Pathway to 2020 for Increased Stringency in New Building Energy Efficiency Standards: Benefit Cost Analysis

FINAL REPORT

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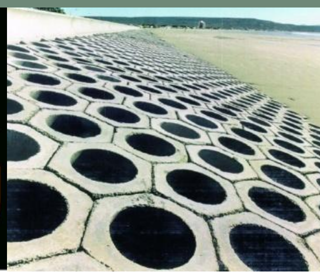

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	Name	Signature	Date
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Glossary of Key Terms

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
AC	Air-conditioner
AGA	Australian Gas Association
AGO	Australian Greenhouse Office
BCA	Building Code of Australia. This was incorporated into the National Construction Code in 2011.
BCA2010	The 2010 version of the Building Code of Australia
BCA2010-40%	An energy performance target representing a 40% reduction on the energy consumption allowed for a building minimally compliant with BCA 2010
BCA2010-70%	An energy performance target representing a 70% reduction on the energy consumption allowed for a building minimally compliant with BCA 2010
BCA2010-100%	An energy performance target representing a 100% reduction on the energy consumption allowed for a building minimally compliant with BCA 2010. This scenario also includes an allowance for 'plug load'
BCR	Benefit Cost Ratio, measured as the present value of benefits divided by the present value of costs
BOM	Bureau of Meteorology, Australia
CBA	Cost Benefit Analysis
Climate Zone	Both BCA and NatHERS climate zones are referenced in this Report – details are provided in Chapter 1
COAG	Council of Australian Governments
DEWHA	Department of the Environment, Water, Heritage and the Arts
Domestic Services	Under the BCA, domestic services refer to 'fixed appliances' such as lighting equipment, hot water services, pool and spa pumps (residential buildings).
E3	Equipment Energy Efficiency Committee
EES	Energy Efficient Strategies P/L
ESAA	Electrical Supply Association of Australia
GHG	Greenhouse Gas
HIA	Housing Industry Association of Australia
MEPS	Minimum Energy Performance Standards
NatHERS	Nationwide House Energy Rating Scheme
NGGI	National Greenhouse Gas Inventory
NSEE	National Strategy on Energy Efficiency
Plug Load	The energy consumption associated with plug-in appliances, not regulated by the BCA
PV	Photovoltaic panels including, depending upon the context, 'balance of system' components such as inverters and roof mounting hardware.
TMY	Typical Meteorological Year
Zero Net Energy Building	A building which on average is able to cover its annual energy demand from on-site renewable energy systems. In this study, this includes 'plug load' unless noted otherwise.

1. Executive Summary

Purpose

This Report analyses the range of cost-effective savings in the energy consumption of new buildings that could be achieved in Australia by 2015 and 2020, relative to buildings compliant with the current, 2010 version of the Building Code of Australia (BCA2010), based on a number of defined scenarios.

It has been commissioned by the Commonwealth Department of Climate Change and Energy Efficiency as a contribution to the National Building Energy Standard-Setting, Assessment and Rating Framework measure described in the *National Strategy on Energy Efficiency* (NSEE), which was approved by the Council of Australian Governments (COAG) in July 2009. Terms of reference for this study may be found at Appendix 1.

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 order to increase certainty for stakeholders and to facilitate strategic planning and innovation by industry. The Framework is intended to assist industry to anticipate and respond proactively to expected challenges and opportunities, including higher energy prices, carbon pricing, and evolving market trends such as changes in the availability and cost of high performance building technologies.

The performance levels identified in this study as being cost effective should be regarded as indicative only, as they are based on a point-in-time analysis of technical building performance improvement potentials and associated economic costs and benefits, for a limited number of building types, climate zones and policy scenarios.

Should governments agree to adopt particular building performance levels as goals for the Framework, it would be necessary to translate these goals into specific amendments to the BCA to ensure that increased standards are cost effective across the various building classes and climate zones. This process would involve a full regulatory impact assessment, which is outside the scope of this study.

Key Findings

Overall, this study has found that there are <u>very</u> significant cost effective opportunities for energy savings in new commercial buildings in 2015 and 2020 relative to BCA2010. 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 this study. Savings of between 54% and 80% are shown to be cost effective for commercial buildings in the Base Case (ie, 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. With rising energy and carbon prices through time, more such opportunities also become cost effective by 2020.

For residential buildings, this study has produced a 'binary' result with/without PV included in the building solution. Without PV, modest but still worthwhile savings, averaging 12% in the Base Case, are cost effective by 2020, with significant variation by climate zone (up to 32% in Perth). The average savings could increase to 16% if largely cost-free passive solar design changes are made to residential buildings before other measures (see Appendix 5). With PV in the mix, however, zero net energy for new residential buildings is shown to be cost effective by 2020 in all climate zones studied, and even by 2015 in most climate zones. This result follows from the fact that residential PV systems are modelled as cost effective in their own right in most climate zones by 2015, and in all climate zones by 2020 – noting that our analysis ignores all subsidies[1]. Despite being cost effective, there may

[1] In social benefit cost analysis, subsidies are treated as changes in the distribution, rather than in the level, of social costs and benefits. As discussed further in this Report, PV output is assumed to be

nevertheless be financial and/or practical barriers to the inclusion of PV as part of a building solution to meet a performance requirement in the BCA. Also, the financial analysis is based on benefits and costs to the building owner and does not include the value of benefits or costs that may accrue to electricity distribution networks or other third parties.

Approach

This study comprised four key steps. First, we described and simulated the energy performance of 16 different buildings at a range of performance levels in each capital city in Australia. The performance levels begin with the 2010 version of the Building Code of Australia (BCA2010) as a Base Case (not including any jurisdictional variations), and then move through succeedingly challenging energy performance levels: BCA2010 –40%, BCA2010 –70% and BCA2010 –100%, or zero net energy buildings.

Second, independent estimates of the costs of these buildings at each performance level were provided by quantity surveyors, Davis Langdon[2], and also by Dr Mark Snow, a leading expert on building-integrated photovoltaics (BiPV), specifically with respect to PV system costs. This enabled the *incremental* cost of achieving the higher energy performance levels to be calculated with some precision, using conventional costing approaches routinely employed for building commissions in Australia.

Third, benefit cost and break even analysis was carried out for each building type, climate zone, and performance level. For this analysis, the Base Case reflects the decisions announced in the Government's *Clean Energy Package* 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. The Base Case also assumes a rate of industry learning (how rapidly the real incremental cost of complying with new performance requirements declines through time) of 30% over 10 years and a real discount rate of 7%.

The benefit cost analysis assumes that two increases in performance requirements are introduced: the first in 2015 and the second in 2020. Each requirement is assumed to apply to a 'cohort' of buildings constructed between 2015 – 2019 and 2020 – 2024 respectively. All buildings are assumed to have an economic life of 40 years and the benefit cost analysis is conducted over this period. Cost effective levels of energy savings are calculated on a breakeven basis (benefit-cost ratio of 1) to determine the highest potential performance levels that could be achieved (based on the assumptions described within) before the estimated increased construction costs begin to exceed the value of energy savings through time. The estimates are based on modelling of a limited set of building types and climate zones: further work would be required to understand break-even savings levels for all building types and climate zones. Average results are weighted by the expected distribution of different building types in the climate zones studied. It is important to note that the economic analysis in this report is based on energy required for space conditioning, hot water, lighting and swimming pool pumps – all of which are subject to regulation in BCA2010. Like conditioning energy, the energy requirements for hot water and pool pumps are climate sensitive. References to residential building star ratings relate only to conditioning energy.

Fourth, a range of sensitivity analyses was undertaken, combining different carbon prices with different assumptions about the rate of industry learning, and also examining different real discount rates. The scenarios tested in the sensitivity analysis also allow differing degrees of flexibility in complying with the requirements, including trade-offs between improvements to the thermal shell of buildings, their fixed appliances (hot water systems,

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valued at a retail equivalent price, rather than a wholesale price, although we note in practice that the pricing of PV output varies very widely between Australian jurisdictions, including differing thresholds for the application of feed-in tariffs, different tariff rates and differing (or no) market caps. These variations are ignored in this study.

2 An AECOM company.

lighting, pool pumps) and photovoltaic panels (PV). Due to the sensitivity of the residential results to assumptions with respect to PV, results are presented on a with/without PV basis.

Scenario 1 assumes no carbon prices and no industry learning. While this may not be considered realistic, it does provide a 'worst case' or 'frozen technology' (e.g. continuing installation of electric storage hot water at current levels) analysis for comparison with the Base Case. Scenario 2 is based on the High Price scenario from the Treasury Modelling of the Clean Energy Package[3]. Sensitivity analysis is also undertaken to analyse energy savings that would result if the BCR benchmark were set at 1.2 rather than a breakeven value of unity. Also, for the large and small detached residential dwellings, sensitivity analysis was undertaken to determine the extent that thermal performance could be improved through a limited range of 'no cost' design changes (e.g. altering window placement and zoning).

Outputs

The key outputs described in this study are the percentage reductions, relative to BCA 2010, in the energy consumption of services regulated by the BCA[4] that are expected to be cost effective (that is, a benefit cost ratio of at least 1) in 2015 and 2020, given the scenarios and assumptions noted above and detailed in this Report. The results reported for specific climate zones represent the average results for the group of residential and commercial buildings studied, weighted by the prevalence of each building type at either the climate zone level (for residential buildings) or at the national level (for commercial buildings). The 'weighted average' national results at the bottom of each table are weighted by building construction shares in each state and territory. Further details on the results by building type can be found in Chapters 4 and 5 of this Report and in its Appendices, while further details on the methodology are presented in Chapter 3. The Base Case results presented below refer (for convenience) to the 2020 results unless specified otherwise.

Residential Buildings – Key Factors Driving the Results

The key factors that influence the residential building results can be summarised as:

- the expected prices of electricity and gas in each climate zone over time, as these determine the economic value of the energy savings that are achieved;
- differences in climates, as the severity of winter and summer conditions influence the total energy demand for space conditioning purposes, and therefore the benefits of improving thermal shell performance;
- the cost of achieving given levels of improvements in the building shell (in turn reflecting differences in construction techniques and distribution of residential building types by state/territory);
- the cost of achieving energy efficiency improvements in the fixed appliances, such as hot water, lighting and pool pumps (which also vary by state/territory including due to differences in the starting point distribution of hot water appliance types in particular, e.g., solar, electric storage, gas storage, instantaneous gas, etc); and
- the 'starting point' energy efficiency (e.g., 6 star houses required in BCA2010); and
- whether or not PV is allowed as part of the building solution.

Expected residential electricity and gas prices by climate zone are shown in Table ES1 below. It can be noted that electricity prices are significantly higher than gas prices on a $/GJ basis. This means that solutions that save electricity have greater cost effectiveness (per unit of cost incurred) than solutions that save gas. As a result, those climate zones that use more gas (e.g., Melbourne) tend to report lower cost-effective savings, while those

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

[4] Which varies by building type – for residential buildings it includes space conditioning energy consumption and energy consumption associated with services or 'fixed appliances' including hot water, lighting and pool and spa pumps. Where 'zero net energy' is achieved, this is defined to include plug and cooking loads as well.

that use more electricity (e.g., Darwin) tend to report higher cost-effective savings, other things being equal.

A second factor, however, is that both electricity and gas prices vary significantly by climate zone. Those climate zones with higher electricity or gas prices tend to show more cost effective savings. These two factors interact so that, for example, Darwin has a high use of electricity (natural gas is not reticulated in Darwin) but a relatively low electricity price. These two effects tend to cancel each other out, leading to modest savings being reported for Darwin residential buildings in Table ES3 below, for example.

Table ES1: Expected Gas and Electricity Retail Prices (real 2012 prices) - Residential Sector in 2020, by Climate Zone

	Gas ($/GJ)	Electricity ($/GJ)
Sydney	21.1	60.6
Melbourne	17.6	62.3
Brisbane	31.4	66.7
Adelaide	19.2	78.2
Perth	28.4	70.7
Hobart	26.1	65.4
Darwin	-	54.9
Canberra	23.2	46.9

Source: pitt&sherry

With respect to climate zones, Table ES2 below shows, firstly, that houses in the different climate zones covered in this study have widely differing requirements for space conditioning energy, as a function of the severity of the winter and/or summer climates they experience. Brisbane and Perth, for example, are shown as mild climates, with Darwin and Canberra more severe. Generally, since milder climates are using less energy for space conditioning, it is more difficult to identify cost effective opportunities for space conditioning energy savings (i.e., higher star ratings) in those climates.

Second, Table ES2 also shows that as star ratings increase, the space conditioning energy consumption (in all climates) falls in a non-linear fashion. That is, as higher star ratings are reached, the residual space conditioning energy consumption rapidly declines. Since there is less energy left to save, but the cost of achieving those savings continues to climb (indeed, it climbs more rapidly with increasing star ratings), cost effectiveness rapidly declines as higher and higher star bands are tested. This helps to explain why efficiency improvements in fixed appliances (or domestic services) contribute significantly to the cost effective savings modelled in milder climates, to a greater extent than improvements in thermal shells.

Regarding the residential building stock, there are significant differences between climate zones in terms of the distribution of construction types and, to a lesser extent, the prevalence of detached and semi-detached houses and flats. For example, medium-sized detached houses with brick veneer walls and concrete slab on ground (CSOG) represent over 50% of the current housing stock in the ACT and SA, but only 11% in NT and just 6% in WA. Cavity brick walls feature in over 70% of the housing stock in WA and 40% in NT. These differences affect both the potential for realising energy efficiency gains in the new housing stock and the costs of doing so in particular locations. Further details on these trends may be found in Section 4.2 and also in Appendix 3.

Table ES2: Residential Space Conditioning Energy Requirements (MJ/m2.a) by Star Band and Climate Zone

	5 star	6 star	7 star	8 star	9 star	10 star
Sydney	112	87	66	44	23	7
Melbourne	165	125	91	58	27	1
Brisbane	55	43	34	25	17	10
Adelaide	125	96	70	46	22	3
Perth	89	70	52	34	17	4
Hobart	202	155	113	71	31	0
Darwin	413	349	285	22	140	119
Canberra	216	165	120	77	35	2

Source: pitt&sherry, based on http://www.nathers.gov.au/about/pubs/starbands.pdf

Another critical factor influencing the overall magnitude of the reported cost effective savings, for both residential and commercial buildings, is the starting point stringency of the energy performance provisions of BCA 2010. While a detailed analysis of this factor fell outside our terms of reference, we note that the BCR that was estimated for residential buildings in BCA2010 was around one. This indicates that, prima facie, *all* improvement opportunities that were even marginally cost effective at that time were already included in BCA2010. This tends to limit the scope for further cost effective savings beyond that level - at least, in the absence of PV, as discussed below.

Residential Buildings – Results

In the Base Case, the weighted average level of energy savings that are cost effective for new residential buildings, relative to BCA2010 and without including photovoltaic panels (PV), is around 12% in 2020 and 8% in 2015 (see Table ES3 below). It can be noted that there is significant variation in the results by climate zone, and also that the overall level of savings is modest in most climate zones. The reasons behind these results are not immediately obvious and require some teasing out.

Table ES3: Break Even Energy Savings Relative to BCA2010, All Residential Buildings, Without PV, Base Case

	Space Conditioning and Fixed Appliance Savings		**2020 Break Even Thermal Shell Star Rating#**	**2020 % Space Conditioning Energy**	**2020 Space Conditioning Energy at Break Even**
	2015	2020			
Sydney West (CZ6)	9%	14%	6.0	30%	4.7GJ
Darwin (CZ1)	3%	3%	6.0	69%	17.3GJ
Brisbane (CZ2)	7%	7%	6.0	20%	1.6GJ
Adelaide (CZ5)	11%	11%	6.0	45%	6.9GJ
Hobart (CZ7)	14%	17%	6.4	67%	18.3GJ
Melbourne (CZ6)	3%	7%	6.2	66%	21.8GJ
Perth (CZ5)	18%	32%	6.0	29%	2.8GJ
Canberra (CZ7)	4%	7%	6.2	70%	26.8GJ
Weighted Average:	**8%**	**12%**			

Source: pitt&sherry

Notes: # = composite star rating for Class 1 and Class 2 buildings. Space conditioning energy consumption is shown in Column 5 as a percentage of total energy consumption excluding plug load and cooking energy then, in Column 6, in absolute terms.

First, as noted above, 6-star building shell performance means that in mild climates (Brisbane, Perth, Sydney, Adelaide) the space conditioning energy requirement is small both in absolute terms and as a share of total energy consumption (excluding plug load and cooking which are not regulated under the BCA). As a result, there is relatively little space conditioning energy remaining to save in these climates and, in the base case scenario, there are very few improvements that can be shown to be cost-effective for these climate zones. By contrast, in the locations with the highest space energy requirements (Canberra, Melbourne and Hobart), some improvements in the building shell performance are cost effective in this scenario.

In the milder climates (Brisbane, Perth, Sydney, Adelaide), the cost effective energy savings that are shown in Table ES3 relate almost exclusively to savings in the energy consumption of domestic services (water heating, lighting and pool/spa pumps). The significantly higher than average cost effective savings in Perth are driven primarily by relatively high electricity and gas prices making more efficient domestic services cost effective. The predominance of double brick construction in that (mild) climate zone already delivers reasonable thermal performance, but also means that it is relatively expensive to further improve that performance (for example by fitting insulation into the cavity between the two brick layers). Such expense is not justified by the modest, $200/year space conditioning cost on average, notwithstanding higher priced electricity in this climate zone. In Brisbane in 2020, the annual cost of space conditioning at the break even solution is just $107. This is the primary reason why further improvements in the thermal performance of building shells in the milder climates cannot be shown to be cost effective.

Price effects can also be seen in the cases of Darwin and Canberra. Despite both of these climate zones consuming significant amounts of space conditioning energy, relatively low energy prices constrain the cost-effectiveness of thermal shell improvements relative to climate zones with higher energy prices. A similar effect occurs in Melbourne, where gas is the predominant fuel used for space heating. Melbourne's low gas prices relative to other climate zones militate against further cost effective improvements in thermal shells.

Table ES3 also indicates (in Column 5) that in the milder climates, domestic services (or fixed appliances) are expected to account for the majority of total energy consumption (excluding plug load and cooking energy), while in the cooler climates, space conditioning continues to account for the majority of consumption. Note however that the potential for cost effective improvements in domestic services can also arise in the cooler climates. For example, the higher than average savings reported for Hobart are boosted in this analysis because the least cost solution involves preferring high performance gas hot water systems over the 'frozen efficiency' solution of electric storage hot water systems, which have high lifecycle costs.

Finally, differences in the composition of the new dwelling stock by climate zone also impact upon the potential for cost effective building shell energy savings. This study finds that there is significantly greater potential for cost effective energy savings in Class 2 buildings (flats) than in Class 1 buildings (refer to Sections 4.2 and 4.3.1). Therefore, climate zones with a higher share of Class 2 buildings (Sydney, Brisbane, Adelaide, Perth, Canberra) tend to show higher cost effective savings overall. Note that this effect is modest as Class 2 dwellings make up less that 15% of the stock even in these climate zones.

Analysis was conducted to illustrate the sensitivity of the results, for the detached residential dwellings only, to 'cost free' changes in design to improve passive solar performance. These included relocation of glazing (without changing total window area) and repositioning of living areas to the North (without changing total floor areas)[5]. On average, about an additional half a star arises from the cost free re-design, and up to 0.9 star in Perth (see Table ES4 below). Given the low overall results for cost-effective improvements in thermal shells of houses in the absence of design changes, these results

[5] While not strictly zero cost, such changes could generally be made with a one-off investment in redesign and be cost free thereafter – see more details in Appendix 5.

are quite significant, particularly as they are based on very modest design changes. The details regarding this analysis are provided in Appendix 5.

Table ES4: Performance Improvement from Solar Passive Re-Design in 2020 (AccuRate Stars)

Location/AccuRate Zone	Medium Detached, BV Walls, CSOG	Large Detached, BV Walls, CSOG	Medium Detached, CB Walls, CSOG	Large Detached, CB Walls, CSOG
Sydney (CZ6)	0.4	0.5	0.7	0.5
Darwin (CZ1)	0.3	0.2	0.2	0.3
Brisbane (CZ2)	0.2	0.4	0.4	0.8
Adelaide (CZ5)	0.5	0.4	0.6	0.7
Hobart (CZ7)	0.3	0.1	0.4	0.5
Melbourne (CZ6)	0.3	0.3	0.4	0.4
Perth (C5)	0.8	0.4	0.9	0.9
Canberra (CZ7)	0.4	0.4	0.5	0.6
Weighted Average	0.4	0.4	0.6	0.6

Source: *pitt&sherry*

Table ES5 below shows the overall benefits of the passive re-design for the specified building types (which comprise 60-80% of dwellings in all jurisdictions) when all buildings are modelled – the passive improvements are applied to only the dominant building types identified in Table ES4[6]. By comparing the results in Table ES5 with those in Table ES3 it can be seen that the largest benefits from passive re-design occur for the colder climates (Melbourne, Hobart and Canberra). More details can be found in Section 1.3 of Appendix 5.

Table ES5: Break Even Energy Savings Relative to BCA2010, All Residential Buildings, Without PV, Base Case, Passive Improvements to BV/CSOG and CB/CSOG Dwellings

	Space Conditioning and Fixed Appliance Savings	
	2015	2020
Sydney West (CZ6)	12%	16%
Darwin (CZ1)	7%	7%
Brisbane (CZ2)	8%	8%
Adelaide (CZ5)	16%	16%
Hobart (CZ7)	21%	23%
Melbourne (CZ6)	11%	16%
Perth (CZ5)	23%	36%
Canberra (CZ7)	18%	26%
Weighted Average:	12%	16%

Source: *pitt&sherry*

When PV is allowed as part of the building solution, the results change dramatically (see Table ES6 below). Even in the base case, zero net energy housing is shown to be cost effective by 2020 in all climate zones studied.

Underlying this result is the fact that the cost of PV panels has declined dramatically in recent years, and indeed the cost is projected to decline further by 2020. This, combined with rising electricity prices, is making the electricity produced from PV installations increasingly cost effective. Indeed by 2015, PV installations are cost-effective in their own right in most climate zones studied[7], and by 2020 this is true for all climate zones. Where

[6] While the other residential forms used in this study (see Chapter 3) were not simulated with design changes, it is likely that there would be somewhat less opportunity for design-based energy savings with the flat and semi-detached buildings, given lesser flexibility in window placement in particular.
[7] No capital subsidies, Small Renewables Certificates or explicit feed-in tariffs are taken into account in this calculation. By assumption, however, the electrical output of the PV installations is valued at

PV is cost effective, and since PV systems can be sized to cover essentially any residential load (subject only to physical limitations such as the availability of appropriate roof area), PV systems can cost effectively reduce the consumption of purchased energy to zero. As soon as this condition occurs in a particular climate zone, the break even or cost effective level of energy savings for new houses in that climate zone immediately rises to 100% (i.e., zero net energy).[8]

Table ES6: Break Even Energy Savings Relative to BCA2010, All Residential Buildings, With PV, Base Case

	2015	2020
Sydney West (CZ6)	100%	100%
Darwin (CZ1)	100%	100%
Brisbane (CZ2)	100%	100%
Adelaide (CZ5)	100%	100%
Hobart (CZ7)	100%	100%
Melbourne (CZ6)	3%	100%
Perth (CZ5)	100%	100%
Canberra (CZ7)	4%	100%
Weighted Average:	79%	100%

Source: pitt&sherry

Another way to interpret these results is to note that the various 'treatments' or upgrades that may be applied to a 6 star, BCA2010-compliant house have different costs and benefits. In our analysis, these treatments are selected in declining order of cost effectiveness (that is, the most cost effective are selected first). As soon as PV panels become the next most cost effective treatment, no further treatments (and hence no further costs) are required to reduce the house's energy consumption to zero.

Note that PV in Melbourne and Canberra is not cost effective until after 2015 (although only very slightly so in the case of Melbourne) due to lower electricity prices and somewhat lower PV output in those climate zones.

Commercial Buildings – Key Factors Driving the Results

As with the residential buildings, a critical driver of the commercial building 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[9]. Such high BCRs indicate that many highly cost-effective energy savings options for commercial buildings were not captured in BCA2010, unlike for residential buildings. 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. These effects are accentuated in commercial, as compared to residential, buildings due to their significantly higher energy intensity (energy use per square metre). A snapshot of commercial energy prices is provided in Table ES7 below. These display a similar pattern to the residential

the prevailing retail price. Given that this price includes network charges, this may be considered a subsidy. If a lower price were assumed, PV systems would be shown to be proportionately less cost effective. For further information, see Section 4.1.

[8] Including the 'plug load', or the energy consumption related to cooking and plug-in appliances.

[9] The regression analysis on all commercial building types indicated a benefit cost ratio of 2.2 associated with the y-axis intercept, or zero percent incremental savings relative to BCA2010. This result is not directly comparable with past benefit cost analyses of BCA2010 for commercial buildings, but is nevertheless consistent with those results.

prices but generally at a somewhat lower absolute level, reflecting trends in the National Energy Market.

To a greater degree than the residential buildings, the 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.

Table ES7: Expected Gas and Electricity Prices (Real Prices 2012) Commercial Sector in 2020, by Climate Zone

	Gas $/GJ	Electricity $/GJ
Sydney	17.2	57.1
Melbourne	14.7	59.1
Brisbane	22.9	62.7
Adelaide	15.9	73.8
Perth	21.5	64.1
Hobart	19.4	60.6
Darwin	-	52.0
Canberra	18.5	44.8

Source: pitt&sherry

Relatedly, where co- or tri-generation is selected as part of a solution for a building, purchased electricity consumption is effectively swapped for gas consumption. This reflects the fact that gas is significantly cheaper than electricity. As a result it can be cost effective to back out electricity purchases with a co- or tri-generation unit, even if increasing gas purchases lead to higher total energy consumption in the building overall (this effect is noted to occur in some building solutions – refer to Chapter 5).

Commercial Buildings – Results

On average, 68% energy savings are expected to be cost effective for commercial buildings by 2020 (see Table ES8 below) relative to BCA2010. These results are much higher than for residential buildings and also show a reasonable spread of results by climate zone, from Canberra at 54% to Darwin at 80%.

The relatively lower level of cost effective savings in Canberra, Hobart and Melbourne is largely attributable to higher gas use in these cooler climates, with gas savings being less valuable than electricity savings, and also to lower than average electricity prices in these climate zones. By contrast, the hotter climate zones with greater electricity use for space conditioning, and also those with higher electricity prices, tend to show more cost effective savings.

Table ES8: Break Even Energy Savings Relative to BCA2010, All Commercial Buildings, Base Case

	2015	2020
Western Sydney (CZ6)	58%	68%
Darwin (CZ1)	74%	80%
Brisbane (CZ2)	70%	77%
Adelaide (CZ5)	67%	76%
Hobart (CZ7)	49%	61%
Melbourne (CZ6)	52%	63%
Perth (CZ5)	66%	75%
Canberra (CZ7)	41%	54%
Weighted Average:	**58%**	**68%**

Source: pitt&sherry

The primary reason for the higher absolute level of cost effective savings for commercial, when compared to residential, buildings is the large difference in the thermal efficiency implicit in BCA2010 for these building types, as noted above. In this study, the level of cost effective savings is measured at BCR = 1, which enables many more savings to be shown to be cost effective than when a much higher benefit cost ratio is used. The regression analysis performed in this study suggests a BCR in 2010 of around 2.2[10]. This, combined with rising energy and carbon prices over time, accentuates the ability for relatively modest additional capital costs to be cost effectively repaid by energy savings. For example in the base case, all of the buildings studied are able to achieve at least 40% energy savings in most climate zones at quite modest incremental construction costs of 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.

There is nevertheless a significant variation in the cost effective savings potential of the different commercial building types studied. The supermarket shows by far the highest BCRs, although this result has only a modest impact on the weighted average results as the supermarket building holds just over a 6% share of the weightings. In the warmer climates (Darwin, Brisbane), a 40% energy saving can be achieved in the supermarket modelled with an incremental cost of around $60/square metre or 4%. Since the energy saved is high-value electricity, the present value of the energy savings exceeds the present value of the costs by around 6 times. The 10-storey office building has a much higher weighting within the overall results at 68%. While improvements to this building are not as cost effective as for the supermarket, the incremental costs of achieving 40% and even 70% savings are around 4% and 12% respectively. Even in the base case, the 40% reduction is cost effective for the 10-storey office.

As noted above, the selection of trigeneration (onsite heating, cooling and electricity generation) – which in this study is modelled only for the larger office and healthcare buildings - has a significant impact on both benefits and costs. The trigeneration units represent a 'lumpy' investment, increasing the capital cost of the buildings, but also causing a large change in the fuel mix. The trigeneration units are optimised to displace as much electricity consumption as possible, and this is replaced by additional gas consumption (to fuel the trigeneration units). In more extreme cases (where the buildings attempt to meet 70% or 100% energy savings, for example), the increased consumption of gas outweighs the electricity savings leading to higher total energy consumption overall – even though, since gas is much cheaper than electricity, this can be cost effective and also lead to lower greenhouse gas emissions in many cases. Since these buildings are not amenable to carrying large areas of PV panels, they sometimes fail to meet these high performance targets.

Chapter 5 provides more detailed analysis of these results.

Sensitivity Analysis - Residential Buildings

In Scenario 1, with no carbon prices or industry learning, cost effective improvements from BCA 2010 for residential buildings are limited to 6% on average as compared to 12% in the base case. However the spread of results by climate zone is broad, with 1-2% in Darwin and Canberra, and 18% in Perth in 2020 (see Table ES9 below).

The lower results in Darwin and Canberra reflect the relatively low energy costs in these climate zones, while the higher result in Perth in particular is aided by higher electricity costs, which favour heat pump hot water systems which generate relatively large (and valuable) energy cost savings in that climate zone. Cost effective improvements in thermal shell performance are not available in this scenario, except for Class 2 dwellings.

10 Note that this value cannot be directly compared with the targeted value of 2, as the two analyses utilise different data assumptions and time periods.

The cost effective improvements in Perth, Adelaide and Hobart are due to improvements in water heating and lighting, with minor building shell improvements in Hobart (to flats, where the potential for improvement at low cost is much greater than for other residential building types). Note that PV is not cost effective in this Scenario, and therefore the inclusion of PV within the set of solutions does not change the results below.

Table ES9: Break Even Energy Savings Relative to BCA2010, All Residential Buildings, Scenario 1

Scenario 1	**2015**	**2020**	**2015**	**2020**
Real discount rate	**@ 5%**	**@ 5%**	**@ 7%**	**@ 7%**
Sydney West (CZ6)	4%	3%	4%	3%
Darwin (CZ1)	3%	3%	2%	2%
Brisbane (CZ2)	7%	7%	7%	5%
Adelaide (CZ5)	11%	11%	7%	11%
Hobart (CZ7)	15%	15%	14%	14%
Melbourne (CZ6)	3%	3%	3%	3%
Perth (CZ5)	18%	18%	18%	18%
Canberra (CZ7)	1%	4%	1%	1%
Weighted Average:	7%	7%	7%	6%

Source: pitt&sherry

In Scenario 2 – with higher carbon prices and a higher rate of industry learning than in the base case – the cost effective level of energy savings, relative to BCA2010 and without PV, is significantly higher than in either the base case or Scenario 1, reaching 23% on a weighted average basis (see Table ES10 below). More improvements can occur cost effectively across all climates in this scenario, as costs fall faster through learning effects and as energy prices increase more rapidly. The spread of results by climate zone continues to reflect differences in relative fuel prices, which are accentuated by carbon pricing, increasing the relative attractiveness of electricity savings. Note that this also leads to higher greenhouse gas emission savings.

Table ES10: Break Even Energy Savings Relative to BCA2010, All Residential Buildings, Scenario 2, Without PV

Scenario 2	**2015**	**2020**	**2015**	**2020**
	@ 5%	**@ 5%**	**@ 7%**	**@ 7%**
Sydney West (CZ6)	19%	26%	14%	19%
Darwin (CZ1)	5%	23%	3%	15%
Brisbane (CZ2)	7%	30%	7%	22%
Adelaide (CZ5)	11%	22%	11%	22%
Hobart (CZ7)	19%	30%	16%	25%
Melbourne (CZ6)	13%	33%	4%	25%
Perth (CZ5)	32%	32%	26%	32%
Canberra (CZ7)	13%	43%	7%	29%
Weighted Average:	15%	30%	11%	23%

Source: pitt&sherry

Examining these results more closely, the break even reductions without PV in 2020 at 7% discount rate highlight the differences between warmer and cooler climates. The energy reductions at breakeven are very similar, such as for Perth and Canberra, but the causes fall into two clear groups. As discussed in Appendix 5, there is around a 1-star improvement in building shell performance in Melbourne, Hobart and Canberra, while for the other locations all energy improvements result from water heating, lighting and pool pumps, except for a small change in Darwin.

When PV is modelled in this scenario (see Table ES11), the average level of cost effective savings rises to 100% as residential PV is cost effective in its own right in all climate zones except for Canberra in 2015 in this scenario. The structure of the economic model means that 100% cost effective savings at break even gives the same result as the -100% energy result, with plug load and cooking backed out by PV in the zero net energy dwelling.

Table ES11: Break Even Energy Savings Relative to BCA2010, All Residential Buildings, Scenario 2, With PV

Scenario 2	2015	2020	2015	2020
Real discount rate:	@ **5%**	@ **5%**	@ **7%**	@ **7%**
Sydney West (CZ6)	100%	100%	100%	100%
Darwin (CZ1)	100%	100%	100%	100%
Brisbane (CZ2)	100%	100%	100%	100%
Adelaide (CZ5)	100%	100%	100%	100%
Hobart (CZ7)	100%	100%	100%	100%
Melbourne (CZ6)	100%	100%	100%	100%
Perth (CZ5)	100%	100%	100%	100%
Canberra (CZ7)	100%	100%	7%	100%
Weighted Average:	**100%**	**100%**	**100%**	**100%**

Source: pitt&sherry. Note that column 4 average is 100% despite the Canberra result, as some results exceed 100% in the model (due to 'lumpiness' in the selection of PV capacity, where 100W is the minimum increment) and have been rounded down.

When a BCR of 1.2 rather than 1.0 is targeted, there are modest reductions in the level of savings that are classed as cost effective. On average in the base case, savings fall from 12% to 8%, while in Scenario 1 they fall from 6% to 5% and in Scenario 2 from 23% to 20%. Sensitivity of residential results to solar passive re-design was outlined above.

Sensitivity Analysis – Commercial Buildings

In Scenario 1, without carbon pricing or learning, the cost effective level of energy savings relative to BCA2010, falls significantly to 44% on average in 2020 from 68% in the Base Case (see Table ES12 below). Despite the drop, due to both lower energy prices and higher costs through time, the cost effective savings remain very significant.

Table ES12: Break even energy savings relative to BCA2010, all commercial buildings, scenario 1

Scenario 1	**2015**	**2020**	**2015**	**2020**
Real discount rate:	@ **5%**	@ **5%**	@ **7%**	@ **7%**
Western Sydney (CZ6)	56%	57%	41%	43%
Darwin (CZ1)	75%	74%	66%	66%
Brisbane (CZ2)	69%	70%	58%	59%
Adelaide (CZ5)	67%	68%	54%	56%
Hobart (CZ7)	48%	49%	31%	34%
Melbourne (CZ6)	50%	51%	33%	35%
Perth (CZ5)	65%	66%	52%	54%
Canberra (CZ7)	37%	39%	18%	21%
Weighted Average:	**57%**	**58%**	**42%**	**44%**

Source: pitt&sherry

As in the base case, the warmer climates and those with higher electricity prices show greater levels of cost effective savings than the cooler climates with higher gas use and lower energy prices. In Appendix 5 these results are examined more carefully, where it is noted for example that the supermarket and 3-storey office buildings remain quite cost effective in this scenario, as they do not rely on trigeneration. By contrast the larger buildings modelled struggle to achieve the 70% energy reduction target in this scenario without having to purchase Green Power offsite, except in the cooler climates where trigeneration is deployed. For commercial buildings in this scenario, PV is not cost effective.

In Scenario 2, with higher energy prices and learning, cost effective savings in commercial buildings reach very high levels indeed - 80% on average in 2020 when compared with BCA2010, and 68% by 2015 (see Table ES13 below). The results vary by building type and climate zone in a consistent manner with the other scenarios, with the supermarket cost effective in all climate zones even at zero net energy. In Western Sydney, for example, the incremental costs associated with a zero net energy supermarket relative to BCA2010 are repaid in about 8 years. For a building that may stand for up to 40 years, and even with discounting of future savings, this represents an attractive investment. In climates and scenarios where PV is cost effective, a supermarket typically has plenty of roof area upon which to install PV systems and so is not constrained in the amount of PV that can be deployed. Most building types are cost effective at BCA2010 -70%, at least in the warmer and higher electricity cost climate zones. Details may be found in Appendix 5.

Table ES13: Break even energy savings relative to BCA2010, all commercial buildings, scenario 2

Scenario 2	2015	2020	2015	2020
Real discount rate:	@ 5%	@ 5%	@ 7%	@ 7%
Western Sydney (CZ6)	77%	86%	67%	80%
Darwin (CZ1)	90%	97%	84%	93%
Brisbane (CZ2)	84%	91%	76%	86%
Adelaide (CZ5)	83%	92%	74%	86%
Hobart (CZ7)	71%	82%	60%	74%
Melbourne (CZ6)	73%	84%	62%	76%
Perth (CZ5)	82%	90%	73%	85%
Canberra (CZ7)	66%	77%	54%	70%
Weighted Average:	**77%**	**87%**	**68%**	**80%**

Source: pitt&sherry

National Energy and Greenhouse Gas Emissions Savings

The total national energy and greenhouse gas emissions savings that could result from the introduction of higher energy performance requirements in the BCA will, on our analysis, vary greatly depending upon the factors that make up the scenarios in this Report: the level of carbon pricing, assumptions about the rate of industry learning through time, and the degree of trade-off allowed between different elements, notably including PV.

For residential buildings, in the Base Case scenario, and by the end of 2024 (the final year in which the savings measures are assumed to apply), the annualised greenhouse gas emissions savings is approximately 362kt CO_2-e, without PV, but would be significantly higher if zero net energy (with PV) were targeted.

In the commercial sector, in the Base Case scenario, the annualised greenhouse gas savings by 2024 reach about 2 Mt CO_2-e. In Scenarios 1 and 2 at 7% discount rate, emissions savings of around 1.27 Mt CO_{2-e} and 2.5 Mt CO_2-e respectively, are achieved by 2024.

Further Analysis

The conclusions in this Report have been subject to peer review and found to be robust. However, a range of additional analyses could be undertaken to better understand these results and/or to test their sensitivity to additional factors. As discussed in Chapter 6, these could include:

1. Sensitivity analysis for commercial buildings with respect to changes in 'plug load'. While internal appliances and equipment, commonly known as 'plug load', are explicitly included in the BCA2010 -100% solutions only, assumed efficiency gains for these loads can create a 'free ride' for commercial buildings at all performance levels, leading to lower incremental costs (and therefore higher cost-effective energy savings) than would otherwise be the case. The sensitivity of the results to these assumptions could be tested by remodelling the buildings with a static plug load assumed for all performance levels through time.
2. Closer examination of the cost effectiveness of cogeneration and trigeneration solutions in different climate zones. As these are 'lumpy' investments, which trigger significant fuel mix changes as well as different design optimisation strategies (see Chapter 5), the relative cost effectiveness of this solution is likely to play a major role in overall cost effective savings, particularly around the saving levels revealed in this study. It is likely, therefore, that the breakeven results will be sensitive to this variable. In this study, trigeneration is only deployed in the 10 storey office and healthcare facility.
3. For residential buildings, sensitivity analysis with respect to the degree and cost effectiveness of improvements in fixed appliances. While the efficiency of residential domestic services was not the major focus of this study, it was found this to be an important source of cost effective energy savings, particularly in the milder climate zones. The residential break-even savings are therefore likely to be sensitive to assumptions made in these areas, and this could be tested with more careful analysis of a range of efficiency trajectories for each of the fixed appliance classes (hot water, lighting, pool pumps).
4. For residential buildings, additional sensitivity analysis on low cost design changes for residential buildings. Given that the small number and modest nature of the 'no cost' design changes modelled in this study for the stand alone dwellings showed quite significant cost effective improvements were available, relative to the case without such design changes, a more extensive analysis of this factor could be undertaken. Such a study could examine a larger number of house designs, include modest size changes, changes in glazing ratios and more extensive floor plan changes, but also examine 'real world' constraints including those associated with solar access and sub-division design. Design optimisation costs could also be analysed. In principle, this additional study could also examine commercial building design variations, or (given the wider scope of commercial buildings) a separate study could be commissioned to examine these questions for commercial buildings.
5. More generally, the results of this benefit cost analysis could be enhanced by considering additional building types and climate zones. Educational buildings, other retail buildings, and climate zones outside capital cities, did not form part of this study. While there is no *a priori* reason to assume the overall results would change significantly with wider coverage of building types and climate zones, this could be tested with additional analysis.

2. Introduction

This study aims to identify a range of cost-effective targets for building energy performance requirements, for potential application in the Building Code of Australia in 2015 and 2020.

It forms part of the National Building Energy Standard-Setting, Assessment and Rating Framework measure described in the *National Strategy on Energy Efficiency* (NSEE)[11], which was approved by the Council of Australian Governments (COAG) in July 2009. This measure (3.1.1) states that "…all jurisdictions will work together to develop a consistent outcomes-based national building energy standard setting, assessment and rating framework for driving significant improvement in the energy efficiency of Australia's building stock".

In essence, the Framework seeks to improve approaches to rating the energy performance of buildings and to lay out a pathway for future stringency increases in the Building Code of Australia (BCA) to 2020. The NSEE states that this measure will be used to increase the energy efficiency of new residential and commercial buildings with minimum standards to be reviewed and increased periodically. The Framework will increase certainty for industry and other stakeholders, helping to facilitate strategic planning and innovation by industry in response to expected challenges, including higher energy prices, carbon pricing and market trends including changes in the availability and cost of high performance building technologies.

In this context, this study indicates 'break even' energy performance levels that are expected to be cost effective in 2015 and 2020, for a wide range of building types and climate zones, given a range of assumptions including energy and carbon prices, changes in compliance costs through time, and real discount rates. Chapter 3 below describes the methodology deployed in this study, with the appendices providing additional details with respect to particular building types.

2.1 Indicative Stringency Study

This study builds upon an earlier report *The Pathway to 2020 for Low-Energy, Low-Carbon Buildings in Australia: Indicative Stringency Study*, which was undertaken by pitt&sherry for the Department in 2010[12]. The primary purpose of this earlier report was to articulate indicative upper and lower bound options for a 2020 goal for both reduced energy use and greenhouse gas emissions in new residential and commercial buildings that could be implemented through the Building Code of Australia (BCA), as well as to advise on the nature of an optimal regulatory pathway to 2020.

The *Indicative Stringency Study* was a technical assessment that aimed to identify indicative outcomes and to inform further research, analysis and consultation. It was neither a regulatory impact assessment nor a benefit-cost analysis. While it included simulation of a limited set of building types and climate zones, it noted the need for further quantitative analysis in order to describe the full scope of buildings and climate zones covered by the BCA. The study reviewed international and national literature on the potential for cost-effective improvements in building energy performance and on rates of 'industry learning' that might lead to reducing compliance costs with new performance standards through time. The international literature in particular created an expectation that energy and greenhouse performance improvements in the order of 50% – 70% could be available on cost-effective terms by 2020 for both residential and commercial buildings. The Australian literature on the whole was noticeably more conservative, with estimates for cost-effective savings by 2020 clustering around 30%, although a few detailed estimates range as high as the international literature.

The *Indicative Stringency Study* noted that almost any level of energy/greenhouse gas performance is technically achievable even today for most building classes. This includes

[11] COAG (2009).
[12] Available at http://www.climatechange.gov.au/en/what-you-need-to-know/buildings.aspx

zero net energy or zero net emissions, or even energy or carbon positive buildings, with the addition of on-site energy generation from renewable sources. However, it noted that these performance levels may not currently be *cost-effective* in the terms required in the BCA, which aims to apply 'minimum necessary' standards that are rigorously tested to create net economic benefits.

At the same time, the study observed that an increasing number of building owners and tenants are already demanding very low energy and carbon buildings in Australia, thereby helping to familiarise architects, designers and the whole building supply chain – as well as other building owners and users – with required techniques, designs and technologies. Such actions also help to build economies of scale and scope – generically labelled 'industry learning' - lead to greater cost-effectiveness through time. In addition, higher energy prices (including but not only because of carbon pricing), reductions in the real cost of key building technologies, related policy initiatives such as improved minimum energy performance standards for appliances and equipment, would all enable higher performance levels to become increasingly cost effective. The study noted that many of these factors will be affected by a range of policy settings, and there is scope for governments to actively assist the achievement of higher, cost-effective energy performance levels in Australian buildings through judicious policies and programs.

2.1.1 Quantitative Results

The *Indicative Stringency Study* simulated the change in energy/greenhouse performance of a small but representative sample of buildings and climate zones under a range of different scenarios. The scenarios comprised:

- a base case of building energy/greenhouse performance under the 2009 BCA (later revised to BCA2010);
- a 'current best practice' scenario (modelled as BCA2010 but illustrated with best practice case studies); and
- low, medium and high (stringency) scenarios for 2020.

The three 2020 scenarios reflected expectations of a business-as-usual world (low stringency), an optimised outcome based on the current building and policy paradigm (medium stringency), and an outcome which would be optimal provided steps were taken to evolve the current building and paradigm to fully embrace low-energy, low-carbon performance (high stringency).

The study found that for residential buildings, savings of between 21% (low), 30% (medium) and 46% (high) were expected to be cost effective by 2020 compared with the BCA2010 – although it was stressed that this study was not a benefit cost analysis. For commercial buildings, energy savings in 2020 relative to BCA2010 of around 21-22% (low); 35 – 37% (medium); and 46 % - 47% (high) were expected to be cost effective on the same 'indicative' basis.

As discussed in more detail in Chapters 4 (residential) and 5 (commercial), the primary explanation of the differences between the expected results in the *Indicative Stringency Study* and the actual results in this benefit cost analysis are the significant differences in the starting point energy efficiency of residential and commercial buildings in BCA2010 – a factor not examined or anticipated in the *Indicative Stringency Study*. As noted, BCA2010 is shown in this study to have captured essentially all of the savings in thermal shell performance that were cost effective <u>at that time</u> for residential buildings while, by contrast, it left a very significant amount of the savings that were cost effective at that time for commercial buildings 'on the table'. With rising energy prices and generally falling compliance costs through time, these savings are even more cost effective today and into the future. Also, for residential buildings in particular, the *Indicative Stringency Study* did not examine the impact of PV panels which, in this study, are shown to offer the largest scope for cost effective energy savings in residential buildings to 2020 (where allowed in the building solution).

