywater.com.au/SW/your-business/managing-your-water-use/benchmarks-for-water-use/index.htm

1.4.3 Building Operations Assumptions

The following assumptions apply to the assessments undertaken for the Building Operations targets:

- Carbon offset pricing was based on products available at the time of writing the report

1.4.4 Financial Assumptions

All costs have been developed in conjunction with AECOM cost planners and are based on AECOM's knowledge of open market rates with equipment supplier input where possible.

Financial parameters used in the assessment have been on the following general assumptions:

- Estimates are based on past project data combined with available inputs from AECOM cost planners and equipment suppliers/manufacturers where possible;
- Costs are based on prices in the Sydney market;
- Estimates do not consider cost/savings associated with upgrade/reduction of service infrastructure sizing due to proposed initiatives (e.g. changes to authority power supply due to demand changes);
- Estimates do not consider cost/savings associated with lettable area loss/gains due to

The following table details the assessments assumptions in determining operational costings (OPEX):

Table 4. Operational costing assumptions

Parameter	Value
Electricity Price (Flat Tariff) – *no Green Power*	$0.20/kWh
Additional Cost for Green Power Electricity (Flat Tariff)	+$0.05/kWh
Natural Gas Price (Flat Tariff)	$28/GJ

The following table details the assumptions in determining carbon offset costs:

Table 5. Carbon offset costing assumptions

Parameter	Value
International Market Carbon Offset	$0.50/T
Australian Carbon Credit Units	$17.00/T

The costings and analysis detailed in the assessment are intended for comparative guidance purposes only. The costs may vary from actual costs due to many reasons and should not be relied upon to be an actual or true reflection of construction costs.

2. Assessment

2.1 Case 1A – New Office Building in Sydney

2.1.1 Energy & Refrigerants

The potential roadmap targets associated with Energy (efficiency & sourcing) and Refrigerants have been assessed in application to the case study building design to determine the necessary design adjustments and extra over measures to support the targets.

The following table details these building design adjustments and uplift measures as well as the estimated difference in capital expenditure. The attributes for both the Reference and Carbon Roadmap buildings have been described where appropriate relative to the minimum requirements of the NCC 2016.

Table 6. Case 1A – Detailed Comparison of Reference & Roadmap Building Attributes with CAPEX Uplift

Element	Reference Building	Carbon Roadmap Building Changes	CAPEX Uplift
General	• 6 Star Design & As Built v1.2 • 6 points achieved under credit 15E • Standard electricity (no green power) • Fossil fuels used • Standard refrigerants of today	• Target 60% total energy reduction compared to 2016 NCC DTS • Full electric powered – no fossil fuels • 100% Green Power • Target zero GWP refrigerants	-
Heating Plant and	• Gas fired boiler hot water generators - efficiency > 92%	• Electrical heat pump hot water generators • Air sourced units for high load (low ambient	≈ $6.65/m^2

Pumps	• Variable primary only hot water pumping arrangement - pump power reduced (≈75%) from NCC limits	temps) with seasonal EER > 2.8 • Water sourced units for low load (high ambient temps) with seasonal EER >3.5 • 4th generation refrigerants - ODP: 0 / GWP: 1	
Cooling Plant and Pumps	• High efficiency variable speed screw compressor water cooled chillers with low load unit - COP ≈ 6, IPLV ≈ 10+ • R134a Refrigerant – ODP: 0 / GWP: 1300 • Variable primary only chilled water pumping arrangement - pump power reduced (≈30%) from NCC limits • Condenser water pumps selected as close NCC maximum power limit as possible	• Main load bespoke high efficiency variable speed piston compressor water cooled chillers for main load with evaporator & condenser heat exchanger vessels oversized to improve efficiency – COP ≈ 6.5, IPLV ≈ 11.5+ • R717 Ammonia Refrigerant for main load chillers – ODP: 0 / GWP: 0 • Low load variable speed magnetic bearing centrifugal compressor water cooled chiller that operates at very low condenser water temperatures (e.g. York YZ series) • 4th generation R1233zd refrigerant for low load chiller - ODP: 0 / GWP: 1	≈ $5.70/m^2
Heat Rejection	• Induced draft cooling towers with variable speed fans meeting NCC power limit	• Same tower type with optimised design for low fan power - reduced ≈15% from NCC limits and Reference building	≈ $0.83/m^2
Air Handling	• Central plant • Full VAV system with dedicated AHU to each perimeter zone and centre zone • Low system pressure with AHU / RA fans having 40% input power reduction compared to NCC DTS	• System pressures reduced through oversized AHUs, filters and low pressure loss duct fittings • 10%+ reduction in fan input power compared to Reference building – 46% reduction compared to NCC limits	≈ $2.48/m^2
Lighting	• Standard to high efficiency (130-150 lm/W) LED fitting selections throughout • Illumination power density ≈57% reduced compared to NCC DTS	• High efficiency (150+ lm/W) LED fitting selections throughout • Illumination power density ≈60% reduced compared to NCC DTS	≈ $3.00/m^2
Potable Hot Water	• Gas fired boilers - Efficiency > 85% • Solar thermal pre-heat system	• Electrical heat pump hot water generators • Air sourced heat exchange with seasonal EER > 2.8 • R744 CO2 Refrigerant – ODP: 0 / GWP: 1	≈ $0.48/m^2
Façade	• Floor to ceiling vision glazing (WWR: 72%) • Curtain wall glazing with thermally broken aluminium framing (U-Value: 2.1W/m^{2}K, SHGC: 0.22)	• No Change • Improvements considered but minimal gains for extensive cost. See Section 3.1 for further discussion.	-
		Total Cost Uplift	**≈ $19.13/m^2**
		Percentage Cost Uplift (based on $4,500/m^2 construction cost rate)	***≈ 0.43%***

Implementing the nominated initiatives above is seen to come to a total CAPEX uplift of around $20/m^2. Relative to a nominal overall construction cost, that is in the order of $4,500-5,100/m^2 for a commercial property of this performance level, the uplift is quite small increasing the cost by only around half a percent.

