Cost Effective Energy Savings in Australian Commercial Buildings to 2020

Phil Harrington[1], Trevor Lee[2], David Devenish[3], Phil McLeod[4]

Abstract

This paper analyses the level of cost-effective energy savings that new commercial buildings could achieve in Australia by 2015 and 2020, relative to buildings compliant to the Building Code of Australia (BCA2010). It draws on research undertaken by the authors for the Australian Government (Department of Climate Change & Energy Efficiency). The study involved modelling typical a healthcare/hospital building form, a supermarket form, and 3-storey and 10-storey office building forms in all capital city climate zones in Australia, at a range of energy performance levels down to zero net energy (where achievable).

The results show that there are very significant cost effective opportunities for energy savings in new commercial buildings in Australia even by 2015, and greater opportunities by 2020. While there are variations in the degree of cost effective savings by climate zone and by building type, these variations are around mean values which are high and quite robust in the face of the sensitivity analyses included in the study. Savings of between 54% and 80% are shown to be cost effective for commercial buildings in the Base Case (*i.e.* on current policy settings), with an average value of 68% by 2020. This high level of cost effective savings is attributed primarily to the relatively low stringency for commercial buildings in BCA2010, which means that many opportunities for energy savings that were cost effective at that time were not taken up. Energy prices for electricity and gas, and also the mix of fuels used in different building types and climate zones, influence the results. With rising energy and carbon prices through time, more such opportunities also become cost effective by 2020.

Keywords: commercial buildings, energy savings, cost effectiveness

1. Background

The study from which the results are drawn is a contribution to the National Building Energy Standard-Setting, Assessment and Rating Framework measure described in the *National Strategy on Energy Efficiency* (NSEE), approved by the Council of Australian Governments (COAG) in July 2009 (COAG 2009). The COAG Framework aims *inter alia* to lay out a pathway for future stringency increases in the Building Code of Australia (BCA) to 2020, in

[1] Principal Consultant, Pitt&Sherry, GPO Box 94, Hobart TAS 7000
[2] Director, Energy Partners, PO Box 1211, Fyshwick ACT 2609
[3] Senior Mechanical Engineer, Engineering Solutions Tasmania, 199 Macquarie St, Hobart TAS 7000
[4] Consultant, Pitt&Sherry, GPO Box 94, Hobart TAS 7000

order to increase certainty for stakeholders and to facilitate strategic planning and innovation by industry. The study commenced in the first half of 2011, and initial assumptions on gas electricity prices were revised to take into account the carbon price. It should also be noted that assumptions on photovoltaic costs are in hindsight conservative, with costs having fallen more dramatically than assumed in the modelling.

2. Methodology

This section outlines the approach used to undertake the study.

2.1 Building types

Four commercial building types form part of the study; a 3-storey and 10-storey office building, a supermarket, and a health-care building.

2.1.1 3-storey and 10-storey office building details

Table 1 below shows the details of the 3-storey and 10-storey office buildings. The Base Case assumes minimal compliance with BCA 2010 using conventional technologies, such as variable air volume (VAV) HVAC plant with economy cycle and hot water terminal reheat, and air cooled chiller and gas-fired boiler with 80% efficiency.

Table 1: 3-storey and 10-storey office form

	10-Storey Office	**3-Storey Office**
Area Total (GFA)	10,000 m^2	2,000 m^2
NLA	9,000 m^2, (10% services and common areas)	1,800 m^2, (10 % services and common areas)
Ratio of length to width	1:1	1:2
Storeys	10 storeys of 3.6m overall height each	3 storeys of 3.6m overall height each
Floor Plan	Carpeted, open plan within zones	
Replication	All floors identical	
Occupancy	1 person per 10 m^2 of NLA	
Ventilation	7.5 l/s per person	
Internal loads	15 W/m2	
Electric hot water	4 litre/person/day	
Lighting	Offices- 9 W/m^2 Services & Common areas - 5 W/m^2	
Air changes	Allowance of 1.5 l/s.m2 for the perimeter zone	
Lifts	Annual energy consumption 24 MWhr.	