2.2 Scope

The scope of this Benefit Cost Analysis study was given by the Statement of Requirements, which is reproduced at Appendix 1. It includes establishing a reference level of energy use and greenhouse gas emissions for a range of new residential and non-residential (commercial) buildings built to current building standards, or BCA2010. This includes the energy use associated with fixed equipment and appliances regulated by the BCA.

Eight primary building forms, with some sub-variants, are used in this study:

- Class 1a – medium, single storey dwelling
- Class 1a – larger, double storey dwelling
- Class 1a – semi-detached dwelling
- Class 2 – flat
- Class 5 – 10-storey office building
- Class 5 – 3-storey office building
- Class 6 – supermarket
- Class 9a – health-care building

Detailed descriptions of these buildings and sub-variants may be found in the appendices to this Report.

The study focuses on the performance of these buildings in capital cities, as required by the terms of reference. In particular, it covers:

- NSW: Richmond Zone 28 (BCA Zone 6)
- Vic: Moorabbin Zone 62 (BCA 6)
- Qld: Brisbane Zone 10 (BCA 2)
- SA: Adelaide Zone 16 (BCA 5)
- WA: Perth Zone 13 (BCA 5)
- Tas: Hobart Zone 26 (BCA 7)
- NT: Darwin Zone 1 (BCA 1)
- ACT: Canberra Zone 24 (BCA 7).

Where aggregate results are reported, these are weighted by the prevalence of the different building types within the stock (although for commercial buildings, where the stock is less well described, weightings are applied at a national rather than state level).

Each of the above buildings are simulated at different energy performance levels representing BCA2010, BCA2010 – 40%, BCA2010 – 70% and BCA 2010 – 100%. Note that the latter performance level includes internal appliances, or plug load, in order to attain zero net energy consumption, while the other three scenarios do not include plug load or cooking energy.

For further details of the methodology used in this study, please refer to Chapter 3.

2.2.1 Process

There were several phases involved in producing this Final Report. A Draft Report was presented to a meeting of the Commonwealth-State Senior Officials Group on Energy Efficiency Framework Subgroup on 5 April 2011. Feedback on that document was included in a Draft Final Report completed in June 2011, which was then peer reviewed by ACIL Tasman. ACIL Tasman suggested minor revisions be made to some electricity and gas prices forecasts in several jurisdictions. These revisions have been adopted for this Final Report (see Chapter 3 for further detail).

Furthermore, in the period after completing the Draft Final Report, the Federal carbon pricing legislation was passed in November 2011. The analysis was therefore updated such that the Base Case results in this Report reflect the Government Policy package as modelled by the Federal Treasury.

This Final Report reports the Base Case scenario as the primary results (e.g., Chapters 4 and 5), and then presents sensitivity analysis separately in Appendix 5. This includes sensitivity analysis to compare break-even energy savings at BCR 1.2 as compared to BCR 1, as well as, for the large and small detached dwellings only, determining the extent to which thermal performance could be improved through 'no cost' design changes (e.g. altering window placement and zoning).

2.2.2 Project Team

This study has been undertaken by a large team comprising:

pitt&sherry

Phil Harrington, Principal Consultant – Climate Change and Project Manager
Dr Hugh Saddler, Principal Consultant – Energy Strategies
Dr Tony Marker, Senior Consultant – Buildings and Appliances
Dr Mark Snow, Renewable Energy Specialist
Phil McLeod, Buildings Analyst

Davis Langdon (an AECOM company)

Alan Jenkins, Director – Capability Development
Michael Manikas – Associate Director

Energy Efficient Strategies

Robert Foster, Principal

Energy Partners

Trevor Lee, Principal
Andrew Bell, Senior Engineer
Peter Lyons, Principal – Peter Lyons & Associates

Engineering Solutions Tasmania

David Devenish, Hobart Manager

pitt&sherry wishes to acknowledge with thanks the very substantial contributions made to this study by all members of project team, and for the direction and comments provided by DCCEE officers over the course of the study.

3. Methodology

This Chapter describes the methodology used in this study, along with key assumptions. Further details are provided with respect to residential and commercial building forms, and cost estimation, in the appendices to this Report.

3.1 Overview

This study comprises four key elements or stages. First, we describe and simulate the performance of a number of typical buildings, as noted in Section 2.2 above, at a range of different performance levels. These begin with the BCA2010 Base Case, and then move through succeedingly challenging energy performance levels: BCA2010 –40%, BCA2010 –70% and BCA2010 –100%. The latter performance level describes a 'zero net energy' building, or a building which, on average, is able to cover its total annual energy demand (including plug load and cooking) from on-site renewable energy systems. The purpose of this stage is to physically describe both the Base Case building and its higher-performance variants in sufficient detail to enable accurate costings to be compiled in Stage 2.

Stage 2 involves an independent quantity surveyor, Davis Langdon, preparing detailed, element-by-element cost estimates for each building type, in each climate zone, at each performance level. This in turn enables us to understand the *incremental* costs associated with moving to progressively higher energy performance levels. As detailed below, Dr Mark Snow – a recognised authority in Australia and internationally on building integrated PV – provided cost and yield estimates for PV systems by climate zone, along with expectations for the evolution of costs through time. Davis Langdon also provided a cost of PV for commercial buildings which is higher than Mark Snow's estimate. Davis Langdon's more conservative figure was used in the costing of the scenarios for commercial buildings as well as for the separate benefit-cost analysis of PV for commercial buildings.

Stage 3 compiles the energy savings data from Stage 1 and the incremental cost data from Stage 2 into a benefit cost analysis model by building type, climate zone, scenario and performance level. Benefit cost ratios are calculated for each permutation, and then regression analysis is performed to identify break even energy savings points for 2015 and 2020. As detailed below, slightly different methodologies were followed for residential and commercial buildings, in two different models, however in both cases, benefit cost ratios were generated for the required performance levels, as well as the breakeven level of energy savings relative to BCA2010.

Stage 4 involves extensive sensitivity analyses. Different carbon price assumptions are tested in combination with different assumptions about the rate of 'industry learning' (how rapidly the real incremental cost of complying with new performance requirements declines through time), including due to technological change and changes in real market prices. A 5% real discount rate is also tested. The scenarios also allow differing degrees of flexibility in complying with the requirements, including trade-offs between improvements to the thermal shell of buildings, their fixed appliances (hot water systems, lighting, pool pumps) and photovoltaic panels (PV). Due to the sensitivity of the residential results to assumptions with respect to PV, results are presented on a with/without PV basis. Scenario 1 assumes no carbon prices and no industry learning. While this may not be considered a realistic scenario, it does provide a 'worst case' analysis for comparison with the Base Case. Scenario 2 is based on the High Price scenario from the Treasury Modelling (Update) of the Clean Energy Package. Sensitivity analysis is also undertaken to analyse energy savings that would result if the BCR benchmark were set at 1.2 rather than 1. Also, for the large and small detached residential dwellings, sensitivity analysis was undertaken to determine the extent thermal performance could be improved through a limited range of "no cost" design changes (e.g. altering window placement and zoning).

3.2 Building Simulations

Technical details of the building simulations are provided in the Appendices to this report. This section is intended to provide a general overview of the buildings studied, and readers should refer to the Appendices for further information.

3.2.1 Residential Buildings

Residential building simulations were undertaken by *Energy Efficient Strategies.* As noted in Appendix 3, four primary building types and a number of construction detail sub-variants are modelled. Key data for the building types is summarised in Table 3.1 below.

Table 3.1: Overview of Residential Buildings Analysed

	Medium Detached Dwelling - Single Storey	**Large Detached Dwelling - Two Storey**	**Semi Detached Dwelling**	**Flat – middle Unit**	**Flat – corner Unit**
Ground floor area (m^2)	188.6	153.5	92.6	120	108.8
Upper floor area (m^2)	0	112.1	70.9	0	0
Total floor area (m^2)	188.6	265.6	163.5	120	108.8
Ceiling area (below Roof) (m^2)	188.6	102.9	130.8	120	108.8
Wall area (includes windows) (m^2)	179.5	263.2	177.4	48.1	74.8
Glazing area (m^2)	44.1	52.6	37.9	29.1	30.7
Glass to floor area ratio	23%	20%	23%	24%	28%

Source: Energy Efficient Strategies

Each dwelling type is modelled in a number of different construction formats designed to represent the most common construction types currently utilized by the building industry, as summarised in Table 3.2 below.

Table 3.2: Residential Construction Variations Analysed

Dwelling	**Floor**	**Walls**	**Roof**	**Orientation Options**
Single Storey Detached	CSOG	Brick Veneer	Pitched - Tiled	Closest to average performance
	Suspended timber	Brick Veneer	Pitched - Tiled	
	Suspended timber	Lightweight	Pitched - Tiled	
	CSOG	Cavity Brick	Pitched - Tiled	
Two Storey Detached	CSOG	Brick Veneer	Pitched - Tiled	Closest to average performance
	Suspended timber	Brick Veneer	Pitched - Tiled	
	Suspended timber	Lightweight	Pitched - Tiled	
	CSOG	Cavity Brick	Pitched - Tiled	
Semi Detached	CSOG	Brick Veneer	Pitched - Tiled	Closest to average performance
	Suspended timber	Brick Veneer	Pitched - Tiled	
Flat Mid Unit	Suspended concrete	Precast	Concrete	N,E,S &W
Flat Corner Unit	Suspended concrete	Precast	Concrete	N,E,S &W

Source: Energy Efficient Strategies

Plans/images of the four building types studied are indicated below.

Figure 3.1: Single Storey Detached Dwelling

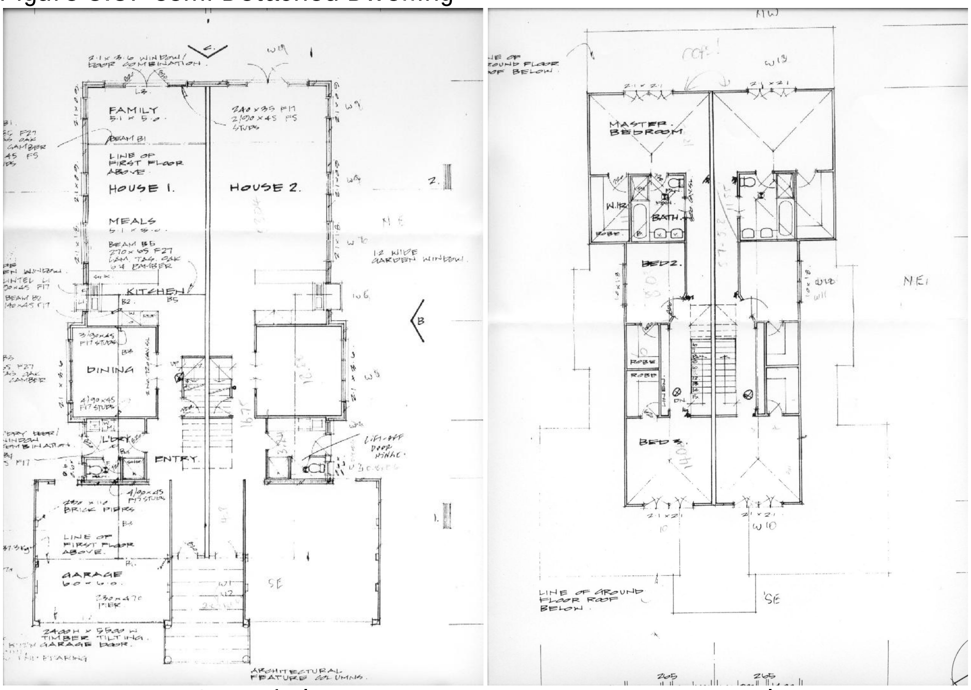
Source: Energy Efficient Strategies

Figure 3.2: Double Storey Detached Dwelling

Upper Floor

Source: Energy Efficient Strategies

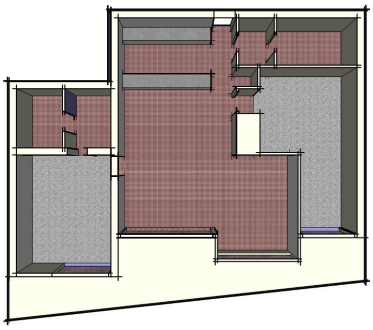
Figure 3.3: Semi Detached Dwelling



Ground Floor Upper Floor

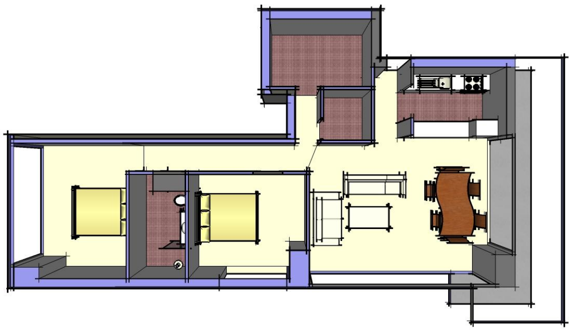
Source: Energy Efficient Strategies

Figure 3.4: Flat (non-corner)



Source: Energy Efficient Strategies

Figure 3.5: Flat (corner)



Source: Energy Efficient Strategies

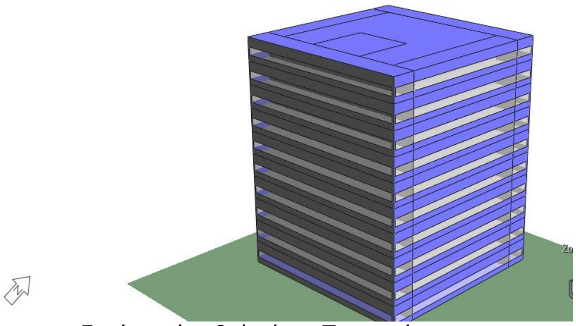
3.2.2 Commercial Buildings

Commercial building simulations were undertaken by *Energy Partners,* including *Peter Lyons and Associates* (3 storey office and supermarket), and by *Engineering Solutions Tasmania* (10 storey office and health facility). The buildings have been selected as typical examples of each type in Australia; however it is evident that the building forms modelled represent only a small sample of new building types and designs. Please refer to Appendix 4 for further details.

10 Storey Office

The 10 storey office used in this study has a gross floor area (GFA) of 10,000 sqm and a net lettable area (NLA) of 9,000 sqm, and is depicted in Figure 3.6 below. The Base Case assumes minimal compliance with BCA2010 using conventional technologies, such as variable air volume (VAV) HVAC plant with economy cycle and hot water terminal reheat. An air cooled chiller (100kW) and gas-fired boiler with 80% efficiency are used. All floors are open plan, carpeted and identical. Further technical parameters may be found in Appendix 4.

Figure 3.6: 10 Storey Office Building

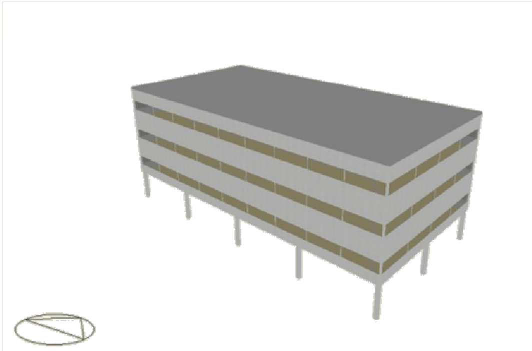


Source: Engineering Solutions Tasmania

3 Storey Office

The 3 storey office has a GFA of 2,000 sqm and a NLA of 1,800 sqm (that is, 10% services and common areas). Like the healthcare facility, it has an aspect ratio of 1:2. Floors are open plan, carpeted and identical. Fenestration (windows) are identical in each orientation.

Figure 3.7: 3 Storey Office Schematic



Source: Energy Partners

Table 3.3 below summarises the key variations modelled, for both the 10 storey and 3 storey offices, to achieve the required performance levels (-40%, -70% and -100%). The treatments for both buildings are identical unless otherwise specified.

Table 3.3: Office Building Improvements by Performance Target

Office – 10 Storeys	Office – 3 Storeys – where different
BCA 2010	BCA 2010
Appliances 15 W/m²	
Electric DHW	
VAV with Economy cycle	CAV with Economy cycle
BCA-40%	BCA-40%
HVAC "VAV paradigm"	
HVAC IPLV on Cooling 8.0 / Heating 4.0	Dry condensers (IPLV 6.0 / 3.0)
Infiltration down to 0.5 l/s per m²	
6.0 W/m² lighting levels – managed average	
Extra insulation, solar absorptance of walls (0.5) and roof (0.4)	BCA + 50% increase in R-value of installed insulation but with little increase in wall thickness (from mineral wool to EPS foam)
Improved fenestration (U-value 2.2; 1.5 in climates 6 and 7)	Reorientation trialled in CZ1 and CZ7.
Lifts with regenerative braking	
Heat or enthalpy reclaims ventilation (70%)	
Occupancy driven ventilation rates (CO_2 sensors)	
Condensing boilers for DHW	

Table 3.3 (cont.): Office Building Improvements by Performance Target

Office – 10 Storeys	Office – 3 Storeys – where different
BCA-70%	BCA-70%
4.5 W/m² lighting levels – managed average	Task lighting with daylight dimming
VRV Systems – Darwin, Radiant Systems elsewhere	
Cogeneration (cold climates only)	Nil cogen
Advanced fenestration (U-value 1.5, all climates, SHGC to suit climate)	Shading with clear glass trialled in CZ1.
Preheating of DHW (cogen or solar)	
Photo-voltaic utilisation of roof as necessary	
	BCA + 100% increase in R-value of installed insulation but with little increase in wall thickness (from mineral wool to PIR foam)
BCA-100%	BCA-100%
Improved internal equipment – 10W/m^2	Skylights for top floor
Heat or enthalpy reclaim ventilation (80%)	
DHW ex HVAC condenser (BCA1, 2) or Trigen.	
Appliances 10 W/m²	
Cutting-edge fenestration (U-value 1.5 and electrochromically switchable SHGC, all climates)	
Maximum utilisation of photo-voltaic systems	
Trigen	Nil cogen
Untried	Reasons
Hybrid HVAC	Sensitive to occupant behaviours
Exposed thermal mass	Aesthetic and acoustic penalty
Indirect evaporative cooling	Perceived Legionnaires' Disease risk
GSHP	Results and costs are site specific
Bigger ducts and smaller fans	Impact on overall height (wall area) and cost

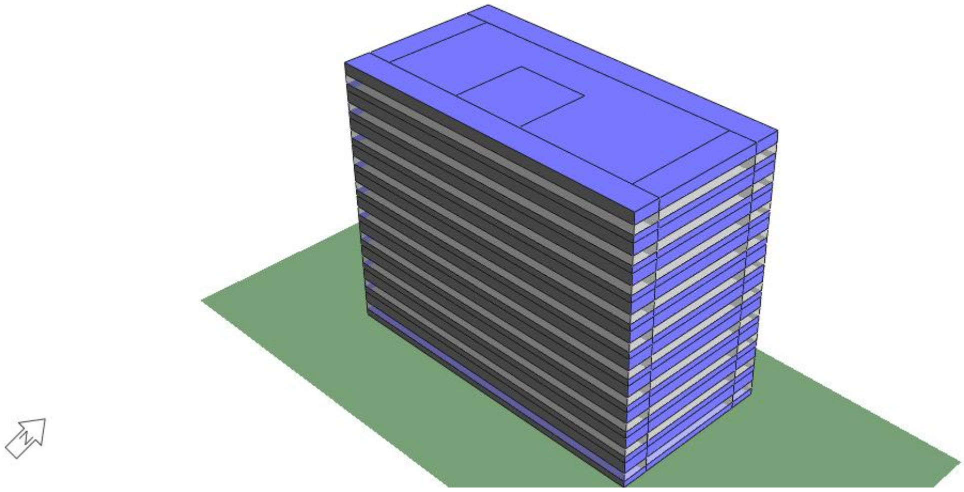
Source: Energy Partners and Engineering Solutions Tasmania

Healthcare Facility

The healthcare facility depicted in Figure 3.8 below is similar to the office building in size but reflects the greater importance of external views for patient care. It therefore has a 2:1 aspect ratio compared with unity for the office building. It also has 10 storeys of 1,000m^2 each with a total NLA of 9,000m^2, which is to say that 10% of the area is services and common areas.

When compared to offices, healthcare facilities are more diverse in their operation and more difficult to typify. The approach of this modelling has been to capture two main aspects of healthcare building usage, firstly the ward type environment and secondly, the intensive treatment environment. This has been performed by defining ward areas on all the perimeters and treatment areas in the centre zone. Both ward and treatment areas operate 24 hours, 7 days per week.

Figure 3.8: Healthcare Facility Schematic



Source: Engineering Solutions Tasmania

Table 3.4 below provides an overview of the treatments deployed in the healthcare facility to improve its energy performance, with the 10 storey office building treatments provided for reference. The treatments for both buildings are identical unless specified otherwise.

Table 3.4: Energy Performance Enhancements by Performance Target: 10-Storey Office and Health Buildings

Office – 10 Storeys	Health – where different
BCA 2010	BCA 2010
Appliances 15 W/m²	Appliances 20 W/m²
Electric DHW	Gas DHW
BCA-40%	BCA-40%
HVAC "VAV paradigm"	
HVAC IPLV on Cooling 8.0 / Heating 4.0	
Infiltration down to 0.5 l/s per m^2	
6.0 W/m² lighting levels – managed average	
Extra insulation, shading, solar absorptance	
Lifts with regenerative braking	
Heat or enthalpy reclaim ventilation (70%)	
Economy cycle and night purge	
Occupancy driven vent'n rates (CO_2 sensors)	
Condensing boilers for DHW	Preheat of DHW with HVAC Condenser

Table 3.4 (cont.): Energy Performance Enhancements by Performance Target: 10-Storey Office and Health Buildings

Office – 10 Storeys	Health – where different
BCA-70%	BCA-70%
4.5 W/m² lighting levels – managed average	
VRV Systems – Darwin, Radiant Systems elsewhere	
Cogeneration (cold climates only)	Trigeneration
Advanced and cutting edge fenestration	
Preheating of DHW (cogen or solar)	
Photo-voltaic Utilisation of roof as necessary	
Fenestration U value 2.2	
BCA-100%	BCA-100%
Improved internal equipment – 10W/m²	
Heat or enthalpy reclaim ventilation (80%)	
DHW ex HVAC condenser (BCA1, 2) or Trigen.	
Appliances 10 W/m²	Appliances 15 W/m²
Fenestration U value 1.5 and switchable SHGC	
Maximum utilisation of photo-voltaic systems	
Trigen	

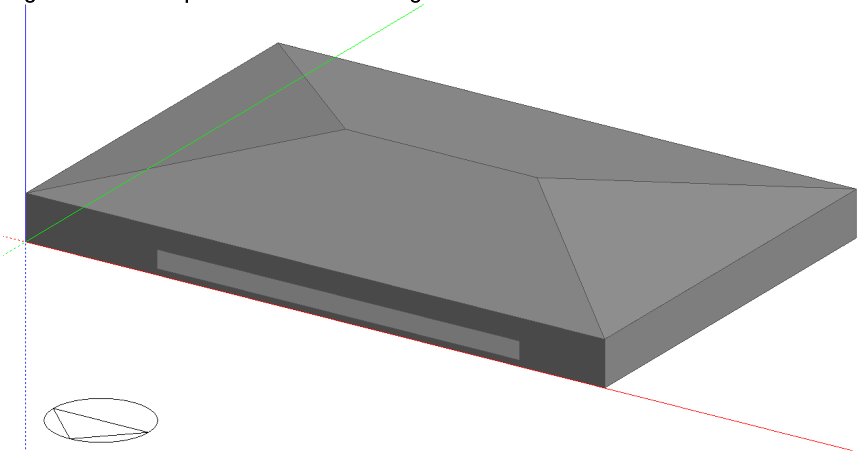
Source: Engineering Solutions Tasmania

Supermarket

The supermarket building selected for this study is intended to be a typical suburban or regional centre, stand-alone supermarket (see Figure 3.9 below). It has a NLA of 4,061 sqm. It has a steel outer skin with glass fibre quilting and building foil as a conventional BCA2010 solution. It has a large, north-facing roof area (1399 sqm) with a 10 degree slope, which provides for a large area of PV to be deployed. The building is all-electric and space cooling dominates energy use. A ducted direct expansion heat pump Constant Air Volume HVAC system is used in the BCA2010 solution. Space heating is limited and confined to cooler climate zones. While plug loads, not regulated by the BCA, are only explicitly included in the -100% solution, the energy consumption of refrigerated cabinets is carefully modelled given their importance, along with lighting systems, in creating cooling loads in this building type (at the same time, these heat sources are also why limited space heating is required, even in cooler climates). Walk-in cool room and zoning assumptions are also specified. Technical details are provided in Appendix 4.

The energy improvement measures for the supermarket are summarised in Table 3.5 below, using the 3-Storey Office for comparison purposes. The treatments for both buildings are identical unless specified otherwise.

Figure 3.9: Supermarket Building



Source: Energy Partners

Table 3.5: Supermarket and 3-Storey Office Improvement Measures by Performance Target

Office – 3 Storeys	Supermarket – where different
BCA 2010	BCA 2010
Appliances 15 W/m²	Refrigeration Cabinets to MEPS
Electric DHW	
CAV with Economy cycle	CAV with Economy cycle
BCA-40%	BCA-40%
HVAC "VAV paradigm"	CAV
HVAC Dry condensers (IPLV C6.0 / H3.0)	
Infiltration down to 0.5 l/s per m^2	
6.0 W/m² lighting levels – managed average	Schedule as above -25%
Solar absorptance of walls (0.5) and roof (0.4)	
BCA + 50% increase in R-value of installed insulation but with little increase in wall thickness (from mineral wool to EPS foam)	Cold and Freezer Rooms insulated as per schedule
Improved fenestration (U-value 2.2; 1.5 in climates 6 and 7)	
Reorientation trialled in CZ1 and CZ7.	Trial also of SHGC=0.3 (advertising posters)
Lifts with regenerative braking	NA
Heat or enthalpy reclaim ventilation (70%)	
Occupancy driven vent'n rates (CO_2 sensors)	
Condensing boilers for DHW	
	Refrigeration Cabinets to HEPS
BCA-70%	BCA-70%
4.5 W/m² lighting levels – managed average Task lighting with daylight dimming	Schedule as above -50%
VRV Systems – Darwin, Radiant Systems elsewhere	CAV with IPLV C7.0 / H3.5
Cogeneration (cold climates only)	No cogen
Advanced fenestration (U-value 1.5, all climates, SHGC to suit climate) Shading with clear glass trialled in CZ1	
Preheating of DHW (cogen or solar)	
Photo-voltaic Utilisation of roof as necessary	
BCA + 100% increase in R-value of installed insulation but with little increase in wall thickness (from mineral wool to PIR foam)	
	Refrigeration Cabinets to HEPS

Table 3.5 (cont.): Supermarket Improvement Measures by Performance Target

Office – 3 Storeys	Supermarket – where different
BCA-100%	BCA-100%
Improved internal equipment – 10W/m^2	Refrigeration Cabinets to HEPS with selective heat sink to ambient
Skylights for top floor	
Heat or enthalpy reclaim ventilation (80%)	
DHW ex HVAC condenser (BCA1, 2) or Trigen.	Solar DHW
Appliances 10 W/m²	
Cutting-edge fenestration (U-value 1.5 and electrochromically switchable SHGC, all climates)	Retain Advanced fenestration (U-value 1.5, all climates, SHGC to suit climate)
Maximum utilisation of photo-voltaic systems	Required utilisation of photo-voltaic systems
Trigen	No trigen

Source: Energy Partners

3.3 Cost Estimation

An independent quantity surveyor, Davis Langdon[13], was retained to provide robust estimates of the costs associated with achieving the different energy performance levels for each building type and climate zone studied (see separate Technical Appendices document- Appendix 7). Their approach was to model the costs of each building on the basis of the materials or elements specified by the building modellers[14] as being necessary to achieve the required performance levels at least cost, in exactly the same way as would occur if the building was being commissioned for construction by a commercial client. Costs are reported in absolute terms, as rates and quantities for different categories of elements, and as costs per m^2 of building. Regional variations in the costs of plant and materials, as well as climate zone based variations in the building specifications, were taken into account.

This analysis generated, firstly, robust estimates of the total costs of each building type in each climate zone as specified to comply with the BCA2010 Base Case (noting that this version of the Code is not yet in force for all building types in all states/territories). Secondly, 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.

In practice, different approaches were taken for commercial and residential buildings, reflecting the different models used for the two sectors. For commercial buildings, the total costs associated with each building type, climate zone and performance level were calculated by Davis Langdon on an 'elemental' basis, following the building specifications provided to them by the building modellers. The cost optimisation of the commercial buildings was left primarily to the judgement of the building modellers, albeit with input from Davis Langdon. pitt&sherry then calculated the *incremental* or additional costs of each scenario relative to the BCA2010 Base Case, as an input into the benefit cost analysis. For the residential buildings, Davis Langdon provided the elemental costs to Energy Efficient Strategies, as the model developed by that firm uses 'rates' or elemental costs as a way of selecting least cost improvements to the building shell and fixed appliances.

The key rates or elemental costs used are set out in Appendix 3 for residential buildings and Appendix 4 for commercial buildings.

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[13] An AECOM company.

[14] *Energy Partners, Energy Efficient Strategies* and *Engineering Solutions Tasmania*

Photovoltaics (PV)

PV system output (yield) and cost data was provided by Dr Mark Snow. PV modules can be rack mounted on the roof, integrated as part of building's roof system, or incorporated into a building's façade. For the purposes of determining a system's output and its cost, it was assumed that residential buildings would use standard PV modules mounted on the roof top, which is currently the most common method of installation.

Using current technology, the area required for 1kWpeak mono-crystalline module (m-Si) system with 15% efficiency is 7m². However, module efficiency is expected to improve in the future, thus reducing the area required for a 1kWp system over time. To calculate the energy savings and benefit-cost ratios for PV systems in each of the modeled climate zones, the output of a 1kWp system in each of the capital cities was needed. Outputs assuming differing tilts of 0 degrees, 22.5 degrees and 90 degrees were included, with 22.5°being modeled as close to (but not exactly) optimal in all capital cities. Table 3.6 below shows the annual output of a 1kWp system in MJ per year in each capital city with a 22.5 degree tilt.

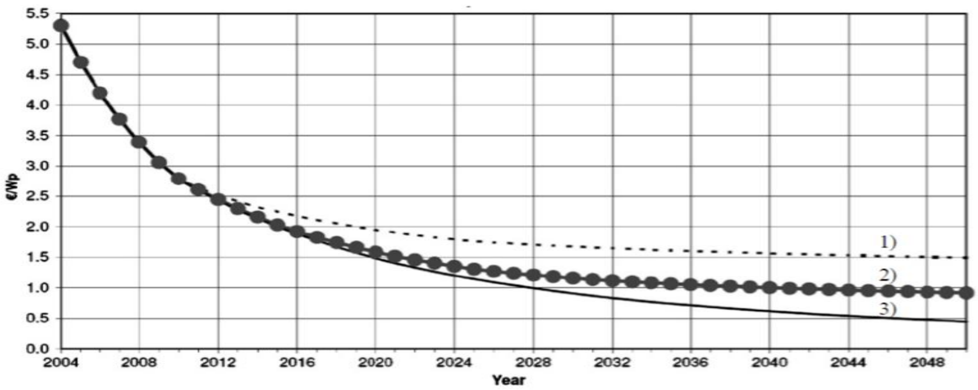
Table 3.6: PV Yield by Location

Latitude	LOCATION	Est. Yield - tilt 22.5^0
		MJ/yr
-42.50	Hobart	5,036
-37.49	Melbourne	5,137
-35.34	Canberra	5,180
-34.52	Adelaide	5,854
-33.52	Sydney	5,418
-31.57	Perth	6,401
-27.51	Brisbane	5,555
-12.24	Darwin	6,566

Source: Dr Mark Snow

In Australia, the current price range of standard PV modules varies between $800-900/m². For the purposes of costing, an average price (for residential systems) of $850/m² was assumed. On this basis, the 2010 price of a 1kWp system is $5,950. However, it should be noted that the cost of PV systems is predicted to fall appreciably in the future as technology improves and their uptake increases. Figure 3.10 below shows the expected reduction in capital cost of building integrated PV (BiPV) systems under three scenarios, with a fall of 40% between 2012 and 2024 in the median value. Even the more pessimistic scenario shows a marked fall in cost.

Figure 3.10: Projected Reductions in Building Integrated PV Systems to 2050



Source: L Raugei et al (2009). Notes: Scenario 1 'pessimistic'; Scenario 2 'optimistic/realistic'; Scenario 3: 'optimistic/technology breakthrough'.

We note that the installed capacity of photovoltaics globally has grown at rate of 40% per year over the last decade. As the industry has grown, PV module prices have declined along a well established learning curve, which has seen cost reductions of 22% for each doubling of cumulative capacity, over the last few decades. The International Energy Agency (IEA) and the European Photovoltaic Industry Association (EPIA) expect further cost reduction with increased production capacities, improved supply chains and economies of scale. China has experienced a 20-fold increase in production capacity in four years, increased expansion of global production capacities for key components (including modules and inverters) and is continuing to exert downwards pressure on prices. A surge in silicon production capacity (a key commodity) has both alleviated supply constraints, and continued to increase. Technological cost reduction opportunities include improvements in efficiency for the different cell types. Based on these drivers, the IEA and EPIA have made cost projections using learning rates of 18%, slightly lower than the historical average of 22% (Hearps & McConnell 2011, p, 2).

Based on scenario 3 of Figure 3.10 above, Table 3.7 below shows the predicted fall in cost of a 1kWp system in Australia from 2010 to 2020, for residential applications. By 2020 its cost is expected to have fallen by about 50%.

Table 3.7 – Cost of 1kWp system (standard PV modules) 2010-2020

	2010	2015	2020
Turnkey price (AU$/kWp)	AU$/kWp	AU$/kWp	AU$/kWp
Standard PV modules	$5,950	$4,400	$2,990

Source: Dr Mark Snow

The PV cost for commercial buildings was assumed to be $9,240 a kWp system at 2015, with learning rates, where applicable, applying thereafter. Note PV cost is greater than it is for residential buildings. This is because, when compared to residential PV systems, a far greater proportion of the total cost of commercial PV systems is made up by costs associated with installation and fixings. However, these costs are assumed to fall over time.

3.4 Benefit Cost Analysis

3.4.1 Target Metrics

When considering the energy and greenhouse performance of buildings and how these may change over time, the outcomes may be different depending upon whether energy performance or greenhouse performance is taken as the primary target. As an example, if greenhouse savings were targeted, space or water heating by natural gas (or solar energy) would generally be preferred over electrical space or water heating, as the greenhouse gas intensity of gas is lower than for electricity on average in Australia. However, if energy savings are targeted, a high-efficiency heat pump might be preferred for space or water heating, as these may produce three or four times the amount of useful energy as they consume in electrical energy. Depending upon the greenhouse intensity of that electricity, however, absolute greenhouse gas emissions may still be higher than the alternative solution.

In consultation with the Department, energy was selected as the target metric for this study. The reasons for this include the fact that it is energy that is priced and therefore defines the value of savings that may be available, while the value of greenhouse gas emissions is represented, in the Base Case and Scenario 2, as a carbon price on top of the energy price. Secondly, it is the case that the greenhouse intensity of electricity in particular firstly varies greatly by jurisdiction, and that it is expected to change considerably through time, as discussed in Section 3.4.5 below. Thus the realised performance of a building constructed with greenhouse savings as the target would also vary from place to place and from time to time. This effect is overcome by using energy as a metric, although it is still necessary to take into account jurisdictional variations in both energy prices (see Section 3.4.4) and – to the extent feasible – in greenhouse gas intensity of electricity supply (Section 3.4.5).

3.4.2 Energy Savings

The benefit cost analysis considers 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[15]. Separate calculations are made for each scenario, building type, climate zone and performance level (over 3000 permutations including sensitivity analysis), from 2015 (the first year in which savings are assumed, due to application of higher building energy performance standards) through to 2060.

The energy savings are measured in MJ/m^2.a for commercial buildings and MJ/dwelling.a for residential buildings. Electricity and gas are treated separately, and use of minor fuels (e.g., wood, LPG) is also measured for residential buildings and is taken into account in the benefit cost analysis. Electricity and gas price assumptions, along with carbon price assumptions, are described below. All prices and costs are represented as *real* 2010 prices, so that the effect of inflation is excluded.

Since our terms of reference require consideration of buildings that use 40%, 70% and 100% less energy than BCA2010, the targeted levels of energy savings are largely given. However, it should be noted that the building simulations described in the appendices have to deal with real world considerations, such as the sizing of plant (like trigeneration units or photovoltaic arrays) which are 'lumpy' investments and not infinitely scalable. Therefore certain buildings as modelled achieve somewhat more or less energy savings than those targeted. However, since each building is costed 'as built', the parallelism between costs and benefits is preserved and therefore no changes to break-even points arise because of this effect[16].

Relatedly, and as described in the appendices for the commercial buildings, these buildings were modelled to achieve the required 40%, 70% and 100% energy savings levels on the basis of an 'electricity equivalence' approach for natural gas. This approach treats one unit of gas as equivalent to 1/3 of a unit of electricity on the basis that gas is a primary fuel, while electricity is a secondary energy source which, on average, is generated in Australia with around 33% conversion efficiency from primary fuels. However, for the purposes of benefit cost analysis, we must take into account the actual cost of the fuels consumed in the building, as these define the value of savings that may be captured by the building owner/occupier. Therefore for the benefit cost analysis, the natural gas consumption is converted back into the actual number of MJ consumed, and this has the effect of changing somewhat the realised performance levels from those targeted on an electricity equivalent basis. As noted above, however, this effect does not change the break even or benefit cost analysis: the costs and benefits associated with the buildings are treated equally regardless of the performance level achieved.

Finally, it should be recalled that the energy costs considered for these buildings exclude those costs associated with internal appliances and equipment that are not currently regulated by the BCA. (Cooking energy is also not regulated by the BCA). This is commonly referred to as 'plug load', as it refers to the (generally electrical) load of devices that are plugged into power points in the buildings. The exception to this rule is the -100% or 'zero net energy' buildings, where the terms of reference require us to include plug load and cooking energy. This has the effect of increasing the incremental costs of this solution, when compared to the other performance levels targeted, as the PV system or other plant

[15] 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.
[16] Technically, this is confirmed in the linear BCR functions described below with high r^2 values.

(such as co- or trigeneration) has to be sized to also cover this plug load. While this lack of parallelism is not likely to introduce significant errors, as it is restricted to the BCA2010 - 100% scenario only, it is noted in Chapter 6 as one of the factors that could be further examined. If plug load were not included at this performance level, the incremental cost of achieving it would be lower, and may increase somewhat the level of energy savings that is cost effective.

3.4.3 Discount Rates

The value of energy savings in the future, and indeed of incremental costs as discussed below, are discounted back to a present value. The primary rationale for discounting is the observation that people display 'time preference'; that is, a dollar today (of benefit or cost) tends to be valued more highly than a dollar in the future. This effect is reinforced by the 'opportunity cost of money', which in effect is defined by the real interest rate. That is, one can choose to spend a dollar today or next year, but the value of the dollar next year is increased by the real interest rate available. In effect, the real interest rate represents the amount that must be offered to induce someone to defer the value of present consumption. In this way, the real interest rate is taken as a working proxy for the time value of money.

The Office of Best Practice Regulation requires a 7% real interest rate to be used for present value calculations. Energy savings at break-even and at 40%, 70% and 100% have been calculated using a 7% discount rate. It may be noted that this is considerably higher than current real interest rates in Australia. At the lower discount rate, the present value of future benefits and costs is weighted more highly. At the higher discount rate, the present value of future benefits and costs has a smaller weighting.

In addition to a discount rate of 7%, the sensitivity analyses (Scenarios 1 and 2) test the results at a 5% discount rate. The effect of these choices is to change the present value of costs or benefits that arise in the more distant future when compared to those that arise today or in the near future. Since most investments, including in building energy savings and greenhouse gas abatement, require an additional up-front capital cost to be incurred, which then generates a stream of energy savings through time, the higher discount rate reduces the present value of this investment as compared to the lower discount rate. The results reported in Appendix 5-Sensitivity Analyses, clearly display this pattern. At the same time, those energy savings scenarios reported that have a benefit cost ratio of greater than 1 at a 7% real discount rate can be considered to be more robust and secure financial investments than those which only achieve that level with a real discount rate of 5%.

3.4.4 Energy and Carbon Prices

Estimates were prepared of prospective consumer prices for electricity and natural gas in each city out to 2060. All prices are real 2012 prices. While electricity and natural gas are by a wide margin the two most important sources of energy used in residential and commercial buildings, minor contributions are made by other fuels, including LPG, diesel oil, black coal, brown coal briquettes, and fuel wood. According to the most recent data in ABARE's *Australian Energy Statistics*, these fuels provided about 15% of energy used in the Commercial, Services and Residential sectors of the economy, of which residential use of fuel wood was the largest part (8%). EES price projections for the minor fuels were used.

Electricity prices - residential

Prices for electricity have been constructed as the sum of major cost components, comprising wholesale costs, network (transmission and distribution) cost, retail operating costs, and retail margin. The starting point for estimating residential prices in all cities except Melbourne is the energy component of published maximum or default tariffs, as at June 2010, i.e. prior to price increases effective 1 July in a number of States, as set by the relevant regulatory agency or process in each State and Territory[17]. In Melbourne, the initial price is the approximate average of AGL's published standing offer prices in each network region within the Melbourne metropolitan area. The fixed or standing charge component of total annual residential supply costs is ignored, meaning that the prices used are slightly lower than full average costs per kWh (though more representative of marginal costs). However, since the fixed component accounts for only a small proportion of total annual costs, this is not a great distortion.

Price component shares for Sydney, Brisbane, Adelaide, Hobart and Canberra are from AER (2010), plus a variety of individual AER network price determination reports, as are the trends in the network cost component out to 2014 or 2015 for these cities plus Melbourne. The latter figures have been supplemented by more recent estimates of network cost increases provided by ACIL Tasman in its peer review report. Over the longer term, real network costs are 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 retail margin is calculated as a percentage of wholesale plus retail operating costs and the percentage itself is similarly assumed to be constant, though the percentage itself varies between cities.

The wholesale cost component is calculated as the sum of two sub-components. The lesser sub-component is costs other than the direct cost of purchased electricity; it includes various ancillary services and costs associated with wholesale trading. For each city, this was calculated from the various State and Territory cost breakdowns described above. It was assumed to remain constant in real terms for the whole projection period. An adjustment was made to the original estimate for Brisbane, on the basis of information provided by ACIL Tasman.

The major sub-component is the average pool price of sent out cost of electricity generated. This report uses the values for “average wholesale electricity price” published by Treasury (2011) as part of its economic modelling of the Clean Energy Future legislative package. Five separate policy scenarios were modelled and for each the tabulated values supporting Chart 5.27 of Treasury’s report provides a single national figure for each year out to 2050 under five policy scenarios. Three of the five scenarios were used as the bases for the three energy cost scenarios used in this study. For Scenario 1, which has no carbon price, Treasury’s “Global action” scenario was used, while the Base Case Scenario and Scenario 2 are based respectively on the “Government policy” and “High price” scenarios in the Treasury modelling. Government policy is effectively the provisions of Clean Energy Future, while High price corresponds to policies, including a much higher carbon price, consistent with achieving national emissions reductions of 25% by 2020 (compared with 5% for the Government policy scenario).

Separate prices are not provided for the separate grid systems (the National Electricity Market (NEM), the two systems in WA and the NT), or for the separate State market regions within the NEM. At present there is some variation in wholesale prices between regions within the NEM and between the NEM and the separate WA and NT systems, though these are not large relative to the total delivered price of electricity. The introduction of a carbon price will initially cause further differences to emerge, caused by differences in the mix in generation types between regions and systems. However, in the absence of any basis for projecting separate State emission intensity values, the single national figure is used for all NEM States. This is consistent with an assumption that the marginal kWh saved is one which may be sourced from anywhere in the NEM. In the case of WA, its mix of generating plant in 2009 was not greatly different from a notional national average, and neither was the estimated wholesale cost. It is therefore reasonable to use the weighted average national value for WA also.

[17] Note that for this Final Report, all prices were updated in late 2011 and represent 2011-12 real prices, as described later in this Section.

The use of published default or standing offer prices is likely to over-state prices paid by consumers who take advantage of individual contract prices which are available in cities with significant levels of retail competition. These include Sydney, Melbourne, Brisbane, Adelaide and Canberra. Following the suggestion of ACIL Tasman, a 5% discount has been applied to the wholesale cost component in the respective cost build-ups.

Electricity prices - commercial

While regulated and/or published default tariff prices provide a sound starting point for projecting future residential prices, there is no such basis for commercial prices. Many retailers publish default or standing offer prices for small business, which are invariably slightly higher than residential prices. Larger commercial consumers, on the other hand buy at individual contract prices. All that is known about the price aspects of such contracts is that the overall level is lower than that of residential prices and that they include both an energy component and a power component; the latter is normally a price per maximum monthly load (in MVA) and typically accounts for a non-negligible part of the total cost of electricity.

In the absence of better information about typical or average commercial electricity prices, and having regard to the wide range of building sizes and types to which the BCA applies, it has been decided to use, for the assessment of commercial building energy efficiency measures, an average price which is slightly lower than the residential price. This was done by using the same wholesale cost component as for residential, but setting the network and retail operating cost components at 90% of the residential level. As for residential, prices are expressed in terms of energy only, i.e. as $ per MWh. This approach implicitly assumes that, in the case of consumers paying on the basis of both energy and peak load, any energy efficiency improvement undertaken reduces both energy consumption and peak load in the same proportion. This is a broad generalisation, which will not be correct for every efficiency measure, but is a necessary approach, in default of detailed analysis of every individual measure and better knowledge of the structure of actual contract prices.

Natural gas prices

The approach used to construct projected natural gas prices was similar to that used for electricity. The major cost components for natural gas prices are wholesale costs (including carbon price costs if applicable), network (transmission and distribution) cost, retail operating costs, and retail margin. Only two jurisdictions, NSW and SA, regulate maximum residential gas prices; these regulated prices, as at June 2010, were used as the starting point for estimating residential prices in Sydney and Adelaide[18]. For Melbourne and Brisbane the initial price is the approximate average of AGL's published standing offer prices in a representative sample of locations in each city, covering each network region within the respective metropolitan areas. In Perth, Canberra and Hobart, published default prices of the sole or dominant gas retailer in each city are used. There is no general reticulated supply of natural gas in Darwin.

Price component shares for Sydney and Adelaide are from AER (2010). For other cities the various components were directly estimated, applying professional judgement to data gathered from a variety of sources. Various individual AER network price determination reports provided guidance on the size and trend in network costs over the next few years in Sydney, Brisbane, Adelaide and Canberra. Thereafter, network costs are assumed to increase by 1% per year until 2030 and then remain constant.