The following table details the operational energy consumption and energy costs for the buildings including an NCC 2016 compliant building for additional reference.

Table 7. Case 1A – Annual Energy Consumption and Energy Cost Comparison

Item	NCC 2016 Compliant Building	Reference Building	Carbon Roadmap Building	Difference (Roadmap vs Reference)
Electrical Energy (kWh/m^2/yr)	104.84	58.86	58.75	-0.11
Gas Energy (MJ/m^2/yr)	46.68	28.15	0.00	-28.15
Total Energy (MJ/m^2/yr)	**424.09**	**240.03**	**211.50**	**-28.53**
Percentage Energy Difference to NCC 2016	-	*-43.4%*	*-50.1%**	
Percentage Energy Difference to Reference	*+76.7%*	-	*-11.9%*	
Electricity Cost ($/m^2/yr)	$20.97	$11.77	$11.75	-$0.02

Additional Cost for Green Power ($/m^2/yr)	$0.00	$0.00	$2.94	+$2.94
Gas Cost ($/m^2/yr)	$1.31	$0.79	$0.00	-$0.79
Total Energy Cost ($/m^2/yr)	**$22.27**	**$12.56**	**$14.69**	**+$2.13**
Percentage Energy Cost Difference to NCC 2016	-	*-43.6%*	*-34.1%*	
Percentage Energy Cost Difference to Reference	*+77.4%*	-	*+16.9%*	

* Performance fell short of target 60%. See Section 3.1 for further discussion.

From the results above it can be seen a reduction in overall energy consumption is achieved through implementing the roadmap building initiatives at around 12% relative to the Reference building. However even though electrical energy has reduced slightly and gas use is completely avoided, the added cost of Green Power has led to an increase in the annual energy cost at around 17%.

2.1.2 Embodied Carbon

The embodied carbon target has been assessed to determine extra over measures required to achieve the road map targets and balance of carbon requiring offsetting. Assessment was undertaken in accordance with EN 15804.

A 10% reduction over the reference building is possible using low carbon concrete (e.g. product such as Envisia) and reduced carbon content steel from supply chain using Electronic Arc Furnace (EAF).

For an office building already targeting 6 Star Green Star there are currently limited opportunities to achieve a further 10% reduction through selection of decarbonised materials. Achieving 20% reduction through material selections would require improved decarbonisation of building materials supply chain.

The extra over CAPEX to achieve 10% embodied carbon reduction and cost to offset remaining embodied carbon would be as follows:

Table 8. Case 1A – CAPEX for 10% Embodied Carbon Reduction

Material	Extra over material costs	Extra over cost per $/m^2
Concrete	$50/m^3	$35/m^2
Steel	$200/t	$26/m^2
Total		**$61/m^2**
Percentage Cost Uplift (based on a on $4,500/m^2 construction cost rate)		***1.36%***

Extra over CAPEX to offset the remaining embodied carbon is as follows:

Table 9. Case 1A – CAPEX to Offset Remaining Embodied Carbon

Offset	Unit Price	Extra over annual cost $/m^2	Percentage extra cost *
International sourced offset	$0.50/t	$0.49/m^2	0.01%
ACCU offset	$17/t	$16.80/m^2	0.37%

* Based on a construction cost rate of $4,500/m^2

2.1.3 Building Operations

Estimations of carbon emissions arising from potable water, waste water and waste have been completed as detailed in the following table to determine extra over OPEX to offsets these ongoing carbon emissions associated with building operations.

Table 10. Case 1A – Operational Carbon Emissions and Offset Costs

Category	T/CO_2	T/CO_2/m^2	Offset cost range $/m^2	
			*$0.50**	*$17.00***
General Waste	786	0.0197	$0.010	$0.334
Recycling (Paper)	94	0.0023	$0.000	$0.001

Potable Water (incl. cooling towers)	64	0.0016	$0.001	$0.027
Waste Water	6	0.0002	$0.000	$0.003
Totals	**950**	**0.027**	**$0.01**	**$0.36**

* International sourced offset

** ACCU offset

2.2 Case 1B – New Office Building in Melbourne

2.2.1 Energy & Refrigerants

The potential roadmap targets associated with Energy (efficiency & sourcing) and Refrigerants have been assessed in application to the case study building design to determine the necessary design adjustments and extra over measures to support the targets.

The following table details these building design adjustments and uplift measures as well as the estimated difference in capital expenditure. The attributes for both the Reference and Carbon Roadmap buildings have been described where appropriate relative to the minimum requirements of the NCC 2016.