Source: Engineering Solutions Tasmania and Energy Partners

Table 2 below shows the HVAC details for the 3 and 10-storey offices.

Table 2: Office building HVAC details

	10-Storey Office	3-Storey Office
Zoning	4 perimeter zones, 1 interior zone. Central core unconditioned. Note the zoning visible in the figure above. The perimeter zones are 3.6m deep.	
Plant type	Central plant, VAV with economy cycle and hot water terminal reheat	
Boilers	Gas-fired with 80% efficiency	
AHUs	Single AHUs for each zone, *i.e.* 5 AHUs serving whole building	
Control Strategy	14°C supply air temp which is reset in the perimeter zones based on room temperature.	

Source: Engineering Solutions Tasmania and Energy Partners

Table 3 below shows the glazing details of the office buildings.

Table 3: Office building glazing details

Location	U-Value	SHGC	Fenestration height	Window to Wall Ratio	
				External	Internal
Climate Zone 1	4.7	0.44	0.9m	25%	31%
Climate Zone 2 & 5	4.7	0.44	1.2m	33%	41%
Climate Zone 6	3.4	0.38	0.9m	25%	31%
Climate Zone 7	3.4	0.41	0.9m	25%	31%

Source: Engineering Solutions Tasmania and Energy Partners

2.1.2 Healthcare Building

The Healthcare model is similar to the 10-storey office building but reflects the greater importance of external views for patient care and has a 2:1 length to width ratio compared with 1:1 for the office building. The healthcare simulation is based on guidance provided by the BCA under the simulation protocol for a Class 9a Ward and that of actual experience with a healthcare facility as provided by Partridge et al (2008). Table 4 below summarises the Healthcare building details.

Table 4: Healthcare building details

Storeys	10
Ratio of length to width	2:1
NLA	9,000m^2
Occupancy	Ward: 1 person per 10 m^2 Treatment: 1 person per 5 m^2
Hot Water	70 litres/patient.day 430 patients total Gas-fired boiler (80% efficiency)
Internal Loads	Ward: 5 W/ m^2

	Treatment: 15 W/m^2
Lighting	Ward: 10 W/m^2 (Continuous) Treatment: 7 W/m^2 (JV3 Profile)
Plant Operation	24/7
Lifts	147 MW/hr annual energy consumption

2.1.3 Supermarket

The Supermarket model is a typical suburban, standalone, single-storey supermarket. The external walls are steel clad, insulated with glass fibre quilting and building foil, and lined internally with plasterboard. The building is all-electric with space cooling dominating energy use. A ducted direct expansion heat pump system (Constant Air Volume (CAV) HVAC) is used in the BCA2010 solution. Space heating is limited to cooler climate zones, where it makes up a small portion of total energy use. The building dimensions, insulation details and window areas of the BCA 2010 supermarket are shown below in Tables 5, 6, and 7, respectively.

Table 5: Supermarket building dimensions

	External Wall Dimensions (m)	**Internal Floor Dimensions (m)**
Width	79.8	79.3
Depth	53.4	52.9
Ceiling Height	4.2	

Source: Energy Partners

Table 6: Supermarket insulation details

Climate Zone	**Insulation Type**	**Total R-Value (m^{2}K/W)**	**Total U-Value (W/m^{2}K)**
1 and 2	Medium Weight Glass Wool (high performance panels)	3.37	0.297
5, 6 and 7	With EPS Expanded Polystyrene (Standard)	2.808	0.356

Table 7: Window area (front of building) to meet DTS when facing north

Climate Zone	**1**	**2**	**5**	**6**	**7**
Height of Window (m)	2.12	2.12	2.25	2.23	2.06
Total Width of Window (m)	53	53	53	53	53
Window Area (m^2)	112.36	112.36	119.25	118.19	109.18

2.2 Energy saving improvements

Starting with a BCA 2010 minimally compliant design using standard technology, the energy consumption baseline of each building type was established. Then, using the thermal analysis package, 'Virtual Environment' Version 6.2, the Base Case buildings were modelled with various improvements in order to meet increasingly higher energy performance levels: BCA2010 –40%, BCA2010 –70% and BCA2010 –100% (or zero net energy buildings). Modelling was undertaken in each state/territory capital city climate zone of Australia.