Estimates of wholesale costs draw on various AER documents and other sources. In completing this report, advantage was taken of the recommendations regarding current wellhead gas prices in the peer review report by ACIL Tasman. It should be noted that wholesale costs vary considerably between cities, but it is assumed that there will be a general convergence towards export parity netback levels, as the gas markets of eastern

[18] As with electricity prices, gas prices were updated for this Final Report in late 2011 and may be taken as 2011-12 real prices.

Australia become increasingly strongly inter-connected and LNG export projects come on stream in Queensland. Over the longer term, rapidly growing demand for natural gas for electricity generation is expected to place steady upward pressure on wholesale costs for gas.

These trends were accommodating by setting wholesale prices in each city to converge towards a projected export netback level by 2020. This level was defined to be $7.5/GJ in Perth, $7.0/GJ in Brisbane, $6.5/GJ in Sydney, Adelaide and Canberra, and $6.0/GJ in Melbourne and Hobart. Thereafter, wholesale prices were projected to increase at a constant slow rate throughout the projection period.

Retail operating costs and retail margin were estimated in similar way to that used for the corresponding components of electricity costs. The same three carbon price cases were used as for electricity, taken for Chart 5.1 of Treasury (2011), and an emissions intensity value of 51.3 t CO_2-e per TJ was used for every city for greenhouse intensity. A multiplier of 1.1 was applied to the calculation of direct carbon price cost, to allow for gas used in processing, transmission and distribution.

The overall outcome is that natural gas prices are projected to increase steadily throughout the projection period, but more slowly than electricity prices.

3.4.5 Emissions Intensity of Electricity Supply

In order to convert a carbon price into a component of the cost of delivered electricity, it is necessary to know the emissions intensity of electricity. DCCEE provided projections of the emissions intensity of electricity supplied, including the effect of the Large Renewable Energy Target scheme, but without a carbon price. Up to 2030 two separate sets were provided, one for the NEM, applicable to Sydney, Melbourne, Brisbane, Adelaide, Canberra and Hobart, and a second combined one for the South West Interconnected system, covering Perth, and the Darwin-Katherine System, covering Darwin. From 2030 onward only a single national average data set was provided. Pro-rating assumptions were made to convert this data set into extensions of the two separate sets described above.

Since the modelling results provided by DCCEE are for the without carbon price case, they could not be used for this purpose for the other two cases. In the absence of more recent data, the intensity figures for two of the Treasury CPRS modelling cases were used. To 2040 the emissions price in the High scenario is very similar to the emissions price modelled by Treasury for the CPRS-15 case. The price in the Low scenario is very similar to the Treasury CPRS-5. This relationship implies that it would be appropriate to use the Treasury emissions intensity of sent out electricity (called emissions intensity of generation but clearly, in fact, sent out intensity) as the emissions intensity for the two cases. As it happens, the Treasury modelling results show virtually identical grid emissions intensity in the two cases, with the intensity for the CPRS-5 scenario actually slightly lower in most years. We have therefore taken the Treasury CPRS-5 emissions intensity of electricity sent out as the basis for emissions intensity in both Low and High cases.

In summary, the greenhouse intensity of the NEM is assumed to fall from around 895 t CO2-e/GWh in 2011 to 687 t CO2-e/GWh in 2030, and to just 170 t CO2-e/GWh in 2060. This trend indicates a declining greenhouse 'dividend' per unit of electricity saving through time. In the NT and WA, the equivalent values for the same time periods are assumed to be 575, 402 and 157 t CO2-e/GWh respectively.

3.4.6 Learning Rates

Learning rates refer to the rate of reduction in incremental costs through time, consequent upon at least two factors: first, innovation in designs, methods, tools, techniques and know-how; and second, reductions in the unit costs of components, particularly those induced by the measure (for example, regulation may lead to increased economies of scale or induce innovation in the supply chain). Learning rates (sometimes referred to as 'experience curves') were discussed in greater detail in pitt&sherry (2010).

In short, significant reductions in the cost of technology are likely to occur over time and, because of this, current cost effectiveness is no guide to future cost effectiveness (Hinnells 2005). In the UK, it has been suggested (Boardman 2005) that houses could reduce their CO2-e by 60% by 2050 (The 40% House). The economic feasibility of achieving such a reduction has been contentious, however. Hinnells (2005) believes that experience curves as well as energy price scenarios bring the payback of measures down to reasonable levels, thus making the scenario plausible. Experience curves applied to the 40% House scenarios show many new technologies falling to a fraction of their current price. The consequent change in capital costs for measures for the 40% House as a result of learning is shown in Table 3.8 below. As noted in pitt&sherry (2010), we are unaware of similar studies in the Australian building industry.

Table 3.8: Learning Rates: UK '40% House'

	Solar Hot water	LED Lighting	New insulation material	PV
Current cost	£3250	£20	£10000	£12600
2050 expected cost	£2328	£5	£2634	£642

Source: Boardman (2005)

In regard to improving the energy efficiency of housing, experience curves have been demonstrated with progress ratios of 80-85% for a range of technologies including PV and insulation. A progress ratio of 80-85% indicates that with every doubling of a measure's uptake, its cost decreases to 80-85% of former levels. In the UK, Shorrock (cited in Hinnells, 2005) describing reductions in the cost of insulation as a result of Government programs, estimated a progress ratio of around 88% for insulation. Similarly, Jakob and Madlener (2003) found a progress ratio for wall insulation of between 82% and 85% based on Swiss data.

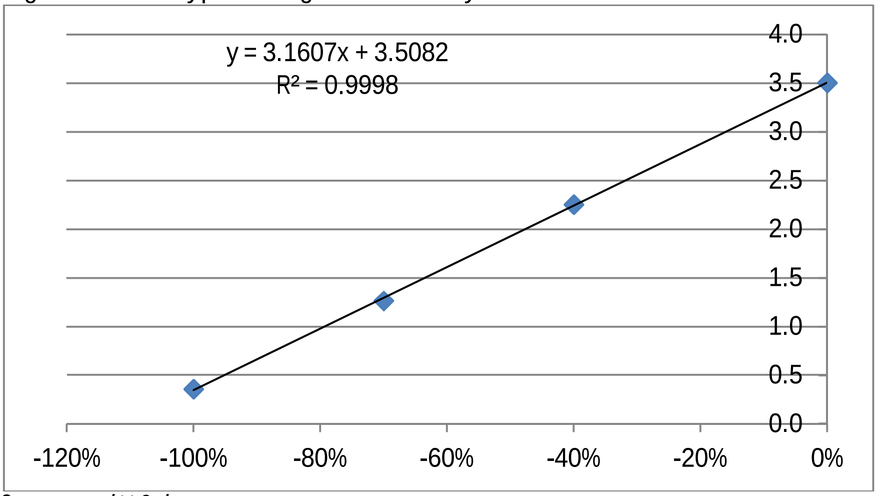
For this study, and pending specific quantitative analysis of actual learning rates in the Australian building industry, our Base Case scenario assumes a learning rate of 30% (that is, a 30% reduction in incremental compliance costs over ten years), with 0% in Scenario 1 and 50% in Scenario 2, for all building types. We note that learning rates in this study are assumed to be linear; that is, cost reductions are assumed to occur evenly through time. We consider these assumptions to be conservative, as the references reviewed in the *Indicative Stringency Study* tended to show rapid learning in the initial years, with either a small 'tail' of incremental cost persisting for some time or, depending upon on technology, zero incremental costs after as little as 3 – 5 years. However, our view is that strong assumptions should not be made in this area until detailed quantitative analysis of historical learning rates in the Australian building industry is undertaken.

3.4.7 Regression and Break Even Analysis

The benefit cost analysis described above has two key objects: first, to describe the ratio of the present value of benefits to the present value of costs (benefit cost ratio or BCR) for each building type, climate zone and performance level, for 2015 and 2020, and for each policy scenario; and second, to calculate the breakeven level of energy performance (percentage of energy savings compared to BCA2010), where the BCR = 1.

Again, differences in structure of the residential and commercial building models used required different approaches to these tasks. For the commercial buildings, benefit cost ratios were calculated for each of the -40%, -70% and -100% performance levels (by building type, scenario and climate zone) and then plotted in XY space to enable regression analysis to establish the function that described these data points. Simple linear equations (of the form y = ax +/- b, where a is the slope and b the intercept) described these functions very well, with r^2 values (a measure of data dispersion) of .98 or more. An example is shown in Figure 3.11 below.

Figure 3.11: Typical Regression Analysis



Source: pitt&sherry

For residential buildings (for each climate zone and for each scenario), the energy savings from thermal shell improvements (in 0.1 star increments) were combined with the different energy saving levels available from improvements in lighting, water heating and pool pumping/heating (fixed appliances), as well as from PV, into a list that sorted each measure in order of cost effectiveness. Measures with a break-even point of 1 or slightly above were then added together. The -40%, -70% and -100% scenarios were then analysed by deploying further treatments, again in order of cost effectiveness but with increasingly smaller benefit cost ratios, until the targeted performance level was reached.

Note that, as described in Chapter 4 below, as soon as PV systems become cost effective in their own right - as a function of their own cost, the cost of energy/carbon and the climate zone in which they are deployed - then the break even energy savings point for the entire building may reach -100%, as any level of (residual) energy demand may be able to covered cost effectively by the PV system. This effect would only be limited in the presence of physical constraints, such as limitations on the area of north-facing roof/facade space, and the capital cost. With higher thermal shell performance and more efficient fixed appliances (and plug load), the residual electrical load at high performance levels is generally modest and therefore such physical constraints are less likely to occur for residential buildings and supermarkets than in the case of taller, narrower commercial buildings (where over-shading may also present a greater risk, for example in central business districts).

3.4.8 Weightings

For residential buildings, the break even energy savings for the thermal shell were calculated separately for each building/construction type. The overall breakeven results for each climate zone and scenario were then calculated as the weighted average of the thermal shell improvements by building/construction type, weighted by the prevalence of each building/construction type in the projected stock in that climate zone through time. The cost-effectiveness of fixed appliances was calculated for each climate zone at local prices. Similarly, the cost-effectiveness of PV was calculated for each climate zone on the basis of local solar yields and energy prices. These latter factors – the deployment of fixed appliances and PV - do not affect the *weightings* in the aggregate results reported by scenario and climate zone, as their cost effectiveness is largely independent of the building type.

For commercial buildings, the break even energy savings were calculated on the basis of the weighted average benefit cost ratios at the required performance levels (-40%, -70% and -100%), for each scenario and climate zones, with the weightings attached to each building type reflecting their prevalence in the *national* building stock. This approach was necessitated by the current poor levels of documentation of the commercial building stock in Australia. The distribution of different building types by state is not currently documented in the literature[19]. Using estimates of the national commercial building stock, which are a compilation of a number of sources (see Section 3.4.9 below), we assume a distribution by building type as shown in Table 3.9 below. Since not all of these building types are represented in this study, the weightings used are adjusted to reflect the prevalence of the building types studied as percentage of the portion of the stock covered by this study, rather than as a proportion of the total stock.

Table 3.9: Commercial Building Stock Distribution and Weightings

Building Type	Share of 2011 Total Stock	Weightings Share
Commercial offices less than 2000 sqm GFA	9.8%	13.2%
Commercial offices greater than 2000 sqm GFA	50.5%	68.3%
Supermarkets	4.6%	6.2%
Health facilities	9.1%	12.3%
Other retail	12.6%	0%
Education	13.4%	0%
Totals:	100%	100%

Source: pitt&sherry from various sources
Notes: in line with DEWHA 2009, we assume the share of commercial offices <2000 sqm GFA will grow slowly over time, rising from an assumed 9.8% in 2011 to 10.5% in 2024. As a result, we assume the share of commercial offices >2000 sqm GFA falls to 49.8% in 2024. In weighted terms the share of offices <2000 sqm rises to 14.2% by 2024, while the share of those >2000 sqm falls to 67.3%, in linear steps over the period.

For commercial buildings and in consultation with Department, the 'weighted average' break-even energy savings for all capital cities was calculated using Construction Forecasting Council (CFC) forecasts of the value of commercial building activity. CFC forecasts of annual building activity in all capital cities (except Darwin) are provided for a 10-year period for various commercial building types, including Office and Health and Aged Care. For each state/territory, the forecasts of the value of Office, and Health and Aged Care building activity for 2015 and 2020, together with an estimate for Supermarkets, were aggregated to calculate their respective share of the total value of all capital city building activity of those building types. (An estimate for Supermarkets was based on their national average share of the retail/wholesale sector). These shares were used to calculate the weighted figure for break-even energy savings. CFC forecasts for the NT were used as a proxy for Darwin, which is reasonable given that most construction of the commercial building types covered in this study in the NT will be in Darwin.

3.4.9 Building Stock

The majority of the analysis in this study - including of variables such as energy costs, savings and incremental construction costs - is carried out on the basis of values per metre squared per annum (for commercial buildings) and per dwelling per annum (for residential buildings). This approach has been taken so that the primary results are independent of the future evolution of the building stock, which is currently poorly characterised in Australia, notably for commercial buildings.

Further, the study focuses on two cohorts of buildings, the last of which is assumed to be built during 2020 - 2024. Even though we expect these buildings to stand for 40 years on average, the behaviour of the *whole* building stock past 2024 is not material to this study. Nevertheless, in order to weight the results by building type – at either climate zone or

[19] Note that a project known as the *Commercial Buildings Baseline Study* has been commissioned by DCCEE in 2011 to address this important gap in the knowledge base. This study is expected to be completed in mid-2012.

national level – and also in order to estimate total national energy and greenhouse gas savings – some picture of the building stock and its expected evolution through time is required.

Projections of the increase in residential building stock for each state and territory were undertaken by Energy Efficient Strategies (EES). EES's methodology was based on the one they used for their study, *Energy Use In The Australian Residential Sector 1986-2020*. This involved using ABS data on past building activity in conjunction with many secondary data sources, and basing estimates of new stock on future ABS household projections.

For commercial buildings, we constructed a basic stock model drawing on the Property Council of Australia's Office Market Report, assumptions used for the RIS analysis of BCA2010 by the *Centre for International Economics* (published as ABCB 2009) and the Decision RIS on Mandatory Disclosure of Commercial Office Building Energy Efficiency, prepared by the *Allen Consulting Group* and published as DEWHA (2009). As results are prepared on a per square metre basis, absolute stock characteristics are only required to be estimated for weightings purposes and estimating national energy and greenhouse gas savings.

4. Residential Buildings – Results

The results of the benefit cost analysis are presented first at the most highly aggregated or overview level, by climate zone. A second section examines the results by building type and state in more detail, including cost-effectiveness at the BCA2010 –40%, -70% and -100% levels. Further details of the buildings, technical parameters and energy savings measures may be found in Appendix 3. Section 4.1 below provides background and explanatory material that may assist in the interpretation of the results.

4.1 Key Factors Driving the Results

4.1.1 Energy Prices

Expected residential electricity and gas prices by climate zone are shown in Table 4.1 below. It can be noted that electricity prices are significantly higher than gas prices on a $/GJ basis. This means that solutions that save electricity have greater cost effectiveness (per unit of cost incurred) than solutions that save gas. As a result, those climate zones that use more gas (e.g., Melbourne) tend to report lower cost-effective savings, while those that use more electricity (e.g., Darwin) tend to report higher cost-effective savings, other things being equal.

A second factor, however, is that both electricity and gas prices vary significantly by climate zone. Those climate zones with higher electricity or gas prices tend to show more cost effective savings. These two factors interact so that, for example, Darwin has a high use of electricity (natural gas is not reticulated in Darwin) but a relatively low electricity price. These two effects tend to cancel each other out, leading to modest savings being reported for Darwin residential buildings in Table 4.5 below, for example.

Table 4.1: Expected Gas and Electricity Retail Prices (real 2012 prices) - Residential Sector in 2020, by Climate Zone

	Gas ($/GJ)	Electricity ($/GJ)
Sydney	21.1	60.6
Melbourne	17.6	62.3
Brisbane	31.4	66.7
Adelaide	19.2	78.2
Perth	28.4	70.7
Hobart	26.1	65.4
Darwin	-	54.9
Canberra	23.2	46.9

Source: pitt&sherry

4.1.2 Climate Effects

Table 4.2 below shows, firstly, that houses in the different climate zones covered in this study have widely differing requirements for space conditioning energy, as a function of the severity of the winter and/or summer climates they experience. Brisbane and Perth, for example, are shown as mild climates, with Darwin and Canberra more severe. Generally, since milder climates are using less energy for space conditioning, it is more difficult to identify cost effective opportunities for space conditioning energy savings (i.e., higher star ratings) in those climates.

Second, Table 4.2 also shows that as star ratings increase, the space conditioning energy consumption (in all climates) falls in a non-linear fashion. That is, as higher star ratings are reached, the residual space conditioning energy consumption rapidly declines. Since there is less energy left to save, but the cost of achieving those savings continues to climb (indeed, it climbs more rapidly with increasing star ratings), cost effectiveness rapidly declines as higher and higher star bands are tested. This helps to explain why efficiency improvements in fixed appliances (or domestic services) contribute significantly to the cost effective savings modelled in milder climates, to a greater extent than improvements in thermal shells.

Table 4.2: Residential Space Conditioning Energy Requirements (MJ/m2.a) by Star Band and Climate Zone

	5 star	6 star	7 star	8 star	9 star	10 star
Sydney	112	87	66	44	23	7
Melbourne	165	125	91	58	27	1
Brisbane	55	43	34	25	17	10
Adelaide	125	96	70	46	22	3
Perth	89	70	52	34	17	4
Hobart	202	155	113	71	31	0
Darwin	413	349	285	22	140	119
Canberra	216	165	120	77	35	2

Source: pitt&sherry, based on http://www.nathers.gov.au/about/pubs/starbands.pdf

4.1.3 Composition of the Housing Stock

There are significant differences between climate zones in terms of the distribution of construction types and, to a lesser extent, the prevalence of detached and semi-detached houses and flats. For example, medium-sized detached houses with brick veneer walls and concrete slab on ground (CSOG) represent over 50% of the current housing stock in the ACT and SA, but only 11% in NT and just 6% in WA (see Table 4.3 below). Cavity brick walls feature in over 70% of the housing stock in WA and 40% in NT. These differences affect both the potential for realising energy efficiency gains in the new housing stock and the costs of doing so in particular locations. Further details on these trends may be found in Appendix 3.

Table 4.3: Distribution of Residential Building Types by Location (%)

Building Types	NSW (%)	VIC (%)	QLD (%)	SA (%)	WA (%)	TAS (%)	NT (%)	ACT (%)
Med Detached – BV Walls, CSOG	37	37	40	53	6	31	11	52
Med Detached – BV Walls, Suspended Timber Floor	3	9	3	1	0	8	6	0
Med Detached – Lightweight, Suspended Timber Floor	4	5	6	5	1	13	5	0
Med Detached – Cavity Brick Walls, CSOG	5	4	13	3	57	11	25	0
Large Detached – BV Walls, CSOG	31	15	13	15	1	9	7	26
Large Detached – BV Walls, Suspended Timber Floor	2	3	1	0	0	2	4	0
Large Detached – Lightweight, Suspended Timber Floor	3	2	2	1	0	4	3	0
Large Detached – Cavity Brick Walls, CSOG	4	2	4	1	14	3	15	0
Semi-Detached, BV Walls, CSOG	4	7	6	10	11	7	5	12
Semi-Detached, BV Walls, Suspended Timber Floor	0	2	2	0	1	1	5	0
Mid-Flat – Precast Walls, Concrete Floor	3	7	5	5	4	4	7	5
Mid-Flat – Precast Walls, Concrete Floor	3	7	5	5	4	4	7	5
	100	100	100	100	100	100	100	100

Source: Energy Efficient Strategies

The varying composition of the housing stock is taken into account when weighting results in this Report. The results below for each individual climate zone are the weighted averages of the results for that climate zone of the 12 building types modelled, with weightings for each climate zone based on ABS building stock surveys reflecting the prevalence of each building type in the state stock. Further details can be found in Appendix 3.

The 'weighted average' result at the bottom of each table in Section 4.3 below is an average of the results by climate zone, weighted by the shares of new starts in each state expected in 2015 and 2020. The weighted average result therefore is mostly influenced by the breakeven results for the climate zones in Queensland (29.3% of new starts in 2015 and 30.2% in 2020), New South Wales (27.6% of new starts in 2015 and 27.4% in 2020) and Victoria (21.9% of new starts in 2015 and 21.8% in 2020). Generally these weighted averages are within 1 percentage point of the simple average of all climate zones, except in those cases where PV becomes cost effective and drives one or more of these climates to be cost effective overall at BCA2010 -100% (as discussed below). Note that the weighted averages should not be read as an 'Australian average'; rather, they are the weighted averages of those climate zones modelled (essentially capital cities).

4.1.4 Starting Point

Another critical factor influencing the overall magnitude of the cost effective savings reported in this Chapter – indeed for commercial as well as residential buildings - is the starting point stringency of the energy performance provisions of BCA2010. While a detailed analysis of this factor fell outside our terms of reference, we note that the BCR that was estimated for residential buildings in BCA2010 was around one. This indicates that, prima facie, *all* improvement opportunities that were even marginally cost effective at that time were already included in BCA2010. This tends to limit the scope for further cost effective savings beyond that level - at least, in the absence of PV, as discussed below.

4.1.5 Impact of PV

Where PV is allowed as part of the building solution, it has a dramatic effect on the break-even level of energy savings reported. Because of this, results are presented below on a with PV and without PV basis. The impact of PV in turn affects higher level aggregates such as the Australian-average level of break-even savings in those scenarios where PV is allowed.

Where, for a given climate zone, PV becomes cost effective in its own right, then the break even energy savings for residential buildings in that climate zone becomes 100%. This is because any level of residual energy demand can be covered cost effectively by the PV system due to the scalability of PV systems to any size through the addition of extra modules and components, subject only to physical constraints such as suitable roof area, and the capital cost. The results *without PV* are driven by the cost effectiveness of a) improvements to the thermal shells and b) improvements to fixed appliances.

In this study, PV systems are treated as if they are another 'fixed appliance' which may (depending upon the scenario) be traded off against efficiency gains in the thermal shell and those fixed appliances already regulated by the BCA (hot water, lighting, pool pumps) in determining a least cost mix of measures that provide at least break-even benefits (BCR = 1.0). We therefore analysed the cost effectiveness of PV systems in each climate zone, taking into account the differences in electricity prices and PV yield by climate zone.

As previously discussed, the cost of PV is projected to fall dramatically into the future. The most significant price reduction is occurring for the cost of panels (and to a lesser extent for inverters). While these costs represent a large share (60+%, depending on total installed capacity) of the current total cost of the turnkey price of a solar energy installation, there is no certainty about future market prices of these components in Australia. The capital cost assumes a 20-year life for the PV panels and replacement of the inverter after 10 years, both of which are conservative. We have estimated turnkey capital costs of $5,950/kWp in 2010, $4,400/kWp in 2015, and $2,990/kWp in 2020. No government subsidies of any form are taken into account. The resulting NPV costs (7% discount rate) of 1kWp of PV are about $4,900 in 2015 and $3,600 in 2020.

Table 4.4 below shows the resulting BCRs for residential PV systems. It can be seen that in 2020 PV is cost effective in all climates. All the economic modelling for residential buildings is based upon improvements being added to dwellings in order of declining BCRs until the break even or specified energy reduction is achieved. This means that building shell or other improvements are made up to the point when the BCR of PV is reached but no further. Moreover, when the BCR >1 for PV, any required level of energy reduction can be achieved cost effectively (i.e. above breakeven), although not necessarily at low absolute cost. Further, there may be a practical limit in terms of suitably oriented and unshaded roof area for real dwellings, which has not been explicitly taken into account in the modelling.

Table 4.4: Benefit Cost Ratios for Residential PV by Climate Zone, Base Case Scenario @7%

	Sydney West (CZ6)	Darwin (CZ1)	Brisbane (CZ2)	Adelaide (CZ5)	Hobart (CZ7)	Melbourne (CZ6)	Perth (CZ5)	Canberra (CZ7)
2015	1.01	1.07	1.12	1.36	1.01	0.98	1.39	0.77
2020	1.41	1.47	1.57	1.89	1.41	1.37	1.96	1.09

Source: pitt&sherry
Notes: values indicated in red are those where the BCR > 1.

4.2 Break Even Analysis

Section 4.2 reports and then analyses the summary results for residential buildings in the Base Case scenario. The results referred to below are those available at a 7% real discount rate in 2020 unless specified otherwise.

Table 4.5: Break Even Energy Savings Relative to BCA2010, All Residential Buildings, Without PV, Base Case

	Space Conditioning and Fixed Appliance Savings		**2020 Break Even Thermal Shell Star Rating#**	**2020 % Space Conditioning Energy**	**2020 Space Conditioning Energy at Break Even**
	2015	2020			
Sydney West (CZ6)	9%	14%	6.0	30%	4.7GJ
Darwin (CZ1)	3%	3%	6.0	69%	17.3GJ
Brisbane (CZ2)	7%	7%	6.0	20%	1.6GJ
Adelaide (CZ5)	11%	11%	6.0	45%	6.9GJ
Hobart (CZ7)	14%	17%	6.4	67%	18.3GJ
Melbourne (CZ6)	3%	7%	6.2	66%	21.8GJ
Perth (CZ5)	18%	32%	6.0	29%	2.8GJ
Canberra (CZ7)	4%	7%	6.2	70%	26.8GJ
Weighted Average:	**8%**	**12%**			

Source: pitt&sherry
Notes: # = composite star rating for Class 1 and Class 2 buildings. Space conditioning energy consumption is shown in Column 5 as a percentage of total energy consumption excluding plug load and cooking energy then, in Column 6, in absolute terms.

In the Base Case, the weighted average level of energy savings that are cost effective for new residential buildings, relative to BCA2010 and without including photovoltaic panels (PV), is around 12% in 2020 and 8% in 2015 (see Table 4.5 below). It can be noted that there is significant variation in the results by climate zone, and also that the overall level of savings is modest in most climate zones. The reasons behind these results are not immediately obvious and require some teasing out.

First, as noted above, 6-star building shell performance means that in mild climates (Brisbane, Perth, Sydney, Adelaide) the space conditioning energy requirement is small both in absolute terms and as a share of total energy consumption (excluding plug load and cooking which is not regulated under the BCA). As a result, there is relatively little space conditioning energy remaining to save in these climates and, in the Base Case scenario, there are very few improvements that can be shown to be cost-effective for these climate zones. By contrast, in the locations with the highest space energy requirements (Canberra, Melbourne and Hobart) some improvements in the building shell performance are cost effective in this scenario.

In the milder climates (Brisbane, Perth, Sydney, Adelaide), the cost effective energy savings that are shown in Table 4.5 relate almost exclusively to savings in domestic services (water heating, lighting and pool/spa pumps). The significantly higher than average cost effective savings in Perth are primarily driven by relatively high electricity and gas prices making more efficient domestic services cost effective. The predominance of double brick construction in that (mild) climate zone already delivers reasonable thermal performance, but also means that it is relatively expensive to further improve that performance (for example by fitting insulation into the cavity between the two brick layers). Such expense is not justified by the modest, $200/year space conditioning cost on average, notwithstanding higher priced electricity in this climate zone. In Brisbane in 2020, the annual cost of space conditioning at the break even solution is just $107. This is the primary reason why further improvements in the thermal performance of building shells in the milder climates cannot be shown to be cost effective.

Price effects can also be seen in the cases of Darwin and Canberra. Despite both of these climate zones consuming significant amounts of space conditioning energy, relatively low energy prices constrain the cost-effectiveness of thermal shell improvements relative to climate zones with higher energy prices. A similar effect occurs in Melbourne, where gas is the predominant fuel used for space heating. Melbourne's low gas prices relative to other climate zones militates against further cost effective improvements in thermal shells.

Table 4.5 also indicates (in Column 5) that in the milder climates, domestic services (or fixed appliances) are expected to account for the majority of total energy consumption (excluding plug load and cooking energy), while in the cooler climates, space conditioning continues to account for the majority of energy consumption. Note however that the potential for cost effective improvements in domestic services can also arise in the cooler climates. For example, the higher than average savings reported for Hobart are boosted in this analysis because the least cost solution involves preferring high performance gas hot water systems over the 'frozen efficiency' solution of electric storage hot water systems, which have high lifecycle costs.

Finally, differences in the composition of the new dwelling stock by climate zone also impact upon the potential for cost effective building shell energy savings. This study finds that there is significantly greater potential for cost effective energy savings in Class 2 buildings (flats) than in Class 1 buildings (discussed further in Section 4.3.1 below). Therefore, climate zones with a higher share of Class 2 buildings (Sydney, Brisbane, Adelaide, Perth, Canberra) tend to show higher cost effective savings overall. Note that this effect is modest as Class 2 dwellings make up less that 15% of the stock even in these climate zones.

Appendix 5 provides additional sensitivity analysis around these 'without PV' results, including the impact of assuming a range of 'no cost' design changes to the detached dwelling forms.

When PV is added into the mix, the results change dramatically (see Table 4.6 below). Even in the Base Case, zero net energy housing shown to be cost effective by 2020 in all climate zones studied. The cost of PV panels has declined dramatically in recent years and is projected to decline further by 2020. This combined with rising electricity prices is making the electricity produced from PV installations increasingly cost effective. Indeed by 2015 in most climate zones studied, PV installations are cost-effective in their own right[20], and by 2020 this is true for all climate zones. This means that essentially any level of energy savings, relative to BCA2010, is also cost effective when PV is allowed in the building solution - constrained only by physical considerations such as the area of North-facing roof upon which to mount PV systems. As soon as this condition occurs in a climate zone, the break even or cost effective level of energy savings immediately rises to 100% (i.e., zero net energy).[21]

Table 4.6: Break Even Energy Savings Relative to BCA2010, All Residential Buildings, With PV, Base Case

	2015	2020
Sydney West (CZ6)	100%	100%
Darwin (CZ1)	100%	100%
Brisbane (CZ2)	100%	100%
Adelaide (CZ5)	100%	100%
Hobart (CZ7)	100%	100%
Melbourne (CZ6)	3%	100%
Perth (CZ5)	100%	100%
Canberra (CZ7)	4%	100%
Weighted Average:	79%	100%

Source: pitt&sherry

Another way to interpret these results is to note that the various 'treatments' or upgrades that may be applied to a 6 star, BCA 2010 house have different costs and benefits. In our analysis, these treatments are selected in declining order of cost effectiveness (that is, the most cost effective are selected first). As soon as PV panels become the next most cost effective treatment, no further treatments (and hence no further costs) are required to reduce the house's energy consumption to zero.

Note that PV in Melbourne and Canberra is not cost effective until after 2015 (although only very slightly so in the case of Melbourne) due to lower electricity prices and somewhat lower PV output in those climate zones.

4.2.1 Class 1 vs Class 2 Dwelling Results

A feature noted in the modelling was the consistently higher level of cost effective energy savings able to be attained by the Class 2 dwellings, when compared to the Class 1 dwellings, noting that the Class 2 dwellings contribute only a small share of the weighted results as they are fewer in number. As each building type was modelled separately, in order to calculate the weighted average energy improvement for each location, it was then possible to calculate the weighted average building shell star rating (and therefore percentage energy reduction due to building shells alone) for the Class 1 and Class 2 dwellings separately.

Table 4.7 below shows the results for 2020 without PV. Note that it is more difficult to justify the 'with PV' solution for flats, as the availability of a sufficient area of appropriately oriented roof space is less likely than with a single dwelling. Similar considerations may apply to two-storey houses for which there is relatively less roof area compared to single storey houses of the same floor area. It can be noted that for many

[20] No subsidies or feed-in tariffs are taken into account. By assumption, the electrical output of the installations is valued at the retail price, discounted over an assumed 20 year panel life at 7% real. For further information, see Section 4.1.

[21] Excluding 'plug load', or the energy consumption of plug-in appliances.

climate zones, much greater energy savings are cost effective for flats (Class 2) than for houses (Class 1). Individual flats share common walls with other flats and, particularly for those in central rather than corner locations, significant energy savings are often feasible through simple strategies such as improved insulation and glazing.

Table 4.7: Energy Reductions from Building Shell Improvements for Class 1 and Class 2 Dwellings at Break Even, 2020

Climate Zone	Class 1	Class 2
Sydney West (CZ6)	0%	0%
Darwin (CZ1)	0%	1%
Brisbane (CZ2)	0%	0%
Adelaide (CZ5)	0%	0%
Hobart (CZ7)	7%	51%
Melbourne (CZ6)	1%	31%
Perth (CZ5)	0%	0%
Canberra (CZ7)	0%	51%

Source: pitt&sherry

Table 4.8 below shows the weighted average incremental costs of achieving break-even energy savings, without PV, for Class 1 and Class 2 dwellings in each climate zone. The weighted figures are based on the prevalence of residential building types modelled that make up each building Class and their respective incremental costs.

Table 4.8: Incremental Costs at Break Even: Class 1 and Class 2 Dwellings, Without PV

Climate Zone	**2015**	**2020**
Sydney (Class 1)	$336	$466
Sydney (Class 2)	$336	$466
Darwin (Class 1)	$246	$206
Darwin (Class 2)	$246	$311
Brisbane (Class 1)	$194	$164
Brisbane (Class 2)	$194	$164
Adelaide (Class 1)	$599	$496
Adelaide (Class 2)	$599	$496
Hobart(Class 1)	$1407	$1362
Hobart (Class 2)	$3172	$3435
Melbourne (Class 1)	$140	$328
Melbourne (Class 2)	$1295	$1690
Perth (Class 1)	$608	$1545
Perth (Class 2)	$608	$1545
Canberra (Class 1)	$177	$327
Canberra (Class 2)	$2319	$3720

Source: pitt&sherry

In the cooler climates (Melbourne, Canberra and Hobart), the cost to achieve break-even energy savings is higher for Class 2 than Class 1 dwellings, reflecting the fact that the Class 2 dwellings are able to achieve much higher levels of thermal performance cost effectively, as indicated in Table 4.5 above. For the other climates, apart from Darwin in 2020, there is no difference in cost between Class 1 and 2 dwellings to achieve break-even energy savings. To achieve break-even energy savings, the level of thermal performance remains the same as the base-case dwelling for both Class 1 and 2 dwellings *i.e.* no change in building shell cost. Break-even energy savings are achieved through either one of or a combination of lighting, water heating or pool pump energy efficiency improvements.

Table 4.9 below presents the same incremental cost data for Class 1 and Class 2 dwellings in each climate zone as shown in Table 4.8, but this time with PV included in the mix. In all climates PV is cost effective in Class 1 & 2 dwellings. In those cases, the cost of PV means that incremental construction costs are significantly higher than they are for the Without PV scenario. In addition to cost, Table 4.9 shows the size of PV installed at the breakeven point. In most Class 2 cases it is unrealistic to expect the required roof area (7m^2 per 1kWp) to be available. Even for Class 1 dwellings, especially two-storey, sufficient appropriate roof area (north oriented and unshaded) may not be available for 6kWp of PV and a solar hot water system.

Table 4.9: Incremental Costs at Break Even: Class 1 and Class 2 Dwellings, with PV (including PV peak capacity installed)

Climate Zone	2015	2020
Sydney (Class 1)	$15562 (3.1kW)	$11662 (3.2kW)
Sydney (Class 2)	$15562 (3.1kW)	$11662 (3.2kW)
Darwin (Class 1)	$19457 (3.9kW)	$14164 (3.9kW)
Darwin (Class 2)	$19457 (3.9kW)	$14164 (3.9kW)
Brisbane (Class 1)	$7090 (1.4kW)	$5552 (1.5kW)
Brisbane (Class 2)	$7090 (1.4kW)	$5552 (1.5kW)
Adelaide (Class 1)	$13607 (2.7kW)	$10356 (2.8kW)
Adelaide (Class 2)	$13607 (2.7kW)	$10356 (2.8kW)
Hobart(Class 1)	$29977 (5.8kW)	$21688 (5.7kW)
Hobart (Class 2)	$29977 (5.8kW)	$22975 (5.7kW)
Melbourne (Class 1)	$305	$24292 (6.7kW)
Melbourne (Class 2)	$305	$25111 (6.7kW)
Perth (Class 1)	$9967 (1.9kW)	$7326 (1.9kW)
Perth (Class 2)	$9967 (1.9kW)	$7326 (1.9kW)
Canberra (Class 1)	$182	$27056 (7.4kW)
Canberra (Class 2)	$2401	$29994 (7.4kW)

Source: pitt&sherry

4.3 Benefit Cost Analysis at Targeted Performance Levels

Modelling was undertaken to determine the benefit cost ratios at reductions of 40% and 70% from the BCA 2010 level (covering the building shell, water heating, lighting and pool pumps). Additionally, at 100% reduction, a net zero energy solution was required in which all cooking and plug load energy was also offset by renewable energy. It should be noted that energy reductions of 40% and 70% below the BCA 2010 of 6-star represent AccuRate star ratings in the range 7.5 - 8.2 stars and 8.7 - 10 stars, respectively. The results shown in Table 4.10 are the 'without PV' solutions. There are no cost effective solutions, with the best results occurring for the three cool climates. For both -70% and -100% energy reductions, the best results occur for Canberra at around 40% BCR.

The results shown in Table 4.11 below are the 'with PV' solutions. All climates except Canberra and Melbourne have cost effective solutions for each energy reduction target. As soon as other improvements with BCRs better than that of PV are exhausted, PV is then used to reach the required energy reduction at the BCR of the PV. If the BCR of PV exceeds break even, any level of energy reduction is possible at better than break even because of the scalability of PV systems. It should be noted, however, that the upfront cost of PV systems may be significant, even if they are cost effective: the current net present costs per kWp of PV installed are about $7,300, $4,900 and $3,600 (7% discount rate) in 2010, 2015, and 2020, respectively. It should also be noted that around 7m^2 of appropriately oriented and un-shaded roof is required per 1kWp.

Table 4.10: Benefit Cost Ratios without PV in Solution, at 40%, 70% and 100% Reduction from BCA2010 by Climate Zone

	-40%		-70%		-100%	
Climate Zone	2015	2020	2015	2020	2015	2020
Sydney	0.17	0.21	0.13	0.17	0.13	0.17
Darwin	0.25	0.31	0.24	0.31	0.24	0.31
Brisbane	0.35	0.41	0.10	0.12	0.10	0.12
Adelaide	0.25	0.33	0.16	0.21	0.16	0.21
Hobart	0.47	0.60	0.27	0.35	0.27	0.35
Melbourne	0.37	0.47	0.20	0.26	0.20	0.26
Perth	0.20	0.26	0.19	0.25	0.19	0.25
Canberra	0.40	0.55	0.30	0.41	0.31	0.42

Source: pitt&sherry

Table 4.11: Benefit Cost Ratios with PV in Solution, at 40%, 70% and 100% Reduction from BCA2010 by Climate Zone

	-40%		-70%		-100%	
Climate Zone	2015	2020	2015	2020	2015	2020
Sydney	1.03	1.43	1.02	1.43	1.01	1.42
Darwin	1.07	1.47	1.07	1.47	1.07	1.47
Brisbane	1.14	1.58	1.13	1.58	1.13	1.57
Adelaide	1.38	1.90	1.38	1.90	1.37	1.90
Hobart	1.10	1.53	1.05	1.47	1.03	1.44
Melbourne	0.98	1.38	0.98	1.37	0.98	1.37
Perth	1.43	1.99	1.41	1.98	1.40	1.97
Canberra	0.77	1.09	0.77	1.09	0.77	1.09

Source: pitt&sherry. Note: values shown in red are greater than 1; i.e., cost effective.

4.4 Greenhouse Savings at Break-Even

It is possible to estimate the national GHG savings at the various break even points modelled in this study. The model itself calculates the energy savings at break even for the weighted average dwelling in each climate zone. Using projected greenhouse gas intensities for electricity (declining over time as described in Chapter 3) and gas (essentially constant over time), the greenhouse gas emissions savings compared to the BCA 2010 Base Case can be calculated for any particular year, and future greenhouse gas benefits can be projected on the basis of expected changes in greenhouse gas intensities for the calculated energy savings. The next step is to multiply the single dwelling greenhouse gas savings by the number of new houses expected to be built in each state. National dwelling construction is modelled to be about 175,000 new dwellings in both 2015 and 2020.

The implicit assumption made here is that the climate of the single capital modelled is approximately representative of an average jurisdictional climate, which would be created by weighted contributions on the basis of new dwellings for each climate zone within a jurisdiction (if we happened to know where houses would be built in 2015 and 2020 by AccuRate climate zone, and modelled the housing stock in every relevant climate zone). In fact, the approach taken can only provide an indicative estimate of the percentage reduction by jurisdiction, and therefore for Australia by adding the jurisdictional contributions. This approach is reasonable on the basis that a majority of new houses are likely to be built within the chosen climate zone (or a very similar climate zone). This approach is robust in the ACT and Tasmania; reasonable for Victoria, South Australia and the Northern Territory, and less rigorous in NSW, Queensland and Western Australia. In NSW, the climate used (Richmond, Z28) will reflect the climate of many new houses in

Sydney West, but not the milder coastal climate from Wollongong to the Queensland border, and not the more extreme climates of inland NSW. In the case of Queensland, a high proportion of dwellings will be built in south-east Queensland, but some will be built in less benign inland and tropical climates. For Western Australia, the Perth climate (Z13) is representative of much of the south-west, but a small proportion of dwellings will be built in the dry inland and the tropical north of the state.

Table 4.12 below shows the estimates of the greenhouse gas emissions savings at the break-even energy savings rates, with and without PV. The values represent the break even energy savings per dwelling in each period, relative to a BCA2010 base, multiplied by the number of dwellings expected to be constructed in two cohorts - 2015-2019 and then 2020-2024. The energy savings are converted to greenhouse units using the greenhouse gas intensity for electricity supply values noted in Chapter 3. Since the savings accumulate as the stock of buildings built to the new standards increases (up to 2024, the final year in which the measure is assumed to apply), the savings shown in the final column can be read as the annualised savings from the measure in 2024. The reason for the very significant difference between the *with* and *without* PV results is that by 2020 all cities achieve 100% energy savings at break-even with PV (see Table 4.6), which means GHG savings jump to very high levels.

Table 4.12: Estimates of National Annual Greenhouse Emissions Savings, Residential Buildings, at Break Even Energy Efficiency, for the Base Case Scenario, With and Without PV

	GHG savings (kt CO_2-e)		
	2015-19 cohort	2020-24 cohort	2015-2024 cohort
Without PV	165	196	361
With PV	3742	5658	9400

Source: pitt&sherry

5. Commercial Buildings - Results

The results of the benefit cost analysis for commercial buildings are presented first at the most highly aggregated or overview level, by climate zone. Subsequent sections set out the results by building type and climate zone in more detail, including cost-effectiveness at the BCA2010 –40%, -70% and -100% levels. Further details of the buildings, technical parameters and energy savings measures may be found in Appendix 4. Sensitivity analyses are presented in Appendix 5.

Note that differences between the residential and commercial building models used for this study meant that the commercial building results were not able to be presented on a with/without PV basis. Section 5.3 below, however, examines the cost effectiveness of PV for commercial buildings on a stand-alone basis, and discusses the sensitivity of the break-even results below to this factor.

The results presented below by climate zone represent average values for the four building forms studied weighted by their projected shares in the new building stock according to the Construction Forecasting Council, with the share of each building type factored up so that the four forms studied represent 100% of the stock. The 10-storey office is weighted at 68.4% of the stock in 2010, declining slowly through time, while the 3-storey office share increases from 13% in 2010, reflecting a projected shift in the composition of office-style building stock. The health building share remains constant at a little over 12% of new build, as does the supermarket share at a little over 6%. Clearly this simplifies the expected diversity of the new building stock, and therefore the average values should be regarded as indicative only.

5.1 Key Factors Driving the Results

As with the residential buildings, a critical driver of the commercial building 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[22]. Such high BCRs indicate that many highly cost-effective energy savings options for commercial buildings were not captured in BCA2010, unlike for residential buildings. 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. These effects are accentuated in commercial, as compared to residential, buildings due to their significantly higher energy intensity (energy use per square metre). A snapshot of commercial energy prices is provided in Table 5.1 below. These display a similar pattern to the residential prices but generally at a somewhat lower absolute level, reflecting trends in the National Energy Market.

To a greater degree than the residential buildings, the 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.

[22] The regression analysis on all commercial building types indicated a benefit cost ratio of 2.2 associated with the y-axis intercept, or zero percent incremental savings relative to BCA2010. This result is not directly comparable with past benefit cost analyses of BCA2010 for commercial buildings, but nevertheless is consistent with those results.

Table 5.1: Expected Gas and Electricity Prices (Real Prices 2012) Commercial Sector in 2020, by Climate Zone

	Gas $/GJ	Electricity $/GJ
Sydney	17.2	57.1
Melbourne	14.7	59.1
Brisbane	22.9	62.7
Adelaide	15.9	73.8
Perth	21.5	64.1
Hobart	19.4	60.6
Darwin	-	52.0
Canberra	18.5	44.8

Source: pitt&sherry

Relatedly, where co- or tri-generation is selected as part of a solution for a building, purchased electricity consumption is effectively swapped for gas consumption. This reflects the fact that gas is significantly cheaper than electricity. As a result it can be cost effective to back out electricity purchases with a co- or tri-generation unit, even if increasing gas purchases lead to higher total energy consumption in the building overall.

5.2 Break-Even Energy Savings

On average, 68% energy savings are expected to be cost effective for commercial buildings by 2020 (see Table 5.2 below) relative to BCA2010. These results are much higher than for residential buildings and also show a reasonable spread of results by climate zone, from Canberra at 54% to Darwin at 80%.

Table 5.2: Break-Even Energy Savings Relative to BCA2010, All Commercial Buildings

Climate Zone	2015	2020
Western Sydney (CZ6)	58%	68%
Darwin (CZ1)	74%	80%
Brisbane (CZ2)	70%	77%
Adelaide (CZ5)	67%	76%
Hobart (CZ7)	49%	61%
Melbourne (CZ6)	52%	63%
Perth (CZ5)	66%	75%
Canberra (CZ7)	41%	54%
Weighted Average:	**58%**	**68%**

Source: pitt&sherry

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.

The relatively lower level of cost effective savings in Canberra, Hobart and Melbourne is largely attributable to higher gas use in these cooler climates, with gas savings being less valuable than electricity savings, and also lower electricity prices. By contrast, the hotter climate zones with greater electricity use for space conditioning, and also those with higher electricity prices, tend to show more cost effective savings.

The primary reason for the higher absolute level of savings for commercial, when compared to residential, buildings is the large difference in the thermal efficiency implicit in BCA2010 for these building types, as noted above. In this study, the level of cost effective savings is measured at BCR = 1, which enables many more savings to be shown to be cost effective than when a higher benefit cost ratio is used. The regression analysis performed in this study suggests a BCR in 2010 of around 2.2. This, combined with rising energy and carbon prices over time, accentuates the ability for relatively modest additional capital costs to be cost effectively repaid by energy savings. For example in the Base Case, all of the buildings studied are able to achieve at least 40% energy savings in most climate zones at quite modest incremental construction costs of 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.