The attributes for these building are the same as that of the Sydney location with only minor differences for the Reference building. These differences are lower efficiency for the supply & return fans and DHW boilers, removal of a DHW solar preheat system and higher lighting power. The capital cost to deliver the uplift performance is therefore larger that for Sydney as the Reference building is at a lower performance point.

Table 11. Case 1B – Detailed Comparison of Reference & Roadmap Building Attributes with CAPEX Uplift

Element	Reference Building	Carbon Roadmap Building Changes	CAPEX Uplift
General	• 6 Star Design & As Built v1.2 • 6 points achieved under credit 15E • Standard electricity (no green power) • Fossil fuels used • Standard refrigerants of today	• Target 60% total energy reduction compared to 2016 NCC DTS • Full electric powered – no fossil fuels • 100% Green Power • Target zero GWP refrigerants	-
Heating Plant and Pumps	• Gas fired boiler hot water generators - efficiency > 92% • Variable primary only hot water pumping arrangement - pump power reduced (≈75%) from NCC limits	• Electrical heat pump hot water generators • Air sourced units for high load (low ambient temps) with seasonal EER > 2.8 • Water sourced units for low load (high ambient temps) with seasonal EER >3.5 • 4th generation refrigerants - ODP: 0 / GWP: 1	≈ $6.65/m^2
Cooling Plant and Pumps	• High efficiency variable speed screw compressor water cooled chillers with low load unit - COP ≈ 6, IPLV ≈ 10+ • R134a Refrigerant – ODP: 0 / GWP: 1300 • Variable primary only chilled water pumping arrangement - pump power reduced (≈30%) from NCC limits • Condenser water pumps selected as close NCC maximum power limit as possible	• Main load bespoke high efficiency variable speed piston compressor water cooled chillers for main load with evaporator & condenser heat exchanger vessels oversized to improve efficiency – COP ≈ 6.5, IPLV ≈ 11.5+ • R717 Ammonia Refrigerant for main load chillers – ODP: 0 / GWP: 0 • Low load variable speed magnetic bearing centrifugal compressor water cooled chiller that operates at very low condenser water temperatures (e.g. York YZ series) • 4th generation R1233zd refrigerant for low load chiller - ODP: 0 / GWP: 1	≈ $5.70/m^2
Heat Rejection	• Induced draft cooling towers with variable speed fans meeting NCC power limit	• Same tower type with optimised design for low fan power - reduced ≈15% from NCC limits and Reference building	≈ $0.83/m^2
Air Handling	• Central plant • Full VAV system with dedicated AHU to each perimeter zone and centre zone • Low system pressure with AHU / RA fans having 30% input power reduction compared to NCC DTS	• System pressures reduced through oversized AHUs, filters and low pressure loss duct fittings • 23%+ reduction in fan input power compared to Reference building – 46% reduction compared to NCC limits	≈ $5.23/m^2

Lighting	• Standard to high efficiency (130-150 lm/W) LED fitting selections throughout • Illumination power density ≈55% reduced compared to NCC DTS	• High efficiency (150+ lm/W) LED fitting selections throughout • Illumination power density ≈60% reduced compared to NCC DTS	≈ $3.90/m^2
Potable Hot Water	• Gas fired boilers - Efficiency > 85%	• Electrical heat pump hot water generators • Air sourced heat exchange with seasonal EER > 2.8 • R744 CO2 Refrigerant – ODP: 0 / GWP: 1	≈ $1.93/m^2
Façade	• Floor to ceiling vision glazing (WWR: 72%) • Curtain wall glazing with thermally broken aluminium framing (U-Value: 2.1W/m^{2}K, SHGC: 0.22)	• No Change • Improvements considered but minimal gains for extensive cost. See Section 3.1 for further discussion.	-
		Total Cost Uplift	**≈ $24.23/m^2**
		Percentage Cost Uplift (based on $4,500/m^2 construction cost rate)	***≈ 0.54%***

Implementing the nominated initiatives above is seen to come to a total CAPEX uplift of around $25/m^2. Relative to a nominal overall construction cost, which is in the order of $4,500-5,100/m^2 for a commercial property of this performance level, the uplift is quite small increasing the cost by just over half a percent.

The following table details the operational energy consumption and energy costs for the buildings including an NCC 2016 compliant building for additional reference.

Table 12. Case 1B – Annual Energy Consumption and Energy Cost Comparison

Item	NCC 2016 Compliant Building	Reference Building	Carbon Roadmap Building	Difference (Roadmap vs Reference)
Electrical Energy (kWh/m^2/yr)	95.20	52.74	54.81	+2.07
Gas Energy (MJ/m^2/yr)	85.96	67.20	0.00	-67.20
Total Energy (MJ/m^2/yr)	**428.68**	**257.06**	**197.30**	**-59.76**
Percentage Energy Difference to NCC 2016	-	*-40.0%*	*-54.0%**	
Percentage Energy Difference to Reference	*+66.8%*	*0.0%*	*-23.2%*	
Electricity Cost ($/m^2/yr)	$19.04	$10.55	$10.96	+$0.41
Additional Cost for Green Power ($/m^2/yr)	$0.00	$0.00	$2.74	+$2.74
Gas Cost ($/m^2/yr)	$2.41	$1.88	$0.00	-$1.88
Total Energy Cost ($/m^2/yr)	**$21.45**	**$12.43**	**$13.70**	**+$1.27**
Percentage Energy Cost Difference to NCC 2016	-	*-44.2%*	*-38.5%*	
Percentage Energy Cost Difference to Reference	*+72.5%*	-	*+10.2%*	

* Performance fell short of target 60%. See Section 3.1 for further discussion.