Table 8 below summarises the key variations modelled[5], for both office buildings and the health building, to achieve the required performance levels.

Table 8: Energy savings improvement to Health building and Offices

Health Building and Offices		
40% energy reduction	70% energy reduction	100% energy reduction
• Increased insulation levels (including lower U-value glazing) • Improved HVAC • Reduced infiltration to perimeter zone of building • Condensing boilers for HW • Regenerative braking in lifts [6] • Lighting improvements (lower W/m^2)	• Further lighting improvements • Advanced glazing • Co-generation in 10-storey office (cold climates only), • Trigeneration (health building) • Preheating hot-water (through PV or cogen) • Roof-top photovoltaics	• Reclaim ventilation • 'Switchable' glazing • Trigeneration (10-storey office) • Maximum utilisation of PV

Table 9: Energy savings improvement to Health building and Offices

Supermarket		
40% energy reduction	70% energy reduction	100% energy reduction
Same as 3 storey office, expect: • Greater improvements in lighting • Improved insulation to cold and freezer rooms • More efficient refrigeration cabinets • CAV HVAC	Same as offices except; • Further lighting improvements • More efficient CAV	• Solar HW • Refrigeration Cabinets to HEPS with selective heat sink to ambient • Advanced fenestration SHGC to suit climate • Maximum utilisation of PV

[5] Comprehensive details of energy saving improvements, and savings that individual improvements provide, can be found in the report at http://www.climatechange.gov.au/publications/nbf/pathway2020-increased-stringency-in-building-standards.aspx

[6] Note that regenerative drive systems reduce Base Case lift energy consumption down to 17.6 MWhr and 107.8 MWhr for the office and health buildings respectively. They are considered in all the reduced energy scenarios.

The implementation of Cogen/Trigeneration systems affected the design strategy of the building, in that the availability of 'waste' heat from these systems means that the building needs to be designed to minimize the cooling requirements rather than heating requirements. As a result improving the energy performance of the building involved balancing the availability of waste heat and the U-values of windows. Furthermore, it was found that there was noticeable difference in the glazing requirements of the Health building (24 hour operation) and the Offices. For the office buildings in warmer climates, the same reductions in U value as the Health building could not be justified since they generally benefit from being able to passively release heat through windows at night.

2.3 Cost estimation

A quantity surveyor, Davis Langdon, provided cost estimates associated with achieving the different energy performance levels for each building type and climate zone studied, based on the building specifications detailed above. Regional variations in the costs of plant and materials, as well as climate zone based variations in the building specifications, were taken into account. The analysis provided a commercially-relevant incremental cost to be established for improving each building type to the required 40%, 70% and 100% energy savings relative to BCA2010. The *incremental* or additional costs of each scenario relative to the BCA2010 Base Case were then calculated as an input into the benefit cost analysis.

2.4 Benefit Cost Analysis

The benefit cost analysis considered the value of (purchased) energy savings over an assumed 40 year building life arising from the higher energy performance requirements modelled, compared to the energy costs that would have been incurred had the same buildings been constructed to BCA2010. This means, for instance, that energy derived from a building's PV installation is represented as a reduced requirement for purchased electricity[7]. Separate calculations were made for each scenario, building type, climate zone and performance level from 2015 (the first year in which savings are assumed, due to application of higher building energy performance standards) through to 2060.