There is nevertheless a significant variation in the cost effective savings potential of the different commercial building types studied. The supermarket shows by far the highest BCRs, although this result has only a modest impact on the weighted average results as they hold just over a 6% share of the weightings. In the warmer climates (Darwin, Brisbane), a 40% energy saving can be achieved in the supermarket modelled with an incremental cost of around $60/square metre or 4%. Since the energy saved is high-value electricity, the present value of the energy savings exceeds the present value of the costs by around 6 times. The 10-storey office building has a much higher weighting within the overall results at 68%. While improvements to this building are not as cost effective as for the supermarket, the incremental costs of achieving 40% and even 70% savings are around 4% and 12% respectively. Even in the Base Case, the 40% reduction is cost effective for the 10-storey office.

The selection of trigeneration (onsite heating, cooling and electricity generation) – which is this study is modelled only for the larger office and healthcare buildings - has a significant impact on both benefits and costs. The trigeneration units represent a 'lumpy' investment, increasing the capital cost of the buildings, but also cause a large change in the fuel mix. The units are optimised to displace as much electricity consumption as possible, and this is replaced by additional gas consumption (to fuel the trigeneration units). In more extreme cases (where the buildings attempt to meet 70% or 100% energy savings, for example), the increased consumption of gas outweighs the electricity savings leading to higher total energy consumption overall – even though, since gas is much cheaper than electricity, this can be cost effective and also lead to lower greenhouse gas emissions in many cases. Since these buildings are not amenable to carrying large areas of PV panels, they sometimes fail to meet these high performance targets.

The average results are broken down by building type below, and further detail of the analyses is provided in Appendix 4.

5.3 Break-Even Greenhouse Gas Savings

Table 5.3 below shows the estimates of the greenhouse gas emissions savings at the break-even energy savings rates calculated for each scenario for commercial buildings. The values represent weighted average break even energy savings (per m^2.a) in each period, relative to a BCA2010 base, multiplied by the number of sqm expected to be constructed in two cohorts - 2015-2019 and then 2020-2024. The energy savings are converted to greenhouse units using the greenhouse gas intensity for electricity supply values noted in Chapter 3. As mentioned above, the method of weighting the commercial building types used in this study simplifies the expected diversity of the new building stock. The greater diversity of commercial building stock than what is covered in this report will also mean there is greater range in the stock's energy use and associated greenhouse gas emissions (per m2.a). Therefore the greenhouse gas savings of the commercial buildings reported here should be regarded as indicative only.

Since the savings accumulate as the stock of buildings built to the new standards increases (up to 2024, the final year in which the measure is assumed to apply), the savings shown in the final column can be read as the annualised savings from the measure in 2024.

Table 5.3: Estimates of National Annual Greenhouse Emissions Savings, Commercial Buildings, at Break Even Energy Savings, for Base Case Scenario

Scenario	Real Discount Rate	GHG savings (kt $CO_{2\text{-}e}$)		
		2015-19 cohort	2020-24 cohort	2015-2024 cohort
Base Case	7%	887	1163	2050

Source: pitt&sherry

5.4 Detailed Results

5.4.1 10-Storey Office

Table 5.4 below shows the BCRs that are attained by the 10 storey office. By 2020, the 10 storey office 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, assist in this result.

Table 5.4: 10 Storey Office: Benefit Cost Ratios by Climate Zone, Year

Summary Table - 10 Storey Office	2015	2020
BCR @ -40%		
Western Sydney (CZ6)	1.0	1.2
Darwin (CZ1)	1.6	1.9
Brisbane (CZ2)	1.3	1.6
Adelaide (CZ5)	1.1	1.3
Hobart (CZ7)	0.7	0.9
Melbourne (CZ6)	0.8	1.0
Perth (CZ5)	1.1	1.4
Canberra (CZ7)	0.7	0.8
Average:	**1.0**	**1.3**

Table 5.4 (cont.): 10 Storey Office: Benefit Cost Ratios by Climate Zone, Year

Summary Table - 10 Storey Office	2015	2020
BCR @ -70%		
Western Sydney (CZ6)	0.6	0.7
Darwin (CZ1)	0.9	1.1
Brisbane (CZ2)	0.8	1.0
Adelaide (CZ5)	0.7	0.9
Hobart (CZ7)	0.5	0.6
Melbourne (CZ6)	0.6	0.7
Perth (CZ5)	0.7	0.9
Canberra (CZ7)	0.4	0.4
Average:	**0.6**	**0.8**
BCR @ -100%		
Western Sydney (CZ6)	0.1	0.2
Darwin (CZ1)	0.2	0.3
Brisbane (CZ2)	0.2	0.2
Adelaide (CZ5)	0.2	0.2
Hobart (CZ7)	0.1	0.1
Melbourne (CZ6)	0.1	0.1
Perth (CZ5)	0.2	0.2
Canberra (CZ7)	0.1	0.1
Average:	**0.1**	**0.2**

Source: pitt&sherry

5.4.2 3-Storey Office

Table 5.5 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 5.5: 3 Storey Office: Benefit Cost Ratios by Climate Zone, Year

Summary Table - 3 Storey Office	2015	2020
BCR @ -40%		
Western Sydney (CZ6)	1.3	1.6
Darwin (CZ1)	1.2	1.5
Brisbane (CZ2)	1.4	1.6
Adelaide (CZ5)	1.6	1.9
Hobart (CZ7)	1.5	1.8
Melbourne (CZ6)	1.2	1.5
Perth (CZ5)	1.4	1.8
Canberra (CZ7)	1.2	1.5
Average:	**1.4**	**1.7**

Table 5.5 (cont.): 3 Storey Office: Benefit Cost Ratios by Climate Zone, Year

Summary Table - 3 Storey Office	2015	2020
BCR @ -70%		
Western Sydney (CZ6)	1.3	1.6
Darwin (CZ1)	1.4	1.6
Brisbane (CZ2)	1.4	1.7
Adelaide (CZ5)	1.7	2.0
Hobart (CZ7)	1.4	1.8
Melbourne (CZ6)	1.3	1.6
Perth (CZ5)	1.5	1.8
Canberra (CZ7)	1.1	1.4
Average:	**1.4**	**1.7**
BCR @ -100%		
Western Sydney (CZ6)	0.4	0.5
Darwin (CZ1)	0.4	0.5
Brisbane (CZ2)	0.5	0.6
Adelaide (CZ5)	0.5	0.6
Hobart (CZ7)	0.4	0.5
Melbourne (CZ6)	0.4	0.5
Perth (CZ5)	0.5	0.6
Canberra (CZ7)	0.3	0.4
Average:	**0.4**	**0.5**

Source: pitt&sherry

5.4.3 Supermarket

Table 5.6 below shows the BCRs that are attained by the supermarket in the Base Case. 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 are 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 5.6: Supermarket: Revised Benefit Cost Ratios by Climate Zone, 2015 and 2020

Summary Table - Supermarket	2015	2020
BCR @ -40%		
Western Sydney (CZ6)	3.9	4.7
Darwin (CZ1)	4.8	5.9
Brisbane (CZ2)	5.0	6.0
Adelaide (CZ5)	4.5	5.4
Hobart (CZ7)	3.0	3.6
Melbourne (CZ6)	3.2	3.9
Perth (CZ5)	4.4	5.4
Canberra (CZ7)	2.7	3.3
Average:	**3.9**	**4.8**
BCR @ -70%		
Western Sydney (CZ6)	1.5	1.8
Darwin (CZ1)	2.2	2.6
Brisbane (CZ2)	1.7	2.1
Adelaide (CZ5)	1.7	2.1
Hobart (CZ7)	1.3	1.6
Melbourne (CZ6)	1.3	1.6
Perth (CZ5)	1.7	2.1
Canberra (CZ7)	1.1	1.4
Average:	**1.6**	**1.9**
BCR @ -100%		
Western Sydney (CZ6)	0.9	1.0
Darwin (CZ1)	0.9	1.0
Brisbane (CZ2)	1.0	1.2
Adelaide (CZ5)	1.0	1.2
Hobart (CZ7)	0.7	0.9
Melbourne (CZ6)	0.8	1.0
Perth (CZ5)	1.0	1.2
Canberra (CZ7)	0.6	0.8
Average:	**0.9**	**1.1**

Source: pitt&sherry

5.4.4 Healthcare Facility

Table 5.7 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 5.7: Healthcare Facility: Benefit Cost Ratios by Climate Zone in 2015,2020

Summary Table - Health	2015	2020
BCR @ -40%		
Western Sydney (CZ6)	1.8	2.2
Darwin (CZ1)	3.0	3.7
Brisbane (CZ2)	2.6	3.1
Adelaide (CZ5)	2.4	2.9
Hobart (CZ7)	2.0	2.5
Melbourne (CZ6)	1.9	2.4
Perth (CZ5)	2.5	3.0
Canberra (CZ7)	1.9	2.3
Average:	**2.3**	**2.8**
BCR @ -70%		
Western Sydney (CZ6)	0.9	1.1
Darwin (CZ1)	0.9	1.1
Brisbane (CZ2)	1.0	1.2
Adelaide (CZ5)	1.3	1.5
Hobart (CZ7)	0.9	1.0
Melbourne (CZ6)	0.8	0.9
Perth (CZ5)	1.1	1.3
Canberra (CZ7)	0.6	0.8
Average:	**0.9**	**1.1**
BCR @ -100%		
Western Sydney (CZ6)	0.3	0.3
Darwin (CZ1)	0.4	0.5
Brisbane (CZ2)	0.3	0.4
Adelaide (CZ5)	0.5	0.5
Hobart (CZ7)	0.2	0.3
Melbourne (CZ6)	0.3	0.3
Perth (CZ5)	0.3	0.4
Canberra (CZ7)	0.1	0.2
Average:	**0.3**	**0.4**

Source: pitt&sherry

Given this performance at BCA2010 -70%, the health 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.

5.5 Benefit-Cost Analysis of PV in Commercial Buildings

As noted in Section 5.0 above, the commercial buildings results are not transparent as to whether PV is deployed at the break even performance level. Regression analysis was used to calculate the break even energy savings levels based on three distinct performance levels (BCA2010 -40%, BCA2010 -70% and BCA2010 -100%). 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 5.8 below shows the projected cost effectiveness of PV for commercial buildings by climate zone. 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 5.8: Benefit Cost Ratios for PV: Commercial Buildings in 2020

	5%	7%
Western Sydney (CZ6)	0.52	0.56
Darwin (CZ1)	0.52	0.62
Brisbane (CZ2)	0.55	0.61
Adelaide (CZ5)	0.67	0.75
Hobart (CZ7)	0.48	0.57
Melbourne (CZ6)	0.48	0.56
Perth (CZ5)	0.65	0.97
Canberra (CZ7)	0.38	0.44

Source: pitt&sherry

6. Conclusions and Further Analysis

Overall, this study has found that there are very significant cost effective opportunities for energy savings in new commercial buildings in 2015 and 2020, relative to BCA2010. 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 this study.

With respect to residential buildings, this study has produced a 'binary' result with/without PV included in the building solution. Without PV, modest but still worthwhile savings, averaging 12% in the Base Case, are cost effective by 2020, albeit with significant variation by climate zone. This could increase to 16% if no-cost passive solar design changes are made to residential buildings before other measures. With PV in the mix, zero net energy becomes cost effective in all climate zones by 2020, and even by 2015 in most climate zones. This result follows from the fact that residential PV systems are modelled as cost effective in their own right in most climate zones by 2015, and in all climate zones by 2020. We note that despite being cost effective, including PV on residential buildings would increase the initial capital cost of the building by a significant amount. Further, and in some climate zones in particular, it may not be feasible to install the amount of PV required to attain zero net energy, given limitations on roof area and solar access.

While this study has included a range of sensitivity analyses, we have identified a number of opportunities where further investigations could be undertaken to test aspects of its findings. These include:

1. Sensitivity analysis for commercial buildings with respect to changes in 'plug load'. While internal appliances, or plug load, explicitly included in the BCA2010 -100% solutions only, assumed efficiency gains for these loads can create a 'free ride' for commercial buildings at all performance levels, leading to lower incremental costs (and therefore higher cost-effective energy savings) than would otherwise be the case. The sensitivity of the results to these assumptions could be tested by remodelling the buildings with a static plug load assumed for all performance levels through time.
2. Closer examination of the cost effectiveness of cogeneration and trigeneration solutions in different climate zones. As these are 'lumpy' investments, which trigger significant fuel mix changes as well as different design optimisation strategies (see Chapter 5), the relative cost effectiveness of this solution is likely to play a major role in overall cost effective savings, particularly around the saving levels revealed in this study. It is likely, therefore, that the breakeven results will be sensitive to this variable. In this study, trigeneration or cogeneration are only deployed in the 10 storey office and healthcare facility.
3. For residential buildings, sensitivity analysis with respect to the degree and cost effectiveness of improvements in fixed appliances. While the efficiency of residential domestic services was not the major focus of this study, this study found this to be an important source of cost effective energy savings, particularly in the milder climate zones. The residential break-even savings are therefore likely to be sensitive to assumptions made in these areas, and this could be tested with more careful analysis of a range of efficiency trajectories for each of the fixed appliance classes (hot water, lighting, pool pumps).
4. For residential buildings, additional sensitivity analysis on low cost design changes for residential buildings. Given that the small number and modest nature of the 'no cost' design changes modelled in this study for the stand alone dwellings showed quite significant cost effective improvements were available, relative to the case without such design changes, a more extensive analysis of this factor could be undertaken. Such a study could examine a larger number of house designs, include modest size changes, changes in glazing ratios and more extensive floor plan changes, but also examine 'real world' constraints including those associated with solar access and sub-division design. Design optimisation costs could also be analysed. In principle, this additional study could also examine commercial building design variations, or (given the wider scope of commercial buildings) a

separate study could be commissioned to examine these questions for commercial buildings.

5. More generally, the results of this benefit cost analysis could be enhanced by considering additional building types and climate zones. Educational buildings, other retail buildings, and climate zones outside capital cities, did not form part of this study. While there is no *a priori* reason to assume the overall results would change significantly with wider coverage of building types and climate zones, this could be tested with additional analysis.

Appendix 1: Statement of Requirements

The following text reproduces the original Statement of Requirements from the Request for Tender issued by the Department of Climate Change and Energy Efficiency on 16 December 2010.

Note: Within this Report, and as agreed with the DCCEE, Scenario 2 outlined below was adopted as the Base Case scenario (using 7% discount rate only) after the Government released its Clean Energy Future Plan. The results for this scenario were reported in Chapters 4 and 5. In Appendix 5- Sensitivity Analyses, Scenario 1 as outlined below is reported as Scenario 1, whereas Scenario 3 is reported as Scenario 2.

PATHWAY TO 2020 FOR INCREASED STRINGENCY IN NEW BUILDING ENERGY EFFICIENCY STANDARDS

Purpose

The Department is seeking a consultant to identify low, medium and high options for an indicative 2020 goal for increased energy efficiency and reduced greenhouse gas reduction in new residential and non-residential buildings and the intermediate steps needed to achieve these options.

This study builds upon the study The Pathway to 2020 for Low-Energy, Low-Carbon Buildings in Australia undertaken by Pitt and Sherry for the Department in 201023.

Background

The National Strategy on Energy Efficiency (NSEE), measure 3.1.1, states that all jurisdictions will work together to develop a consistent outcomes-based national building energy standard setting, assessment and rating framework for driving significant improvement in the energy efficiency of Australia's building stock.

In essence, the Framework seeks initially to improve approaches to rating the energy performance of buildings and to lay out a pathway for future stringency increases in the Building Code of Australia (BCA) out to 2020. The NSEE states that this measure will be used to increase the energy efficiency of new residential and commercial buildings with minimum standards to be reviewed and increased periodically.

Service to be provided

The consultant is to produce a report that covers the following points (these are expanded upon in the 'considerations' section below):

1. An estimation of average building energy use and the related greenhouse gas emissions for new residential and non-residential buildings in Australia under the 2010 building standards, for those components of building energy use which are or could be regulated (i.e. building fabric and fixed equipment and appliances).
   1.1. This should be broken down by building classification and by state and territory and representative climate zones.
2. Calculation of the benefit cost ratios of three options for an indicative 2020 goal for reduced energy use and related greenhouse gas emissions in new buildings relative to the 2010 baseline (point 1 above):
   - 40 percent
   - 70 percent
   - net zero energy/ emission building[24]

[23] Available at http://www.climatechange.gov.au/en/what-you-need-to-know/buildings.aspx

The benefit cost ratios of these goals should each be calculated under three different scenarios:

	Scenario 1	Scenario 2	Scenario 3
Energy prices	Based on existing projections of gas and electricity price rises due to network augmentation (and rising costs of natural gas where appropriate	Scenario 1 plus a low carbon price	Scenario 1 plus a higher carbon price
Marginal construction cost increases from current standard	'business as usual' approach to construction costing	Some reduction in costs calculated under scenario 1 due to industry learning and technology changes to 2020	Scenario 2 and assuming a 'least-cost' approach to compliance, including changes to building design
Degree of flexibility allowed in achieving building standard	A. 'whole of building' approach that allows trade-offs between the thermal shell, and fixed appliances B. as above and including on-site renewable energy systems	A. 'whole of building' approach that allows trade-offs between the thermal shell and fixed appliances B. as above and including on-site renewable energy systems	'whole of building' approach that allows trade-offs between the thermal shell, fixed appliances and on-site renewable energy systems
Discount rate	5 percent and 7 percent for each option		

2.1 Separate calculations will also need to be undertaken for residential and non-residential buildings (and possibly further breakdowns by building classification).

3. Proposals for intermediate step changes in 2015 towards the 2020 goals proposed under point 2, in terms of identifying the benefit cost ratios and quantum reductions that could be achieved at that time towards each 2020 goal option;

4. Estimated total national energy (by fuel type) and greenhouse gas savings that could be achieved for the 2015 and 2020 goal options, both annually and cumulatively over the life of the buildings;

5. Sensitivity analysis of the benefit cost ratios calculated under point 2, based on agreed factors;

6. A recommendation on a 2015 and 2020 reduction goal that would be closest to the break-even point (i.e. benefits should at least equal costs), and the related scenario assumptions.

Considerations

The study is expected to be based on modelling of building energy use in at least eight representative climate zones covering all capital cities.

[24] This should be taken to be net zero for the energy use of the whole building. An allowance will therefore need to be made for the assumed plug loads from portable appliances that the renewable energy system will have to offset, in addition to the energy use of fixed appliances and equipment.

For residential, the study should model at least four typical new residential buildings in each climate zone: single storey, double storey, townhouse and apartment.

For non-residential, the study should model at least four typical building forms: office (3 and 10 storey), retail centre, and healthcare facility.

The energy and carbon prices to be used in the modelling will be subject to agreement with the Department.
In relation to the calculation of different outcomes for different building types, the level of disaggregation possible may be dependent on the availability of data.

The study should assume that future thermal shell standards would not drop below the BCA 2010 standard (e.g. 6 star or equivalent for residential) but individual buildings may choose to have a higher thermal shell performance as part of achieving the 'whole of building' reduction targets.

Estimated energy use of equipment and appliances should take into account any planned increases in relevant minimum energy performance standards by 2020.

Consultancy process

It is not expected that the consultant prepare a full regulatory impact statement (RIS). The RIS would occur as a separate process.

The consultant must provide details of the proposed modelling methodology to meet this statement of requirements. The consultant is free to propose an alternative modelling approach provided that it still covers a representative sample of new buildings and the range of assumptions in the three scenario options above.

The consultant's proposal must include the following tasks:

- An inception meeting in Canberra with the Department to clarify the consultant's tasks and the milestones to be achieved;
- A report outline (including proposed modelling and assumptions) and consultation meeting in Canberra with government officials organised by the Department before the modelling work is commenced;
- A draft report in line with the agreements made at the inception and consultation meetings;
- A presentation in Canberra to government officials organised by the Department outlining the key findings of the draft report;
- A final report taking into account comments provided on the draft report and presentation.

The consultant must also provide an electronic copy of the benefit cost ratio modelling in a form that will enable it be used in later projects by the Department.

The consultant will also be required to provide email and telephone reports on progress with the study at least fortnightly or as needed to deliver a high quality report that meets the requirements of the Department.

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Appendix 3: Residential Building Modelling

The residential building modelling for this study was undertaken by Energy Efficient Strategies Pty Ltd (EES), led by Robert Foster. This appendix sets out the key methodology and assumptions used to generate the results reported in Chapter 4 of the Report.

1. Overview

This appendix details the various residential building improvement scenarios examined and the methodology used for determining the impacts of those improvement measures both in terms of estimated capital costs to the householder and benefits in terms of both reductions in energy demand and fuel cost savings.

These estimates rely on several sources of data, some of which are detailed in other sections of this report. In particular, details relating to fuel costs (including costs incorporating varying carbon prices) were developed by Dr Hugh Saddler of pitt&sherry and are detailed in the main report. Details relating to building shell improvement costs were developed by Davis Langdon and are detailed in the main report. Housing stock projections were derived by applying the housing stock methodology set out in the 2008 study by Energy Efficient Strategies- *Energy Use In The Australian Residential Sector 1986-2020*. Details in relation to the costs and benefits of photovoltaics (PVs) were developed by Dr Mark Snow on contract to pitt&sherry and are detailed in the main report.

Benefits and costs were determined across a range of performance stringencies for each of the end uses that were the subject of this study (also included were PVs). These estimates were conducted across a range of dwelling types, climate zones, jurisdictions, years and financial scenarios. The resulting benefit/cost ratios were then analysed to determine the following:

1. The estimated energy savings at the break even point (ie benefit/cost ≥ 1)
2. The least cost pathway to achieving a reduction in annual energy consumption from new residential dwellings equivalent to 40% of the total energy consumption from all end uses except plug loads and cooking loads.
3. The least cost pathway to achieving a reduction in annual energy consumption from new residential dwellings equivalent to 70% of the total energy consumption from all end uses except plug loads and cooking loads.
4. The least cost pathway to achieving a reduction in annual energy consumption from new residential dwellings equivalent to 100% of the total energy consumption from all end uses <u>including</u> plug loads and cooking loads.

Items 3 and 4 above were found to rely on large inputs from PVs to meet the nominated targets. In the case of the 70% target, PV contribution requirements necessitated the installation of PVs that ranged from 0.8 to 4.4 kW and in the case of the 100% target, from 3.9 to 9.5 kW. To some degree the level of PVs used was a function of their cost effectiveness in the particular location. In some cases the BCR for PV could exceed 1.5 (e.g. in WA assuming a high carbon price) meaning that in these circumstances PVs were favoured to the exclusion of other less cost effective options. In reality PV installations above 5kW could prove impractical in many applications due to limitations on available mounting locations. Generally the larger installations were associated with locations where total residential energy demand is expected to be the highest (generally the colder climates).

1.1 Scope

The scope of the residential analysis included for all new dwellings constructed in Australia from the 2010 – 2011 (2011) financial year to the 2019-2020 (2020) financial year, although the focus was on the years 2015 and 2020.

Residential sector modeling included the following dwelling types:

- Class 1a(i) detached

- Class 1a(ii) semi detached
- Class 2 – Flats.

Modelling of energy impacts for the various scenarios was conducted on each of the following categories of end use:

- Space heating and cooling
- Water Heating
- Lighting
- Pool pumps / heating
- Cooking
- Other Appliances (Electrical).

It should be noted that policy options examined in this study did not include cooking or "Other Appliance" end uses. Energy consumption for these end uses are identical in each scenario examined for a given year and location. In addition, space heating and cooling analysis includes only the impact of higher building shell thermal performance stringencies. The performance of space conditioning equipment itself is assumed to follow the business as usual case in each scenario examined.

Space heating and cooling was modelled for a range of dwelling types in each of eight climate zones representing growth areas in each state and territory. Water heating, lighting and pool pumps/heating was modelled at an aggregate level for each state and territory and the average taken and used on a per dwelling basis. The final modelled energy reported in this study represents "at the meter energy".

In addition to the assessment of the impact of energy efficiency measures relating to the first four end uses noted above, the potential costs and benefits of including on-site photovoltaics (PV) were also integrated into the model.

The methodology for determining impacts on end use energy consumption of the energy efficiency measures was generally based on that used in the study *Energy Use in the Australian Residential Sector 1986-2020* (EES 2008). A schematic of the model is shown in Figure A3.1 below. This is believed to be the most comprehensive "bottom up" model of residential energy use available and has been verified against top down (ABARE) data.

Within the scope, a total of twelve different financial scenarios were examined in addition to the business as usual case. These are summarised in Table A3.1 below. In this table the carbon price relates to the expected real increase in energy costs as a result of a potential price being put onto carbon emissions (the actual assumptions relating to these carbon prices are detailed elsewhere in this report).

The "% Reduction in improvement cost through learnings" is an assumed level of cost reduction in the cost of the various improvement measures needed to meet the particular target noted in Section 4.4. In the case of residential buildings this primarily relates to cost reductions in PVs, high performance glazing, high performance lighting and high performance water heaters. All of these items have already started a downward trend in real cost. This is partly in response to current and past regulatory initiatives to improve residential building efficiency and partly in response to greater competitiveness in the world markets. The expected reductions through learnings in 2020 were set at twice the level of those modelled in 2015 in recognition of the fact that such reductions can reasonably be expected to continue throughout this decade particularly if more stringent performance standards are introduced in or around 2015.

Figure A3.1 : Schematic of EES End Use Model (EES 2008)

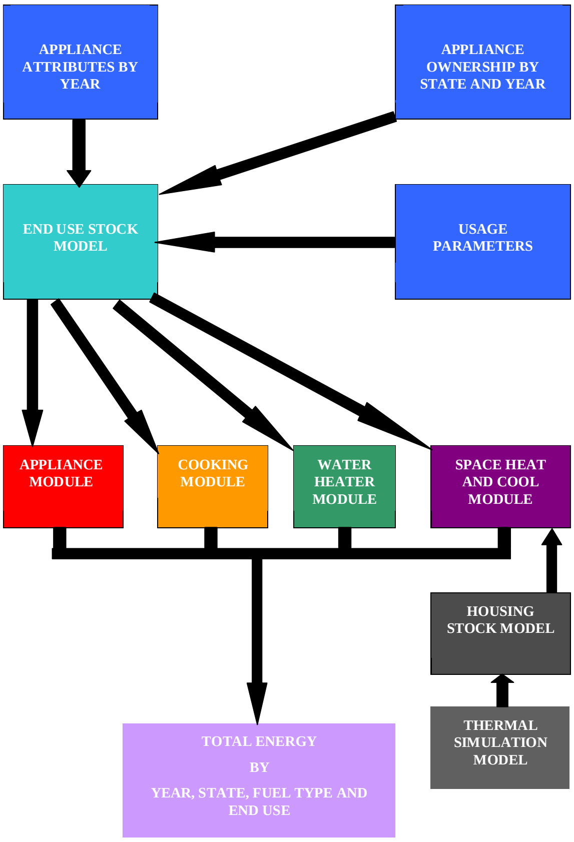


Table A3.1: Residential Scenarios examined

Scenario	Carbon Price	Discount Rate	% Reduction in improvement cost through "Learnings"
1A 2015	Nil	5%	0%
Base Case A 2015	Low	5%	15%
2A 2015	High	5%	25%
1B 2015	Nil	7%	0%
Base Case B 2015	Low	7%	15%
2B 2015	High	7%	25%
1A 2020	Nil	5%	0%
Base Case A 2020	Low	5%	30%
2A 2020	High	5%	50%
1B 2020	Nil	7%	0%
Base Case B 2020	Low	7%	30%
2B 2020	High	7%	50%

1.2 Performance Improvement Options Examined

With the exception of PVs, the various improvement options examined in this study have been based on the scenarios developed in an earlier phase of this study entitled "The Pathway to 2020 for Low-Energy, Low-Carbon Buildings in Australia: Indicative Stringency Study. Details of these measures are described in the following subsections.

1.2.1 Space Conditioning (Building Shell)

Various potential levels of improvement to building shell performance were examined as a means for reducing space conditioning energy loads. At the direction of the client, the Base Case was assumed to be a performance standard of 6 stars (NatHERS rating) for all dwelling types. This is the level specified in BCA 2010 and expected to be introduced by all jurisdictions in the near future.

Potential reductions in space conditioning loads were assessed for building shell performances ranging from the BAU case of 6 stars up to the maximum of 10 stars in 0.1 star increments. Very high performance levels close to 10 stars are in most cases examined theoretically only. For this study a range of improvement measures were applied to each building type. The combination of measures that delivered the highest performance level was then used as the basis for setting an upper practical limit to performance improvements for the building shell. This upper limit was set at 0.5 stars above the highest performance level determined using the particular improvement measures detailed in this study. This 0.5 star extension to the potential maximum performance limit was applied in recognition of the fact that this study did not exhaustively cover all potential forms of building shell improvement measure. Alternative forms of improvement measures could have included:

- Reorganising the plan to improve efficiency by improving window orientation and potential cross flow ventilation;
- Insulation of internal walls and floors between living/sleeping and unconditioned parts of the house;
- Insulating subfloor walls;
- Differential insulation of walls floors and ceilings in living, sleeping and unconditioned areas;
- Reducing sub floor ventilation by laying polythene over the soil and reducing the number of subfloor vents;
- In lightweight construction the use of deeper framing members, (i.e. upgrade from 90mm to 120mm or even 140mm) would allow for higher performance insulation to be installed.

In addition it must be recognised that technology improvements such as super efficient glazing systems with U values less than 1.0 may potentially be readily available by 2020.

Despite the existence of these potential alternative options for improvement beyond that modelled in this study it must be recognised that at the relatively high levels of performance already achieved by the measures included in this study (typically 7.5 stars and above) additional measures will only provide modest incremental increases in performance. It would be problematical to demonstrate that more than 0.5 stars above the maximum performance levels found in this study was in fact practically achievable and even if achievable such additional measures are highly unlikely to be cost effective.

1.2.2 Water Heating

For water heating a total of 3 levels of improvement options or scenarios were examined in addition to the BAU case. Each of the 3 levels examined (low, medium and high) included a suite of water heater types relevant to each jurisdiction.

The BAU case was based on analysis undertaken in the study "Energy Use In The Australian Residential Sector 1986 – 2020" (EES 2008). Estimates for the expected propensities of the various types of water heaters for the BAU case were provided by George Wilkenfeld and Associates – see Table A3.2.

The scenarios examined were:

LOW Scenario
In terms of performance and energy outcomes and cost the "Low" scenario was simply assumed to be at the mid point between the BAU case (noted above) and the Medium Scenario Case (detailed below)

MEDIUM Scenario
Systems were limited to the following:

- Flat plate solar electric high efficiency (not including evacuated tube)
- Flat plate solar gas with instantaneous boost
- Solar in tank gas high efficiency
- Gas storage 6 star
- Gas instantaneous 6 star
- Heat pump best currently available (COP = 3.1 at 20MJ/Day)

See Table A3.2 below for the assumed market shares of each of these technologies.

HIGH Scenario
Systems were limited to the following:

- Flat plate solar gas with instantaneous boost
- Solar electric evacuated tube pumped 3.9m2 collector area
- Solar in tank gas high efficiency
- Gas instantaneous 7 star[25]
- Heat pump best R&D (COP = 3.8 at 20MJ/Day)

See Table A3.2 below for the assumed market shares of each of these technologies.

The assumed share of each technology in the medium and high scenarios was based upon a redistribution of the shares shown in the BAU case, taking into account fuel type availability. In the case of heat pumps it was assumed that their share would rise to 10% (medium case) and 20% (high case) in all jurisdictions.

Table A3.2 : Schedule of Water Heater System Stringencies

System Type	Assumed System Share By State							
	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
BAU Scenario								
Electric storage Primarily smaller day rate units in class 2 dwellings	3%	2%	0%	10%	12%	50%	10%	5%
Gas storage 4 star	31%	31%	13%	11%	43%	12%	10%	30%
Gas instant 5 star	46%	35%	17%	53%	21%	21%	4%	50%
Flat plate solar medium efficiency hor. tank integral	6%	3%	50%	8%	3%	12%	57%	0%
Flat plate solar gas inst boost 302J	7%	19%	12%	13%	14%	3%	14%	10%
Solar in tank gas high efficiency	2%	8%	3%	3%	7%	1%	5%	4%
Heat pump current average (COP = 2.5 at 20MJ/Day)	5%	2%	5%	2%	0%	1%	0%	1%

[25] At present a gas instantaneous water heater with a 7 star performance level is yet to be available in Australia. This is therefore a theoretical performance level. If such a product were not to be available by 2015 or 2020 than the High scenario would need to exclude this type from the list of options noted

LOW Scenario – Energy Consumption assumed to be midway between BAU and Medium Scenario Case								
MEDIUM Scenario								
Flat plate solar Electric high eff hor. tank integral	6%	3%	50%	8%	3%	12%	57%	0%
Flat plate solar gas inst boost 302J	7%	19%	12%	13%	14%	3%	14%	10%
Solar in tank gas high efficiency	2%	8%	3%	3%	7%	1%	5%	4%
Gas storage 6 star	31%	31%	13%	11%	43%	12%	10%	30%
Gas instant 6 star	44%	29%	12%	55%	23%	62%	4%	46%
Heat pump best available (COP = 3.1 at 20MJ/Day)	10%	10%	10%	10%	10%	10%	10%	10%
HIGH Scenario								
Flat plate solar gas inst boost 302J	7%	19%	12%	13%	14%	3%	14%	10%
Solar electric evacuated tube pumped 3.9m2	6%	3%	50%	8%	3%	12%	57%	0%
Solar in tank gas high efficiency	2%	8%	3%	3%	7%	1%	5%	4%
Gas instant 7 star	65%	50%	15%	56%	56%	64%	4%	66%
Heat pump best R&D (COP = 3.8 at 20MJ/Day)	20%	20%	20%	20%	20%	20%	20%	20%

It should be recognised that if the objective were to reduce energy consumption alone then the non solar boosted gas type water heaters would be excluded from the mix. These have however been retained as they represent a low cost means for achieving significant greenhouse gas savings.

1.2.3 Lighting

For lighting a total of 3 levels of improvement options were examined in addition to the BAU case. Each of the 3 levels examined (low, medium and high) were principally defined by an average performance level (maximum W/m^2). These performance levels were then further delineated in terms of performance levels in living spaces (i.e. where higher than average illumination levels are generally expected) and non living spaces (i.e. where lower than average illumination levels are generally expected).

Table A3.3 Residential lighting energy performance levels

Scenario	Average Max (W/m^2)	Living Spaces Max (W/m^2)	Non Living Spaces Max (W/m^2)
BAU	5	8.75	2.5
Low	4.5	7.5	2.5
Medium	4.0	6.5	2.5
High	2.0	2.75	1.5

The BAU case was based on the analysis in the study “Energy Use In The Australian Residential Sector 1986 – 2020” (EES 2008).

1.2.4 Pool Pumps and Pool Gas Heating

Pool Pumps

The BAU case for pool pumps was based upon on analysis undertaken in the study "Energy Use In The Australian Residential Sector 1986 – 2020" (EES 2008).

Advice relating to potential improvement options was sought from George Wilkenfeld and Associates who authored the current Commonwealth Regulatory Impact Statement for the introduction of MEPS and labelling for pool pumps.

For pool pumping it is estimated in the RIS that the proposed MEPS level will produce an approximate 10% savings in energy consumption, this was assumed to form the "Low" scenario case. The "High" scenario case was assumed to involve the use of variable speed drive pumps that are expected to produce savings of approximately 25%[26]. The "Medium" scenario was set between the "Low" and "High" scenarios at 85% representing the highest level of performance that may be achieved without resorting to the expense of state of the art variable speed drives. These settings are summarized in Table A3.4.

Gas Heating of Pools

For gas heating of pools there are no existing performance standards. The BAU case for pool gas heating was based upon on analysis undertaken in the study "Energy Use In The Australian Residential Sector 1986 – 2020" (EES 2008). Advice received from George Wilkenfeld and Associates suggested that the use of condensing flue water heaters (uncommon in Australia but used in the northern hemisphere) would be expected to reduce energy consumption by approximately 15% below the BAU case. This then was assumed to form the "High" scenario case. The low and medium cases were simply set with performance levels equally spaced between the "High" scenario and the BAU case i.e. Low scenario = 5% reduction in energy consumption and Medium scenario = 10% reduction in energy consumption below the BAU case. These settings are summarized in Table A3.4.

Table A3.4: Schedule of Pool Pump / Pool Heating Stringencies (% BAU Energy Consumption)

Scenario	Pumping	Gas Heating
BAU	100%	100%
Low	90%	95%
Medium	85%	90%
High	75%	85%

1.3 Methodology : Thermal Performance

1.3.1 Overview

The model used in this study to estimate likely costs and benefits of the various performance improvement options as noted in Section 1.2.1 above is based on the model developed by Energy Efficient Strategies in the study "Energy Use In The Australian Residential Sector 1986 – 2020" (EES 2008)". The building shell / space conditioning section of that model is shown in Figure A3.2 below.

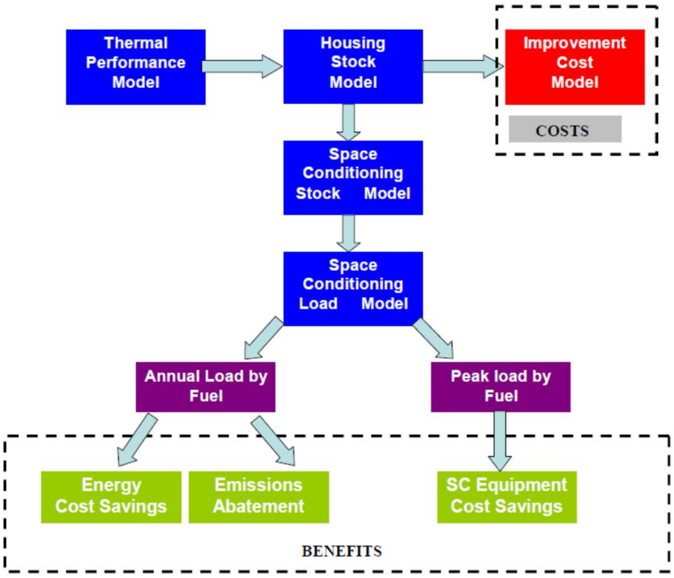
At the heart of the model is a model of Australia's housing stock, in particular the cohorts of housing expected to be affected by regulation during the study period.

[26] Advice received from George Wilkenfeld and Associates

Estimates of benefits and costs associated with various building shell improvement measures are undertaken in two separate processes, one to determine benefits and one to determine costs as described further below.

The determination of benefits in energy reduction terms was simply estimated for each performance target (6 star to 10 star in 0.1 increments) by taking the NatHERS performance standard at the particular star rating adjusted for floor area, splitting it into heating and cooling components, adjusting for actual user behaviour in terms of occupancy and thermostat settings and then constraining those results in accordance with the space conditioning model.

Figure A3.2: Schematic of thermal performance stringency assessment model



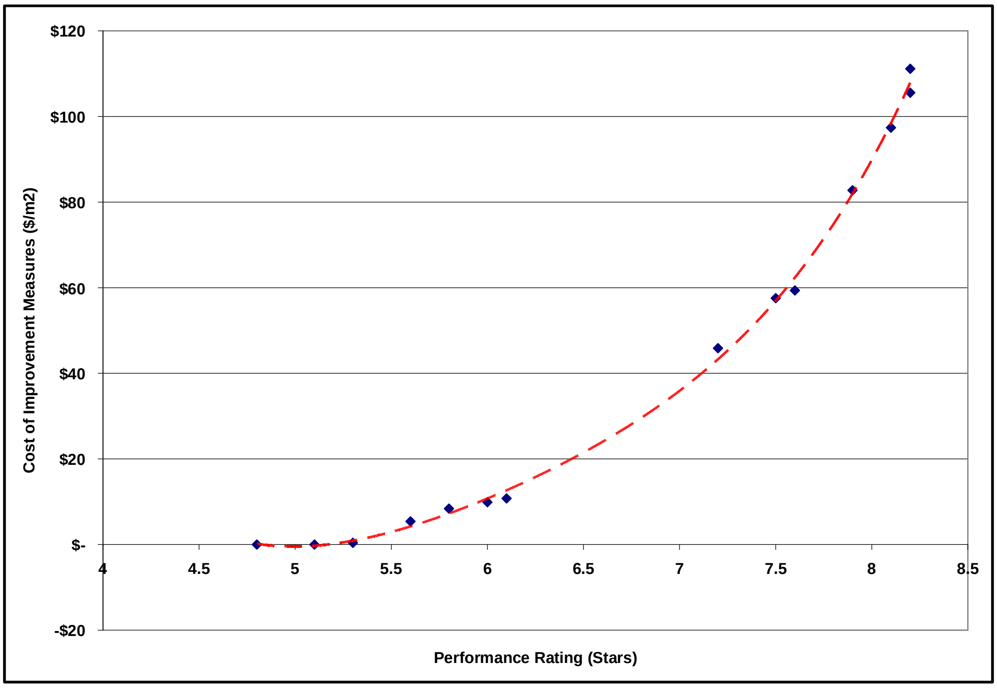
The determination of the cost of improvement measures was undertaken using AccuRate simulations of each dwelling type examined in each climate zone. Improvement measures were added progressively to each dwelling using a least cost approach. The results comparing cost of aggregate improvements with achieved star rating were then plotted and a polynomial curve fitted to each set of points to allow extrapolation of results (Average fit for polynomials was better than 0.99). A total of 12 dwelling types (18 variants in total including 4 orientation options for each of the class 2 dwellings) had cost benefit curves developed in each of the eight climate zones examined (i.e. 144 curves developed in total).

The dwelling types included detached, semi detached and flats and the climate zones modelled, one for each jurisdiction, were:

NSW = Richmond 28 = BCA 6
VIC = Moorabbin 62 = BCA 6
Qld = Brisbane 10 = BCA 2
SA = Adelaide 16 = BCA 5
WA = Perth 13 = BCA 5
TAS = Hobart 26 = BCA 7
NT = Darwin 1 = BCA 1
ACT = Canberra 24 = BCA 7

A sample of the improvement cost vs performance benefit curves can be found in Figure A3.3. Complete data sheets for all dwelling types in all climate zones are available in the separate technical appendices document (see Appendix 6). These datasheets include the improvement cost vs benefit curves as well as details of the improvement measures (and their costs) applied to achieve the various levels of performance.

Figure A3.3 : Sample Improvement Cost vs Benefit Curve – Small Detached Dwelling BV Walls / Concrete Floor - Moorabbin Climate Zone 62



Source: Energy Efficient Strategies

1.4 Estimating Benefits

1.4.1 Space Conditioning Load Model

In this study "performance based" loads were utilized. Performance based loads refer to the expected heating and cooling loads associated with those dwellings that have been designed to meet a particular thermal performance requirement, in this case a minimum NatHERS star rating at or above the BAU case of 6 stars. For dwellings built in accordance with performance requirements, their expected heating and cooling loads are defined by the stringency of the particular performance requirement as applicable.

The specified performance levels in NatHERS for each star band cannot however be simply used as the basis for the expected space conditioning loads. Firstly, the loads are total loads only and do not differentiate between heating and cooling loads. Secondly, the loads ascribed to the different star bands are based on a number of assumptions that do not accurately reflect actual user behaviour. To deal with these issues the following modifications to the NatHERS loads at each modelled star band were undertaken:

- A split of the load between heating and cooling components;
- An adjustment for floor area;
- An adjustment for the occupancy to better reflect actual user behaviour;
- An adjustment for the thermostat operation to better reflect actual user behaviour.

The nature of these modifications is described in more detail in the following sub-sections:

Split for Heating and Cooling

Performance levels specified in NatHERS are a combined heating and cooling performance measure i.e. a total heating and cooling load that must not exceed so many MJ per m^2 per annum. For the purposes of this study which considers space heating and space cooling end uses separately, these values had to be split into heating and cooling components. The basis for the apportionment of load was an analysis of 625 sample dwellings used in the BCA thermal performance standard development process. This analysis provides an expected split of heating and cooling load for each of the 69 climate zones.

Adjustment for Floor Area

The AccuRate performance calculation includes a floor area adjustment factor. This factor effectively adjusts the space conditioning load performance requirement needed to meet a particular star rating level according to the net conditioned floor area of the dwelling. The adjustment factor is in the form of a 5th level polynomial. Generally the effect of this factor is, within certain limits, to increase the stringency level of the star rating with increasing floor area. For the purposes of this study this meant that star band threshold levels need to be adjusted in accordance with the floor area of each dwelling type modelled.

Adjustment for Occupancy

The default settings for occupancy (i.e. hours of occupation) used in the NatHERS rating scheme assume that the dwelling is to be occupied 24 hours a day (although not all zones within the dwelling are assumed to be continuously occupied e.g. living spaces 7am until midnight, bedroom spaces 4pm until 9am). These default settings are reflected in the stringency levels for the star bands i.e. the target load for a particular star rating assumes that this 24 hour occupancy profile will prevail.

In the study *Energy Use In The Australian Residential Sector 1986 – 2020* (EES 2008) it was determined that on average, householders will occupy their dwellings somewhat less than the hours of occupancy assumed in the default settings embodied in AccuRate. The impact of this lower occupancy will be to reduce the expected space conditioning load. This reduction is however less than one might expect due to the fact that an unoccupied dwelling will to some degree store heat gained or lost during hours of non occupancy and this heat surplus or deficit will then be addressed once the dwelling is re-occupied. The exact impact is subject to a complex set of variables and has been assessed by comparing loads in sample houses under default AccuRate conditions with loads in the same houses under the occupancy conditions assumed in the EES 2008 study. From this comparative analysis the derived ratio is then applied as a scaling factor to the various star band stringency levels examined.

Adjustment for Thermostat Operation

The default settings for thermostat operation (i.e. at what temperature is it assumed that an occupant shall initiate and at what temperature they shall maintain their heating or cooling) are specified in the thermal performance modelling software that is used to determine NatHERS ratings. These default settings are reflected in the stringency levels for the star bands i.e. the target load for a particular star rating assumes that householders will behave in accordance with those assumptions. As noted in the study Energy Use In The Australian Residential Sector 1986 – 2020" (EES 2008) it has been assumed that the thermostat settings for heating operation are realistic and therefore valid for use in this study. However in terms of cooling operation it has been postulated on the basis of some survey evidence that householders, following initiation of cooling, will on average expect a higher level of comfort than that adopted as the default in AccuRate. This is particularly apparent in the warmer climates.