From the results above it can be seen a significant reduction in overall energy consumption is achieved through implementing the roadmap building initiatives at over 23% relative to the reference building. This largely due to the entire removal of gas energy. However due to the need for slightly more electrical energy and the added cost of Green Power, the annual energy cost is seen to increase in the order of 10%.

2.2.2 Embodied Carbon

As per Case 1A for Sydney (see Section 2.1.2).

2.2.3 Building Operations

As per Case 1A for Sydney (see Section 2.1.3).

2.3 Case 2 – Existing Office Building Upgrade in Melbourne

2.3.1 Energy & Refrigerants

The potential roadmap targets associated with Energy (efficiency & sourcing) and Refrigerants have been assessed in application to the case study building design to determine the necessary design adjustments and extra over measures to support the targets.

The following table details these building design adjustments and uplift measures as well as the estimated difference in capital expenditure. The attributes for both the Reference and Carbon Roadmap buildings have been described where appropriate relative to the minimum requirements of the NCC 2016.

Table 13. Case 2 – Detailed Comparison of Reference & Roadmap Building Attributes with CAPEX Uplift

Element	Reference Building	Carbon Roadmap Building Changes	CAPEX Uplift*
General	• 4 Star Design & As Built v1.2 • 4.4 points under credit 15D for 5 Star NABERS Energy • Standard electricity (no green power) • Fossil fuels used • Standard refrigerants of today	• Target 60% total energy reduction compared to 2016 NCC DTS • Full electric powered – no fossil fuels • 100% Green Power • Target zero GWP refrigerants	-
Heating Plant and Pumps	• Replace existing boiler plant with new gas fired condensing hot water generators - efficiency > 92%	• Replace existing boiler plant with electrical heat pump hot water generators • Air sourced units for high load (low ambient temps) with seasonal EER > 2.8 • Water sourced units for low load (high ambient temps) with seasonal EER >3.5 • 4th generation refrigerants - ODP: 0 / GWP: 1	≈ $7.42/m^2
	• Refurbish existing hot water pumps, replace motors and install VSDs. Pumps configured in a variable primary only pumping arrangement - pump power reduced (≈60%) from NCC limits.	• Replace existing hot water pumps with new pumps, high efficiency motors and VSDs. Pump power reduced (≈75%) from NCC limits.	≈ $0.38/m^2
Cooling Plant and Pumps	• Replace existing chiller plant with 2x equal size high efficiency variable speed screw compressor water cooled chillers with low load unit - COP ≈ 5.8, IPLV ≈ 9.5+ • R134a Refrigerant – ODP:0 / GWP: 1300	• Replace existing chiller plant with 2x equal size bespoke high efficiency variable speed piston compressor water cooled chillers with evaporator & condenser heat exchanger vessels oversized to improve efficiency – COP ≈ 6, IPLV ≈ 10.5+ • R717 Ammonia Refrigerant – ODP: 0 / GWP: 0	≈ $4.52/m^2
Heat Rejection	• Refurbish existing cooling towers, replace fan motors and install VSDs. Fan power reduced ≈15% from NCC limits.	• No change	-
Air Handling	• Central plant • Refurbish existing 2x AHUs (Centre & Perimeter), replace coils and motors, and install VSDs. Coils selected for lower off coil temperature to reduce air volume and system pressure. • Install VAV boxes throughout building to convert system to variable air volume. • Low system pressure with AHU / RA fans having ≈42% input power reduction compared to NCC DTS	• Replace existing AHUs with oversized AHUs to reduce coil velocities and filter box compartments. • Average reduction in fan input power of ≈51% compared to NCC limits	≈ $3.53/m^2
Lighting	• New standard efficiency (up to 130 lm/W) LED fitting selections throughout. • Illumination power density reduced ≈37% compared to NCC DTS	• New high efficiency (150+ lm/W) LED fitting selections throughout. • Illumination power density ≈50% reduced compared to NCC DTS	≈ $4.74/m^2
Potable Hot Water	• Gas fired water heaters • Efficiency > 85%	• Electrical heat pump hot water generators • Air sourced heat exchange with seasonal EER >	≈ $4.26/m^2

		2.8 • R744 CO2 Refrigerant – ODP: 0 / GWP: 1	
Façade	• Curtain wall glazing with standard aluminium framing (U-Value: 3.3W/m^{2}K, SHGC: 0.28)	• No Change • Improvements considered but minimal gains for extensive cost. See Section 3.2 for further discussion.	-
			Total Cost Uplift ≈ $25.68/m^2
			Percentage Cost Uplift (based on $3,800/m^2 refurbishment cost) ≈ 0.68%

Implementing the nominated initiatives above is seen to come to a total CAPEX uplift of around $26/m^2. Relative to a nominal overall refurbishment construction cost, that is in the order of $3,800-4,500/m^2 for a commercial property refurbishment of this performance level, as seen for the new office case the uplift is quite small increasing the cost just under 0.7%.

The following table details the operational energy consumption and energy costs for the buildings including an NCC 2016 compliant building for additional reference.