Electricity prices were constructed as the sum of major cost components, comprising wholesale costs, network (transmission and distribution) cost, operating costs, and retail margin. Real network costs were assumed to increase by 1% per year to 2020, and remain constant thereafter. Retail operating costs, derived from the cost component data, are assumed to remain constant in real terms throughout the projection period. The wholesale cost component was calculated as the sum of two sub-components. The lesser sub-component is costs other than the direct cost of purchased electricity and the major sub-component is the average pool price of sent out cost of electricity generated. The approach used to construct projected natural gas prices was similar to that used for electricity. For this

[7] Note that this values the output of PV systems at the prevailing retail price – other assumptions could be made, but we note that different arrangements for the pricing of PV apply in each state.

analysis, energy prices reflect the decisions announced in the Government's *Clean Energy Package* (2011) and underpinning Treasury modelling, including a carbon price of $23/t in 2012 rising at 2.5% (in real terms) per year for two years and then assumed to increase 4% per year. Learning rates were modelled by assuming reductions in the real costs of building materials used to reduce future energy costs for the Base Case (15% by 2015, 30% by 2020). The cost reduction is meant to encompass reduced labour costs resulting from learning, lower manufacturing costs from scale economies and market competition, and new technology developments that offer equivalent outcomes at lower costs. The benefit cost analysis used a real discount rate of 7% in accordance with The Office of Best Practice Regulation for present value calculations.

3. Results

Table 10 below shows the BCRs that are attained by the 10 storey office. By 2020, it is cost effective at BCA2010 -40% in all climate zones except Hobart and Canberra. Even at the BCA2010 -70% level, it remains cost effective in Brisbane and Darwin. Higher electricity costs in Brisbane, and the high cooling load in Darwin, help explain this result.

Table: 10 Storey Office - Benefit Cost Ratios of Energy Savings by Capital city, Year

	40%		**70%**		**100%**	
	2015	**2020**	**2015**	**2020**	**2015**	**2020**
Sydney	1.0	1.2	0.6	0.7	0.1	0.2
Darwin	1.6	1.9	0.9	1.1	0.2	0.3
Brisbane	1.3	1.6	0.8	1.0	0.2	0.2
Adelaide	1.1	1.3	0.7	0.9	0.2	0.2
Hobart	0.7	0.9	0.5	0.6	0.1	0.1
Melbourne	0.8	1.0	0.6	0.7	0.1	0.1
Perth	1.1	1.4	0.7	0.9	0.2	0.2
Canberra	0.7	0.8	0.4	0.4	0.1	0.1
Average	**1.0**	**1.3**	**0.6**	**0.8**	**0.1**	**0.2**

3.1 3-Storey Office

Table 11 below shows the BCRs that are attained by the 3 storey office. The 3 storey office responds better than the 10 storey office. It is cost-effective in all climate zones at BCA-40%, and preserves this cost-effectiveness at BCA2010 -70%. In percentage terms, the incremental construction costs required to reach these energy performance levels are quite modest, of around 7% and 11% respectively. This may be explained by the absence of trigeneration systems in this building. Incremental costs and benefits remain reasonably proportionate until at least the 70% energy reduction level, leaving BCRs relatively unchanged. At the -100% level, however, incremental costs jump up to around 46% above the Base Case, rendering this step not cost effective in all climate zones

Table 11: 3-Storey Office: Benefit Cost Ratios of Energy Savings by Capital city, Year

	40%		70%		100%	
	2015	2020	2015	2020	2015	2020
Sydney	1.3	1.6	1.3	1.6	0.4	0.5
Darwin	1.2	1.5	1.4	1.6	0.4	0.5
Brisbane	1.4	1.6	1.4	1.7	0.5	0.6
Adelaide	1.6	1.9	1.7	2.0	0.5	0.6
Hobart	1.5	1.8	1.4	1.8	0.4	0.5
Melbourne	1.2	1.5	1.3	1.6	0.4	0.5
Perth	1.4	1.8	1.5	1.8	0.5	0.6
Canberra	1.2	1.5	1.1	1.4	0.3	0.4
Average	**1.4**	**1.7**	**1.4**	**1.7**	**0.4**	**0.5**

3.2 Supermarket

Table 12 below shows the BCRs that are attained by the supermarket. The supermarket reaches very attractive benefit cost ratios. In Darwin and Brisbane, for example, the present value of energy savings at BCA2010 -40% in 2020 exceeds that of cost by around 6 times. Even in Canberra, which has the lowest cost effectiveness for this building type, the BCR is greater than 3 at this performance level. At BCA2010 -70%, the supermarket remains cost-effective in all climates. Even at BCA2010 -100% - that is, zero net energy – the supermarket is cost effective in 2020 on average across Australia registering BCRs of at least 1 in all climates except Hobart and Canberra.