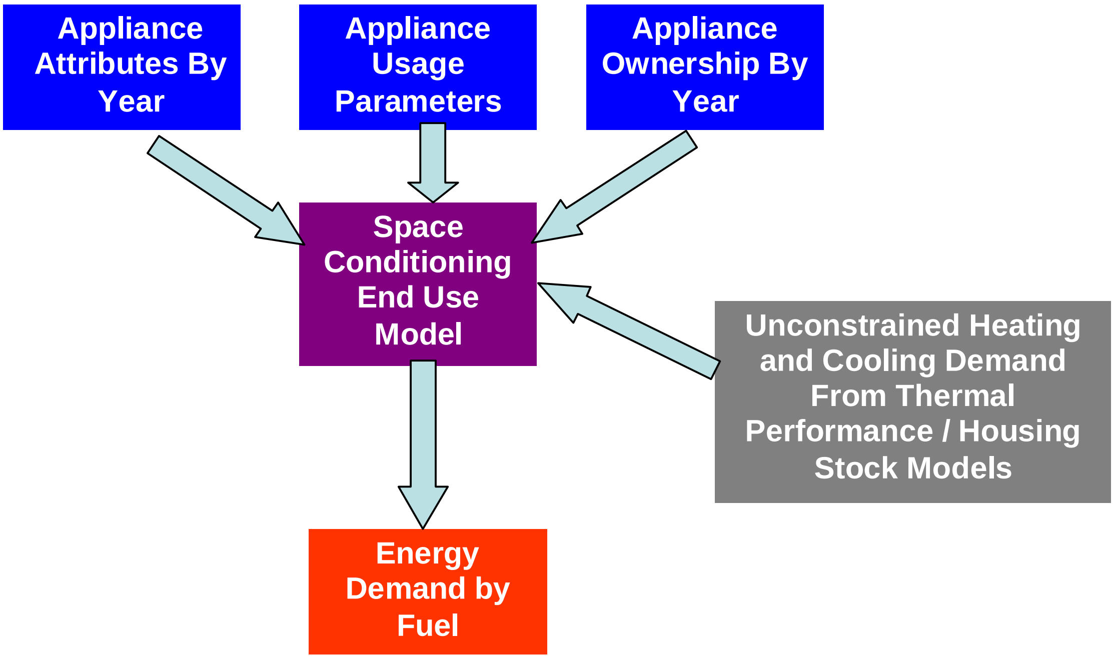
The exact impact is subject to a complex set of variables and has been assessed by comparing loads in sample houses under default AccuRate conditions with loads in the same houses under the occupancy conditions assumed in the EES 2008 study. From this comparative analysis the derived ratio is applied as a scaling factor to the cooling component of the various star band stringency levels examined in this study.

1.4.2 Space Conditioning Equipment Model

Overview

This section provides details of the input data and assumptions regarding appliance and equipment attributes as well as usage patterns that have been applied to determine total energy consumption estimates for space conditioning equipment.

Figure A3.4: Space Conditioning Equipment Model



Source: *Energy Efficient Strategies*

From a modelling perspective, there are a number of important elements that can affect the energy consumption of appliances and equipment. These are:

- Attributes – some of the key characteristics of the product will affect its energy consumption such as size, capacity, energy consumption (energy consumption rate) and/or energy efficiency.
- User interaction with the product.
- Climate and weather – this is most important for heating and cooling loads, but also for some products that are affected by temperature such as refrigeration. The performance of the building shell itself is a key determinant for heating and cooling requirements for a given climate.
- Stock – the number of products in use will impact on the total energy consumption. The stock is estimated using ownership (ratio of stock to the number of households). As the share of equipment type varies between states (mostly driven by the availability of mains gas), separate factors have been developed for each region for modelling purposes.

For heating and cooling loads, the parameters for climate and weather effects are determined from the AccuRate modelling for "in use" mode. In terms of user interaction with the appliances, occupancy profiles are built into the AccuRate models as set out below. Another important factor for space heating and cooling equipment is zoning – this reflects the technical capacity of each type of appliance to heat or cool the whole home or only part of the home. Note that zoning assumptions are assumed to be constant over time for the purposes of this report.

The end-use model developed for this project is not a formal forecasting model for future end-use energy consumption and should not be treated as one. However, it provides insights into the relative energy consumption for space heating and cooling to maintain equivalent levels of energy service for future changes in building shell performance. For all building shell scenarios, the same ownership forecasts and appliance attributes are used.

The approach adopted for this study for modelling purposes is similar to that used for the study titled *Energy Use in the Australian Residential Sector 1986-2020* (EES 2008).

Attribute overview

Appliance attributes are key parameters that affect, directly or indirectly, the energy consumption of a product. For heating and cooling equipment, the key attributes are the size (capacity) and the energy efficiency.

For each product modelled in this study, the average attributes of new products that flow into the stock for each year of the modelling period are estimated to 2020. No attempt has been made to estimate the distribution of energy consumption or attributes of products sold within each year, but in reality there will be products that use both more energy and less energy than the assumed average values (or will be more efficient and less efficient than the average). The attributes of products installed in each state in each year are assumed to be uniform across that state for modelling purposes (even where ownership varies by region). For example, the average efficiency of new gas ducted heaters installed in the Melbourne metropolitan area are assumed to be of the same efficiency as those installed in regional Victoria (even though ducted gas heaters are less prevalent).

The main data sources used to estimate appliance and equipment attributes in this study are:

- Registration data – Air conditioners are regulated for energy efficiency and there is detailed data on the attributes lodged with state regulators, including energy efficiency and capacity data. EES has access to this registration data and the attributes by year of registration and this has been examined to determine trends in attributes of new products over time.
- The AGA Certified Directory of Gas Appliances (AGA 2007) provided useful data for gas space heaters and gas ducted heaters in terms of capacity and efficiency.
- Sales data – Sales data has been used to determine the sales-weighted efficiency trends of products over time for air conditioners. This is the most accurate approach where sales of individual models can be cross-matched to registration data to derive an accurate estimate of overall average sales weighted new energy consumption (as well as other key attributes) by year. Most detailed sales data has been obtained from GfK Marketing (based in Sydney) which is a commercial monitoring service that collects model sales information (including actual price paid) from retailers for a very wide range of products. Access to this data is purchased by subscription by E3. Some data on sales is also obtained from BIS Shrapnel in their biennial report titled *The household appliances market in Australia* (BIS 2006) (climate control report) for space heating and cooling equipment.
- Information published by *Informark* was used to corroborate air conditioner sales weighted data.
- Published product information – For some products, data published by manufacturers or suppliers on attributes and energy consumption was used to determine the profile of attributes over time for some products.

For the purposes of determining future average attributes by product, the impacts of the following energy programs have been included (programs that have been proposed but which are not included in future attributes trend estimates are shown in [square brackets]):

- Air conditioners (single phase, vapour compression, air to air) – cooling: MEPS and Labelling programs to start 2011.
- Air conditioners (single phase, vapour compression, air to air) – heating: MEPS and Labelling programs to start 2011.

- Air -conditioners – Evaporative: No future programs [water labelling or energy/water consumption standards not included].
- Electric Space Heating (resistive): No future programs (assumed to be 100% effective efficiency).
- Gas Space Heating (ducted/room): AGA energy labelling scheme since late 1980s including nominal MEPS requirements [proposals for new government MEPS not included].
- Wood Space Heating: No programs other than emission requirements (virtual elimination of open fireplaces by 2000).

Ownership

The number of products in use (together with their attributes) will impact on the total energy consumption of each type of equipment. Ownership data relates to the average number of each equipment type in households. The ownership of some products varies considerably across states (e.g. gas space heating is prevalent in Melbourne and less common in regional areas) while other types are more uniform. Data on future ownership to 2020 is estimated as a modelling input for this report. A household that does not have a particular equipment type (e.g. an air conditioner) is assumed to have no energy attributable to that equipment type.

The following important definitions are used in this report:

Penetration – the proportion of households in which one or more of a particular appliance type is present (irrespective of the number of units of that appliance in the household). This value is usually given as a percentage and the maximum value is 100%.

Stock – the total number of a particular appliance type in use within households. This value is given as an integer (usually thousands or millions). The stock refers to the number in regular use, or a proxy for the number in regular use.

Ownership – the ratio of stock to the total number of households. This value is usually given as a decimal number and can exceed 1.0.

Saturation – the average number of appliances per household only for those households with one or more of the appliance. The minimum value is 1.0.

The following important relationships are used in this report:

Stock = Ownership × Number of Households

Ownership = Penetration × Saturation

One of the main points of interest in this study is the impact of building shell efficiency improvements for new buildings on the energy consumption for space heating and space cooling. Changes in ownership over time reflect the existing stock of appliances and equipment in existing homes (including increases or decreases in the prevalence of each appliance type) plus the ownership of these appliances in new homes. Where there is a marked difference in ownership of a particular appliance type between the average stock and new homes (e.g. for gas ducted space heating), separate analysis has been conducted to explicitly capture the trends applying to new homes in the modelling data projected to 2020.

Space heaters are tracked as the “main” type of space heater by ABS4602 so only one main heater per house is assumed. In most households there will be some secondary heating sources, although their use will be highly variable. Secondary space heating is not modelled explicitly for this study.

Projecting or extrapolating future ownership levels based on historical trends has inherent uncertainties. For example, the explosion in air conditioner ownership after 2000 could not be reasonably predicted on the basis of historical data prior to 2000, as air conditioner ownership remained fairly steady through the 1990s.

Information on ownership of equipment installed in new homes was drawn from surveys from the BIS Shrapnel reports titled *Household Appliances Installed in New Dwellings and Renovations* (BIS 1999, 2003, 2007) plus analysis of the underlying trends in total stock derived from analysis of the ABS data over the modelling period. More detail on these elements is provided in the following sections.

Space cooling equipment

These products are broken into:

- Air conditioners reverse-cycle non-ducted (room type systems);
- Air conditioners cooling only non-ducted (room type systems);
- Air conditioners ducted (includes cooling only and reverse cycle types);
- Evaporative air conditioners (mostly central).

Non-ducted systems (room type) include window wall types and split systems.

The most important attribute for air conditioners is the overall energy efficiency, called the EER (energy efficiency ratio) for cooling and COP (coefficient of performance) for heating (where applicable). To a lesser extent capacity (maximum output) is of some interest, but this really only has an impact on energy estimates if the air conditioner is substantially undersized and only on peak heating or cooling days. Even in these cases, the energy impact is generally very small.

There are a number of sources for trends in air conditioner EER and COP. The main ones are MEPS and energy labelling registration data held by government, which have been available since the late 1980s, and more recently, GfK sales data, which provides actual sales and price by model for more that 80% of the total non-ducted market (this has been available since 2003). Other data sources provide data on capacity and sales (e.g. Informark 2007) and there is other data on share by type and by brand and complementary ownership data is also available (BIS Shrapnel 2006).

It has to be said that the air conditioner market is very complex with some 200 brands now in the market. None of the data sources cited above appear to be complete and this is made more complex by the fact that identical products can be installed in commercial and residential applications making these markets hard to quantify separately.

The primary data source used to track efficiency trends for air conditioners was the energy labelling and MEPS registration data which has been available since 1987. Average values by year were determined and then smoothed to remove annual random perturbations. While this approach assumes equal sales for each model registered, the actual sales weighted data from GfK from 2003 to 2006 closely mirrors the smoothed registration data, which provides added confidence to the accuracy of the analysis over a much longer period. The period from 2003 to 2006 was one of rapid change in the efficiency of air conditioners, with the introduction of MEPS for single phase units (which predominate the residential sector) in 2004 and a more stringent MEPS levels again in 2006 for most configurations (or 2007 for remaining types).

For ducted systems, the coverage by GfK is much lower than for non-ducted systems and the total market is much smaller. However, for these products the two data sets (registration data and GfK model sales) provide comparable values for efficiency.
A detailed sub-model of the trends and market share of each of the main air conditioner types is shown in Appendix B of EES (2008) and has been adapted for this study.

The registration system for ducted systems only provides data on the system efficiency at the entry point to the duct (as determined under AS/NZS3823.1.2). The overall performance of ducting is complex and a range of factors affect the overall losses (Delp 2007). For this study, a flat value of 25% energy losses (leaks and conduction losses) for all ducted systems are assumed on top of the claimed system efficiency. This has been applied to both air conditioning systems (heating and cooling) as well as central gas ducted systems. This factor effectively reduces the apparent system efficiency (and hence increases total energy consumption to maintain the specified internal conditions).

Inclusion of data on evaporative systems is always a vexed issue, as the energy service provided by refrigerative and evaporative systems is quite different. Based on published data from a range of manufacturers, an "equivalent" EER value was calculated. Equivalence in this sense relates to the relative energy consumption of these systems rather than the energy service which is delivered. An equivalent EER of 12 has been used as this is representative of a range of central ducted models which make up the majority of these systems. A lower equivalent EER (of the order of 5 to 8) would apply to smaller systems. The water consumption of these systems is significant but this has not been quantified for this study. Accurate water consumption data for these systems is difficult to find as most suppliers are reluctant to publish this data. A range of advances in pump and fan technology and in evaporators means that some new systems have much improved energy and water consumption attributes, but these have not been factored into the estimates. This is an area that warrants a more detailed study which focuses on these products.

Space heating equipment

These products are broken into:
- Electric resistive space heating;
- LPG gas non-ducted space heating;
- Mains gas ducted space heating;
- Mains gas non-ducted space heating;
- Reverse-cycle ducted space heating;
- Reverse-cycle non-ducted space heating;
- Wood space heating.

The most important attribute for heating is the overall efficiency (output over input in W/W or MJ/MJ). The capacity (maximum output) is also of interest, but this really only has an impact on energy estimates where the heater is sized only to heat part of the home, which is fairly common for some types of space heaters. This aspect is taken into account as the zoning factor applied to each technology type. The assumed zoning factor by type of heater is a reflection of the percentage of the floor area of the house that can be effectively heated by a typical (average capacity) space conditioning product.

There are a range of sources for trends in heater efficiency data. For reverse-cycle air conditioners, the same data sources for air conditioners have been used.

For resistive heating systems, a constant efficiency of 100% has been assumed for all years.

For gas heating systems (ducted and non-ducted), the primary source of data was the gas energy labelling data collected and published by the Australian Gas Association as part of the gas energy labelling scheme (AGA 2007), together with selected laboratory data to determine key parameters to enable modelling of the data. The attributes for room heaters assume that the combustion products are flued externally, which is the typical configuration in Victoria (this is not so true in some other states).

As described for air conditioners, a flat value of 25% for ducting losses for all ducted systems has been assumed on top of the system efficiency for gas ducted heaters. This factor effectively reduces the apparent system efficiency (and hence increases total energy consumption to maintain the specified internal conditions).

The efficiency attributes for gas heaters running on natural gas are assumed to be the same as for LPG. It is assumed that practically all ducted gas heaters will be operating on mains gas as operation on LPG would be prohibitively expensive in most cases. LPG is only used in a small number of households, almost exclusively in regional areas where mains gas is not available.

For wood heaters, data supplied by John Todd of the University of Tasmania was reviewed (Todd, 2007) together with certified product listing from the Australian Home Heating Association (AHHA, 2008). In January 2008 some 274 separate wood heater models were listed together with their efficiency data[27]. For these heaters the model average efficiency (based on three output levels) was 60%. However, John Todd suggests that these values are often somewhat overstated as the testing is done in ideal laboratory conditions with controlled fuel quality (compared to normal use in the home) and in some cases the products sold in the market appear to have a different specification to the approved models (which may be based on optimised prototypes). So the average assumed efficiency for wood heaters offered for sale in 2008 was downgraded by 8% to account for these factors. There has been a trend of gradual improvement over many years for solid fuel heaters as these have slowly increased their efficiency and decreased their particulate emission outputs. These improvements are being driven by recent requirements for suppliers to undertake testing to AS/NZS4012 and AS/NZS4013.

The share of open fires as a main space heater was significant in the 1960s and 1970s but this has shown a substantial decline in market share in recent years. In 2005 ABS4602 reported that only 7.5% of houses that used wood as their main heating source had an open fire in Victoria. This effectively constitutes an overall share of about 1% of space heating and this is steadily declining. The efficiency of an open fire is assumed to be 10% and Jetmaster ™ style open fires with some flue control are estimated to be 18%, these will make up a significant percentage of modern open fire places.

1.5 Estimating Costs

1.5.1 Sample dwellings

Selection of Class 1 sample houses

Tony Isaacs Consulting developed a model of Victorian housing stock to test a variety of energy saving programs for Sustainability Victoria in 2007 (TIC 2007a). This involved the development of three house plans which statistically matched the characteristics of a detailed sample of contemporary Victorian Housing. These house plans matched the average design and construction characteristics of the small (lower third of floor areas), medium (middle third) and large (upper third) houses from that sample.

The small and large house plans developed by Tony Isaacs and adopted in this study not only matched the average area of windows, orientation of windows, house size and construction materials found in the sample but also closely approximated the FirstRate4 point scores for Walls, Floors, Roofs, Windows and Air Leakage. In other words, the heat flow through all elements (as predicted by FirstRate4) of the selected dwellings matches that found in the 5 star sample.

Because the distribution of windows in the model houses approximates the window orientation found in the field the need to simulate the detached houses on multiple orientations was eliminated. It should be noted that the sample dwellings showed very little sensitivity to orientation.

As noted, the 5 star detached sample used in this study was based on houses constructed before the 5 star regulations were brought in to effect. The ACIL – Tasman report "Evaluation of the Victorian 5 star building standard" prepared for the Department of Sustainability and Environment (ACIL-Tasman, 2008) surveyed builders responses to the 5 star standard and confirmed that to a significant extent the dwellings produced post regulation were simply re specified versions of those produced before the introduction of

[27] see http://www.homeheat.com.au/certified.php

the regulations. The study did however find that in some cases builders were adopting some of the following re-design strategies:

- Reducing window sizes;
- Maximising north and east facing window areas, and minimising south and west facing windows;
- Locating living rooms to suit multiple orientations; and
- Reducing the use of courtyards and alfresco areas.

The information available in the ACIL Tasman report was not sufficiently detailed to allow statistical analysis of these trends. The improved design practice adopted by some builders as suggested in the ACIL Tasman report suggests that the estimates of the costs in this report are likely to be higher than found in the field (i.e. conservative).

The sample semi detached dwelling used for modelling was sourced from a set of approximately 160 house plans compiled by the Australian Greenhouse Office (now DCCEE). The adopted representative plan had a gross floor area of 160m^2 (NCFA = 144 m^2) which closely approximated the expected average size for semi detached dwellings.

In an early study the selected sample semi detached dwelling was rotated to face the four cardinal orientations and then simulated in a range of climate zones. The orientation which most closely approximated the average heating and cooling energy use of the four orientations was then selected to represent the average case for cost modelling. In all cases the case where the street orientation was to the south (bolded) was the case closest to the mean. Total space conditioning loads (in rating mode) for the other orientation options varied from the selected orientation by not more than 10%.

Plans of the sample class 1 sample houses can be found at the end of this Appendix.

Table A3.5: Evaluation of semi detached sample dwelling at 4 orientations

Floor	**Orientation**			**Heating**			**Cooling**			**Stars**
	Street	Back-yard	Side	Average heating	MJ/m2	% of average for climate and floor type	Average Cooling'	MJ/m2	% of average for climate and floor type	
						Cooler (Ballarat)				
Slab	W	E	S		237.1	105%		34.2	70%	5
Slab	N	S	W		236.5	105%		51.1	105%	4.8
Slab	E	W	N		209.8	93%		61.4	126%	5
Slab	S	N	E	225.0	216.6	**96%**	48.8	48.5	**99%**	5.1
Timber	W	E	S		223.4	105%		41.3	73%	5.1
Timber	N	S	W		224.9	106%		58.7	104%	4.8
Timber	E	W	N		197.9	93%		69.4	123%	5.1
Timber	S	N	E	212.2	202.5	**95%**	56.5	56.4	**100%**	5.2
						Milder (Moorabin)				
Slab	W	E	S		147.1	107%		27.4	76%	5
Slab	N	S	W		145.4	105%		37	103%	4.9
Slab	E	W	N		126.6	92%		42.3	118%	5.2
Slab	S	N	E	138.0	133	**96%**	36.0	37.1	**103%**	5.1
Timber	W	E	S		138.4	106%		32.1	78%	5.1
Timber	N	S	W		138.4	106%		42.1	102%	4.9

Floor	Orientation			Heating			Cooling			Stars
	Street	Back-yard	Side	Average heating	MJ/m2	% of average for climate and floor type	Average Cooling'	MJ/m2	% of average for climate and floor type	
Cooler (Ballarat)										
Slab	W	E	S		237.1	105%		34.2	70%	5
Slab	N	S	W		236.5	105%		51.1	105%	4.8
Slab	E	W	N		209.8	93%		61.4	126%	5
Slab	S	N	E	225.0	216.6	**96%**	48.8	48.5	**99%**	5.1
Timber	W	E	S		223.4	105%		41.3	73%	5.1
Timber	N	S	W		224.9	106%		58.7	104%	4.8
Timber	E	W	N		197.9	93%		69.4	123%	5.1
Timber	S	N	E	212.2	202.5	**95%**	56.5	56.4	**100%**	5.2
Milder (Moorabin)										
Slab	W	E	S		147.1	107%		27.4	76%	5
Slab	N	S	W		145.4	105%		37	103%	4.9
Slab	E	W	N		126.6	92%		42.3	118%	5.2
Slab	S	N	E	138.0	133	**96%**	36.0	37.1	**103%**	5.1
Timber	W	E	S		138.4	106%		32.1	78%	5.1
Timber	N	S	W		138.4	106%		42.1	102%	4.9
Timber	E	W	N		119.9	92%		47.8	116%	5.2
Timber	S	N	E	130.2	124	**95%**	41.3	43.1	**104%**	5.2
Warmer (Mildura)										
Slab	W	E	S		87.6	108%		90	81%	4.4
Slab	N	S	W		87.1	107%		114.5	103%	3.9
Slab	E	W	N		71.2	88%		129.3	117%	4
Slab	S	N	E	81.3	79.2	**97%**	110.8	109.4	**99%**	4.2
Timber	W	E	S		83.9	107%		99	81%	4.3
Timber	N	S	W		85.8	110%		123.6	102%	3.8
Timber	E	W	N		68.3	87%		142	117%	3.8
Timber	S	N	E	78.2	74.9	**96%**	121.6	121.7	**100%**	4

Source: Energy Efficient Strategies

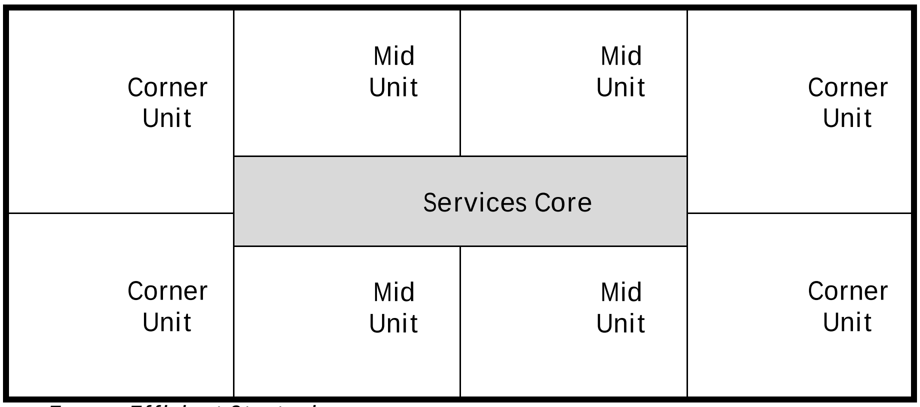
Selection of Class 2 sample dwellings

Apartments were divided into the following subgroups for thermal modelling purposes:

- Units located on the corners of the block (i.e. exposed on 2 sides);
- Units located on the face of the block (i.e. exposed on one side only).

In terms of costs of compliance the more exposed an apartment the higher the compliance costs are likely to be. For this study it was assumed that the apartments would have a relatively high level of exposure. The assumption was that the particular apartment block consisted of 50% corner units and 50% face units and that all units had an exposed roof. This represents a high cost (conservative) case. In reality most apartment blocks, particularly high rise apartment blocks are likely to have a lower level of exposure than assumed in this study.

Figure A3.5 : Schematic Floor Plan of Block of Flats



Source: Energy Efficient Strategies

The floor plans for modelling were selected to approximately match the average floor areas recorded by the ABS for class 2 dwellings. The apartment plans were loosely based on plans used in the Victorian Docklands development in terms of gross floor area, area of glazing and area of externally exposed surfaces and were developed by Tony Isaacs Consulting.

Class 2 dwellings will almost always share some of their walls with adjacent units. This limits the number of orientations where glazing can be installed. Consequently, class 2 dwellings are far more sensitive to orientation than class 1 dwellings which generally have a fairly even distribution of window orientations. Because of this sensitivity to orientation, this study includes performance and (more significantly) cost of improvement assessments for four different orientation scenarios i.e. the 4 cardinal orientations. This sensitivity to orientation may also prove to be significant when framing any future regulations, i.e., where thermal performance averaging provisions may be employed over an entire block of flats.

Plans of the sample class 2 houses can be found at the end of this Appendix.

A summary of the dwelling area characteristics follows:

Table A3.6: Overview of Dwelling Area Characteristics

	Small Detached Dwelling - Single Storey	**Large Detached Dwelling - Two Storey**	**Semi Detached Dwelling**	**Flat – middle Unit**	**Flat – corner Unit**
Ground Floor Area* (m^2)	188.6	153.5	92.6	120	108.8
Upper floor area (m^2)	0	112.1	70.9	0	0
Total floor Area* (m^2)	188.6	265.6	163.5	120	108.8
Ceiling Area (below Roof) (m^2)	188.6	102.9	130.8	120	108.8
Wall area (includes windows) (m^2)	179.5	263.2	177.4	48.1	74.8
Glazing area (m^2)	44.1	52.6	37.9	29.1	30.7
Glass to floor area ratio	23%	20%	23%	24%	28%

Source: Energy Efficient Strategies
** Excludes the area of any garages, verandahs courtyards etc*

Construction formats

Each dwelling type is modelled in a number of different construction formats designed to represent the most common construction types currently utilized by the building industry.

Table A3.7: Residential (Class 1) Dwelling Construction Variations

Dwelling	Floor	Walls	Roof	Orientation Options
Single storey Detached	CSOG	Brick Veneer	Pitched - Tiled	Closest to average performance
	Suspended timber	Brick Veneer	Pitched - Tiled	
	Suspended timber	Lightweight	Pitched - Tiled	
	CSOG	Cavity Brick	Pitched - Tiled	
Two Storey Detached	CSOG	Brick Veneer	Pitched - Tiled	Closest to average performance
	Suspended timber	Brick Veneer	Pitched - Tiled	
	Suspended timber	Lightweight	Pitched - Tiled	
	CSOG	Cavity Brick	Pitched - Tiled	
Semi Detached	CSOG	Brick Veneer	Pitched - Tiled	Closest to average performance
	Suspended timber	Brick Veneer	Pitched - Tiled	
Flat Mid unit	Suspended concrete	Precast	Concrete	N,E,S &W
Flat Corner Unit	Suspended concrete	Precast	Concrete	N,E,S &W

Source: Energy Efficient Strategies

1.5.2 Assessing costs

To determine the likely cost of any future regulation it is necessary to determine the improvement measures that would need to be applied to the Base Case sample dwellings such that the various thermal performance stringencies examined in this study can be achieved. All such measures are assessed with AccuRate in "rating mode". In this process it is important that the measures as far as is practical are applied in the order of most to least cost effective measure[28]. Such an approach will ensure the maximum benefit at the least cost and represents a reasonable response from the building industry to new regulations.

The building shell improvement measures to be examined include:

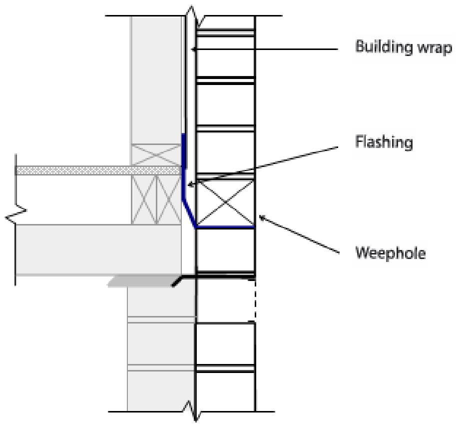
- Sealing strategies;
- Ceiling insulation;
- Wall insulation;
- Floor insulation;
- Improved performance combinations of glazing and window frames;
- Use of external shading devices;
- Improved ventilation;
- Use of ceiling fans.

A number of more specialised variants to these basic strategies shall also be included. These are:

[28] As a caveat to this principle the option of significantly reducing the area of glazing is generally avoided. Whilst this measure is by far the most cost effective improvement measure it is recognised that provision of reasonably sized glazed areas are generally favoured by home buyers and as such were assumed to have a value to home buyers at least equivalent to the savings associated with reductions in such window areas.

- *The application of self sealing dampers to exhaust fans*. These were relatively uncommon until fairly recently but now represent more common and cost effective thermal performance improvement practice.
- *The use of waffle pod concrete floor construction*. Research by Tony Isaacs in the study "Costs for achieving 5,6,7 and "8 star" fabric ratings in new Victorian houses" determined that the insulation properties of waffle pod slabs was superior to that of traditional slab on ground and that "the extra cost of setting up the waffles was compensated for through reduced excavation costs". The conclusion based on quantity surveying advice was that "waffle slabs with polystyrene waffles would not cost more than a conventional slab". This view is also shared by Cement Concrete Aggregate Australia who advise that waffle pod construction is "competitive with traditional slab on ground construction if not cheaper" and can be used "in all applications in which traditional slab on ground construction has been used for residential construction" (CCAA 2008).
- *The effective sealing of wall cavities in dwellings with suspended timber floors*. This relatively new and inexpensive technique is detailed by Tony Isaacs in the study "Costs for achieving 5, 6, 7 and "8 star" fabric ratings in new Victorian houses". It involves elimination of ventilation from the subfloor up a brick veneer wall cavity into an attic space through the application of a cavity flashing as per the following detail prepared by Wood Products Victoria which blocks air flow by repositioning cavity flashing.

Figure A3.6: Repositioning cavity flashing to reduce sub-floor ventilation



Source: Energy Efficient Strategies

This is not the only method of blocking the wall cavity. It could be just as easily sealed at the top as the bottom. This would typically add less than $100 to the cost of the house but has been found to improve the rating by 0.1 to 0.5 stars depending upon the climate.

- *The use of insulated cavity brick wall construction*: As a means of increasing the thermal mass of dwellings and thereby improving their thermal performance in many of the climate zones examined the option of replacing external walls with insulated cavity brick construction will be examined. Other options such as reverse brick veneer construction could also be used as a means for adding thermal mass, however this form of construction is very uncommon (even more so than cavity brick construction) and would not meet an apparent strong preference for an external brick finish.

The process for determining the cost associated with a particular performance target consists of a 2 step process as follows:

Step 1: Initially each individual improvement measure is applied to each dwelling format and then assessed through thermal simulation modelling to determine the most to the least cost effective measure (noting that this is likely to vary somewhat according to the climate zone examined).

Step 2: each dwelling is then modelled in a range of variations whereby improvement measures are added consecutively in the order from most cost effective to least cost effective (as determined in step 1). At each iteration the performance level achieved (i.e. star rating in rating mode) and the total cost of all included measures is assessed. This process then allows a cost of improvement vs performance (star rating) curve to be developed for each dwelling in each climate zone. Reference to these curves shall allow for the assessment of improvement cost at any performance level.

The starting point for this analysis is set somewhat below the expected BAU case of 6 stars. This allows for a more accurate cost curve fitting process. This means that in the initial analysis, the 6 star case has an assumed cost, however given that 6 stars is the BAU case this "cost" is then deducted from the cost of achieving higher than 6 star performance standards such that all costs will be relative to the BAU case.

The full range of improvement measures proposed for examination in this study is detailed in Table A3.8 below.

Table A3.8: Residential Improvement Measures

Element	**Base Case**	**Improvement options to be assessed**		
		Option 1	**Option 2**	**Option 3**
Ceiling Insulation	R2.5	R3	R3.5	R4
Wall Insulation	R1.0	R1.5	R2	R2.5
Floor Insulation (Timber Floors)	Nil	R1.5	R2	R3
Floor Insulation (concrete floors)	Nil	R1.5 (waffle pod)		
Sealing of Exhaust Fans	No	Yes		
Ceiling Fans	Nil	Living	Living + Beds	
Glazing	System 1**	See systems noted below		
Shading (Blinds)	Nil	Living only*	All*	
Ventilation (window opening)	As presented	Double openable area		
Cavity Brick construction	No	Yes + R2.0		

* Excludes southern façade

Source: Energy Efficient Strategies

Notes:

Weather stripping to Windows	*Yes*
Weather Stripping to doors	*Yes*
Holland Blinds	*Yes*
Wall cavities (Timber Floors)	*Sealed*

Glazing systems

Table A3.9: Glazing Systems Modelled

System	Panes	Type	Gap	Frame	U System	SHGC (System)	Library File
System 1 (Base Case)	single	clear	N/A	Std Aluminium	6.44	0.75	Generic 02
System 2	single	Low E (comfort plus)	N/A	Std Aluminium	4.44	0.52	Trend aluminium comfort plus neutral
System 3	Double	clear	10mm Argon	Std Aluminium	3.58	0.64	Trend Aluminium 4-10-4 clear
System 4	Double	Low E	10mm Argon	Std Aluminium	2.79	0.6	Trend Aluminium 4-10-4 advantage Low-E
System 5	Double	Tint +LowE	10mm Argon	Std Aluminium	2.79	0.46	Trend Aluminium Bronze 4-10-4 advantage Low-E
System 6	Double	clear	12mm Argon	High Performance	2.51	0.62	Trend ceder awning 4-12-4 Clear
System 7	Double	Low E	12mm Argon	High Performance	1.73	0.58	Trend cedar awning 4-12-4 Advantage low E
System 8	Double	Tint +LowE	12mm Argon	High Performance	1.74	0.44	Trend cedar awning Bronze 4-12-4 Advantage low E
System 9	Triple	clear + sungate 500	12mm Argon	High Performance	1.3	0.4	Paarhammer Triple glazed 4-12-4-12-4 - clear,clear,sungate 500

Source: Energy Efficient Strategies

1.5.3 Other settings – "in use" mode

Ceiling heights

Presently, the minimum ceiling height permitted in habitable rooms of new dwellings is 2.4 metres. This means that the average ceiling height is likely to be somewhat more than this, although cost impacts associated with higher ceilings mean that for the bulk of housing produced 2.4m will be representative. For this study ceiling heights were set to a value between 2.4m and 2.7m designed to match the sample dwellings external wall area with that determined from the sample used by Tony Isaacs Consulting.

Shading

The overshadowing of dwellings by features other than those that form part of the dwelling (e.g. eaves which are explicitly modelled on the basis of the sample dwelling design) can impact on heating and cooling loads. Examples of sources of overshadowing include; adjoining properties, trees and shrubs, fencing and so on. Unfortunately there is no known source that can provide data on the extent of such shading on an average dwelling in Australia.

Detached Dwellings

For the detached dwellings a solar discount or "suburbia" factor was applied to the AccuRate output results for heating and cooling loads. The suburbia factors used were adapted from those determined in the study "Energy Use in the Australian Residential Sector 1986 – 2020 (EES 2008). The selected factors were as detailed in Table A3.10 below.

Table A3.10: Suburbia factor for detached dwellings

Climate Zone	Suburbia Factor Heating	Suburbia Factor Cooling
Sydney	108%	93%
Melbourne	105%	93%
Brisbane	109%	97%
Adelaide	107%	94%
Perth	107%	94%
Hobart	104%	100%
Darwin	100%	97%
Canberra	104%	88%

Source: Energy Efficient Strategies

Semi-detached Dwellings and Flats

For this sample, overshadowing from features that form part of the dwellings plus the features of dwelling attached to the sample dwelling was accounted for in the analysis. In addition, shading was assumed from a neighbouring property (i.e. on the opposite side to the attached property)

Curtains and Blinds

There is no known source of data on the extent and types of internal and external window coverings used in Australian households. Privacy considerations suggest that most households are likely to have some form of internal window covering at least in some rooms.

For the purposes of this study it has been assumed that all windows were fitted with Holland blinds. This is the default setting adopted in AccuRate in rating mode. In terms of limiting heat transfers, holland blinds rank midway between the least effective option (no internal window coverings) and the most effective option (heavyweight curtains). Operation of the internal blinds was set to be in accordance with the default AccuRate assumptions regarding average user behaviour. The AccuRate software offers no user options to vary these behavioural settings.

For the purposes of this study no external blinds were assumed to be fitted in the Base Cases of the sample dwellings. Where windows have large eaves, verandas or other such shading features, or where the windows face orientations where little direct solar gain is received during the cooling season, the absence of external blinds will make little difference to the thermal performance of the dwelling. For dwellings with windows that are subject to significant solar gain during the cooling season then the potential addition of blinds to these windows has been allowed for by inclusion in the range of improvement strategies applied.

Natural Ventilation

All dwellings in the sample are assumed to be able to be cooled, at least in part, using outside air when favourable conditions exist. By default the AccuRate software opens external openings for ventilation at any time of the day if the zone temperature is too high for comfort and the conditions are favourable. If the house can be kept within comfort parameters using natural ventilation only, then the air conditioning is not activated. If ventilation alone is not able to maintain comfort conditions, the external openings are assumed to be closed and the air conditioning (where available) is started.

For this study the default AccuRate operation of ventilation openings has been utilised, except that the trigger temperatures for switching back to natural ventilation after air conditioning has been initiated have been modified as previously noted. For all windows it has been assumed that during the cooling season that flywire screens are fitted (these will reduce the efficacy of the natural ventilation).

Infiltration

Infiltration of air into and out of a dwelling serves to transfer heat into and out of the dwelling. The level of infiltration is mainly affected by the following factors:

- Whether or not there are any unsealed chimneys;
- Whether or not wall or ceiling vents are present;
- Whether or not exhaust fans are present;
- Whether or not vented down-lights are present;
- How well windows and doors are sealed;
- Whether or not there are vented skylights;
- The external wind speed.

There is little available data on the characteristics of the building stock (existing or incoming) in terms of these factors, so professional judgment was used when setting these parameters. The following assumptions were adopted:

Chimneys

Chimneys, if present (this is unlikely) shall be assumed to be sealed i.e. have dampers fitted. None of the sample dwellings examined in this study had chimneys.

Wall or ceiling vents

In line with current practice no wall or ceiling vents shall be assumed to be present.

Exhaust Fans

For all sample dwellings modelled in this study the following assumptions were made in respect of provision of mechanical ventilation systems:

- All kitchens are fitted with one unsealed exhaust fan;
- All bathrooms are fitted with one unsealed exhaust fan;
- All en-suites (where present) are fitted with one unsealed exhaust fan.

Window and door sealing

Door and window sealing was set to “small” gaps i.e. well sealed. Weather stripping was assumed to have already been included in the BAU case.

Wind speed

Prevailing wind speed and direction is pre-specified in the AccuRate default TMY climate files. Wind speed in the weather file represents air speed at 10 m height. This wind speed is modified to reflect the height of the building and wind resistance provided by a suburban location.

1.5.4 Schedule of Rates

The following schedule of rates was constructed by Energy Efficient Strategies with input from Davis Langdon.

Table A3.11: Schedule of Rates – General market

Insulation Options			
Ceiling Insulation	R value	Rate	Per
Foil	~0.6	$4.50	M^2
Batts	1.5	$6.10	M^2
Batts	2	$7.34	M^2
Batts	2.5	$8.29	M^2
Batts	3	$9.07	M^2
Batts	3.5	$9.28	M^2
Batts	4	$9.49	M^2
Batts	4.5	$9.70	M^2
Wall Insulation	R value	Rate	Per
Foil	~0.9	$5.16	M^2
Batts	1.5	$7.24	M^2
Batts	2	$8.48	M^2
Batts	2.5	$11.00[1]	M^2
Polystyrene (For Cavity Brick option)	2.5	$20.00[2]	M^2
Floor Insulation	R value	Rate	Per
Heavy foil	~1.2	$6.79	M^2
Batts	1.5	$9.94	M^2
Batts	2	$11.19	M^2
Batts	2.5	$12.13	M^2
Batts	3	$13.07	M^2
Glazing Options (Note: costs are cost over aluminium standard frame with single clear glazing)			
		Rate	Per
Double 6 mm gap		$65.00	M^2
Double 12 mm gap		$75.90	M^2
Double 12 mm gap low e coating		$90.00	M^2
Premium Double Glazing 12 mm low e, Argon fill and timber frame		$140.00	M^2
Reduction in window area		-$84.00	M^2
Tint		$22.00	M^2
Single low e (laminated)		$39.80	M^2
Air leakage			
		Rate	Per
Seal gaps		$1.00	per M^2 of floor area
Door seals		$25.00	per door
Window weatherstrip		$10.00	per M^2 openable window
Exhaust Fan Draft Stoppa		$25.00	Per unit
External shading			
Blinds		$75.00	per M^2 of blind
Blinds - small windows		$95.00	per M^2 of blind
Eaves - best		$30.00	per M^2 of eave
Eaves - worst		$55.00	per M^2 of eave
Other			
Cavity Brick Construction (plaster internal)		$78.00[3]	per M^2 of floor area

Notes:
1. Estimate of cost of R2.5 wall insulation determined by Tony Isaacs consulting following consultation with ICANZ. ICANZ in fact estimate costs to builders to be as low as $7.80/m². Allowing 25% for overheads and profit this would equate to a cost of just $9.75/m². Whilst this low value may be achieved once significant increase in production have been realised, it was considered more conservative to use the higher value of $11.00/m²

2. Estimate of cost for increasing insulation in cavity brick construction from an assumed R1.0 to R2.5. R1.0 is the level assumed in the cost attributed to cavity brick construction.
3. There is a degree of uncertainty regarding the cost of cavity brick construction compared to that of the Base Case (brick veneer). Cavity brick construction will cost more than brick veneer construction mainly as a result of the following factors:

- *Higher cost of materials and labour in the construction of the inner brick wall with plaster lining.*
- *Requirement for larger footings to support the additional weight*
- *Increased wall thickness (300mm compared to 250mm)*
- *Increased window frame sizes and or increased reveal and wind mould sizes needed to accommodate thicker walls*
- *Additional scaffolding costs (in some cases)*
- *More costly installation of services into external walls*
- *More costly roof tie down provisions*

Reed construction data (http://www.reedconstructiondata.com.au/news/news02.html) suggests that the price differential between cavity brick and brick veneer was $78/m^2. This figure was derived from Western Australia where cavity brick construction is a popular form of construction. Austral bricks who promote cavity brick construction (http://www.fullbrick.com.au/8_advantages.php) were contacted in relation to the cost differential. Their advice, based on a comparative study of otherwise identical dwellings (one brick veneer and one cavity brick) was that the cost differential was "in the order of 10% extra for cavity brick." Based on the cost analysis of new dwellings in the study, Costs for achieving 5, 6 , 7 and 8 star fabric ratings in new Victorian houses (TIC 2007a) this would equate to an additional cost of approximately $75/m2. For the purposes of this study the more conservative (higher) value of $78/m^2 was used.

In Table A3.12 below, the detailed schedule of rates by State for key building elements, prepared by Davis Langdon, is reproduced.