Table 14. Case 2 – Annual Energy Consumption and Energy Cost Comparison

Item	NCC 2016 Compliant Building	Reference Building	Carbon Roadmap Building	Difference (Roadmap vs Reference)
Electrical Energy (kWh/m^2/yr)	97.79	64.28	56.25	-8.03
Gas Energy (MJ/m^2/yr)	59.73	56.15	0	-56.15
Total Energy (MJ/m^2/yr)	**411.76**	**287.57**	**202.49**	**-85.08**
Percentage Energy Difference to NCC 2016	-	*-30.2%*	*-50.8%**	
Percentage Energy Difference to Reference	*43.2%*	-	*-29.6%*	
Electricity Cost ($/m^2/yr)	$19.56	$12.86	$11.25	-$1.61
Additional Cost for Green Power ($/m^2/yr)	$0.00	$0.00	$2.81	+$2.81
Gas Cost ($/m^2/yr)	$1.67	$1.57	$0.00	-$1.57
Total Energy Cost ($/m^2/yr)	**$21.23**	**$14.43**	**$14.06**	**-$0.37**
Percentage Energy Cost Difference to NCC 2016	-	*-32.0%*	*-33.8%*	
Percentage Energy Cost Difference to Reference	*47.1%*	-	*-2.5%*	

* Performance fell short of target 60%. See Section 3.1 for further discussion.

The results above show a significant reduction in overall energy consumption is achieved through implementing the roadmap building initiatives at almost 30% relative to the Reference building. Although the switch to Green Power increases the costs of electrical energy, the removal of gas and reduction in electrical energy relative to the Reference building has led to a reduction in annual energy costs at around 2.5%.

2.3.2 Embodied Carbon

In projects where the main building super structure is retained there are limited opportunities to achieve the road map targets through material selections with inherent lower carbon content.

Reduction of up to 2% can be achieved using Green Power during construction. Cost of this would equate to an additional $0.95/m^2 that is +0.03% of the refurbishment construction cost at a rate of $3,800/m^2.

Reductions of between 5 and 10% are possible through dematerialisation opportunities such as using polished concrete floor finish instead of carpet / underlay. Or through use of exposed soffits over the tile or plasterboard ceiling finishes. These strategies are however considered to be undesirable for commercial offices due to tenant expectations and impact on other design requirement such as acoustic amenity and have therefore not been adopted.

Offsetting is considered the most viable strategy to reduce embodied carbon in a refurbished building. With the offsets being used either by a supplier of a material or by the contractor or developer. Extra over CAPEX to offset the embodied carbon in a refurbished building is:

- ACCU Offset @ \$17/t = \$9.21/m^2 – +0.24% for a \$3,800/m^2 refurbishment cost
- International offset @ \$0.50/t = \$0.27/m^2 – +0.007% for a \$3,800/m^2 refurbishment cost

2.3.3 Building Operations

Estimations of carbon emissions arising from potable water, waste water and waste have are expected to be equivalent to those in new office buildings. Total cost of offsetting:

- ACCU Offset @ \$17/t = \$0.36/m^2
- International offset @ \$0.50/t = \$0.01/m^2

2.4 Case 3 – Retail Centre Extension in Melbourne

2.4.1 Energy & Refrigerants

The potential roadmap targets associated with Energy (efficiency & sourcing) and Refrigerants have been assessed in application to the case study building design to determine the necessary design adjustments and extra over measures to support the targets.

The following table details these building design adjustments and uplift measures as well as the estimated difference in capital expenditure. The attributes for both the Reference and Carbon Roadmap buildings have been described where appropriate relative to the minimum requirements of the NCC 2016.

Table 15. Case 3 – Detailed Comparison of Reference & Roadmap Building Attributes with CAPEX Uplift

Element	Reference Building	Carbon Roadmap Building Changes	CAPEX Uplift
General	• 5 Star Design & As Built v1.2 • 3 points achieved under credit 15E • Standard electricity (no green power) • Fossil fuels used • Standard refrigerants of today	• Target 60% total energy reduction compared to 2016 NCC DTS • Full electric powered – no fossil fuels • 100% Green Power • Target zero GWP refrigerants	-
Heating Plant and Pumps	• Gas fired condensing boiler hot water generators - efficiency 95% • Variable primary only hot water pumping arrangement - pump power reduced (≈40%) from NCC limits	• Electrical heat pump hot water generators • Air sourced units for high load (low ambient temps) with seasonal EER > 2.8 • Water sourced units for low load (high ambient temps) with seasonal EER >3.5 • 4th generation refrigerants - ODP: 0 / GWP: 1	≈ \$5.37/m^2
Cooling Plant and Pumps	• 2x equal sized variable speed centrifugal compressor water cooled chillers - COP ≈ 6.2, IPLV ≈ 9.5+ • R134a Refrigerant – ODP: 0 / GWP: 1300 • Variable primary only chilled water pumping arrangement - pump power reduced ≈15% from NCC limits • Condenser water pumps selected as close NCC maximum power limit as possible	• Increased chillers efficiency using variable speed screw compressors & ammonia (water cooled) – COP ≈ 6.4, IPLV ≈ 10.6+ • R717 Ammonia Refrigerant for chillers – ODP: 0 / GWP: 0 • Reduced chilled water pump input power through reduced system pressure higher quality fittings and larger pipe sizes – pump power reduced ≈25% from NCC limits	≈ \$7.96/m^2
Heat Rejection	• Induced draft cooling towers with variable speed fans meeting NCC power limit	• Same tower type with optimised design for low fan power - reduced ≈15% from NCC limits and Reference building	≈ \$0.72/m^2
Air Handling	• Central VAV air handling system serving common areas and retail tenancies • Low system pressure with AHU / RA fans having 20% input power reduction compared to NCC limits	• System pressures reduced through oversized AHUs, filters and low pressure loss duct fittings • 45% reduction in fan input power compared to NCC limits	≈ \$5.86/m^2
Lighting	• Standard to high efficiency (130 to 150lm/W) LED fitting selections • Illumination power density ≈40%	• High efficiency (150+ lm/W) LED fitting selections throughout • Illumination power density ≈50% reduced	≈ \$2.50/m^2