The primary explanation of the high cost effectiveness of energy savings for the supermarket is its relatively simple form, including low glazing ratio and single storey, expansive form – together with the modest performance requirements implicit in the BCA2010 starting point. Relatively straightforward treatments to HVAC systems and lighting, and improvements in refrigeration cabinets to currently projected ‘high efficiency performance standard’ or HEPS, and additional insulation of cool and freezer rooms, significantly reduce energy consumption. The building’s mechanical services are able to ‘free ride’ on the reduced heat output modelled from improved refrigeration and lighting systems. Ideally additional sensitivity analysis would be conducted to test the importance of this factor.

Table 12: Supermarket - Benefit Cost Ratios of Energy Savings by Capital city, Year

	40%		70%		100%	
	2015	2020	2015	2020	2015	2020
Sydney	3.9	4.7	1.5	1.8	0.9	1.0
Darwin	4.8	5.9	2.2	2.6	0.9	1.0
Brisbane	5.0	6.0	1.7	2.1	1.0	1.2
Adelaide	4.5	5.4	1.7	2.1	1.0	1.2
Hobart	3.0	3.6	1.3	1.6	0.7	0.9

Melbourne	3.2	3.9	1.3	1.6	0.8	1.0
Perth	4.4	5.4	1.7	2.1	1.0	1.2
Canberra	2.7	3.3	1.1	1.4	0.6	0.8
Average	**3.9**	**4.8**	**1.6**	**1.9**	**0.9**	**1.1**

3.3 Health building

Table 13 below shows the BCRs that are attained by the healthcare facility. The healthcare facility performs well at BCA2010 -40%, being cost effective in all climate zones. As noted earlier, the health facility is unable to reach BCA2010 -70% without purchasing Green Power to supplement on-site renewable energy generation, with the sole exception of in Darwin. Gas savings, relative to the Base Case, are negative – as the buildings are using trigeneration to cover as much electrical load as possible but at the expense of additional gas consumption – with the net result that realised purchased energy savings are much less than 70%, indeed only around 10% to 20%, and even negative in Darwin.

Table 13: Health Building - Benefit Cost Ratios of Energy Savings by Capital city, Year

	40%		**70%**		**100%**	
	2015	**2020**	**2015**	**2020**	**2015**	**2020**
Sydney	1.8	2.2	0.9	1.1	0.3	0.3
Darwin	3.0	3.7	0.9	1.1	0.4	0.5
Brisbane	2.6	3.1	1.0	1.2	0.3	0.4
Adelaide	2.4	2.9	1.3	1.5	0.5	0.5
Hobart	2.0	2.5	0.9	1.0	0.2	0.3
Melbourne	1.9	2.4	0.8	0.9	0.3	0.3
Perth	2.5	3.0	1.1	1.3	0.3	0.4
Canberra	1.9	2.3	0.6	0.8	0.1	0.2
Average	**2.3**	**2.8**	**0.9**	**1.1**	**0.3**	**0.4**

Given this performance at BCA2010 -70%, the Healthcare facility becomes increasingly dysfunctional in its energy use at BCA2010 -100%. As they already have deployed close to the maximum amount of PV, energy efficiency and trigeneration at -70%, the buildings need to purchase additional Green Power to reach the -100% level. As a result, no or few additional *capital* costs are incurred at this performance level. Despite this, the BCRs fall to very low levels (on average, around 0.4) due to the cost of Green Power purchases.