Table A3.12: Schedule of Residential Rates by State

Item	Specification	Rate basis	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Ceiling Insulation	R2.5 batt	per m2	$9.00	$9.00	$9.00	$9.45	$9.45	$9.63	$9.63	$9.18
Ceiling Insulation	R3 Batt	per m2	$12.00	$12.00	$12.00	$12.60	$12.60	$12.84	$12.84	$12.24
Ceiling Insulation	R3.5 Batt	per m2	$13.00	$13.00	$13.00	$13.65	$13.65	$13.91	$13.91	$13.26
Ceiling Insulation	R4 Batt	per m2	$14.00	$14.00	$14.00	$14.70	$14.70	$14.98	$14.98	$14.28
Ceiling Insulation	R5 Batt (added cost of structural provisions???)	per m2	$17.00	$17.00	$17.00	$17.85	$17.85	$18.19	$18.19	$17.34
Wall Insulation	R1 batt or foil	per m2	$5.16	$5.16	$5.16	$5.42	$5.42	$5.52	$5.52	$5.26
Wall Insulation	R1.5 batt	per m2	$7.24	$7.24	$7.24	$7.60	$7.60	$7.75	$7.75	$7.38
Wall Insulation	R2 batt	per m2	$8.48	$8.48	$8.48	$8.90	$8.90	$9.07	$9.07	$8.65
Wall Insulation	R2.5 batt	per m2	$11.00	$11.00	$11.00	$11.55	$11.55	$11.77	$11.77	$11.22
Wall Insulation	R1.0 polystyrene to cavity brick	per m2	$9.00	$9.00	$9.00	$9.45	$9.45	$9.63	$9.63	$9.18
Wall Insulation	R1.5 polystyrene to cavity brick	per m2	$12.00	$12.00	$12.00	$12.60	$12.60	$12.84	$12.84	$12.24
Wall Insulation	R2.0 polystyrene to cavity brick	per m2	$15.00	$15.00	$15.00	$15.75	$15.75	$16.05	$16.05	$15.30
Timber floor Insulation	R1.5 batt	per m2	$9.94	$9.94	$9.94	$10.44	$10.44	$10.64	$10.64	$10.14
Timber floor Insulation	R2.0 batt	per m2	$11.19	$11.19	$11.19	$11.75	$11.75	$11.97	$11.97	$11.41
Timber floor Insulation	R3.0 batt	per m2	$13.07	$13.07	$13.07	$13.72	$13.72	$13.98	$13.98	$13.33
Concrete floor	Slab on ground	per m2	$70.00	$70.00	$70.00	$73.50	$73.50	$74.90	$74.90	$71.40
Concrete floor	Waffle Pod (assumed same cost as slab on ground - QS to advise)	per m2	$70.00	$70.00	$70.00	$73.50	$73.50	$74.90	$74.90	$71.40
Sealing of Exhaust Fans	Draft Stoppa	each	$25.00	$25.00	$25.00	$26.25	$26.25	$26.75	$26.75	$25.50
Ceiling Fan	1200mm sweep ceiling fan (basic)	each	$150.00	$150.00	$150.00	$157.50	$157.50	$160.50	$160.50	$153.00
Window system 1*	single-clear--Std Aluminium Frame-U=6.44- SHGC=0.75	per m2	$250.00	$250.00	$250.00	$262.50	$262.50	$267.50	$267.50	$255.00
Window system 2	single-Low E (comfort plus)--Std Aluminium Frame-U=4.44- SHGC=0.52	per m2	$300.00	$300.00	$300.00	$315.00	$315.00	$321.00	$321.00	$306.00
Window system 3	Double-clear-10mm Argon-Std Aluminium Frame-U=3.58- SHGC=0.64	per m2	$400.00	$400.00	$400.00	$420.00	$420.00	$428.00	$428.00	$408.00
Window system 4	Double-Low E-10mm Argon-Std Aluminium Frame-U=2.79- SHGC=0.6	per m2	$450.00	$450.00	$450.00	$472.50	$472.50	$481.50	$481.50	$459.00
Window system 5	Double-Tint +LowE-10mm Argon-Std Aluminium Frame-U=2.79- SHGC=0.46	per m2	$475.00	$475.00	$475.00	$498.75	$498.75	$508.25	$508.25	$484.50
Window system 6	Double-clear-12mm Argon-High Performance Frame-U=2.51- SHGC=0.62	per m2	$500.00	$500.00	$500.00	$525.00	$525.00	$535.00	$535.00	$510.00
Window system 7	Double-Low E-12mm Argon-High Performance Frame-U=1.73- SHGC=0.58	per m2	$550.00	$550.00	$550.00	$577.50	$577.50	$588.50	$588.50	$561.00
Window system 8	Double-Tint +LowE-12mm Argon-High Performance Frame-U=1.74- SHGC=0.44	per m2	$575.00	$575.00	$575.00	$603.75	$603.75	$615.25	$615.25	$586.50
Window system 9	Triple-clear + sungate 500-12mm Argon-High Performance Frame-U=1.3- SHGC=0.4	per m2	$650.00	$650.00	$650.00	$682.50	$682.50	$695.50	$695.50	$663.00
External Blinds	Canvas or similar external blind	per m2 (average)	$85.00	$85.00	$85.00	$89.25	$89.25	$90.95	$90.95	$86.70
Additional Window Sash	Window system 1* - increase from 35% to 70% openning sashes	per m2 window	$262.50	$262.50	$262.50	$275.63	$275.63	$280.88	$280.88	$267.75
Additional Window Sash	Window system 2 - increase from 35% to 70% openning sashes	per m2 window	$315.00	$315.00	$315.00	$330.75	$330.75	$337.05	$337.05	$321.30
Additional Window Sash	Window system 3 - increase from 35% to 70% openning sashes	per m2 window	$420.00	$420.00	$420.00	$441.00	$441.00	$449.40	$449.40	$428.40
Additional Window Sash	Window system 4 - increase from 35% to 70% openning sashes	per m2 window	$472.50	$472.50	$472.50	$496.13	$496.13	$505.58	$505.58	$481.95
Additional Window Sash	Window system 5 - increase from 35% to 70% openning sashes	per m2 window	$498.75	$498.75	$498.75	$523.69	$523.69	$533.66	$533.66	$508.73
Additional Window Sash	Window system 6 - increase from 35% to 70% openning sashes	per m2 window	$525.00	$525.00	$525.00	$551.25	$551.25	$561.75	$561.75	$535.50
Additional Window Sash	Window system 7 - increase from 35% to 70% openning sashes	per m2 window	$577.50	$577.50	$577.50	$606.38	$606.38	$617.93	$617.93	$589.05
Additional Window Sash	Window system 8 - increase from 35% to 70% openning sashes	per m2 window	$603.75	$603.75	$603.75	$633.94	$633.94	$646.01	$646.01	$615.83
Additional Window Sash	Window system 9 - increase from 35% to 70% openning sashes	per m2 window	$682.50	$682.50	$682.50	$716.63	$716.63	$730.28	$730.28	$696.15
Wall Type	Brick Veneer Construction	per m2 wall	$250.00	$250.00	$250.00	$262.50	$262.50	$267.50	$267.50	$255.00
Wall Type	Cavity Brick Construction	per m2 wall	$180.00	$180.00	$180.00	$189.00	$189.00	$192.60	$192.60	$183.60
Flexible ducting	400mm - Flexible ducting R0.6	per lineal metre	$35.00	$35.00	$35.00	$36.75	$36.75	$37.45	$37.45	$35.70
Flexible ducting	400mm - Flexible ducting R1.0	per lineal metre	$37.00	$37.00	$37.00	$38.85	$38.85	$39.59	$39.59	$37.74
Flexible ducting	400mm - Flexible ducting R2.0	per lineal metre	$40.00	$40.00	$40.00	$42.00	$42.00	$42.80	$42.80	$40.80
Flexible ducting	400mm - Flexible ducting R3.0	per lineal metre	$44.00	$44.00	$44.00	$46.20	$46.20	$47.08	$47.08	$44.88
Flexible ducting	200mm - Flexible ducting R0.6	per lineal metre	$16.00	$16.00	$16.00	$16.80	$16.80	$17.12	$17.12	$16.32
Flexible ducting	200mm - Flexible ducting R1.0	per lineal metre	$17.00	$17.00	$17.00	$17.85	$17.85	$18.19	$18.19	$17.34
Flexible ducting	200mm - Flexible ducting R2.0	per lineal metre	$19.00	$19.00	$19.00	$19.95	$19.95	$20.33	$20.33	$19.38
Flexible ducting	200mm - Flexible ducting R3.0	per lineal metre	$21.00	$21.00	$21.00	$22.05	$22.05	$22.47	$22.47	$21.42

* See sample products in column D below

		Example system
Window system 1	single-clear--Std Aluminium Frame-U=6.44- SHGC=0.75	Standard Aluminium - single clear glazed
Window system 2	single-Low E (comfort plus)--Std Aluminium Frame-U=4.44- SHGC=0.52	Trend aluminium comfort plus neutral
Window system 3	Double-clear-10mm Argon-Std Aluminium Frame-U=3.58- SHGC=0.64	Trend Aluminium 4-10-4 clear
Window system 4	Double-Low E-10mm Argon-Std Aluminium Frame-U=2.79- SHGC=0.6	Trend Aluminium 4-10-4 advantage Low-E
Window system 5	Double-Tint +LowE-10mm Argon-Std Aluminium Frame-U=2.79- SHGC=0.46	Trend Aluminium Bronze 4-10-4 advantage Low-E
Window system 6	Double-clear-12mm Argon-High Performance Frame-U=2.51- SHGC=0.62	Trend ceder awning 4-12-4 Clear
Window system 7	Double-Low E-12mm Argon-High Performance Frame-U=1.73- SHGC=0.58	Trend ceder awning 4-12-4 Advantage low E U=1.73
Window system 8	Double-Tint +LowE-12mm Argon-High Performance Frame-U=1.74- SHGC=0.44	Trend ceder awning Bronze 4-12-4 Advantage low E U=1.74
Window system 9	Triple-clear + sungate 500-12mm Argon-High Performance Frame-U=1.3- SHGC=0.4	Paarhammer Triple glazed 4-12-4-12-4 - clear,clear,sungate 500

Source: Davis Langdon

1.6 Methodology : Water Heaters

1.6.1 Estimating Energy Consumption

For modelling purposes these products were broken into the following main categories of water heater types:

- Electric storage water heaters;
- Gas instant (LPG) water heaters;
- Gas instant (mains gas) water heaters;
- Gas storage (LPG) water heaters;
- Gas storage (mains gas) water heaters;
- Heat pump water heaters;
- Solar electric water heaters;
- Solar gas in line boosted water heaters;
- Solar gas in tank boosted water heaters.

Analysis was based upon the model used in the study "Energy Use in The Australian Residential Sector 1986 – 2020" (EES 2008). This study in turn relied upon a study by Thermal Design Ltd entitled "Annual energy Use of Domestic Water Heaters" (Thermal Design Ltd 2007).

In summary the overall approach to modelling was to:

- Determine the hot water energy demand by state.
- Add in the hot water demand from clothes washers (dependent on selection of water temperature and connection type) and dishwashers by state.
- Allocate the hot water load by ownership share (this assumes that hot water loads do not vary significantly by water heater type – while there is some anecdotal evidence that some water heater types are more prevalent in larger homes, there is no detailed data to support this at the moment).
- Determine the total energy requirement (including conversion efficiency and storage losses) for the particular water heater type – this is a function of hot water load (which varied by year and by state).
- In the case of solar systems, calculate the solar contribution for the hot water load and the relevant climate zone(s).
- In the case of solar systems, subtract the solar contribution to give a net estimated energy demand for boosting by fuel by state by year. An explicit estimate of solar contribution (in PJ) at a state level is also provided by this approach.

The hot water demand model was designed to take into account different average usage levels at a state level. An assumed base consumption of 110 litres of hot water per day per household was used – this declines with household size (50% was assumed to be fixed and not household size dependent) and the overall hot water demand is also expected to decline with an increase in hot water saving devices such as low flow shower heads.

The energy consumption embodied in this demand was adjusted for average cold water temperatures by state. Heat losses from storage type water heaters were adjusted on the basis of average storage temperatures and ambient temperatures by state. External hot water demand by clothes washers and dishwasher, as generated by the stock model for these products used in the study Energy Use in The Australian Residential Sector 1986 – 2020 (EES 2008), was directly added onto the base hot water demand.

1.6.2 Estimating Costs

As noted previously, for water heating a total of 3 levels of improvement options or scenarios were examined in addition to the BAU case. Each of the 3 levels examined (low, medium and high) included a suite of water heater types relevant to each jurisdiction.

Costs associated with the various water heater types were largely based on data derived from the Decision RIS for the water heater phase out (George Wilkenfeld and Associates 2010) That study provided costs for a number of the water heater types included in this study but not all. Where costs were not available from the Wilkenfeld study, estimates were made by Dr Hugh Saddler based on some limited market research[29].

The costs used were exclusive of any value associated with RECs or any subsidies that may be available.

Table A3.13 : Assumed Cost of Various Hot Water Systems (Excludes RECs and subsidies)

System No	Water Heater Type – Cost for Stock average size	Main fuel	Assumed Cost ($)
1	Offpeak electric storage	Electricity	1554
2	Continuous electric storage	Electricity	966
3	Gas storage 4 star	Gas	1297
4	Gas instant 5 star	Gas	1218
5	Flat plate solar medium eff hor tank integral 302J	Electricity	3717
6	Flat plate solar high eff hor tank integral 302K	Electricity	4412
7	Flat plate solar medium eff gas inst boost 302J	Gas	5197
8	Solar electric good evacuated tube pumped 3.9m2	Electricity	6617
9	Solar electric good evacuated tube pumped 2.5m2	Electricity	5514
10	Solar in tank gas high eff 302K	Gas	5699
11	Heat pump good current	Electricity	3873
12	Gas storage 6 star (Based on GWA cost of 5 star)	Gas	1585
13	Gas storage 7 star (Based on GWA cost of 5 star)	Gas	1801
14	Gas instant 6 star	Gas	1488
15	Gas instant 7 star	Gas	1691
16	Heat pump best available	Electricity	4841
17	Heat pump best R&D	Electricity	5809
18	Gas storage 5 star	Gas	1441
19	Gas instant 5.5 star (small)	Gas	1353

Source: Energy Efficient Strategies

1.7 Methodology : Lighting

1.7.1 Estimating Energy Consumption

Base Case assumptions for lighting energy use were based upon the method used in the study "Energy Use in The Australian Residential Sector 1986 – 2020" (EES 2008). Unfortunately there is little metering data against which to confirm the base assumptions.

[29] Noting that in the high efficiency scenario no data was available in relation to the likely cost of some of the systems as they are yet to be either imported into or produced in Australia.

The main technologies included in the Base Case were incandescent (now encapsulated QH type), quartz halogen downlights, linear fluorescent and compact fluorescent and the following parameters were used to estimate lighting energy:

- Technology energy efficiency;
- Typical lighting levels (lux) in living areas and non-living areas by technology type (noting that QH systems tend to have very high lighting levels);
- Resulting power density for each lighting type (calculated);
- Technology share by floor area for living and non-living areas;
- Share of floor area for living and non living areas (40%/60% modelled);
- Total average floor area per house;
- Usage in living (2 hours per day per fitting) and non living areas (0.4 hours per day per fitting).

The BCA 2010 case (BAU) and the three scenarios modelled were based upon a much simplified analysis taking into account the specified maximum power density for lighting (see Table A3.14 below) as well as the average floor area.

Table A3.14: Schedule of Lighting Stringencies (W/m2)

Scenario	Max (W/m^2)	W/m2
LOW	Average	4.5
	Living Spaces	7.5
	Non Living Spaces	2.5
MEDIUM	Average	4
	Living Spaces	6.5
	Non Living Spaces	2.5
HIGH	Average	2
	Living Spaces	2.75
	Non Living Spaces	1.5

Source: Energy Efficient Strategies

The power density has been differentiated between living and non living areas. It has been assumed that non living areas would generally be serviced using compact fluorescent lamps and that the power density in these areas would be lower than in living areas (generally only 2.5W/m^2 except in the "High" Scenario where it has been reduced to 1.5W/m^2).

It was assumed that 60% of the floor area was non living spaces (i.e. serviced by a lighting power density of 2.5/1.5 W/m^2). This left a significantly higher lighting power density (see A3.13) available for servicing living areas (assumed to be 40% of the floor area). This differentiation is important particularly because it is assumed that usage of lighting in living areas is significantly greater than in non living areas.

1.7.2 Estimating Costs

Costs associated with each scenario will be largely dependent upon the particular lighting technologies assumed to be adopted. Whilst lighting power densities can easily be reduced by reducing the service illumination, for this study it was decided that a minimum level of lighting service should be maintained in each scenario (noting that at present in the residential sector there are no provisions in the BCA for minimum service illumination levels).

A recent, yet to be published study commissioned by DCCEE entitled "Standby and Lighting Audit of Australian Households : 2010" indicates that on average, Australian households have installed lamps in fixed lighting that provide service illumination levels of approximately 200 Lux (this value excludes the impact of luminaires on overall illumination). In addition, this study also found that on average dwellings in Australia include approximately 15 down-lights (typically quartz halogen). Assuming that these provisions represent an acceptable standard of lighting service in terms of both illumination level and fitting type it can be assumed that the requirements of the low case (requiring an average lamp efficacy of 45 lumens/watt) and the medium case (requiring an average lamp efficacy of 50 lumens/watt) could be met through a combination of compact fluorescent lamps, compact fluorescent down-lights and a limited number of quartz halogen down-lights.

In the case of the high scenario, in order to maintain the required service illumination, a lamp efficiency of 100 lumens / watt would be required. This is achievable using current linear fluorescent technology (particularly T5) but this form of lighting is likely to be considered unacceptable in many household applications. This means that the High scenario relies on continuing improvements in lamp efficacy in particular the efficacy of compact fluorescent lamps and the efficacy of LED lamps (both currently at a maximum of approximately 65 lumens/Watt). LED lamps currently only account for approximately 1% of the installed lighting but with expected efficacy improvements and cost reductions this form of lighting may be a key to achieving the performance levels associated with the high scenario.

To achieve the Low scenario performance level it was estimated that 5 of the 15 down-lights assumed to be present would need to be changed to the compact fluorescent type attracting a premium of $11 each over and above the cost of Quartz Halogen down-lights. Costs were based on a limited market survey ($19 for standard QH down-light and $30 for CFL down-light)

To achieve the Medium scenario performance level it was estimated that all of the 15 down-lights assumed to be present would need to be changed to the compact fluorescent type attracting a premium of $11 each over and above the cost of Quartz Halogen down-lights. Costs were based on a limited market survey ($19 for standard QH down-light and $30 for CFL down-light)

To achieve the High scenario performance level it was assumed that all of the 15 down-lights assumed to be present would need to be changed to LED type down-lights that, by 2020, may meet the required efficacy target of 100 lumens per watt. Based on current costs this is expected to attract a premium of $66 each over and above the cost of Quartz Halogen down-lights. Costs were based on a limited market survey ($19 for standard QH down-light and $85 for LED down-lights). All other lighting is assumed to be either linear fluorescent or compact fluorescent (assuming compact fluorescent lamps meet the required efficacy target of 100 lumens per watt by 2020).

1.8 Methodology : Pool Pumps and Pool Gas Heating

Modelling of energy usage for pool pumping and heating was based upon the methodology developed by George Wilkenfeld & Associates. For details of this method, reference should be made to *Energy End Use Projections for the Residential Sector: Notes on Submodels for Swimming Pool and Spa Equipment, report prepared for the AGO/EES as part of the EES 2008 Baseline Study, prepared by George Wilkenfeld & Associates, June 2007.* The estimates covered pool filter pumps, pool/spas, pool heating systems (solar and gas) and separate spas and their heating systems (gas).

For pool pumping it is estimated in the RIS that the proposed MEPS level will produce an approximate 10% savings in energy consumption, this was assumed to form the “Low” scenario case. The “High” scenario case was assumed to involve the use of variable speed drive pumps that are expected to produce savings of approximately 25%[30]. The “Medium” scenario was set between the “Low” and “High” scenarios at 85% representing the highest level of performance that may be achieved without resorting to the expense of state of the art variable speed drives.

[30] Advice received from George Wilkenfeld and Associates

For pool heating, advice received from George Wilkenfeld and Associates suggested that the use of condensing flue water heaters (uncommon in Australia but used in the Northern hemisphere) would be expected to reduce energy consumption by approximately 15% below the BAU case. This then was assumed to form the "High" scenario case. The low and medium cases were simply set with performance levels equally spaced between the "High" scenario and the BAU case i.e. Low scenario = 5% reduction in energy consumption and Medium scenario = 10% reduction in energy consumption below the BAU case.

Based on discussions with George Wilkenfeld and Associates and limited market research the following costs were associated with each Scenario (Table A3.15).

Table A3.15: Pool Pump and Heater System Costs

Scenario	Pump Cost above BAU ($)	Heater cost above BAU ($)	Total cost above BAU ($)
Low	150	150	300
Medium	300	300	600
High	1500	1500	3000

Source: Energy Efficient Strategies

1.9 Sample Residential Dwelling Plans

1.9.1 Medium Detached Dwelling

Medium View from street

Plan

Source: Energy Efficient Strategies

1.9.2 Large Detached Dwelling

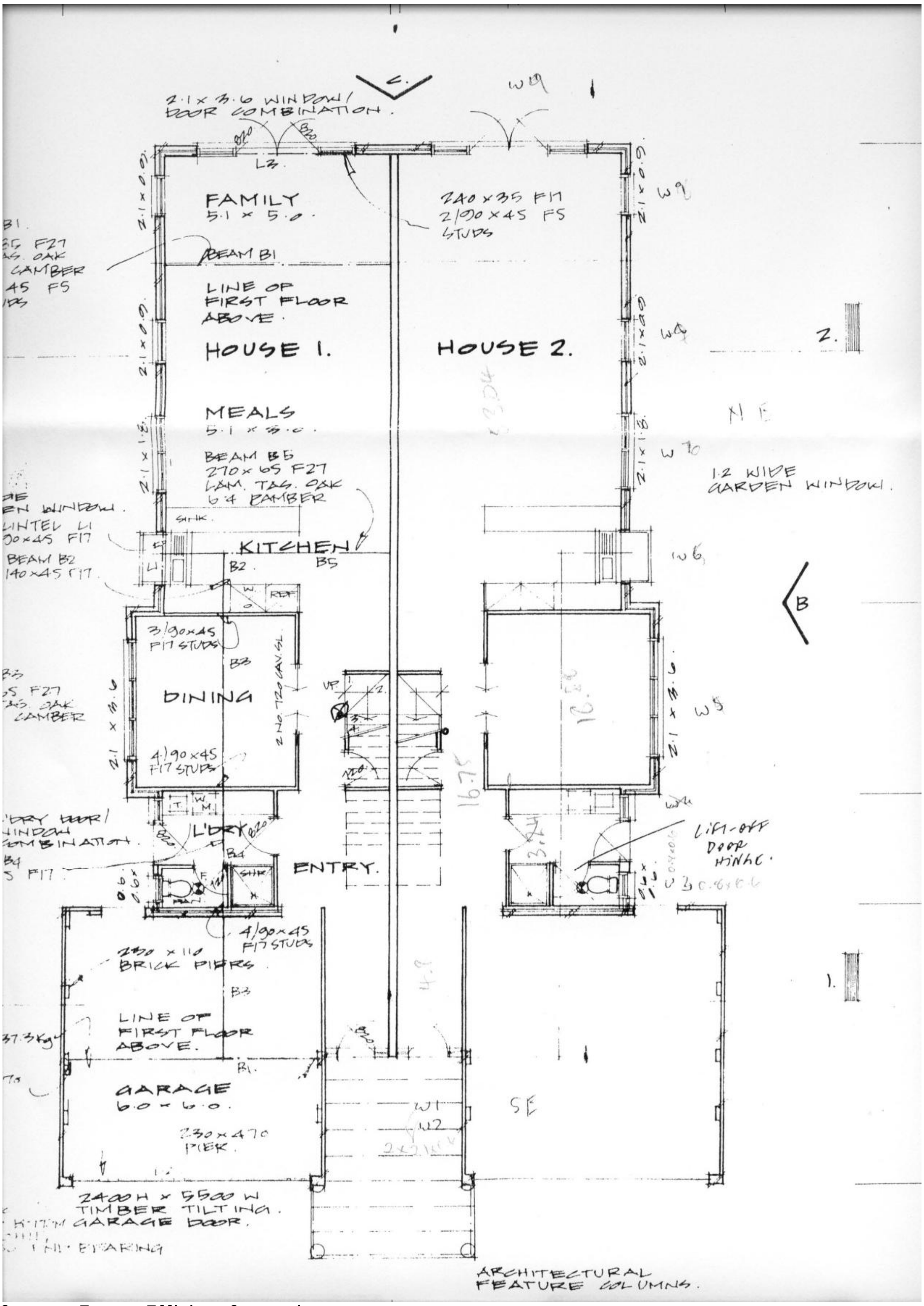
Large
View from
street

Ground

Upper

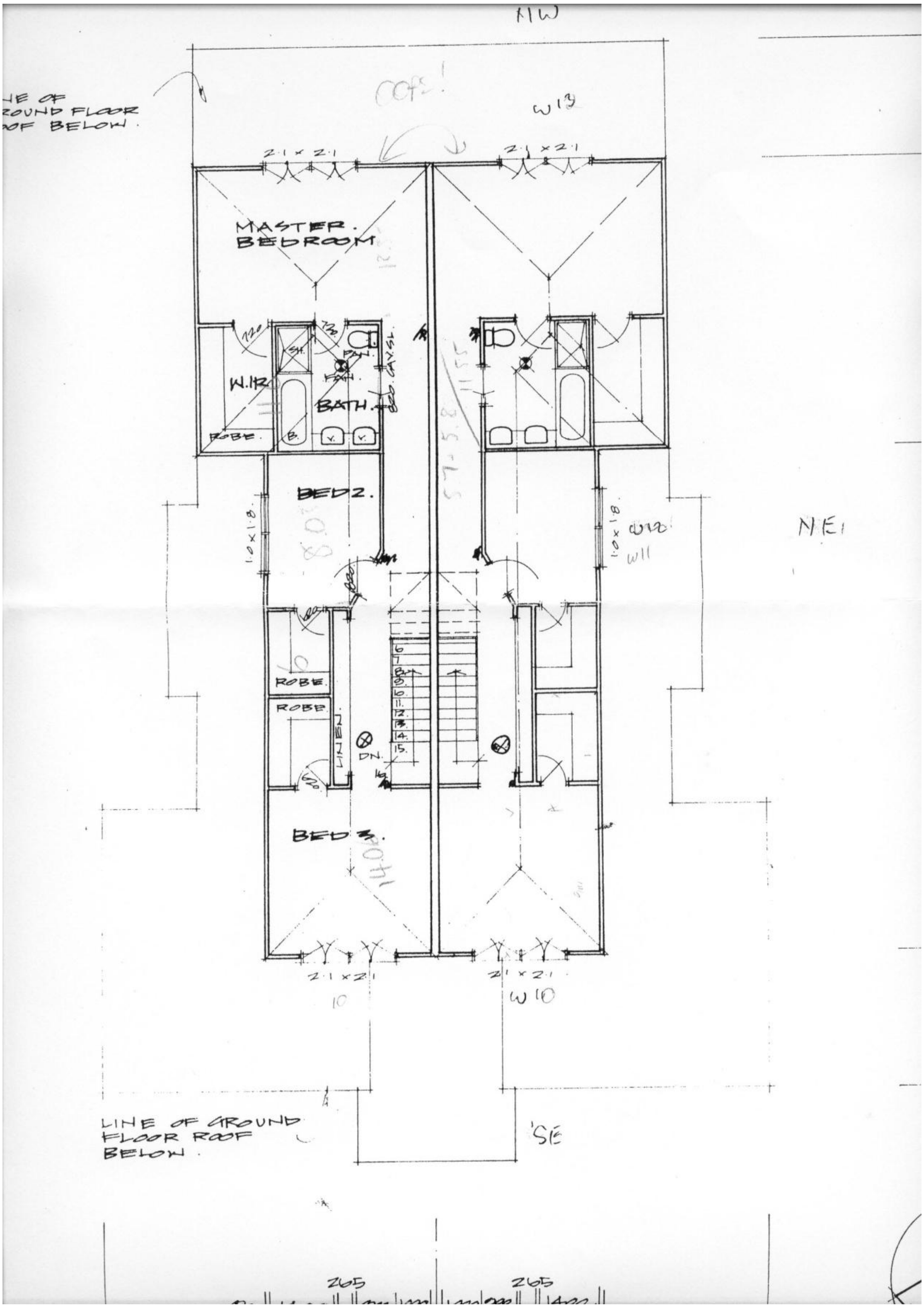
Source: Energy Efficient Strategies

1.9.3 Semi Detached Dwelling: Lower Floor



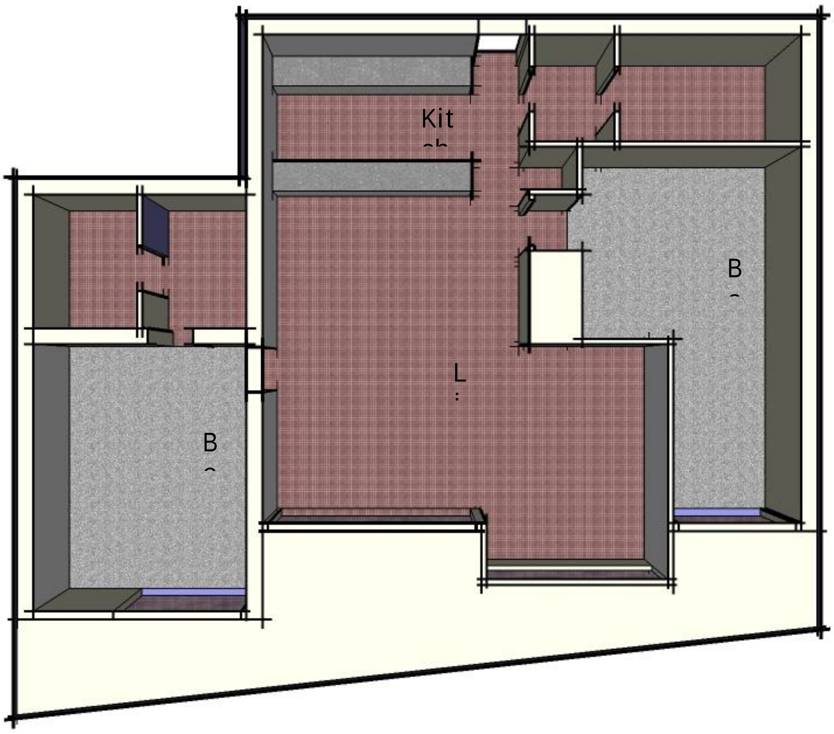
Source: Energy Efficient Strategies

Upper floor



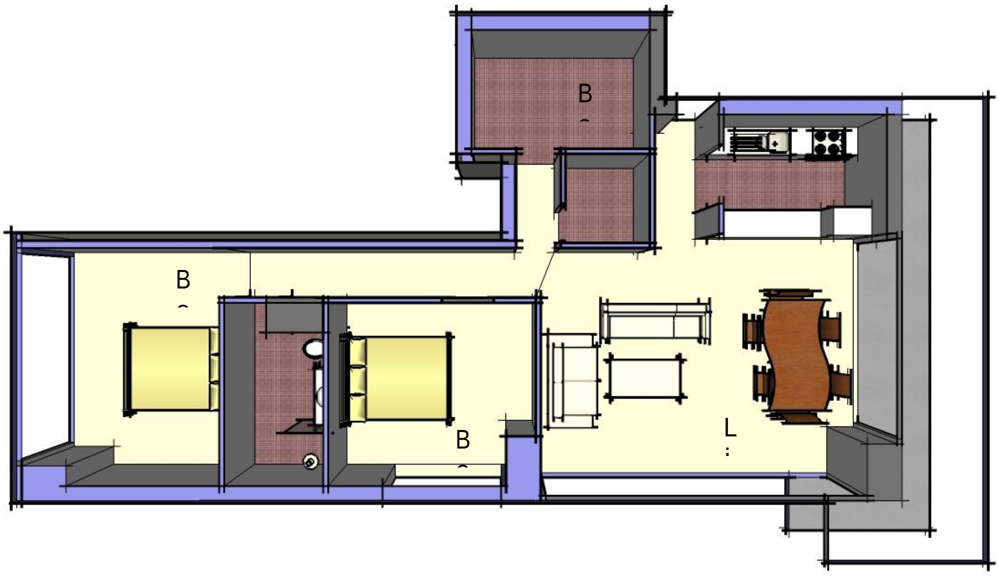
Source: Energy Efficient Strategies

1.9.4 Flat – Face (Non corner)



Source: Energy Efficient Strategies

1.9.5 Flat – Corner



Source: Energy Efficient Strategies

Appendix 4: Commercial Building Modelling

1. 10 Storey Office and Healthcare facility

Engineering Solutions Tasmania (EST) was engaged to conduct building modelling for this project. Specifically this involved investigating two classes of buildings: a 10 storey Class 5 Office and Class 9a Healthcare Facility. A representative building from each of these was modelled in the eight capital cities as follows:

Darwin	Climate Zone 1
Brisbane	Climate Zone 2
Sydney	Climate Zone 5
Perth	Climate Zone 5
Adelaide	Climate Zone 5
Melbourne	Climate Zone 6
Canberra	Climate Zone 7
Hobart	Climate Zone 7

This analysis investigates a baseline case of BCA 2010 along with three stringency levels of energy improvement. These four categories are summarised as follows:

1. BCA 2010 minimally compliant baseline
2. 40% Energy Reduction
3. 70% Energy Reduction
4. Net Zero Energy Scenario (building generates as much energy as it consumes, including for internal appliances or 'plug load').

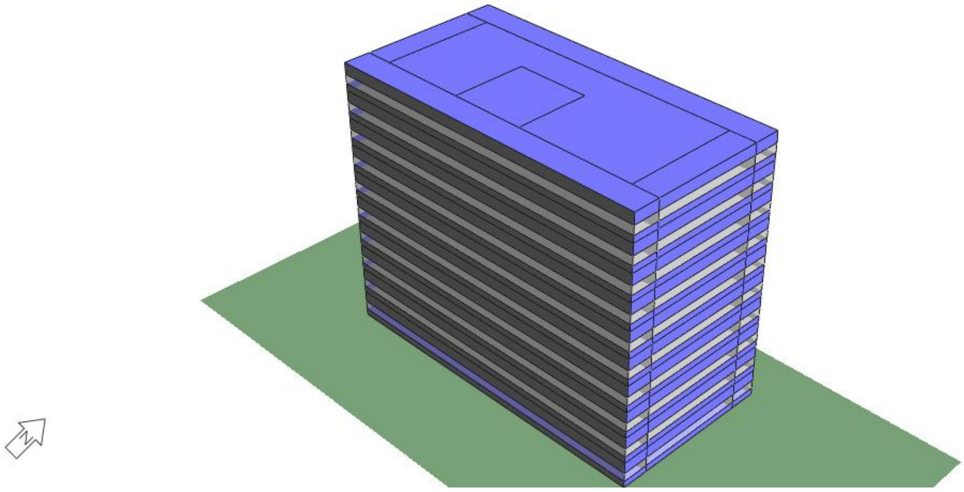
The office building chosen is in line with a previous study (pitt&sherry 2010). It is intended to be typical of office towers in the CBD areas of capital cities. It arbitrarily but conveniently comprises 10 storeys of 1,000m^2 each with a total NLA of 9,000m^2, which is to say that 10% of the area is services and common areas.

The perspective views below show the general form together with the zoning that has been applied to both the office and healthcare models. The healthcare model is similar to the office building but reflects the greater importance of external views for patient care and has a 2:1 aspect ratio compared with unity for the office building. It too has 10 storeys of 1,000m^2 each with a total NLA of 9,000m^2, which is to say that 10% of the area is services and common areas.

The office NLA has been treated uniformly throughout and the modelling parameters are easily defined by using profiles from the JV3 section of the BCA2010.

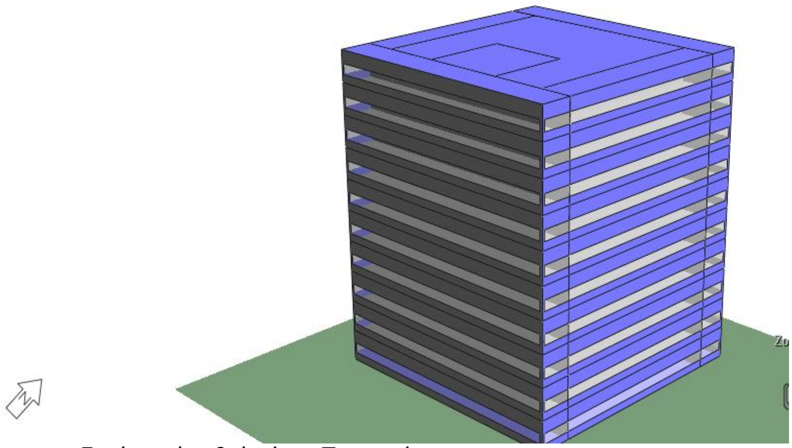
Healthcare facilities, however, are typically diverse in their type of operation and more difficult to typify. The approach of this modelling has been to capture two main aspects of healthcare building usage, firstly the ward type environment and secondly, the intensive treatment type of environment. This has been performed by defining ward areas on all the perimeters and treatment areas in the centre zone. Both ward and treatment areas operate 24 hours, 7 days per week.

Figure A4.1: Perspective View of the Healthcare Facility



Source: Engineering Solutions Tasmania

Figure A4.2: Perspective view of the 10 Storey Office



Source: Engineering Solutions Tasmania

1.1.1 Methodology

Starting with a BCA 2010 minimally compliant design using standard technology, the energy consumption baseline is established. Various improvements are then implemented for the increased stringency levels.

The methodology of the investigation is to use a high level thermal analysis package, 'Virtual Environment' Version 6.2, to perform a simulation of the building where possible. The value of this approach is that it takes into account the complexities of wind, solar and thermal storage effects and so provides a realistic prediction of the actual performance of the building over a representative year.

1.1.2 Treatment of Different Energy Forms

As a default energy form, electricity is assumed. Other forms of energy can be related to electricity in various ways; eg. based on greenhouse gas emissions, thermodynamic criteria, etc. In keeping with the metric of energy rather than carbon, this modelling assumes an energy based approach that 1 MJ of gas is equivalent to 0.33 MJ of electricity. This uses the idea that power generation generally has a conversion efficiency of gas to electricity of the order of 33%. This also works in reverse, that one unit of electricity can produce 3 units of heating (comparable to gas) with a typical heatpump COP of 3.

1.1.3 Treatment of Cogeneration and Trigeneration

An energy balance has been assumed in the case of cogeneration/trigeneration as follows:

- Generation efficiency of 30%
- Absorption COP of 0.64
- Waste Heat Recovery of up to 86%

These conversion efficiencies provide the following scenario:

333MJ of gas can produce:	100kW of electricity generation
233MJ of waste heat can produce:	150kW of cooling and/or
	200 kW of low grade heating

Of interest in this energy balance is that according to the present treatment of gas, the initial 333MJ of gas is equivalent to 111MJ of electricity, although it only produces 100MJ of electricity under the 30% efficiency. This represents a 10% penalty for using local generation of electricity compared with power station generation. This exact percentage may be open to debate, however, the principle of applying a penalty is considered important since central power stations produce at greater efficiency than small generators.

1.1.4 Treatment of Plug Loads

Internal electrical loads (plug load) are not generally part of the base-building power consumption, as this consumption is under the control of the tenant rather than the building designer and is not regulated by the BCA. Hence the baseline, 40% and 70% scenarios exclude tenant plug power from the calculations - except in so far as this power affects the HVAC loads. However, in line with the definition of 'zero energy' buildings as referring to the whole of building consumption, plug load power is included as part of the energy consumption in the -100% or Zero Energy scenario.

Note that this introduces an asymmetry into the four energy performance levels modelled, the effect of which is to reduce somewhat the apparent cost effectiveness of the -100% solutions relative to the other solutions. Since most -100% solutions are not cost effective in any case, while most -70% scenarios are more so, this effect is not moving the break-even point to any material degree.

Note that carpark lighting and exhaust systems have been excluded from the energy calculations.

1.1.5 Base-Case Model Description

An overview of the structure and services in the BCA2010 base-case models is provided here. The common features are treated first and then the areas in which the Office and Health models diverge.

1.1.5.1 Common Features:

Building Form	
Area Total (GFA)	10,000m^2
NLA	9,000m^2 (10% services and common areas)
Storeys	10 storeys of 3.6m overall height
Floor plan	Carpeted, open plan within zones
Replication	All floors identical
Services etc	
Ventilation	7.5 l/s per person
Toilet Exhaust	500 l/s per floor from core area (5 l/s.m^2 of core area)

Infiltration

The BCA 2010 JV3 protocol calls for the modelling to allow 1.5 airchanges per hour for the whole building (no pressurisation). Infiltration is considered to be a function of the façade area and 1.5 airchanges per hour of the perimeter zone only is considered to be more realistic. This infiltration rate conveniently equates to a value of 1.5 l/s.m^2 of façade in this instance.

Perimeter Zones: 1.5 l/s per m^2 of facade

Lighting

Services & Common 5 W/m^2

HVAC Plant

Table A4.1: HVAC Plant Details: Offices

	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, ie. 5 AHUs serving whole building	
Control Strategy	14^{o}C supply air temp which is reset in the perimeter zones based on room temperature.	

Source: Engineering Solutions Tasmania and Energy Partners

Fenestration

Fenestration has been chosen to be minimally compliant but representative of current practice. This means a fenestration ratio of at least 25%, but using single glazing with standard frames where possible. Note that a 25% external ratio amounts to a continuous height of 0.9m around the façade. Base Case fenestration scenarios which balance these desirable attributes are adopted as follows:

Table A4.2: Fenestration Details: 10 Storey Offices

Location	U-Value	SHGC	Fenestration height
Climate Zone 1	4.7	0.44	0.9m
Climate Zone 2 & 5	4.7	0.44	1.2m
Climate Zone 6	3.4	0.38	0.9m
Climate Zone 7	3.4	0.41	0.9m

Source: Engineering Solutions Tasmania

The fenestration is assumed to be uniform for each orientation of the building in which case the type of fenestration can be determined by the worst case façade orientation as has been done for Climate Zones 1, 2 and 5. The fenestration is calculated using Method 2 of Section J2.4. Allowing the fenestration to be determined by the worst case façade gave expensive solutions in the two cooler climates so in those cases the fenestration height has been set at 0.9m, the characteristics set for each orientation and the whole building deemed to be glazed with the fenestration characteristics set as the area-weighted average of the four facades.

Building Fabric

External walls are assumed to be 90mm masonry with an internal lining of insulation and gyprock. Roof is assumed to be 125mm slab with insulation and metal decking above. The following insulation values are used in the model.

Table A4.3: Building Fabric R Values

Location	Insulation (Total R Value)		
	Walls[31]	Exposed Floor	Roof
Climate Zone 1,2,3	3.3	2.0	4.2
Climate Zone 4,5 & 6	2.8 (2.3)	2.0	3.2
Climate Zone 7	2.8 (2.3)	2.0	3.7

Source: Engineering Solutions Tasmania

A solar absorptance of 0.6 for walls and 0.7 for roofs has been adopted in line with the JV3 protocol.

Shading

Based on the parametric analysis of the buildings conducted under the Stage 1 Pathways to 2020 project, the impact of shading is considered to be low and so is not modelled in the first stringency scenarios. The final energy scenarios include the use of switchable glazing which is a form of shading.

1.1.5.2 Differences between the Two Building Types

Table A4.4: Services Profiles for 10-Storey Office and Health Buildings

	10-Storey Office	Health
Occupancy	1 person per 10 m^2 (JV3 Profile)	Ward: 1 person per 10 m^2 Tr'nt: 1 person per 5 m^2
Hot Water	4 l/person.day 900 people total Electric heated	70 l/patient.day 430 patients total Gas-fired boiler (80% effy)
Internal Loads	15 W/m^2	Ward: 5 W/ m^2 Tr'nt: 15 W/m^2
Lighting	9 W/ m^2 (JV3 Profile)	Ward: 10 W/m^2 (Continuous) Tr'nt: 7 W/m^2 (JV3 Profile)
Plant Operation	JV3 profile	Continuous

An aircooled chiller option satisfies the BCA2010 with the following partload COPs.

Office Building - Chiller COP				IPLV
25%	50%	75%	100%	
3.4	3.5	3.3	2.5	3.4

This is the chiller plant that is assumed for the office building. For the health building, it is assumed that cooling tower type of wet-condensing is more appropriate with the following parameters satisfying the BCA2010

Health Building – Chiller COP				IPLV
25%	50%	75%	100%	
4.2	5.4	5.0	5.2	4.2

[31] Less in south wall as per BCA2010, shown in brackets.

Lifts

The figure used is based on advice from a lift manufacturer, KONE, which is based on their best estimate of consumption for the office type of application (2 lifts – 21 person each, 1.6 m/s). A 10% margin has been added to KONE's estimate for safety.

For the health scenario, the same figure has been used with a pro-rata adjustment for hours of operation and doubled to account for the greater occupancy and greater usage pattern.

Annual energy consumption - Office: 24 MWhr.
Annual energy consumption - Health: 147 MWhr.

Note that regenerative drive systems can currently reduce these figures down to 17.6 MWhr and 107.8 MWhr for the office and health buildings respectively and this is considered in all the reduced energy scenarios.

1.1.5.3 Health Care Baseline Model

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.[32], who provide useful load information for various elements of a hospital type facility. Unfortunately, these authors do not provide an area breakdown of their simulation.

Although the 'healthcare' category is extremely diverse as a result of the wide range of activities involved, the essential features, as distinct from an 'office' category, which are adopted in the modelling are:

- Change in aspect ratio from 1:1 to 2:1 to provide greater perimeter exposure (the building foot print is now; 22.35m x 44.7m);
- 24 hour continuous operation (using JV3 profiles);
- Increased occupancy density and ventilation to double that of office;
- Increased internal heat generation from 15 W/m2 to 20 W/m2 of NLA;
- Increased hot water usage from 4 litres/person/day to 35 litres/person/day and generated through gas heating.

Although the BCA 2010 allows hot water to be generated through electric heating, it would seem inappropriate to do this for the large amounts of hot water required under a 'health' scenario. Hence gas heating of domestic hot water is modelled.

1.1.6 Increased Stringency Measures

The energy reduction measures are tabled in the results pages, however some discussion of the main features is appropriate here.

The implementation of Cogen/Trigen systems affects the design strategy of the building, in that the availability of 'waste' heat from these systems now means that the building should be designed to minimize the cooling requirements in preference to the heating requirements. The optimisation of glazing becomes a complicated process in this instance and caution should be used in assuming that more stringent U values are necessarily an 'improvement'.

Furthermore, it was found that there was noticeable difference in the glazing requirements for 24 hour operation (Health) and office hours operation. 24 hour operation helps to justify the reduction in U values of the glazing whereas for climate zones 2 and 5, office hours operation does not experience a significant heating load. This makes reductions in U

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

value difficult to justify since the building generally benefits from being able to passively release its heat through windows at night.

The glazing parameters used in the simulations are summarised in Tables A4.5 and 6.

Table A4.5: Health Building Glazing Parameters

HEALTH										
	Climate Zone									
	1		2		5		6		7	
	U-Value	SHGC	U-Value	SHGC	U-Value	SHGC	U-Value	SHGC	U-Value	SHGC
BCA	4.7	0.44	4.7	0.44	4.7	0.44	3.4	0.38	3.4	0.41
BCA-40	2.2	0.53	2.2	0.53	2.2	0.53	1.5	0.48	1.5	0.48
BCA-70	1.5	0.22	1.5	0.53	1.5	0.53	1.5	0.48	1.5	0.48
BCA-100	1.0	0.03 - 0.30	1	0.03 - 0.53	1	0.03 - 0.53	1	0.03 - 0.48	1	0.03 - 0.48

Source: Engineering Solutions Tasmania

Table A4.6: 10 Storey Office Glazing Parameters

10 STOREY OFFICE										
	Climate Zone									
	1		2		5		6		7	
	U-Value	SHGC	U-Value	SHGC	U-Value	SHGC	U-Value	SHGC	U-Value	SHGC
BCA	4.7	0.44	4.7	0.44	4.7	0.44	3.4	0.38	3.4	0.41
BCA-40	2.2	0.53	4.7	0.53	4.7	0.53	2.2	0.48	2.2	0.48
BCA-70	2.2	0.22	4.7	0.53	4.7	0.53	1.5	0.48	1.5	0.48
BCA-100	2.2	0.03 - 0.30	2.2	0.03 - 0.53	2.2	0.03 - 0.53	1.5	0.03 - 0.48	1.5	0.03 - 0.48

Source: Engineering Solutions Tasmania

Solar Hot Water Heating

Solar heating of domestic cold water has been provided using systems with efficiency based on the current evacuated tube type of collector. In most cases the systems adopted were close to the maximum contribution that could be reasonably expected which is to say for instance that doubling the collector area would have little effect on the overall energy reduction.

1.1.7 Incremental Costs

The construction costs per square metre for BCA2010-compliant buildings, and incremental costs for the -40%, - 70% and -100% solutions, as estimated by Davis Langdon are set out in Table A4.7 below. These costs include cogeneration, trigeneration and PV equipment where these solutions are deployed.

Table A4.7: Commercial Building Costs by Building Type and Climate Zone, 2010 Real $/m^2 GFA

	BCA2010 (total cost)	-40% (incremental cost)	-70% (incremental cost)	-100% (incremental cost)
10 Storey Office				
CZ1	$2,998	$120	$343	$723
CZ2	$2,786	$112	$311	$674
CZ5	$2,786	$112	$311	$674
CZ6	$2,786	$112	$312	$674
CZ7	$2,928	$120	$340	$711
3 Storey Office				
CZ1	$2,278	$149	$221	$1023
CZ2	$2,115	$153	$223	$959
CZ5	$2,115	$153	$223	$959
CZ6	$2,115	$141	$223	$959
CZ7	$2,228	$148	$236	$1015
Supermarket				
CZ1	$1,449	$60	$235	$854
CZ2	$1,344	$55	$302	$731
CZ5	$1,344	$55	$302	$731
CZ6	$1,344	$55	$302	$731
CZ7	$1,483	$57	$311	$771
Healthcare facility				
CZ1	$4,076	$157	$512	$512
CZ2	$3,809	$146	$482	$482
CZ5	$3,809	$146	$482	$482
CZ6	$3,809	$146	$482	$482
CZ7	$4,021	$151	$501	$501

Source: Davis Langdon

Notes: Incremental costs for the health facility at -100% and -70% are the same, as the building is unable to reach these targets and purchases Green Power instead.

1.1.8 Results

In order to gain perspective on the energy rates that have been determined by the modelling, the following graphs show the per annum square metre rates of energy consumption for both categories of buildings. Green Power and internal equipment are excluded since they are largely independent of the building energy efficiency measures under the control of the designer. This means that the Zero Energy scenario requires off-site renewable energy to balance the energy rates shown in these graphs.