	reduced compared to NCC DTS	compared to NCC DTS	
Potable Hot Water	• Gas fired boilers - Efficiency > 85%	• Electrical heat pump hot water generators • Air sourced heat exchange with seasonal EER > 2.8	≈ $3.93/m^2
Façade	• Minimal glazing using curtain wall design with standard aluminium framing meeting NCC DTS requirements	• No change due to negligible impact on energy consumption	-
		Total Cost Uplift	**≈ $26.34/m^2**
		Percentage Cost Uplift (based on $2,600/m^2 construction cost)	***≈ 1.01%***

Implementing the nominated initiatives above is seen to come to a total CAPEX uplift just over $26/m^2. Relative to a nominal overall construction cost, that is in the order of $2,600-3,000/m^2 for a city metro retail centre extension, the uplift is small increasing the cost by around 1%.

The following table details the operational energy consumption and energy costs for the buildings including an NCC 2016 compliant building for additional reference.

Table 16. Case 3 – Annual Energy Consumption and Energy Cost Comparison

Item	NCC 2016 Compliant Building	Reference Building	Carbon Roadmap Building	Difference (Roadmap vs Reference)
Electrical Energy (kWh/m^2/yr)	99.95	73.04	63.18	-9.85
Gas Energy (MJ/m^2/yr)	109.20	94.38	0.00	-94.38
Total Energy (MJ/m^2/yr)	**469.02**	**357.31**	**227.46**	**-129.85**
Percentage Energy Difference to NCC 2016	-	*-23.8%*	*-51.5%*	
Percentage Energy Difference to Reference	*31.3%*	-	*-36.3%*	
Electricity Cost ($/m^2/yr)	$19.99	$14.61	$12.64	-$1.97
Additional Cost for Green Power ($/m^2/yr)	$0.00	$0.00	$3.16	+$3.16
Gas Cost ($/m^2/yr)	$3.06	$2.64	$0.00	-$2.64
Total Energy Cost ($/m^2/yr)	**$23.05**	**$17.25**	**$15.80**	**-$1.45**
Percentage Energy Cost Difference to NCC 2016	-	*-25.2%*	*-31.5%*	
Percentage Energy Cost Difference to Reference	*33.6%*	-	*-8.4%*	

* Performance fell short of target 60%. See Section 3.1 for further discussion.

The results above show a significant reduction in overall energy consumption is achieved through implementing the roadmap building initiatives at over 35% less relative to the Reference building. Although the switch to Green Power increases the costs of electrical energy, the removal of gas and reduction in electrical energy relative to the Reference building has led to a reduction in annual energy costs of over 8%.

2.4.2 Embodied Carbon

The embodied carbon target has been assessed to determine extra over measures required to achieve the road map targets and balance of carbon requiring offsetting. The assessment was undertaken in accordance with EN 15804.

A 20% reduction over the reference building is possible using a combination of low carbon concrete (e.g. product such as Envisia) and reduced carbon content steel from supply chain using Electronic Arc Furnace (EAF).

The extra over CAPEX to achieve a minimum 20% embodied carbon reduction and cost to offset remaining embodied carbon would be as follows:

Table 17. Case 3 – CAPEX for 20% Embodied Carbon Reduction

Material	Extra over material costs	Extra over cost $/m^2
Concrete	$50/m^3	$32/m^2
Steel	$200/t	$16/m^2
Total		**$48/m^2**
Percentage Cost Uplift (based on a on $2,600/m^2 construction cost rate)		***1.85%***

Extra over CAPEX to offset the remaining embodied carbon is as follows:

Table 18. Case 1A – CAPEX to Offset Remaining Embodied Carbon

Offset	Unit Price	Extra over annual cost $/m^2	Percentage extra cost *
International sourced offset	$0.50/t	$0.28/m^2	0.01%
ACCU offset	$17/t	$9.60/m^2	0.37%

* Based on a construction cost rate of $2,600/m^2

2.4.3 Building Operations

Estimations of carbon emissions arising from potable water, waste water and waste have been completed to determine extra over OPEX to offsets these ongoing carbon emissions associated with building operations.