Summary

The general pattern of these results is that those buildings that are able to save the most electricity consumption (such as the supermarket – which is all-electric - and all buildings in cooling-dominated climates) tend to produce the most cost effective savings, as electricity is around three times more expensive than gas. However, some buildings in cooler climates that save significant amounts of gas (for space heating and hot water) are also able to produce significant cost effective savings. Cost-effective savings are generally lower in Canberra than in other cooler climates due to the relatively low price of gas in the ACT.

A further general driver of these results is that all these buildings are able to achieve at least 40% energy savings in most climate zones at quite modest incremental construction costs, of generally around 4% (6% - 7% for the 3-storey office). At these performance levels, none of the buildings adopt the more expensive solutions of cogeneration, trigeneration or photovoltaics, but rather rely on more efficient HVAC equipment, lighting systems and hot water, along with improvements to the thermal shells, deploying technologies that are generally well understood and readily available.

3.4 Break-even energy savings

As described above, benefit cost ratios were calculated for each of the -40%, -70% and -100% performance levels (by building type and climate zone). Simple regression analysis was then undertaken to establish the break-even energy savings *i.e* BCR=1.

On average, 68% energy savings are expected to be cost effective for commercial buildings by 2020 (see Table 14 below) relative to BCA2010. These results show a reasonable spread of results by climate zone, from Canberra at 54% to Darwin at 80%.

Table 14: All Buildings- Break-even energy savings by Capital city, Year

	2015	**2020**
Sydney	58%	68%
Darwin	74%	80%
Brisbane	70%	77%
Adelaide	67%	76%
Hobart	49%	61%
Melbourne	52%	63%
Perth	66%	75%
Canberra	41%	54%
Weighted Average	**58%**	**68%**

3.1 Benefit-Cost Analysis of PV in Commercial Buildings

The results are not transparent as to whether PV is deployed at the break even performance level. Depending upon the building type and climate zone, PV is typically deployed at BCA -70% but not at BCA2010 –40%. When the break even performance level falls in between these two points, it is therefore ambiguous whether or not PV is deployed.

Table 15 below shows the projected cost effectiveness of PV for commercial buildings by climate zone. Future cost projections were based Raugei et al (2009). The benefit cost ratios are generally well below 1 except in Perth, where in 2020 it reaches 0.97. The break-even results for commercial buildings are therefore largely insensitive to the presence or absence of PV.

Table 15: Benefit Cost Ratios for PV- Commercial Buildings in 2020

Sydney	Darwin	Brisbane	Adelaide	Hobart	Melbourne	Perth	Canberra
0.56	0.62	0.61	0.75	0.57	0.56	0.97	0.44

4. Conclusion

A critical driver of the results is the starting point implicit in BCA2010. The targeted BCR for commercial buildings in BCA2010 was 2, while the results in this study imply an even higher starting point. Such high BCRs indicate that many highly cost-effective energy savings options for commercial buildings were not captured in BCA2010. As a result, these savings opportunities remain available, and this significantly increases the overall level of savings that are now available at the break-even level of cost effectiveness. In addition, energy prices for electricity and gas, and also the mix of fuels used in different building types and climate zones, also impact upon the results. Fuel mix is also important. For example, all-electrical buildings in Darwin tend to have higher cost effective savings than buildings with significant gas use (normally in cooler climates such as Canberra and Melbourne), given the lower cost per GJ of gas. Also, supermarkets in this study are all electrical buildings, and this is one factor that contributes to the high level of cost effective savings in this building type.

5. References

Australian Building Codes Board 2010, BCA 2010 Vol 1 : Building Code of Australia, Australian Building Codes Board.

COAG (2009) National Strategy on Energy Efficiency. Commonwealth of Australia. July 2009.

Partridge L, Evans S, Augros R (2008) “Impact of Climate Change on Healthcare Facilities Management Delivery”, Ecolibrium : August, p26-32.

Raugei, Marco and Paolo Frankl (2009). *Life Cycle Impacts and Costs of Photovoltaic Systems: Current state of the art and future outlooks*. Energy 34: 392–399.

The Treasury, *Strong Growth, Low Pollution: modelling a carbon price: update*, Commonwealth of Australia, 2011.