Figure A4.9: Square Metre Rates applied to 10 Storey Office

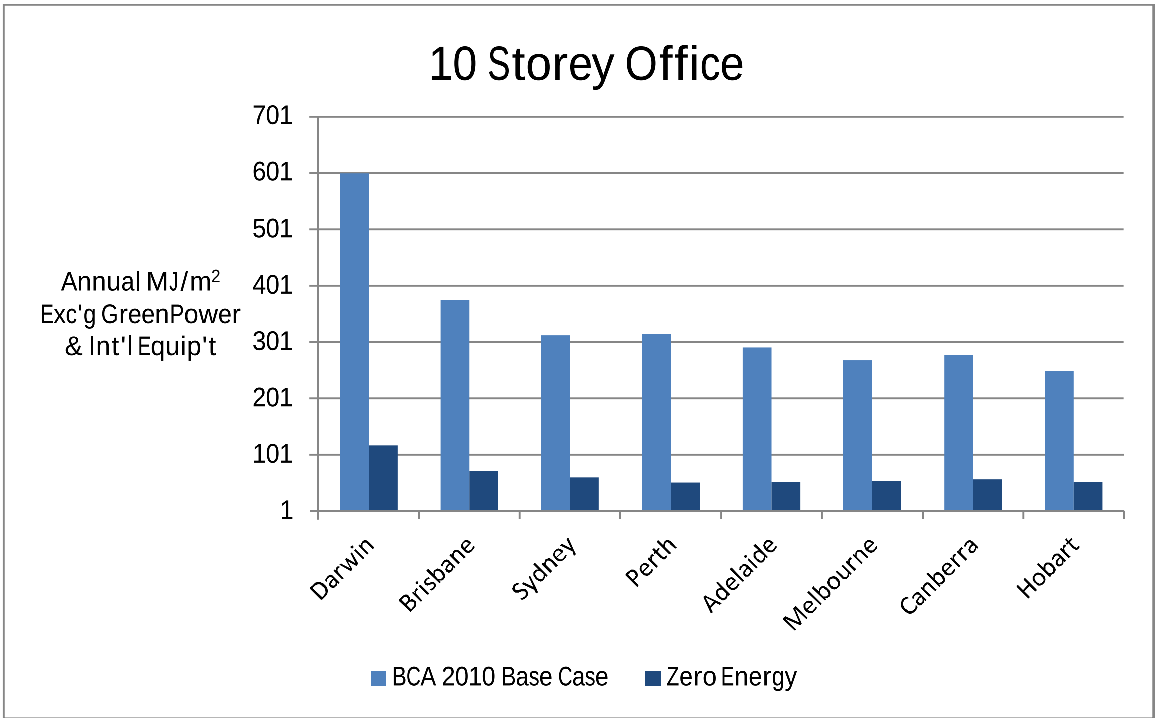
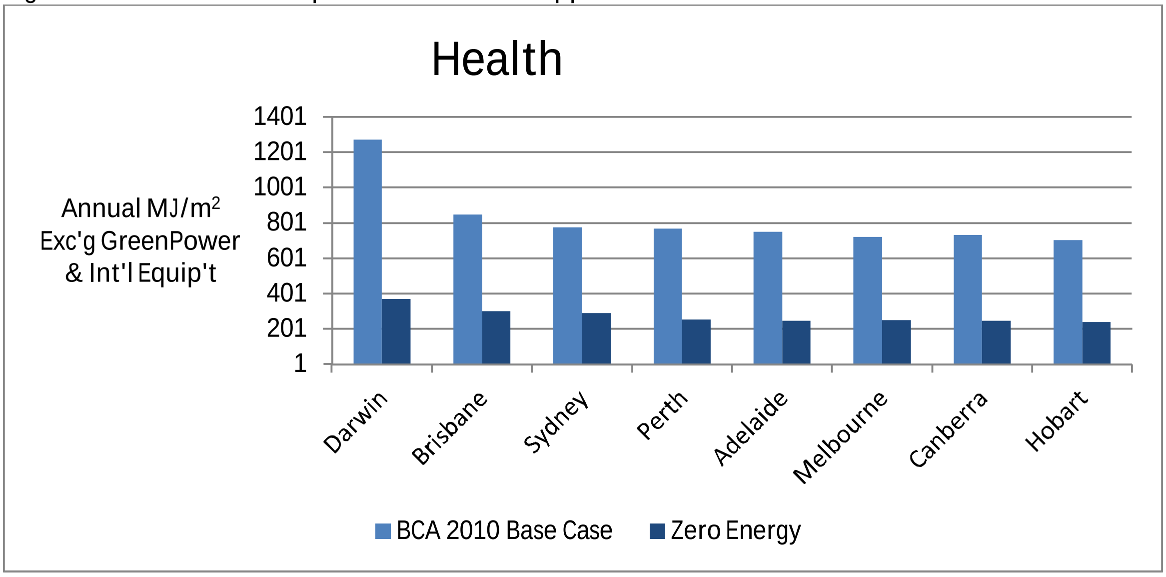


Figure A4.10 Square Metre Rates applied to Health

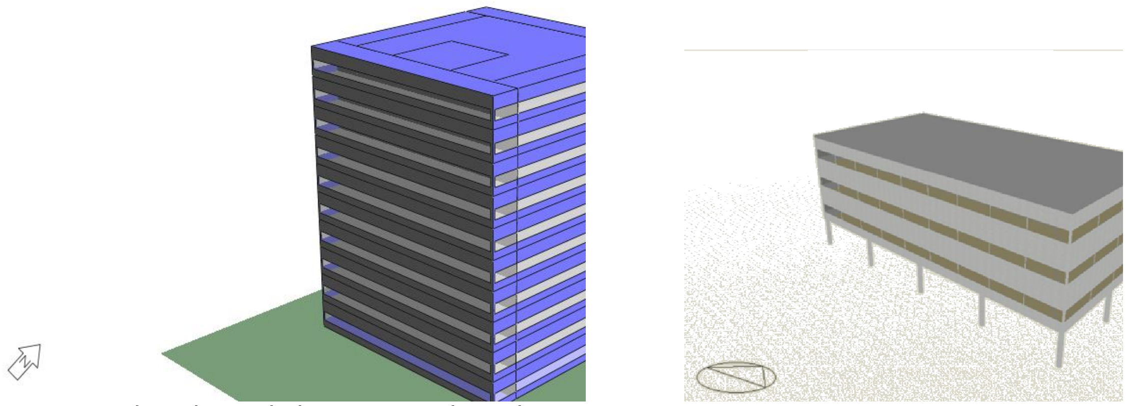


1.2 3-Storey Office

1.2.1 Introduction

The smaller suburban office building is of similar construction to the 10-storey building above, but has a total NLA of 1,800 m2.

Figure A4.11: Office Buildings Schematic



Source: Engineering Solutions Tasmania and Energy Partners

Specifications

Table A4.8: Commercial Office Building 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	

Source: Engineering Solutions Tasmania and Energy Partners

Services

Occupancy	1 person per 10 m2 of NLA
Ventilation	7.5 l/s per person
Toilet Exhaust	500 l/s per floor from core area (5 l/s.m2 of core area)
Internal Loads	15 W/m2 – has been included in HVAC modelling but not as part of the base building energy consumption.
Hot Water	4 litre/person/day (electric heating)

Lighting

Office	9 W/m2
Services & Common	5 W/m2

Infiltration

The BCA 2010 JV3 protocol calls for the modelling to allow 1.5 airchanges per hour for the whole building (no pressurisation). Infiltration is considered to be a function of the façade area and 1.5 airchanges per hour of the perimeter zone only is considered to be more realistic. This infiltration rate conveniently equates to a value of 1.5 l/s.m2 of façade in this instance.

Perimeter Zones 1.5 l/s per m2 of facade

HVAC Plant

Table A4.9: Office HVAC Plant Specifications

	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	
AHUs	Single AHUs for each zone, ie. 5 AHUs serving whole building	
Central Plant	1000 kW aircooled chiller, gas fired boiler of 80% efficiency.	Aircooled chiller (size to be determined by software), gas fired boiler of 80% efficiency.
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

An aircooled chiller option satisfies the BCA 2010 with the following partload COPs.

Table A4.10: Chiller Co-efficients of Performance (COP)

COP				**IPLV**
25%	**50%**	**75%**	**100%**	
3.4	3.5	3.3	2.5	3.4

Source: Engineering Solutions Tasmania and Energy Partners

Fenestration

Fenestration has been chosen to be minimally compliant but representative of current practice. This means a fenestration ratio of at least 25%, but using single glazing with standard frames where possible. Note that a 25% external ratio amounts to a continuous height of 0.9m around the façade. Base Case fenestration scenarios which balance these desirable attributes are adopted as follows:

Table A4.11: Offices: Fenestration 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

The fenestration is assumed to be uniform for each orientation of the building in which case the type of fenestration can be determined by the worst case façade orientation as has been done for Climate Zones 1, 2 and 5. The fenestration is calculated using Method 2 of Section J2.4. Allowing the fenestration to be determined by the worst case façade gave expensive solutions in the two cooler climates so in those cases the fenestration height has been set at 0.9m, the characteristics set for each orientation and the whole building deemed to be glazed with the fenestration characteristics set as the area-weighted average of the four facades.

Building Fabric

External walls are assumed to be 90mm masonry with an internal lining of insulation and gyprock. Roof is assumed to be 125mm slab with insulation and metal decking above. The following insulation values are used in the model.

Table A4.12: Office: Building Fabric Specifications

Location	Insulation (Total R Value)		
	Walls[33]	Exposed Floor	Roof
Climate Zone 1,2,3	3.3	2.0	4.2
Climate Zone 4,5 & 6	2.8 (2.3)	2.0	3.2
Climate Zone 7	2.8 (2.3)	2.0	3.7

Source: Engineering Solutions Tasmania and Energy Partners

A solar absorbance of 0.6 for walls and 0.7 for roofs has been adopted in line with the JV3 protocol.

Lifts

The figure used is based on advice from a lift manufacturer, KONE, which is based on their best estimate of consumption for this type of application (2 lifts – 21 person each, 1.6 m/s). A 10% margin has been added to KONE's estimate for safety.

Annual energy consumption: 24 MWhr.

Note that regenerative drive systems can currently reduce this figure down to 17.6 MWhr and this is considered in all the reduced energy scenarios. It is assumed that the lift energy of the 3-storey office will be 25% of the 10-storey estimates.

Shading

Based on the parametric analysis of the buildings conducted under the Stage 1 Pathways to 2020 project, the impact of shading is not considered to be significant and so is ignored in the first instance with a sensitivity analysis being undertaken for confirmation, especially for Climate Zone 1 as that original study only covered Climate Zones 2 and 6.

1.2.2 Increased Stringency Modelling

The table below summarises the key variations modelled to achieve the required performance levels:

Table A4.13: Increased Stringency Measures: Offices

Office – 10 Storeys	Office – 3 Storeys – where different
BCA 2010	BCA 2010
Appliances 15 W/m²	
Electric DHW	
VAV with Economy cycle	CAV with Economy cycle
BCA-40%	BCA-40%
HVAC "VAV paradigm"	
HVAC IPLV on Cooling 8.0 / Heating 4.0	Dry condensers (IPLV 6.0 / 3.0)
Infiltration down to 0.5 l/s per m^2	

[33] Less in south wall as per BCA2010, shown in brackets.

6.0 W/m² lighting levels – managed average	
Extra insulation, solar absorptance of walls (0.5) and roof (0.4)	BCA + 50% increase in R-value of installed insulation but with little increase in wall thickness (from mineral wool to EPS foam)
Improved fenestration (U-value 2.2; 1.5 in climates 6 and 7)	Reorientation trialled in CZ1 and CZ7.
Lifts with regenerative braking	
Heat or enthalpy reclaim ventilation (70%)	
Occupancy driven vent'n rates (CO_2 sensors)	
Condensing boilers for DHW	
BCA-70%	BCA-70%
4.5 W/m² lighting levels – managed average	Task lighting with daylight dimming
VRV Systems – Darwin, Radiant Systems elsewhere	
Cogeneration (cold climates only)	Nil cogen
Advanced fenestration (U-value 1.5, all climates, SHGC to suit climate)	Shading with clear glass trialled in CZ1.
Preheating of DHW (cogen or solar)	
Photo-voltaic Utilisation of roof as necessary	
	BCA + 100% increase in R-value of installed insulation but with little increase in wall thickness (from mineral wool to PIR foam)
BCA-100%	BCA-100%
Improved internal equipment – 10W/m^2	Skylights for top floor
Heat or enthalpy reclaim ventilation (80%)	
DHW ex HVAC condenser (BCA1, 2) or Trigen.	
Appliances 10 W/m²	
Cutting-edge fenestration (U-value 1.5 and electrochromically switchable SHGC, all climates)	
Maximum utilisation of photo-voltaic systems	
Trigen	Nil cogen
Untried	Reasons
Hybrid HVAC	Sensitive to occupant behaviours
Exposed thermal mass	Aesthetic and acoustic penalty
Indirect evaporative cooling	Perceived Legionaires' Disease risk
GSHP	Results and costs are site specific
Bigger ducts and smaller fans	Impact on overall height (wall area) and cost

Source: Engineering Solutions Tasmania and Energy Partners

Table A4.14: Increased Stringency Measures: Healthcare Facility compared to 10 Storey Office

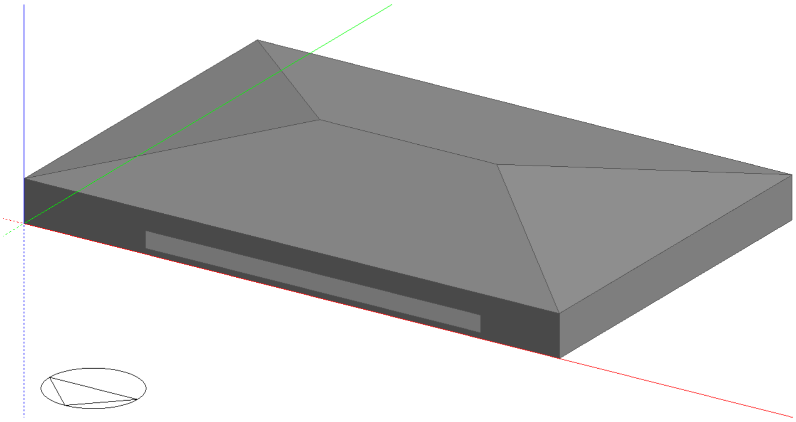
Office – 10 Storeys	Health – where different
BCA 2010	BCA 2010
Appliances 15 W/m²	Appliances 20 W/m²
Electric DHW	Gas DHW
BCA-40%	BCA-40%
HVAC "VAV paradigm"	
HVAC IPLV on Cooling 8.0 / Heating 4.0	
Infiltration down to 0.5 l/s per m²	
6.0 W/m² lighting levels – managed average	
Extra insulation, shading, solar absorptance	
Lifts with regenerative braking	
Heat or enthalpy reclaim ventilation (70%)	
Economy cycle and night purge	
Occupancy driven vent'n rates (CO_2 sensors)	
Condensing boilers for DHW	Preheat of DHW with HVAC Condenser
BCA-70%	BCA-70%
4.5 W/m² lighting levels – managed average	
VRV Systems – Darwin, Radiant Systems elsewhere	
Cogeneration (cold climates only)	Trigeneration
Advanced and cutting edge fenestration	
Preheating of DHW (cogen or solar)	
Photo-voltaic Utilisation of roof as necessary	
Fenestration U value 2.2	
BCA-100%	BCA-100%
Improved internal equipment – 10W/m²	
Heat or enthalpy reclaim ventilation (80%)	
DHW ex HVAC condenser (BCA1, 2) or Trigen.	
Appliances 10 W/m²	Appliances 15 W/m²
Fenestration U value 1.5 and switchable SHGC	
Maximum utilisation of photo-voltaic systems	
Trigen	

Source: Engineering Solutions Tasmania and Energy Partners

1.3 Supermarket

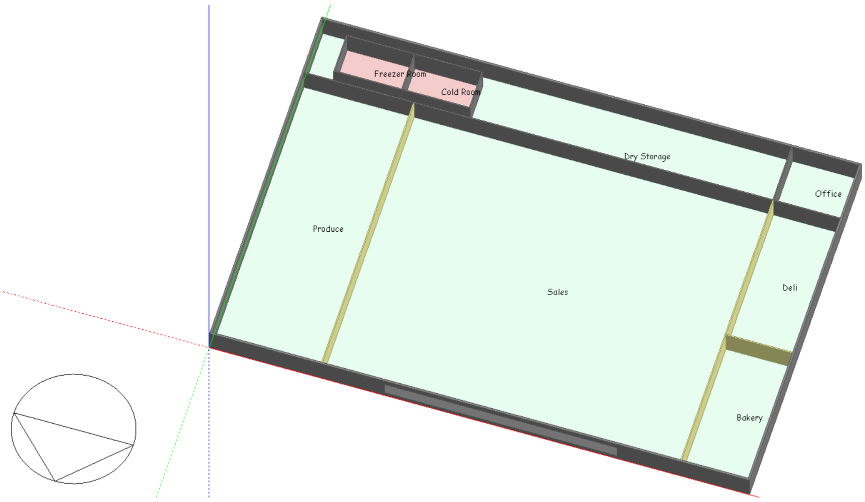
This section describes the structure and services for the BCA2010 compliant version of a typical suburban or regional, stand-alone supermarket with a net lettable area of 4,061 sqm. Performance enhanced versions are described below.

Figure A4.12: Perspective View from the North-West:



Source: Energy Partners

Figure A2.13: Perspective Plan showing designated areas within the Supermarket



Source: Energy Partners

There are six zones for different purposes in this supermarket model. The yellow walls in the figure above are virtual partitions. Virtual partitions exist between 2 zones to divide the space for simulation purposes without physically splitting the space into two.

1.3.1 Building Dimensions

Table A4.15: Building Dimensions for the Supermarket

	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

1.3.2 Roof

Materials

Figure A4.16: Diagrammatic Cross-Section of Roof Structure

Outer Surface

Steel
Glass Fibre Quilt
Building Foil

Inner Surface

Source: Energy Partners

The total U-Value is 0.316 (W/m^2K) and the total R-Value is 3.166 (m^2K/W). The Solar Absorptance value of Steel is chosen to be 0.7 so that the minimum total R-value is 4.2 for climate zone 1 and 2, total R-value of 3.2 for climate zones 5 and 6, and total R-value of 3.7 for climate zone 7. (BCA2010 Table J1.3a).

Dimensions

Table A4.17: Area of Roof surface

	Area on 10° Slope (m^2)
North	1399
East	703
South	1399
West	703
Total Area	4205

Source: Energy Partners

Table A4.18: Summary of thickness and volume of materials required for different climate zones

	Climate Zone 1, 2	Climate Zone 5, 6	Climate 7
	Thickness (m)		
Steel	0.0025	0.0025	0.0025
Glass Fibre Quilt	0.160	0.120	0.142
Building Paper	0.005	0.005	0.005

Source: Energy Partners

1.3.3 Ceiling

Materials

Figure A4.19: Diagrammatic Cross-Section of Ceiling

Roof Space

Plasterboard

Inner Surface

Source: Energy Partners

The total U-Value is 3.226 (W/m^2K) and the total R-Value is 0.310 (m^2K/W).

Dimensions

Table A4.20: Dimensions and Areas of Ceiling

	Ceiling Plasterboard
Thickness (m)	0.01
Dimensions (m)	79.3
	52.9
Area (m2)	4195

Source: Energy Partners

The thickness of the ceiling is the same in all climate zones.

1.3.4 External Walls

Materials

External walls are brick veneer and are represented in the software by three different layers of material and one layer of air, as shown below.

Figure A4.21: Diagrammatic Plan Detail of External Wall

Outer Surface

Brick
Air Gap
EPS Expanded Polystyrene (Standard) / Medium Weight Glass Wool (high performance panels)
Gypsum Plaster

Inner Surface

Source: Energy Partners

The total R-Value and U-Value for the total wall system is shown below. System R value without insulation is R0.5. Glass wool has been chosen for climate zone 1 and 2 so that the required insulation is met for that climate zone, while still retaining the appropriate wall thickness. A solar absorptance of 0.6 has been chosen to match DTS. (BCA2010 Table J1.5a)

Table A4.22: R-value and U-value for Total Wall System

Climate Zone	Insulation Type	Total R-Value (m^2K/W)	Total U-Value (W/m^2K)
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

1.3.5 Dimensions

Table A4.23: Dimensions and Areas of walls (Net of Fenestration)

	Dimensions (m)	Area (m^2)
North	79.77×4.2	252
East	53.38×4.2	224

South	79.77×4.2	335
West	53.38×4.2	224
	Total Gross Wall Area	1624

Table A4.24: Thickness of materials required in different climate zone to achieve the required total R-Value.

	Thickness (m)	
	For Climate Zone 1, 2	For Climate Zone 5, 6 and 7
Brick	0.11	0.11
EPS Expanded Polystyrene	NA	0.09
MW Glass Wool (high performance panels)	0.09	NA
Gypsum Plastering	0.01	0.01

1.3.6 Fenestration

Glazing Type

For the BCA2010 case, single layer Generic clear 6mm glass set in standard commercial aluminium frames is chosen for the glazing type for all climate zones. The U-Value is 5.8 (W/m^2K) and the SHGC is 0.82. The Glazing Calculator was then used to determine the maximum complying height in each climate zone (see Table A4.20).

Dimensions

Table A4.25: Window area in each climate zone to be 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

1.3.7 Sensitivity Tests: Changing Building Orientation and SHGC

The Supermarket BCA2010 and BCA-40% DesignBuilder model for Darwin and Canberra (Climate Zone 1 and 7) were chosen for these sensitivity tests. The heat reclaim function was disabled in the software to increase the differentiation of these sensitivity tests. The model was rotated and simulated with window facing North, East, South and West. The façade window to wall ratio was 35% for Darwin model and 34% for the Canberra model and unchanged for all orientations (i.e. it was not changed to be DTS for each new orientation and is accordingly an exaggerated indication of the sensitivity to orientation in actual supermarkets). Another test carried out was assuming posters were put on all windows in the North facing case. The U-value was unchanged (U=5.8 in the BCA2010 models. U=2.2 in BCA-40% Darwin model and U=1.5 in BCA-40% Canberra model), SHGC was reduced to 0.3 and the Light Transmission was 0.5. Table A4.21 shows the result of these sensitivity tests.

Table A4.26: The sensitivity test results.

Window Facing Direction	Energy Usage (kWh)							
	Darwin				Canberra			
	BCA 2010		BCA -40%		BCA 2010		BCA -40%	
	Gas Heating	Electricity Cooling	Gas Heating	Electricity Cooling	Gas Heating	Electricity Cooling	Gas Heating	Electricity Cooling
North	0	460,541	0	189,064	20,517	123,011	780	36,383
East	0	467,104	0	191,707	20,395	123,131	778	36,620
South	0	467,470	0	189,235	20,283	120,260	831	35,889
West	0	484,219	0	216,700	20,423	121,741	810	36,398
North with Posters	0	429,471	0	188,553	21,175	121,186	2,995	36,140

Note that the heating energy is notional only, as it is not common to have heating in supermarkets even in BCA CZ 5 (as is corroborated by the very low energy consumptions found in this exercise for BCA CZ 7).

Figure A4.17 Sensitivity of Cooling Energy to Orientation and Window with Posters in Darwin

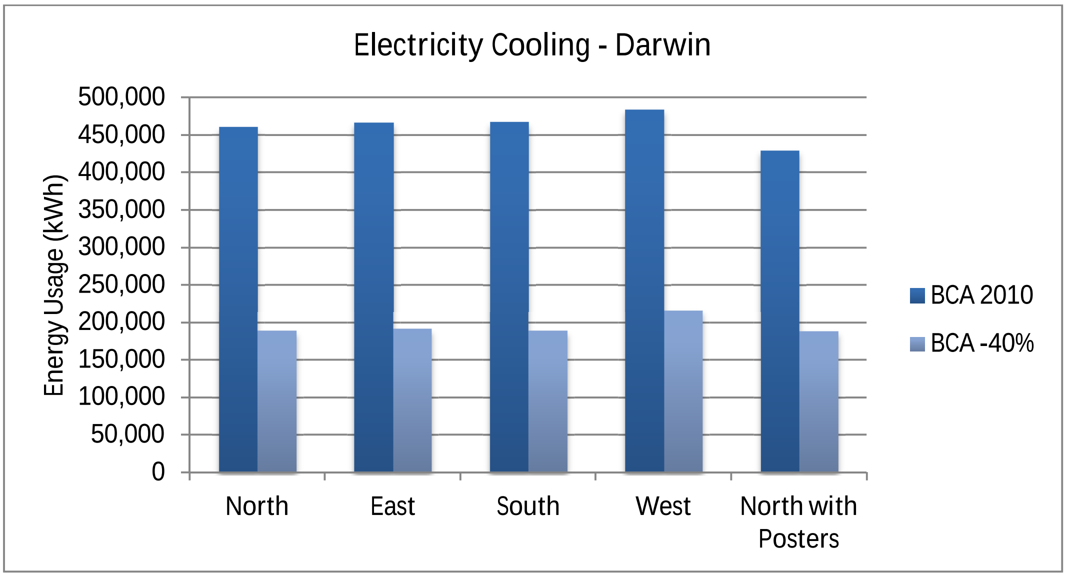


Figure A4.18 Sensitivity of Cooling Energy to Orientation and Window with Posters in Canberra

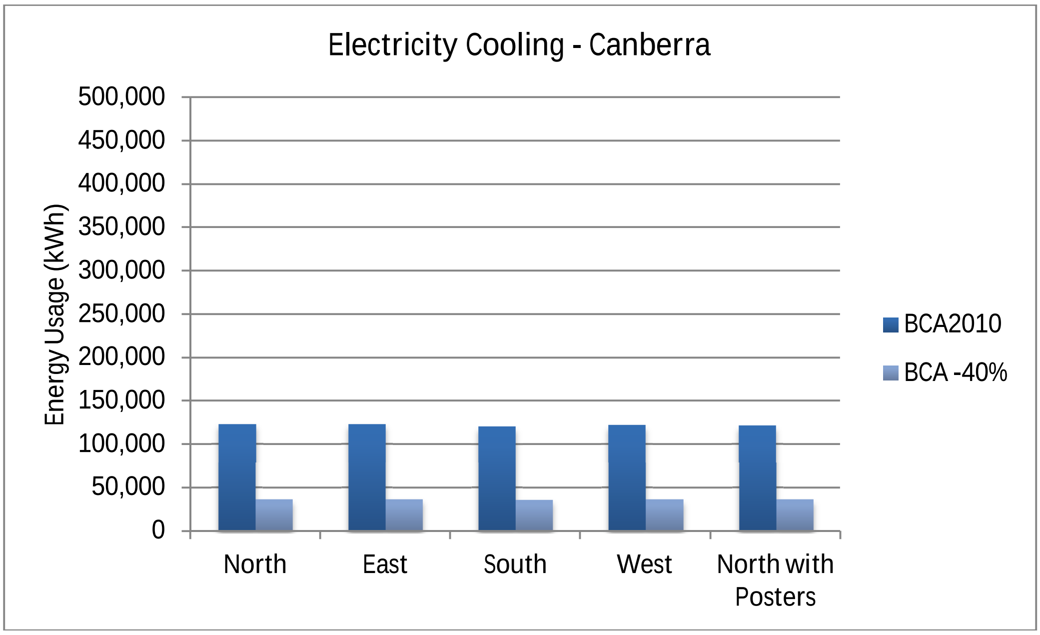


Table A4.27: Energy usage in BCA -40% models for clear glass and with posters plastered all over:

	Energy Usage (kWh)			
	Darwin		Canberra	
SHGC	Gas Heating	Electricity Cooling	Gas Heating	Electricity Cooling
0.53 in Darwin 0.48 in Canberra	0	189,064	780	36,383
0.30	0	188,553	2,995	36,140
Changes (%)	0	-0.3	+284.0	-1.0

After changing the SHGC value to 0.30, the simulated energy usage for gas heating in Darwin remains 0 kWh and electricity for cooling decreases by 0.3%. Gas heating in Canberra increases by 284% (from a small base) and electricity for cooling decreases by 1%.

1.3.8 Floor

Materials

The Concrete slab on ground Floor is constructed by two different layers of material as shown below:

Figure A4.28: Diagrammatic Cross-Section of Floor Structure

Inner Surface

PVC Tiles
Concrete, Reinforced with 2% steel
Gravel or Crushed Rock

Natural Ground

The total U-Value obtained is 2.2 W/m^{2}K (i.e. the R-Value is 0.45 m^{2}K/W).

Dimensions

Table A4.29: The required thickness for materials

	Thickness (m)
PVC tiles or sheet vinyl	0.0033
Concrete (Reinforced with 2% steel for modelling)	0.2
Gravel	0.05

1.3.9 Lighting

The supermarket zone areas and the DTS (BCA2010 TableJ6.2a) lighting power densities are listed in Table A4.25. The type of lighting is not required to be specified in the simulation software.

Table A4.30: Lighting Power Density for different zones in the Supermarket.

	Produce	Sales	Bakery	Deli	Office	Dry Storage
Area (m^2)	711.36	2324.94	209.04	224.72	88.84	621.89
Lighting Energy (W/m^2)	22	22	22	22	8	9

1.3.10 Heating, Ventilation and Air Conditioning (HVAC)

Heating and Cooling

A ducted direct expansion heat pump Constant Air Volume HVAC system has been chosen for this BCA2010 supermarket model. Details of the system are shown below:

Table A4.31: HVAC System for the Supermarket

	Type	Distribution Loss (%)	Min. / Max.off-coil setpoint temperature:	CoP
Heating	DX Heating	5	(Min.) 12 °C	3.4
Cooling	DX Cooling	5	(Max.) 18 °C	3.4

The simulation software has determined the HVAC design load for a DTS system. The table below is a summary of the design load (kW) for different cities. Ducting dimensions are not part of the requirements in the software and will have to be sized by others. Return air is via a ceiling plenum.

There is no heating for climate zones 1, 2 and 5 as the temperature is adequately maintained by the heat coming from the lights and electrical equipment used in the store; especially the refrigeration display cabinets.

Table A4.32: Summary of HVAC Design Load for each City

	CZ1	CZ2	CZ5			CZ6	CZ7	
	Darwin	Brisbane	Perth	Adelaide	Sydney	Melbourne	Canberra	Hobart
Cooling Load	236	232	231	232	232	229	225	218
Heating Load (kW)	NA	NA	NA	NA	NA	13	15	14

1.3.11 Fans

Below is a summary of Pressure Rise (Pa) and Total Efficiency (%) of fan system required by different climate zone.

For a DTS system the simulation software has estimated the fan power (kW), the required Pressure Rise (Pa) and Total Efficiency (%) of the Fan system in each climate zone (Ref: Table A4.28).

Table A4.33: Summary of Fan Power, Pressure Rise and Total Efficiency

	CZ1	CZ2	CZ5			CZ6	CZ7	
	Darwin	Brisbane	Perth	Adelaide	Sydney	Melbourne	Canberra	Hobart
Fan Power (kW)	26	26	26	26	26	26	26	26
Pressure Rise (Pa)	700	700	700	700	700	700	700	700
Total Efficiency (%)	76	72	71	72	71	71	75	70

1.3.12 Pumps

No water or refrigerant circulation pumps are required for this HVAC type.

1.3.13 Display Refrigeration

Table A4.34: Benchmarks to be met by 2013 for different store sizes

Category	Size of floor (GFA) (m^2)	MEPS Energy Intensity (kWh / m^2 per annum.)	MEPS Energy Intensity (W / m^2)
Large	≥ 2,750	820	93.6
Medium	≥1,500 to < 2,750	850	97.0
Small	< 1,500	980	111.8

(Ref: In From the Cold Draft Strategic Plan pg. 24)

Table A4.29 above assumes that the area used in the MEPS calculation, the Total Display Area (TDA), is equivalent to the total gross floor area (GFA). This is as the refrigeration footprint of the store is 20% (approx.) of the sales floor size. Accounting for an average of 5 shelves per refrigeration cabinet, the total refrigerated display area (TDA) is approximately equal to the total sales floor area (GFA).

A High Energy Performance Standard (HEPS) is described as identified higher feasible performance levels used as a reference threshold for procurement, specification, labelling or incentives.

High efficiency performance standards (HEPS) COP levels have been set to reflect the best performing products in the market.

Table A4.35: Indicative MEPS and HEPS levels for compressor COP

	MEPS COP	HEPS COP	Stretch HEPS COP
Medium Temperature (+5°C Evaporator Temp)	$1 + (1.85 * \Phi_0 / (\Phi_0 + 2600))$	$1.4 + (1.60 * \Phi_0 / (\Phi_0 + 2100))$	Extrapolated using percentage change between HEPS and MEPS values
Low Temperature (-25°C Evaporator Temp)	$0.7 + (1.10 * \Phi_0 / (\Phi_0 + 1300))$	$1.1 + (0.79 * \Phi_0 / (\Phi_0 + 1800))$	Extrapolated using percentage change between HEPS and MEPS values

Where: Φ_0 = Cooling Capacity (Wr)
(Ref: In from the Cold Vol2 pg. 23)

1.3.14 Walk-In Cool/Cold Room (WIC)

Table A4.36: WIC categories/nominal sizes, warehouses and types of refrigeration equipment

Description	Dimension	Nominal Capacity Wr at 5^{0}C	Type of Refrigeration Equipment
WIC: Mini	< 9 m^2 x 3 m high	2,250	Small condensing unit and evaporator or DISI packaged unit
WIC: Small	< 24 m^2 x 3 m high	4,100	Small to medium condensing unit and evaporator or DISI packaged unit
WIC: Medium	< 36 m^2 x 4 m high	9,000	Medium condensing unit and evaporator
WIC: Large	< 100 m^2 x 4 m high	20,400	Centralized plant (rack system) or large condensing unit)

A useful 'rule of thumb' used by industry for checking nominal capacity of cool-rooms is 250 to 300 Wr per m^2 on WICs with heights of 3 to 4m and 100 W per m^2 in large distribution centres with heights of 12m or more. (Ref: In from the Cold Vol2 pg. 107)

WIC Peak Load in Closed Operation

The tables below show the calculated peak loads in the Cool Room and the Freezer Room that are adjacent to each other in the Supermarket.

Table A4.37: The Peak Load from Thermal Conduction for the Cool Room

Base Case, Cool Room at a temperature of 5°C							
Zone	Temperature Difference (K)	Area (m2)	Inner Film (K-m2/W)	Outer Film (K-m2/W)	R value (K-m2/W)	U value (W/K-m2)	Heat Flow Q (W)
Ceiling	50	155.47	0.125	0.11	4.8	0.199	1543.91
North	20	72.80	0.125	0.125	4.8	0.198	288.32
East	20	37.70	0.125	0.125	4.8	0.198	149.31
South	30	72.80	0.125	0.125	4.8	0.198	432.48
West	-25	37.70	0.125	0.125	4.8	0.198	-186.63
Floor	15	155.47	0.16	0.367	4.8	0.188	437.78
						Total (W)	2665.16
					Power Index (W/m2)		17.14

Table A4.38: The Peak Load for the Freezer Room at a temperature of -20^0C

Base Case, Freezer room							
Zone	Temperature Difference (K)	Area (m2)	Inner Film (K-m2/W)	Outer Film (K-m2/W)	R value (K-m2/W)	U value (W/K-m2)	Heat Flow Q (W)
Ceiling	75	155.47	0.125	0.110	7.1	0.136	1589.69
North	45	72.80	0.125	0.125	7.1	0.136	445.71
East	25	37.70	0.125	0.125	4.8	0.198	186.63
South	55	72.80	0.125	0.125	7.1	0.136	544.76
West	55	37.70	0.125	0.125	7.1	0.136	282.11
Floor	40	155.47	0.16	0.367	7.1	0.131	815.38
						Total (W)	3864.29
					Power Index (W/m2)		24.86

1.3.15 Modelling of Increased Stringency Measures

The energy improvement measures are summarised in Table A4.34 below using the 3-Storey Office versions for comparison purposes:

Table A4.39: Energy Improvement Measures – Supermarket cf 3 Storey Office

Office – 3 Storeys	Supermarket – where different
BCA 2010	BCA 2010
Appliances 15 W/m²	Refrigeration Cabinets to MEPS
Electric DHW	
CAV with Economy cycle	CAV with Economy cycle
BCA-40%	BCA-40%
HVAC “VAV paradigm”	CAV
HVAC Dry condensers (IPLV C6.0 / H3.0)	
Infiltration down to 0.5 l/s per m²	
6.0 W/m² lighting levels – managed average	Schedule as above -25%
Solar absorptance of walls (0.5) and roof (0.4)	
BCA + 50% increase in R-value of installed insulation but with little increase in wall thickness (from mineral wool to EPS foam)	Cold and Freezer Rooms insulated as per schedule
Improved fenestration (U-value 2.2; 1.5 in climates 6 and 7)	

Reorientation trialled in CZ1 and CZ7.	Trial also of SHGC=0.3 (advertising posters)
Lifts with regenerative braking	NA
Heat or enthalpy reclaim ventilation (70%)	
Occupancy driven vent'n rates (CO_2 sensors)	
Condensing boilers for DHW	
	Refrigeration Cabinets to HEPS
BCA-70%	BCA-70%
4.5 W/m² lighting levels – managed average Task lighting with daylight dimming	Schedule as above -50%
VRV Systems – Darwin, Radiant Systems elsewhere	CAV with IPLV C7.0 / H3.5
Cogeneration (cold climates only)	No cogen
Advanced fenestration (U-value 1.5, all climates, SHGC to suit climate) Shading with clear glass trialled in CZ1	
Preheating of DHW (cogen or solar)	
Photo-voltaic Utilisation of roof as necessary	
BCA + 100% increase in R-value of installed insulation but with little increase in wall thickness (from mineral wool to PIR foam)	
	Refrigeration Cabinets to HEPS
BCA-100%	BCA-100%
Improved internal equipment – 10W/m²	Refrigeration Cabinets to HEPS with selective heat sink to ambient
Skylights for top floor	
Heat or enthalpy reclaim ventilation (80%)	
DHW ex HVAC condenser (BCA1, 2) or Trigen.	Solar DHW
Appliances 10 W/m²	
Cutting-edge fenestration (U-value 1.5 and electrochromically switchable SHGC, all climates)	Retain Advanced fenestration (U-value 1.5, all climates, SHGC to suit climate)
Maximum utilisation of photo-voltaic systems	Required utilisation of photo-voltaic systems
Trigen	

Source: Energy Partners

Appendix 5: Sensitivity Analyses

1.0 Overview

Additional work was undertaken to test the sensitivity of the results to different energy prices and rates of learning, in the first instance. Two scenarios were tested.

Scenario 1 assumes no carbon pricing and also assumes that the incremental costs of complying with the required performance levels do not change through time - that is, there is no learning by industry[34]. We consider the assumption that there will be no change to learning rates as unrealistic. However, with regards to a carbon price there is a possibility that the federal carbon tax legislation, passed in November 2011, could be repealed by a future government. Scenario 1 allows trade-offs to be made between improvements in the thermal shell of buildings, fixed appliances and, where appropriate, on-site renewable energy systems. Only PV is considered for the latter, given practical, site-specific and planning issues associated with other building integrated renewables such as small-scale wind systems.

Scenario 2 assumes a higher carbon price than the current federal carbon price legislation, along with a faster rate of industry learning equivalent to 50% over 10 years for commercial buildings, and 25/50% over 5/10 years for residential buildings. This scenario also allows trade-offs to be made between improvements in the thermal shell of buildings, fixed appliances and, where appropriate, on-site renewable energy systems.

Work was also undertaken to test the sensitivity of the breakeven energy savings with the target BCR set at 1.2 rather than 1. Only the 7% real discount rate is applied. For residential buildings, percentage energy reductions at BCR 1.2 were calculated with and without PV, and the results are reported separately below. For commercial buildings, as per the commercial building results in the body of the report, the percentage energy reductions results at BCR 1.2 do not separate out the influence of PV.

Finally, for the large and small detached dwellings, sensitivity was undertaken determine the extent thermal performance could be improved through "no cost" design changes (e.g. altering window placement and zoning).

1.1 Residential Buildings (Scenario 1&2, and BCR 1.2)

1.1.1 Scenario 1

Break-even energy savings

In Scenario 1, with no carbon prices or industry learning and excluding PV cost effective improvements from BCA 2010 are limited. We find that cost effective savings average around 6% compared with BCA2010. However, the spread of results by climate zone is broad, with 1-2% in Darwin and Canberra, and 18% in Perth in 2020 at 7% discount rate (see Table A5.1 below). The lower results in Darwin and Canberra reflect the relatively high space conditioning loads in those climates (in addition to relative fuel prices), while the higher result in Perth in particular is aided by higher electricity costs, which favour heat pump hot water systems which generate relatively large (and valuable) energy cost

[34] The 'learning rate' refers to the phenomenon that industry learns least cost solutions to new challenges, including new regulatory requirements, through time. This learning leads to reducing incremental costs of compliance. This effect is reinforced by economies of scale and technological change. As more high-performance elements are procured, their supply increases and prices fall. Learning is discussed in detail in the *Indicative Stringency Study*, pitt&sherry 2010. See also Section 3.4.7.

savings in that climate zone. Canberra has the lowest level of electricity prices, and amongst the lowest level of gas prices, of the climate zones studied, which reduces the cost effectiveness of energy savings.

The improvements in Perth, Adelaide and Hobart are due to improvements in water heating and lighting, with minor building shell improvements in Hobart (to flats, where the potential for improvement at low cost is much greater than for other residential building types).

Table A5.1: Break Even Energy Savings Relative to BCA2010, All Residential Buildings, Scenario 1, Without PV

Scenario 1	**2015**	**2020**	**2015**	**2020**
Real discount rate	**@ 5%**	**@ 5%**	**@ 7%**	**@ 7%**
Sydney West (CZ6)	4%	3%	4%	3%
Darwin (CZ1)	3%	3%	2%	2%
Brisbane (CZ2)	7%	7%	7%	5%
Adelaide (CZ5)	11%	11%	7%	11%
Hobart (CZ7)	15%	15%	14%	14%
Melbourne (CZ6)	3%	3%	3%	3%
Perth (CZ5)	18%	18%	18%	18%
Canberra (CZ7)	1%	4%	1%	1%
Weighted Average:	7%	7%	7%	6%

Source: *pitt&sherry*

When PV is taken into account in this Scenario, there is no change in the results (at 7% real discount rate), as PV is not cost effective under these conditions (see Table A5.2 below).

Table A5.2: Break Even Energy Savings Relative to BCA2010, All Residential Buildings, Scenario 1, With PV

Scenario 1	**2015**	**2020**	**2015**	**2020**
Real discount rate:	**@ 5%**	**@ 5%**	**@ 7%**	**@ 7%**
Sydney West (CZ6)	4%	3%	4%	3%
Darwin (CZ1)	3%	3%	2%	2%
Brisbane (CZ2)	7%	7%	7%	5%
Adelaide (CZ5)	11%	11%	7%	11%
Hobart (CZ7)	15%	15%	14%	14%
Melbourne (CZ6)	3%	3%	3%	3%
Perth (CZ5)	18%	18%	18%	18%
Canberra (CZ7)	1%	4%	1%	1%
Weighted Average:	7%	7%	7%	6%

Source: *pitt&sherry*

Class 1 versus Class 2 Dwellings

Table A5.3 below shows the weighted average incremental costs of achieving break-even energy savings, without PV, for Class 1 and Class 2 dwellings in each climate zone. The weighted figures are based on the prevalence of residential building types modelled that make up each building Class (see Table 4.2 in Chapter 4), and their respective incremental costs to achieve each of the above scenarios.

Table A5.3: Incremental Costs at Break-even: Class 1 and Class 2 Dwellings: 7% Discount Rate: Without PV

	Scenario 1, 2015	Scenario 1, 2020
Sydney (Class 1)	$191	$165
Sydney (Class 2)	$191	$165
Darwin (Class 1)	$124	$131
Darwin (Class 2)	$124	$131
Brisbane (Class 1)	$229	$165
Brisbane (Class 2)	$229	$165
Adelaide (Class 1)	$361	$655
Adelaide (Class 2)	$361	$655
Hobart(Class 1)	$1584	$1586
Hobart (Class 2)	$2838	$3099
Melbourne (Class 1)	$165	$165
Melbourne (Class 2)	$1029	$1029
Perth (Class 1)	$715	$694
Perth (Class 2)	$715	$694
Canberra (Class 1)	$0	$0
Canberra (Class 2)	$1372	$1729

Source: pitt&sherry

As was the case for the Base Case results, in the cooler climates (Melbourne, Canberra and Hobart), the cost to achieve break-even energy savings is higher for Class 2 than Class 1 dwellings, and for the other cities there is no difference in cost between Class 1 and 2 dwellings to achieve break-even energy savings. *i.e.* no change in building shell cost. As previously discussed, break-even energy savings are achieved through either one of or a combination of lighting, water heating or pool pump energy efficiency improvements.

These results do not change with the addition of PV (see Table A5.4 below).

Table A5.4: Incremental Costs at Break-even: Class 1 and Class 2 Dwellings: 7% Discount Rate: With PV

	Scenario 1, 2015	Scenario 1, 2020
Sydney (Class 1)	$191	$165
Sydney (Class 2)	$191	$165
Darwin (Class 1)	$124	$131
Darwin (Class 2)	$124	$131
Brisbane (Class 1)	$229	$165
Brisbane (Class 2)	$229	$165
Adelaide (Class 1)	$361	$655
Adelaide (Class 2)	$361	$655
Hobart(Class 1)	$1583	$1585
Hobart (Class 2)	$2838	$3098
Melbourne (Class 1)	$288	$288
Melbourne (Class 2)	$288	$288
Perth (Class 1)	$715	$694
Perth (Class 2)	$715	$694
Canberra (Class 1)	$0	$0
Canberra (Class 2)	$1372	$1729

Source: pitt&sherry

40%, 70% and 100% energy reduction from BCA 2010

The results shown in Table A5.6 are the ‘without PV’ solutions for Scenario 1. For all energy saving targets, there are no cost effective solutions. For the 40% energy saving target the best results are around 30-40% for the three cool climates. For both -70% and -100% energy reductions, the best results occur for Canberra around 25-30% BCR.