Table 19. Case 3 – Operational Carbon Emissions and Offset Costs

Category	T/CO_2	T/CO_2/m^2	Offset cost range $/m^2	
			*$0.50**	*$17.00***
General Waste	1,932	0.138	$0.0690	$2.3455
Recycling (Paper)	115	0.008	$0.0006	$0.0193
Potable Water (incl. cooling towers)	11	0.001	$0.0004	$0.0139
Waste Water	7	0.001	$0.0003	$0.0090
Totals	**2,066**	**0.148**	**$0.07**	**$2.39**

* International sourced offset

** ACCU offset

3. Summary and Key Findings

3.1 Case 1A/1B – New Office

- A 60% energy reduction against 2016 NCC benchmarks for a high rise commercial office building has proved unlikely to be achievable whilst maintaining the expected level of tenant servicing. Building fabric and services performance modifications alone, achievable with current market technologies, completed for this exercise did not support this target.
- A 50% energy reduction for Sydney location and 54% for Melbourne was able to be achieved for the case study building without resorting to a complete building and servicing redesign. Note this is not considering renewables.
- Additional gains can be made using on-site renewables however opportunities are limited for high rise buildings. High floor area to footprint ratios for high rise and likely surrounding building overshadowing impacting façade building integrated PV, energy generation potential is small per floor area. Investigations using the case study building applying BIPV to the spandrel zones of the top 8 floors and a roof mounted PV system to all available roof area only provided an additional 4% energy reduction against the 2016 NCC benchmark.

- Extra over investment required to avoid fossil fuels by moving to a full electric equipment solution may have a long timeframe for return as only small operational cost gains are made due to increased efficiency being offset by increased cost of electricity relative to gas per unit of energy.
- Although operational energy is reduced relative to the Reference building, mainly due to the removal of gas as an energy source, additional premium for Green Power outweigh the reduction and annual energy costs increased.
- Extra over investment required to use very low GWP refrigerants (≤1) is not returned due to no or only minimal gains in system efficiency. High investment costs are contributed to by present low market availability of such products that will likely improve in the future (see further discussion in Section 3.4).
- Investigation of Electrochromic glazing (allows SHGC to be adjusted) showed additional gains of about 1.2% against 2016 NCC benchmark. Due to additional capital cost (>$105/m2 floor area) this option was excluded as unlikely to be commercially viable.
- Servicing strategy redesign investigating efficiency gains of thermal systems interconnection and heat transfer arrangements using thermal storage buffers may yield further performance gains.
- Sites with access to large thermal heat sources/sinks (e.g. lake, bay, ocean) would also be able to improve performance further however not all properties have such access, as is the situation for the case study building.

3.2 Case 2 – Existing Office Upgrade

- As seen for high rise development, a 60% energy reduction against 2016 NCC benchmarks for a medium rise commercial office building has proved unlikely to be achievable whilst maintaining the expected level of tenant servicing. Building fabric and services performance modifications alone, achievable with current market technologies, completed for this exercise did not support this target.
- A 50% energy reduction was able to be achieved for the case study upgraded building without resorting to a complete building and servicing redesign. Note this is not considering renewables.
- Due to the much lower energy consumption and subsequent operational utility costs of the Carbon Roadmap upgrade building compared to the Reference upgrade building, payback on the additional capital expenditure would be realised in a shorter timeframe compared to the new office buildings investigated. This is due to the new office reference buildings having a higher performance starting point and therefore the new office Carbon Roadmap building saves less operational expenditure in comparison.
- Additional gains can be made using on-site renewables providing reasonable returns for a medium rise building. Opportunities are however still limited as for high rise buildings with reasonably high floor area to footprint ratios and higher likelihood of surrounding building overshadowing impacting façade integrated and rooftop PV. Investigation for the case study building showed that applying a roof mounted PV system to all available roof area provided an additional 7% energy reduction against the 2016 NCC benchmark.
- Extra over investment required to avoid fossil fuels by moving to a full electric equipment solution may have a long timeframe for return as only small operational cost gains are made due to increased efficiency being offset by increased cost of electricity relative to gas per unit of energy.
- Annual energy costs reduce relative to the Reference building regardless of the additional premium of Green Power due to the reference starting point (4 Star) being lower than that for the new office cases.
- Extra over investment required to use very low GWP refrigerants (≤1) would not returned due to no or only minimal gains in system efficiency. High investment costs are contributed to by present low market availability of such products that will likely improve in the future (see further discussion in Section 3.4).
- Investigation of higher performance glazing using thermally broken framing showed additional gains of about 0.8% against 2016 NCC benchmark. Due to additional capital cost (>$60/m2 floor area) this option was excluded as unlikely to be commercially viable.
- Servicing strategy redesign investigating efficiency gains of thermal systems interconnection and heat transfer arrangements using thermal storage buffers may yield further performance gains.
- Sites with access to large thermal heat sources/sinks (e.g. lake, bay, ocean) would also be able to improve performance further however not all properties have such access, as is the situation for the case study building.

3.3 Case 3 – Retail Centre Extension

- As for the other cases, a 60% energy reduction against 2016 NCC benchmarks for a retail shopping centre building has proved unlikely to be achievable whilst maintaining the expected level of tenant servicing. Building services performance modifications alone, achievable with current market technologies, completed for this exercise did not support this target.
- Slightly over 50% energy reduction was able to be achieved for the case study upgraded building without resorting to a complete building and servicing redesign. Note this is not considering renewables.
- Due to the much lower energy consumption and subsequent operational utility costs of the Carbon Roadmap upgrade building compared to the Reference upgrade building, payback on the additional capital expenditure would be realised in a shorter timeframe compared to the new office buildings investigated. This is due to the new office reference buildings having a higher performance starting point and therefore the new office Carbon Roadmap building saves less operational expenditure in comparison.
- Additional gains can be made using on-site renewables that would provide reasonable returns for a low rise building such as a retail shopping centre.
- Extra over investment required to avoid fossil fuels by moving to a full electric equipment solution may have a long timeframe for return as only small operational cost gains are made due to increased efficiency being offset by increased cost of electricity relative to gas per unit of energy.
- Annual energy costs reduce relative to the Reference building regardless of the additional premium of Green Power due to the reference starting point (5 Star) being lower than that for the new office cases.
- Extra over investment required to use very low GWP refrigerants (≤1) would not returned due to no or only minimal gains in system efficiency. High investment costs are contributed to by present low market availability of such products that will likely improve in the future (see further discussion in Section 3.4).
- Servicing strategy redesign investigating efficiency gains of thermal systems interconnection and heat transfer arrangements using thermal storage buffers may yield further performance gains.
- Sites with access to large thermal heat sources/sinks (e.g. lake, bay, ocean) would also be able to improve performance further however not all properties have such access, as is the situation for the case study building.

3.4 Considerations for Zero GWP Refrigerants

Research into zero GWP refrigerants has shown:

- R717 ammonia refrigerant products appear to presently be the only GWP: 0 compound in commercially available chillers / heat pumps.
  - Limited range of ammonia products currently exist on the market.
  - Ammonia refrigerant heat pump products available appear to only be water source coupled (i.e. absorb heat from a water loop). This limits application in high rise buildings with extensive heating requirements.
  - Due to higher flammability of ammonia and potential toxicity in high concentrations, additional safety considerations are required.
  - Future products using natural refrigerants (e.g. water) are promising but still in early development.
  - Fourth generation refrigerants (HFOs) some with GWP of 1 and ODP of 0 have recently become available with some manufacturers offering chiller and heat pump products with such refrigerants.
  - Carbon Dioxide (CO2) has a GWP of 1 and ODP of 0 can also be used as a refrigerant in chiller and heat pump equipment.
- These preliminary findings indicate the Zero GWP roadmap target should potentially be raised to allow use of other low GWP refrigerants (e.g. CO2, HFOs) with a target of Zero GWP staged in at a later date &/or be coupled with an alternative equivalent option (e.g. carbon offsets). This will allow time for further capacity to build in the market.

3.5 Recommendations

- Consider reducing Carbon Roadmap Target of 60% energy reduction compared to 2016 NCC to 50%. At annual intervals, review ability and uptake of projects meeting target for consideration of uplift to minimum mandatory requirements for certain rated levels.
- Consider isolating energy reduction target (e.g. separate credit) from any on-site renewable energy generation to ensure building performance is maximised without reliance on renewables.
- Consider introducing a scaled systems to reward projects for reducing use of fossil fuels with points awarded for example based on percentage avoidance relative to building entirely using gas fired heating.

4. Disclaimer

The assessments have been based on theoretical case study building designs as described in the report. The study assesses theoretical design potential only and does not provide estimate or indication of the case study buildings in operation.

The energy consumption estimates established from simulation results presented in this report are based on necessarily simplified and idealised versions of the case study buildings that do not and cannot fully represent all of the intricacies of the buildings once built. As a result, simulation results only represent an interpretation of the potential building performance of the building. No guarantee of building performance in practice can be based on simulation results alone.

Appendix A Acronyms and Abbreviations

A list of acronyms and abbreviations and their definitions used in this report is provided in Table 20 below.

Table 20. Acronyms and abbreviations, and their definitions

Acronym	Definition
AHU	Air-handling unit
CAPEX	Capital expenditure
CBD	Central Business District
COP	Coefficient of performance. Coefficient of performance is a measure of chiller energy efficiency at full (100%) load, as determined by the AHRI 550/590 standard. Can also be known as energy efficiency ratio. Larger numbers are more efficient.
D+AB	Design & As Built (Green Star rating tool)
DTS	Deemed-to-Satisfy
EER	Energy Efficiency Ratio
FCU	Fan coil unit
GBCA	Green Building Council of Australia
GHG	Greenhouse Gas
GLAR	Gross Lettable Area Retail
GWP	Global Warming Potential
IPLV	Integrated part load value. IPLV is measure of chiller energy efficiency at part load and varying ambient conditions, as determined by the AHRI 550/590 standard. IPLV as a comparative metric to compare the chiller energy efficiency when selecting equipment. Larger numbers are more efficient.
IRR	Internal rate of return
LED	Light emitting diode
lm/W	Lumens per watt. A measure of lighting energy efficiency.
MEPS	Minimum Energy Performance Standards, now known as GEMS or the Greenhouse and Energy Minimum Standards. These standards cover the minimum energy efficiency of products sold in Australia.
NABERS	National Australian Built Environment Rating Scheme
NCC	National Construction Code, also known as the Building Code of Australia.
NLA	Net Lettable Area
NPV	Net present value
ODP	Ozone Depletion Potential
OPEX	Operational expenditure
PCA	Property Council of Australia
RA	Return air
SHGC	Solar Heat Gain Coefficient
VAV	Variable air volume
VSD	Variable speed drive

Appendix B Draft Carbon Positive Roadmap

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