Table A5.6: Benefit Cost Ratios without PV in Solution, at 40%, 70% and 100% Reduction from BCA2010 by Climate Zone, Scenario 1

	Scenario 1 @ -40%				Scenario 1 @ -70%				Scenario 1 @ -100%			
	2015	**2020**	**2015**	**2020**	**2015**	**2020**	**2015**	**2020**	**2015**	**2020**	**2015**	**2020**
Real discount rate:	**5%**	**5%**	**7%**	**7%**	**5%**	**5%**	**7%**	**7%**	**5%**	**5%**	**7%**	**7%**
Sydney	0.15	0.16	0.13	0.13	0.12	0.13	0.10	0.10	0.12	0.13	0.13	0.10
Darwin	0.25	0.25	0.20	0.20	0.24	0.25	0.19	0.20	0.24	0.25	0.19	0.20
Brisbane	0.30	0.29	0.27	0.26	0.09	0.09	0.07	0.08	0.09	0.09	0.07	0.08
Adelaide	0.23	0.25	0.19	0.20	0.15	0.16	0.12	0.13	0.15	0.16	0.12	0.13
Hobart	0.45	0.46	0.37	0.38	0.26	0.27	0.21	0.22	0.26	0.27	0.21	0.22
Melbourne	0.34	0.35	0.27	0.28	0.18	0.19	0.14	0.15	0.18	0.19	0.14	0.15
Perth	0.18	0.19	0.16	0.16	0.17	0.18	0.15	0.15	0.17	0.18	0.15	0.15
Canberra	0.39	0.42	0.30	0.33	0.29	0.31	0.31	0.24	0.29	0.32	0.23	0.25

Source: pitt&sherry

The results shown in Table A5.7 are the ‘with PV’ solutions for Scenario 1. Perth is the only climate where an energy saving target (-40%) can be achieved cost effectively. Adelaide almost achieves this target cost effectively. No climate is cost effective for the 70% and 100% energy saving targets.

Table A5.7: Benefit Cost Ratios with PV in Solution, at 40%, 70% and 100% Reduction from BCA2010 by Climate Zone, Scenario 1

	Scenario 1 @ -40%				Scenario 1 @ -70%				Scenario 1 @ -100%			
	2015	**2020**	**2015**	**2020**	**2015**	**2020**	**2015**	**2020**	**2015**	**2020**	**2015**	**2020**
Real discount rate:	**5%**	**5%**	**7%**	**7%**	**5%**	**5%**	**7%**	**7%**	**5%**	**5%**	**7%**	**7%**
Sydney	0.69	0.68	0.59	0.59	0.68	0.67	0.58	0.59	0.67	0.67	0.58	0.58
Darwin	0.70	0.70	0.62	0.62	0.70	0.70	0.62	0.62	0.69	0.69	0.62	0.62
Brisbane	0.76	0.76	0.68	0.68	0.75	0.75	0.67	0.67	0.74	0.74	0.66	0.66
Adelaide	0.94	0.94	0.84	0.84	0.93	0.93	0.82	0.83	0.92	0.92	0.82	0.82
Hobart	0.75	0.76	0.67	0.68	0.70	0.71	0.63	0.63	0.68	0.68	0.60	0.60
Melbourne	0.66	0.66	0.57	0.57	0.66	0.66	0.57	0.57	0.66	0.66	0.57	0.57
Perth	1.01	1.02	0.89	0.90	0.98	0.98	0.85	0.85	0.96	0.96	0.82	0.83
Canberra	0.50	0.50	0.43	0.43	0.50	0.50	0.43	0.43	0.49	0.49	0.43	0.43

pitt&sherry. Note: values shown in red are greater than 1; i.e., cost effective.

Greenhouse benefits at breakeven

Table A5.8 Estimates of National Annual Greenhouse Emissions Savings, Residential Buildings, at Break Even Energy Efficiency, without PV, Scenario 1

Discount Rate	GHG savings (kt CO_{2-e})		
	2015-19 cohort	2020-24 cohort	2015-2024 cohort
5%	147	131	278
7%	139	120	259

(Note: with and without PV produces the same results because PV is not cost effective in this scenario)

1.1.2 Scenario 2

Break-even energy savings

In Scenario 2 – with higher carbon prices and a higher rate of industry learning – the cost effective level of energy savings, relative to BCA2010 and without PV, is significantly higher than in the Base Case and Scenario 1, reaching 23% on a weighted average basis (see Table A5.9 below). The spread of results by climate zone continues to reflect differences in relative fuel prices, which are exacerbated by carbon pricing, increasing the relative attractiveness of electricity savings. Note that in Australian conditions, this result also leads to higher greenhouse gas emission savings than occur from savings of natural gas.

Table A5.9: Break Even Energy Savings Relative to BCA2010, All Residential Buildings, Scenario 2, Without PV

Scenario 2	**2015**	**2020**	**2015**	**2020**
	@ 5%	**@ 5%**	**@ 7%**	**@ 7%**
Sydney West (CZ6)	19%	26%	14%	19%
Darwin (CZ1)	5%	23%	3%	15%
Brisbane (CZ2)	7%	30%	7%	22%
Adelaide (CZ5)	11%	22%	11%	22%
Hobart (CZ7)	19%	30%	16%	25%
Melbourne (CZ6)	13%	33%	4%	25%
Perth (CZ5)	32%	32%	26%	32%
Canberra (CZ7)	13%	43%	7%	29%
Weighted Average:	15%	30%	11%	23%

Source: pitt&sherry

Examining more closely the break even reductions without PV in 2020 at 7% discount rate highlights the difference between warmer and cooler climates. The energy reductions at breakeven are very similar, such as for Perth and Canberra, but the causes fall into two clear groups. As table A5.11 below shows, there is around a 1-star improvement in building shell performance in Melbourne, Hobart and Canberra, while for the other locations all energy improvements result from water heating, lighting and pool pumps, except for a small change in Darwin.

Table A5.10: Break Even Energy Savings Relative to BCA2010, All Residential Buildings, Scenario 2, With PV

Scenario 2	2015	2020	2015	2020
Real discount rate:	**@ 5%**	**@ 5%**	**@ 7%**	**@ 7%**
Sydney West (CZ6)	100%	100%	100%	100%
Darwin (CZ1)	100%	100%	100%	100%
Brisbane (CZ2)	100%	100%	100%	100%
Adelaide (CZ5)	100%	100%	100%	100%
Hobart (CZ7)	100%	100%	100%	100%
Melbourne (CZ6)	100%	100%	100%	100%
Perth (CZ5)	100%	100%	100%	100%
Canberra (CZ7)	100%	100%	7%	100%
Weighted Average:	100%	100%	100%	100%

Source: pitt&sherry

When PV is modelled in this scenario, the average level of cost effective savings rises to 100% as PV is cost effective in its own right in all cities expect Canberra. More improvements can occur cost effectively across all climates in this scenario, as costs fall through learning and as energy prices increase.

Table A5.11 below shows the contribution shell improvements and improvements in water heating, lighting and pool pumps make to breakeven energy reductions. The overall conclusion from all these results is that in Darwin, Brisbane, Sydney, Adelaide, and Perth it does not appear cost effective to significantly improve the building shell beyond the 6-star level, although significant savings in water heating, lighting and pool pump energy efficiency are cost effective. In the colder climates it is probable that the 7-star level would be cost effective.

Table A5.11 Break Even Energy Reductions in 2020 (Scenario 2 @ 7%), No PV

Scenario 2	2020 @ 7%	Shell Star Rating	Weighted Average of BCR of WH, Lighting, Pool Pump at Break Even
Sydney West (CZ6)	19%	6.0	1.65
Darwin (CZ1)	15%	6.3	1.13
Brisbane (CZ2)	22%	6.0	1.42
Adelaide (CZ5)	22%	6.0	1.29
Hobart (CZ7)	25%	6.8	1.91
Melbourne (CZ6)	25%	7.0	1.12
Perth (CZ5)	32%	6.0	1.66
Canberra (CZ7)	29%	7.2	1.07

Source: pitt&sherry

Class 1 versus Class 2 dwellings

Table A5.12 below shows the results at 7% discount rate, distinguishing between Class 1 and Class 2 buildings. As previously described it is more difficult to justify the 'with PV' solution for flats, as the availability of a sufficient area of appropriately oriented roof space is less likely than with a single dwelling. Similar considerations may apply to two-storey houses for which there is relatively less roof area compared to single storey houses of the same floor area. It can be noted that for many climate zones, much greater energy savings are cost effective for flats (Class 2) than for houses (Class 1). Individual flats share common walls with other flats and, particularly for those in central rather than corner locations, significant energy savings are often feasible through simple strategies such as improved insulation and glazing.

Table A5.12 Energy Reductions from Building Shell Improvements for Class 1 and Class 2 Dwellings at Break Even, 2020, 7% real discount rate, scenario 2

Climate Zone	Scenario 2 Class 1	Scenario 2 Class 2
Sydney West (CZ6)	0%	0%
Darwin (CZ1)	6%	8%
Brisbane (CZ2)	0%	0%
Adelaide (CZ5)	0%	7%
Hobart (CZ7)	16%	77%
Melbourne (CZ6)	20%	63%
Perth (CZ5)	0%	0%
Canberra (CZ7)	28%	69%

Source: pitt&sherry

Table A5.13 below shows the weighted average incremental costs of achieving break-even energy savings, without PV, for Class 1 and Class 2 dwellings in each climate zone. The weighted figures are based on the prevalence of residential building types modelled that make up each building Class, and their respective incremental costs to achieve each of the above scenarios.

Table A5.13: Incremental Costs at Break-even: Class 1 and Class 2 Dwellings: 7% Discount Rate: Without PV, scenario 2

	Scenario 2, 2015	Scenario 2, 2020
Sydney (Class 1)	$498	$745
Sydney (Class 2)	$498	$745
Darwin (Class 1)	$232	$2272
Darwin (Class 2)	$232	$2054
Brisbane (Class 1)	$171	$655
Brisbane (Class 2)	$171	$655
Adelaide (Class 1)	$529	$1151
Adelaide (Class 2)	$529	$1413
Hobart(Class 1)	$1377	$2014
Hobart (Class 2)	$3357	$4302
Melbourne (Class 1)	$229	$2253
Melbourne (Class 2)	$1702	$4258
Perth (Class 1)	$1036	$1104
Perth (Class 2)	$1036	$1104
Canberra (Class 1)	$407	$3945
Canberra (Class 2)	$3191	$5533

Source: pitt&sherry

As for the Base Case results and Scenario 1, in the cooler climates (Melbourne, Canberra and Hobart) the cost to achieve break-even energy savings is higher for Class 2 than Class 1 dwellings, and for the other cities, apart from Darwin and Adelaide in 2020, there is no difference in cost between Class 1 and 2 dwellings for all scenarios to achieve break-even energy savings.

Table A5.14: Incremental Costs at Break-even: Class 1 and Class 2 Dwellings: 7% Discount Rate: With PV: Scenario 2

	Scenario 2, 2015	Scenario 2, 2020
Sydney (Class 1)	$15567 (3.1kW)	$10796 (2.9kW)
Sydney (Class 2)	$15567 (3.1kW)	$10796 (2.9kW)
Darwin (Class 1)	$18935 (3.8kW)	$14120 (3.9kW)
Darwin (Class 2)	$18935 (3.8kW)	$14120 (3.9kW)
Brisbane (Class 1)	$7068 (1.4kW)	$5630 (1.5kW)
Brisbane (Class 2)	$7068 (1.4kW)	$5630 (1.5kW)
Adelaide (Class 1)	$13318 (2.6kW)	$10070 (2.8kW)
Adelaide (Class 2)	$13318 (2.6kW)	$10070 (2.8kW)
Hobart(Class 1)	$29309 (5.7kW)	$20786 (5.5kW)
Hobart (Class 2)	$31130 (5.7kW)	$22076 (5.5kW)
Melbourne (Class 1)	$32700 (6.3kW)	$23825 (6.5kW)
Melbourne (Class 2)	$34002 (6.3kW)	$24970 (6.5kW)
Perth (Class 1)	$9996 (1.9kW)	$7213 (1.9kW)
Perth (Class 2)	$9996 (1.9kW)	$7213 (1.9kW)
Canberra (Class 1)	$397	$26085 (6.1kW)
Canberra (Class 2)	$3594	$28755 (6.1kW)

Source: pitt&sherry

Table A5.14 above presents the same incremental cost data for Class 1 and Class 2 dwellings in each climate zone as shown in Table A5.13, but this time with PV included in the mix. In all climates PV is cost effective in Class 1 & 2 dwellings in 2020. In those cases, the cost of PV means that incremental construction costs (figures in red) are significantly higher than they are for the Without PV scenario. In addition to cost, Table A5.14 shows the size of PV installed at the breakeven point.

40%, 70% and 100% energy reduction from BCA 2010

The results shown in Table A5.15 are the 'without PV' solutions for Scenario 2. The cooler climates of Hobart and Canberra are the only ones that can achieve the 40% energy saving target cost effectively. No climate can achieve either the 70% or 100% energy reductions without PV cost effectively.

Table A5.15: Benefit Cost Ratios without PV in Solution, at 40%, 70% and 100% Reduction from BCA2010 by Climate Zone, Scenario 2

	Scenario 2 @ -40%				Scenario 2 @ -70%				Scenario 2 @ -100%			
	2015	2020	2015	2020	2015	2020	2015	2020	2015	2020	2015	2020
Real discount rate:	5%	5%	7%	7%	5%	5%	7%	7%	5%	5%	7%	7%
NSW	0.25	0.40	0.21	0.33	0.20	0.33	0.17	0.27	0.20	0.33	0.17	0.27
NT	0.42	0.69	0.33	0.54	0.42	0.69	0.32	0.54	0.42	0.69	0.32	0.54
QLD	0.48	0.72	0.43	0.64	0.14	0.23	0.12	0.19	0.14	0.23	0.12	0.19
SA	0.38	0.63	0.32	0.52	0.25	0.41	0.20	0.33	0.25	0.41	0.20	0.33
TAS	0.70	1.11	0.58	0.93	0.41	0.65	0.33	0.54	0.41	0.65	0.33	0.54
VIC	0.56	0.97	0.47	0.77	0.33	0.54	0.25	0.42	0.33	0.54	0.25	0.42
WA	0.30	0.48	0.25	0.41	0.28	0.48	0.24	0.39	0.28	0.46	0.24	0.39
ACT	0.68	1.16	0.52	0.88	0.50	0.86	0.38	0.66	0.51	0.87	0.39	0.67

pitt&sherry. Note: values shown in red are greater than 1; i.e., cost effective.

The results shown in Table A5.16 are the 'with PV' solutions for Scenario 2. 100% energy savings can be achieved in all climates cost effectively in 2020. These results are dominated by the benefit cost ratios for PV.

Table A5.16: Benefit Cost Ratios with PV in Solution, at 40%, 70% and 100% Reduction from BCA2010 by Climate Zone, Scenario 2

	Scenario 2 @ -40%				Scenario 2 @ -70%				Scenario 2 @ -100%			
	2015	2020	2015	2020	2015	2020	2015	2020	2015	2020	2015	2020
Real discount rate:	5%	5%	7%	7%	5%	5%	7%	7%	5%	5%	7%	7%
NSW	1.40	1.90	1.16	1.65	1.39	1.87	1.15	1.62	1.38	1.86	1.13	1.60
NT	1.51	2.04	1.28	1.83	1.51	2.04	1.27	1.82	1.51	2.03	1.27	1.82
QLD	1.50	2.00	1.28	1.80	1.48	1.98	1.26	1.78	1.47	1.96	1.25	1.76
SA	1.78	2.37	1.51	2.14	1.77	2.34	1.51	2.11	1.76	2.32	1.50	2.09
TAS	1.45	1.99	1.25	1.81	1.38	1.87	1.18	1.69	1.35	1.80	1.15	1.62
VIC	1.32	1.78	1.09	1.54	1.32	1.78	1.09	1.53	1.32	1.77	1.08	1.52
WA	1.94	2.70	1.63	2.36	1.90	2.61	1.58	2.26	1.89	2.56	1.55	2.21
ACT	1.09	1.37	0.89	1.18	1.08	1.36	0.89	1.17	1.08	1.35	0.89	1.16

Source: pitt&sherry. Note: values shown in red are greater than 1; i.e., cost effective.

Greenhouse benefits at break even

Table A5.17 Estimates of National Annual Greenhouse Emissions Savings, Residential Buildings, at Break Even Energy Efficiency, Scenario 2 with PV

Real Discount Rate	GHG savings (kt CO_2-e)		
	2015-19 cohort	2020-24 cohort	2015-2024 cohort
5%	5855	5511	11366
7%	5730	5545	11275

Source: pitt&sherry

At breakeven with PV in Scenario 2, every dwelling result is cost effective which means that every dwelling becomes zero energy (including plug load and cooking) with the result that the greenhouse gas savings jump to very high levels. By contrast, Table 5.18 below shows the breakeven results without PV.

Table A5.18 Estimates of National Annual Greenhouse Emissions Savings, Residential Buildings, at Break Even Energy Efficiency, Scenario 2 without PV

Real Discount Rate	GHG savings (kt CO_2-e)		
	2015-19 cohort	2020-24 cohort	2015-2024 cohort
5%	281	455	736
7%	193	392	585

Source: pitt&sherry

1.1.3 Benefit Cost Ratio = 1.2

Tables A5.19 – A5.21 below show the comparison of energy savings relative to BCA2010, for residential buildings that are achieved at BCR = 1 and BCR = 1.2 for each climate zone for the main results as well as for scenarios 1 and 2 without PV. Tables A5.22 – A5.24 present the same information with PV in the mix. The 'without PV' results show that, overall, a small reduction in energy saving occurs when the B/C ratio increases from 1.0 to 1.2, however, for a number of climate zones in all of the scenarios, there is no change in the energy savings as a result of the change in the BCR.

Table A5.19: Comparison of % Energy Reduction at BCR =1 and BCR = 1.2, Residential Buildings, Without PV, Base Case Results

Scenario 2	2015 (B/C 1)	2015 (B/C 1.2)	2020 (B/C 1)	2020 (B/C 1.2)
Sydney West (CZ6)	9%	4%	14%	9%
Darwin (CZ1)	3%	2%	3%	3%
Brisbane (CZ2)	7%	7%	7%	7%
Adelaide (CZ5)	11%	11%	11%	11%
Hobart (CZ7)	14%	14%	17%	15%
Melbourne (CZ6)	3%	3%	7%	3%
Perth (CZ5)	18%	18%	32%	18%
Canberra (CZ7)	4%	1%	7%	4%
Weighted average	8%	7%	12%	8%

Source: pitt&sherry

Table A5.20: Comparison of % Energy Reduction at BCR =1 and BCR = 1.2, Residential Buildings, Without PV, Scenario 1

Scenario 1	2015 (B/C 1)	2015 (B/C 1.2)	2020 (B/C 1)	2020 (B/C 1.2)
Sydney West (CZ6)	4%	3%	3%	3%
Darwin (CZ1)	2%	1%	2%	0%
Brisbane (CZ2)	7%	1%	5%	2%
Adelaide (CZ5)	7%	7%	11%	6%
Hobart (CZ7)	14%	12%	14%	13%
Melbourne (CZ6)	3%	3%	3%	3%
Perth (CZ5)	18%	18%	18%	17%
Canberra (CZ7)	1%	1%	1%	1%
Weighted average	7%	5%	6%	5%

Source: pitt&sherry

The percentage energy savings are the same without and with PV, unless PV provides a100% energy saving, which is the case for Perth and Adelaide.

Table A5.21: Comparison of % Energy Reduction at BCR =1 and BCR = 1.2, Residential Buildings, without PV, Scenario 2

Scenario 3	2015 (B/C 1)	2015 (B/C 1.2)	2020 (B/C 1)	2020 (B/C 1.2)
Sydney West (CZ6)	14%	9%	19%	19%
Darwin (CZ1)	3%	3%	15%	10%
Brisbane (CZ2)	7%	7%	22%	16%
Adelaide (CZ5)	11%	11%	22%	15%
Hobart (CZ7)	16%	14%	25%	22%
Melbourne (CZ6)	4%	4%	25%	19%
Perth (CZ5)	26%	18%	32%	32%
Canberra (CZ7)	7%	4%	29%	21%
Weighted average	11%	8%	23%	20%

Source: pitt&sherry

Table A5.22: Comparison of % Energy Reduction at BCR =1 and BCR = 1.2, Residential Buildings, With PV, Base Case Results

Scenario 2	2015 (B/C 1)	2015 (B/C 1.2)	2020 (B/C 1)	2020 (B/C 1.2)
Sydney West (CZ6)	100%	100%	100%	100%
Darwin (CZ1)	100%	100%	100%	100%
Brisbane (CZ2)	100%	100%	100%	100%
Adelaide (CZ5)	100%	100%	100%	100%
Hobart (CZ7)	100%	100%	100%	100%
Melbourne (CZ6)	3%	3%	100%	100%
Perth (CZ5)	100%	100%	100%	100%
Canberra (CZ7)	4%	1%	100%	100%
Weighted Average	79%	79%	**100%**	**100%**

Source: pitt&sherry

Table A5.23: Comparison of % Energy Reduction at BCR =1 and BCR = 1.2, Residential Buildings, With PV, Scenario 1

Scenario 1	2015 (B/C 1)	2015 (B/C 1.2)	2020 (B/C 1)	2020 (B/C 1.2)
Sydney West (CZ6)	4%	3%	3%	3%
Darwin (CZ1)	2%	1%	2%	0%
Brisbane (CZ2)	7%	1%	5%	2%
Adelaide (CZ5)	7%	7%	11%	6%
Hobart (CZ7)	14%	12%	14%	13%
Melbourne (CZ6)	3%	3%	3%	3%
Perth (CZ5)	18%	18%	18%	17%
Canberra (CZ7)	1%	1%	1%	1%
Weighted Average	7%	5%	6%	5%

Source: pitt&sherry

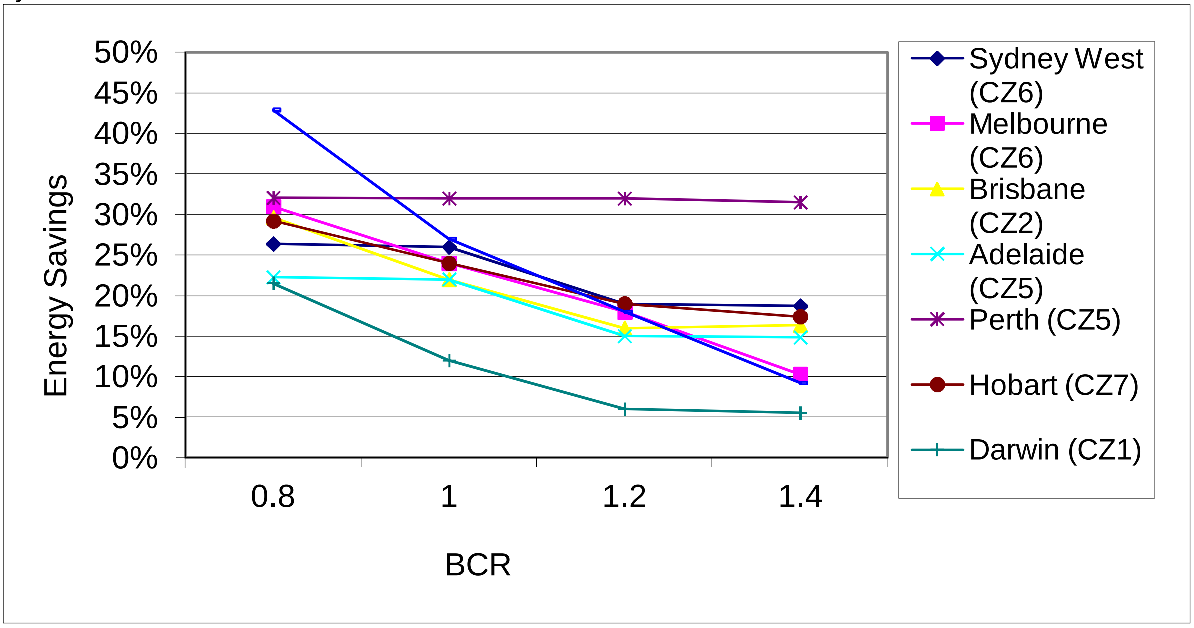
Table A5.24: Comparison of % Energy Reduction at BCR =1 and BCR = 1.2, Residential Buildings, with PV, Scenario 2

Scenario 3	2015 (B/C 1)	2015 (B/C 1.2)	2020 (B/C 1)	2020 (B/C 1.2)
Sydney West (CZ6)	100%	100%	100%	100%
Darwin (CZ1)	100%	100%	100%	100%
Brisbane (CZ2)	100%	100%	100%	100%
Adelaide (CZ5)	100%	100%	100%	100%
Hobart (CZ7)	100%	100%	100%	100%
Melbourne (CZ6)	100%	100%	100%	100%
Perth (CZ5)	100%	100%	100%	100%
Canberra (CZ7)	7%	4%	100%	100%
Weighted Average	**100%**	**100%**	**100%**	**100%**

Source: pitt&sherry

To further test the sensitivity of the results to the BCR, the model was run to generate the relevant percentage reduction values under the 2020 scenario 2 (which shows the largest change). Figure A5.1 illustrates the dependence of the percentage energy reduction over a range of BCRs (0.8 to 1.4). The results demonstrate that 'break even' energy savings fall as the target BCR rises, but with a rather gentle gradient and no unusual sensitivity around breakeven. The line for Perth is explained by the highest performance appliances being cost effective at all BCR.

Figure A5.1- Sensitivity of Energy Reduction to BCR for Composite Residential Dwelling by Climate



Source: pitt&sherry

1.2 Commercial Buildings Sensitivity Analysis

1.2.1 Scenario 1

Break-Even Energy Savings

In Scenario 1, the average level of cost effective energy savings for commercial buildings, relative to BCA2010, is 44% (see Table A5.25 below). As before, this overall result refers to the savings available in 2020 and at a 7% real discount rate. It is derived from the weighted average of all the commercial building types, with the weightings reflecting the prevalence of the different building types in the commercial building stock expected over the study period. The larger, 10-storey office dominates the results on a weighted basis, accounting for some 68% of the average result (refer to Chapter 3 for further details on the weighting procedures).

In the Scenario 1 results, the cost effective level of savings relative to BCA 2010 varies by climate zone, with cooling-dominated climates and those with higher electricity prices, demonstrating a higher level of cost effective savings than others. This is primarily because electricity is worth around three times as much as gas on a gigajoule for gigajoule basis, and space cooling is generally (except in the case of trigeneration) achieved with electricity. As a result, opportunities to save electricity, particularly in climate zones where electricity is relatively expensive, will tend to be more cost effective solutions. By contrast, the lower level of cost effective savings in heating-dominated climates such as Hobart and Canberra reflects the fact that savings opportunities in those climates are more heavily weighted towards natural gas, and to relatively less expensive electricity, meaning that savings in this area are not particularly valuable (in financial terms). The relatively low level of cost effective savings in Canberra in particular reflects the fact that gas prices there are the lowest of the climate zones studied.

The cost-effective level of energy savings, relative to BCA2010, is only slightly higher in 2020 than in 2015. This is because energy prices, in the absence of carbon pricing, rise more slowly, while on the other hand, this scenario assumes that the incremental costs of complying with these break even performance levels do not fall through time. As these constraints (notably for learning rates) are relaxed in the Base Case scenario and scenario 2, the 'spread' of results between 2015 and 2020 increases.

Table A5.25: Break even energy savings relative to BCA2010, all commercial buildings, scenario 1

Scenario 1	**2015**	**2020**	**2015**	**2020**
Real discount rate:	@ **5%**	@ **5%**	@ **7%**	@ **7%**
Western Sydney (CZ6)	56%	57%	41%	43%
Darwin (CZ1)	75%	74%	66%	66%
Brisbane (CZ2)	69%	70%	58%	59%
Adelaide (CZ5)	67%	68%	54%	56%
Hobart (CZ7)	48%	49%	31%	34%
Melbourne (CZ6)	50%	51%	33%	35%
Perth (CZ5)	65%	66%	52%	54%
Canberra (CZ7)	37%	39%	18%	21%
Weighted Average:	**57%**	**58%**	**42%**	**44%**

Source: pitt&sherry

Detailed Results

At BCA2010 – 70%, for example, further improvements to the thermal shell of the supermarket, lighting systems and interior equipment (primarily refrigerated cabinets) make it possible to achieve the performance target with only modest levels of PV (less than 100MJ of output per square metre GFA) and with an increase between 16 – 23% in construction costs. With annual savings per square metre of around $34 in Darwin, for example, and incremental construction costs of around $235, this performance level has a simple payback of just about 7 years *without* carbon pricing. Since the building is assumed to have a life of 40 years, and even with discounting and some (25%) reinvestment in refurbishing plant and equipment at the 20 year point, this investment is highly cost effective. Only Canberra, with its lower initial cooling load and hence opportunity for savings in space cooling, falls (just) below a BCR of 1 in Scenario 1, with a simple payback of about 17 years at the BCA2010 – 70% level.

Likewise, the 3-storey office is able to reach BCA2010 -70% utilising PV in only Darwin and Brisbane and without cogeneration or trigeneration. Therefore the incremental costs remain quite low, at around 11%, and this solution remains cost effective in most climate zones.

By contrast, the 10-storey office and health buildings struggle to achieve BCA2010 –70% in this scenario. As modelled, this level of energy savings is only achieved for the 10-storey office building in Darwin, and then only at a 5% discount rate. For the health building this level of energy savings can only be achieved at a 7% discount rate in Adelaide. In all climates, the 10-storey office requires PV to reach this performance level, in addition to the cited improvements in the thermal shell, HVAC plant and fixed appliances (and indeed plug load). In Sydney, small amounts of Green Power (6 MJ/m^2) are required to meet the target. However, in the cooler climates (Melbourne, Canberra, Hobart), trigeneration is also deployed. This enables the buildings to reach BCA2010 -70% on an 'electricity equivalent basis' (refer to Chapter 3). However, their actual purchases of gas are high, indeed significantly higher than in the BCA2010 Base Case, effectively negating the savings of electricity. In Hobart, net energy savings in this solution, relative to the Base Case, are actually slightly negative, and zero in Melbourne.

A similar effect occurs in the health building. At BCA2010 -70%, PV, trigeneration and offsite Green Power purchases (except in Darwin) are all required to achieve the target on an electricity-equivalent basis. In the case of Darwin, which used only modest levels of gas initially, much of which was saved at BCA2010 -40%, the gas use for trigeneration is such that overall energy savings are negative. Indeed, realised energy savings fall for this performance level, when compared with BCA2010 -40%, in all climate zones. As one analyst put it, the buildings are 'chasing their tail', using more energy to trigenerate than they are able to save in electrical load (trigeneration inevitably involves a loss of energy, even if total conversion efficiencies may be as high as 85% - still, 15% is lost), and lacking the surface area to generate sufficient energy with PV and therefore having to purchase expensive Green Power offsite. Needless to say, these solutions are not cost effective.

In this scenario, only the supermarket in Perth, Adelaide and Brisbane is able to reach BCA2010 -100% cost effectively, and then only at a real discount rate of 5%. Indeed, that this should be so – without the benefit of carbon pricing or learning - is a remarkable result. Incremental construction costs are around 55% higher than the reference case. This is cost effective (BCR = 1.0 @ 5%) in Perth, Adelaide and Brisbane.

At the BCA2010 -100% performance level, the 3-storey office is required to generate up to nearly 300 MJ/m^2 of GFA from PV, although it does not deploy trigeneration (its GFA of 2000 m^2 is too small for this solution) or require offsite renewables. However, the incremental costs of around 45% are too great to be cost effective, given the value of the avoided purchased energy. On average, the 3-storey office manages a BCR of around 0.4 at this performance level. At the same targeted performance level, the 10-storey office and health buildings are both requiring very high levels of offsite renewables (Green Power), in addition to the maximum feasible deployment of PV and trigeneration as well. In Darwin, the health building actually uses 43% *more* energy than in the reference case as it strives to reach this target, using six times as much gas (for trigeneration) but with fewer electrical savings (than in the BCA2010 –70% solution), given the need to also cover plug load. BCRs fall to around 0.2 in this scenario.

10 Storey Office

Table A5.26 below shows the BCRs that are attained by the 10 storey office in Scenario 1; that is, without carbon pricing or learning.

Table A5.26: 10 Storey Office: Benefit Cost Ratios by Climate Zone, Year and Discount Rate - Scenario 1

Summary Table – 10 Storey Office	2015	2015	2020	2020
Real discount rate:	**5%**	**7%**	**5%**	**7%**
Scenario 1 BCR @ -40%				
Western Sydney (CZ6)	1.0	0.8	1.0	0.8
Darwin (CZ1)	1.6	1.3	1.6	1.3
Brisbane (CZ2)	1.3	1.1	1.3	1.1
Adelaide (CZ5)	1.1	0.9	1.1	0.9
Hobart (CZ7)	0.7	0.6	0.7	0.6
Melbourne (CZ6)	0.8	0.6	0.8	0.7
Perth (CZ5)	1.1	0.9	1.1	0.9
Canberra (CZ7)	0.6	0.5	0.7	0.5
Average:	**1.0**	**0.8**	**1.0**	**0.8**
Scenario 1 BCR @ -70%				
Western Sydney (CZ6)	0.6	0.5	0.6	0.5
Darwin (CZ1)	1.0	0.8	1.0	0.8
Brisbane (CZ2)	0.8	0.6	0.8	0.6
Adelaide (CZ5)	0.7	0.6	0.7	0.6
Hobart (CZ7)	0.5	0.4	0.5	0.4
Melbourne (CZ6)	0.6	0.5	0.6	0.5
Perth (CZ5)	0.7	0.5	0.7	0.6
Canberra (CZ7)	0.3	0.3	0.3	0.3
Average:	**0.6**	**0.5**	**0.6**	**0.5**

Table A5.26 (cont.): 10 Storey Office: Benefit Cost Ratios by Climate Zone, Year and Discount Rate - Scenario 1

Summary Table – 10 Storey Office	**2015**	**2015**	**2020**	**2020**
Real discount rate:	**5%**	**7%**	**5%**	**7%**
Scenario 1 BCR @ -100%				
Western Sydney (CZ6)	0.1	0.1	0.1	0.1
Darwin (CZ1)	0.2	0.2	0.2	0.2
Brisbane (CZ2)	0.2	0.2	0.2	0.2
Adelaide (CZ5)	0.2	0.2	0.2	0.2
Hobart (CZ7)	0.1	0.0	0.1	0.0
Melbourne (CZ6)	0.1	0.1	0.1	0.1
Perth (CZ5)	0.2	0.1	0.2	0.1
Canberra (CZ7)	0.0	0.0	0.0	0.0
Average:	**0.1**	**0.1**	**0.1**	**0.1**

Source: pitt&sherry

3-Storey Office

Table A5.27 below shows the BCRs that are attained by the 3-storey office in Scenario 1; that is, without the assistance of carbon pricing or learning.

Table A5.27: 3 Storey Office: Revised Benefit Cost Ratios by Climate Zone, Year and Discount Rate: Scenario 1

Summary Table - 3 Storey Office	**2015**	**2015**	**2020**	**2020**
Real discount rate:	**5%**	**7%**	**5%**	**7%**
Scenario 1 BCR @ -40%				
Western Sydney (CZ6)	1.3	1.0	1.3	1.1
Darwin (CZ1)	1.3	1.0	1.3	1.0
Brisbane (CZ2)	1.3	1.1	1.4	1.1
Adelaide (CZ5)	1.6	1.2	1.6	1.3
Hobart (CZ7)	1.5	1.2	1.5	1.2
Melbourne (CZ6)	1.2	0.9	1.2	0.9
Perth (CZ5)	1.4	1.1	1.5	1.2
Canberra (CZ7)	1.1	0.9	1.2	0.9
Average:	**1.3**	**1.1**	**1.4**	**1.1**
Scenario 1 BCR @ -70%				
Western Sydney (CZ6)	1.3	1.0	1.3	1.0
Darwin (CZ1)	1.4	1.1	1.4	1.1
Brisbane (CZ2)	1.4	1.1	1.4	1.1
Adelaide (CZ5)	1.7	1.3	1.7	1.3
Hobart (CZ7)	1.4	1.1	1.4	1.1
Melbourne (CZ6)	1.3	1.0	1.3	1.0
Perth (CZ5)	1.5	1.2	1.5	1.2
Canberra (CZ7)	1.1	0.9	1.1	0.9
Average:	**1.4**	**1.1**	**1.4**	**1.1**

Table A5.27 (cont.): 3 Storey Office: Revised Benefit Cost Ratios by Climate Zone, Year and Discount Rate: Scenario 1

Summary Table - 3 Storey Office	2015	2015	2020	2020
Real discount rate:	**5%**	**7%**	**5%**	**7%**
Scenario 1 BCR @ -100%				
Western Sydney (CZ6)	0.4	0.3	0.4	0.3
Darwin (CZ1)	0.4	0.3	0.4	0.3
Brisbane (CZ2)	0.5	0.4	0.5	0.4
Adelaide (CZ5)	0.5	0.4	0.5	0.4
Hobart (CZ7)	0.4	0.3	0.4	0.3
Melbourne (CZ6)	0.4	0.3	0.4	0.3
Perth (CZ5)	0.5	0.4	0.5	0.4
Canberra (CZ7)	0.3	0.3	0.3	0.3
Average:	**0.4**	**0.3**	**0.4**	**0.4**

Source: pitt&sherry

Supermarket

Table A5.28 below shows the BCRs that are attained by the supermarket in Scenario 1; that is, without the assistance of carbon pricing or learning.

Table A5.28: Supermarket: Revised Benefit Cost Ratios by Climate Zone, Year and Discount Rate: Scenario 1

Summary Table - Supermarket	2015	2015	2020	2020
Real discount rate:	**5%**	**7%**	**5%**	**7%**
Scenario 1 BCR @ -40%				
Western Sydney (CZ6)	3.8	3.0	3.8	3.1
Darwin (CZ1)	5.0	4.0	5.0	4.0
Brisbane (CZ2)	4.9	3.9	5.0	4.0
Adelaide (CZ5)	4.5	3.6	4.5	3.6
Hobart (CZ7)	2.9	2.3	3.0	2.4
Melbourne (CZ6)	3.1	2.5	3.2	2.6
Perth (CZ5)	4.3	3.4	4.4	3.5
Canberra (CZ7)	2.5	2.0	2.6	2.1
Average:	**3.9**	**3.1**	**3.9**	**3.2**
Scenario 1 BCR @ -70%				
Western Sydney (CZ6)	1.4	1.1	1.4	1.2
Darwin (CZ1)	2.3	1.8	2.2	1.8
Brisbane (CZ2)	1.7	1.4	1.7	1.4
Adelaide (CZ5)	1.8	1.4	1.8	1.4
Hobart (CZ7)	1.3	1.0	1.3	1.0
Melbourne (CZ6)	1.3	1.0	1.3	1.1
Perth (CZ5)	1.6	1.3	1.7	1.3
Canberra (CZ7)	1.0	0.8	1.0	0.8
Average:	**1.5**	**1.2**	**1.6**	**1.3**

Table A5.28 (cont.): Supermarket: Revised Benefit Cost Ratios by Climate Zone, Year and Discount Rate: Scenario 1

Summary Table - Supermarket	2015	2015	2020	2020
Real discount rate:	**5%**	**7%**	**5%**	**7%**
Scenario 1 BCR @ -100%				
Western Sydney (CZ6)	0.8	0.7	0.9	0.7
Darwin (CZ1)	0.9	0.7	0.9	0.7
Brisbane (CZ2)	1.0	0.8	1.0	0.8
Adelaide (CZ5)	1.0	0.8	1.0	0.8
Hobart (CZ7)	0.7	0.6	0.7	0.6
Melbourne (CZ6)	0.8	0.6	0.8	0.6
Perth (CZ5)	1.0	0.8	1.0	0.8
Canberra (CZ7)	0.6	0.5	0.6	0.5
Average:	**0.9**	**0.7**	**0.9**	**0.7**

Source: pitt&sherry

Healthcare Facility

Table A5.29 below shows the BCRs that are attained by the healthcare facility in Scenario 1; that is, without carbon pricing or learning.

Table A5.29: Healthcare Facility: Benefit Cost Ratios by Climate Zone, Year and Discount Rate: Scenario 1

Summary Table - Health	2015	2015	2020	2020
Real discount rate:	**5%**	**7%**	**5%**	**7%**
Scenario 1 BCR @ -40%				
Western Sydney (CZ6)	1.7	1.4	1.8	1.4
Darwin (CZ1)	3.2	2.5	3.2	2.5
Brisbane (CZ2)	2.5	2.0	2.6	2.1
Adelaide (CZ5)	2.3	1.8	2.4	1.9
Hobart (CZ7)	2.0	1.6	2.0	1.6
Melbourne (CZ6)	1.9	1.5	1.9	1.5
Perth (CZ5)	2.4	1.9	2.5	2.0
Canberra (CZ7)	1.8	1.4	1.8	1.4
Average:	**2.2**	**1.8**	**2.3**	**1.8**
Scenario 1 BCR @ -70%				
Western Sydney (CZ6)	0.9	0.7	0.9	0.7
Darwin (CZ1)	1.0	0.8	0.9	0.7
Brisbane (CZ2)	1.0	0.8	1.0	0.8
Adelaide (CZ5)	1.3	1.0	1.3	1.0
Hobart (CZ7)	0.8	0.7	0.8	0.7
Melbourne (CZ6)	0.7	0.6	0.7	0.6
Perth (CZ5)	1.0	0.8	1.1	0.9
Canberra (CZ7)	0.6	0.5	0.6	0.5
Average:	**0.9**	**0.7**	**0.9**	**0.7**

Table A5.29 (cont.): Healthcare Facility: Benefit Cost Ratios by Climate Zone, Year and Discount Rate: Scenario 1

Summary Table - Health	2015	2015	2020	2020
Real discount rate:	**5%**	**7%**	**5%**	**7%**
Scenario 1 BCR @ -100%				
Western Sydney (CZ6)	0.3	0.2	0.3	0.2
Darwin (CZ1)	0.4	0.3	0.3	0.3
Brisbane (CZ2)	0.3	0.2	0.3	0.3
Adelaide (CZ5)	0.5	0.4	0.5	0.4
Hobart (CZ7)	0.2	0.2	0.2	0.2
Melbourne (CZ6)	0.3	0.2	0.3	0.2
Perth (CZ5)	0.3	0.3	0.3	0.3
Canberra (CZ7)	0.1	0.1	0.1	0.1
Average:	**0.3**	**0.2**	**0.3**	**0.2**

Source: pitt&sherry

Benefit-Cost Analysis of PV in Commercial Buildings

Table A5.30: Benefit Cost Ratios for PV: Commercial Buildings: Scenario 1, 2020

Real discount rate:	**@ 5%**	**@ 7%**
Western Sydney (CZ6)	0.41	0.36
Darwin (CZ1)	0.44	0.40
Brisbane (CZ2)	0.44	0.39
Adelaide (CZ5)	0.55	0.49
Hobart (CZ7)	0.39	0.34
Melbourne (CZ6)	0.39	0.34
Perth (CZ5)	0.54	0.47
Canberra (CZ7)	0.30	0.26

Source: pitt&sherry
Note: 2015 results only shown – all BCRs are less than 1 in this scenario

It is apparent that PV is not cost effective in Scenario 1 and therefore does not impact on the break even results.

1.2.2 Scenario 2

Finally, in Scenario 2, the higher carbon prices and more rapid rate of decline in incremental costs sees cost effective savings reach quite high levels: 80% on average (in 2020) when compared to BCA2010 (see Table A5.31 below), and 68% by 2015.

The spread of results between 2015 and 2020 has further increased, as energy savings are becoming increasingly valuable through time, while incremental compliance costs are assumed to fall by 50% over the 10 years from 2015 to 2024 – in our view, a realistic assumption.

Table A5.31: Break even energy savings relative to BCA2010, all commercial buildings, scenario 2

Scenario 2	2015	2020	2015	2020
Real discount rate:	@ 5%	@ 5%	@ 7%	@ 7%
Western Sydney (CZ6)	77%	86%	67%	80%
Darwin (CZ1)	90%	97%	84%	93%
Brisbane (CZ2)	84%	91%	76%	86%
Adelaide (CZ5)	83%	92%	74%	86%
Hobart (CZ7)	71%	82%	60%	74%
Melbourne (CZ6)	73%	84%	62%	76%
Perth (CZ5)	82%	90%	73%	85%
Canberra (CZ7)	66%	77%	54%	70%
Weighted Average:	**77%**	**87%**	**68%**	**80%**

Source: pitt&sherry

Detailed Results

The pattern of performance by building type is similar to that described for Scenario 1. The 10 storey office is cost effective on average at BCA2010 -70%, although there is considerable variation by climate zone, with a strong result in Darwin masking weaker ones in Hobart, Melbourne and Canberra, where the BCRs all fall below 1.

The 3-storey office is comfortably cost effective in all climate zones at BCA2010 -70%, with the average BCR = 2.4 (in 2020 at 7% discount rate). However, it is still not cost effective at zero net energy, given the high incremental costs (around 45% relative to Base Case of this last step (including to cover the plug load of the building).

The supermarket reaches very high levels of cost effectiveness, remaining cost effective in all climates at BCA2010 -100%. In the case of the supermarket, for example, even a zero net energy building in a 'typical' Western Sydney climate zone has a simple investment payback of a about 8 years. For a building that may stand for 40 years, and even with discounting of future savings, this is an attractive investment. In climates and scenarios where PV is cost effective, a supermarket typically has plenty of roof area upon which to install PV systems and so is not constrained in the amount of PV that can be deployed. By contrast, 10 storey office and health buildings have less suitable roof and façade area.

The health building is cost effective at BCA2010 -70% in all climates in this scenario, but at BCA2010 -100% it is only cost effective in Darwin.

10 Storey Office

Table A5.32 below shows the BCRs that are attained by the 10 storey office in Scenario 3; with higher carbon prices and learning rates.

Table A5.32: 10 Storey Office: Benefit Cost Ratios by Climate Zone, Year and Discount Rate: Scenario 2

Summary Table - 10 Storey Office	2015	2015	2020	2020
Real discount rate:	**5%**	**7%**	**5%**	**7%**
Scenario 2 BCR @ -40%				
Western Sydney (CZ6)	1.5	1.2	2.1	1.7
Darwin (CZ1)	2.6	2.0	3.6	2.9
Brisbane (CZ2)	2.0	1.6	2.8	2.2
Adelaide (CZ5)	1.6	1.3	2.2	1.8
Hobart (CZ7)	1.1	0.9	1.6	1.2
Melbourne (CZ6)	1.3	1.0	1.7	1.4
Perth (CZ5)	1.7	1.3	2.4	1.9
Canberra (CZ7)	1.1	0.8	1.5	1.2
Average:	**1.6**	**1.3**	**2.2**	**1.8**
Scenario 2 BCR @ -70%				
Western Sydney (CZ6)	0.9	0.7	1.2	1.0
Darwin (CZ1)	1.5	1.2	2.1	1.7
Brisbane (CZ2)	1.2	0.9	1.6	1.3
Adelaide (CZ5)	1.1	0.8	1.5	1.2
Hobart (CZ7)	0.7	0.6	0.9	0.8
Melbourne (CZ6)	0.9	0.7	1.1	0.9
Perth (CZ5)	1.1	0.8	1.5	1.2
Canberra (CZ7)	0.6	0.4	0.7	0.6
Average:	**1.0**	**0.8**	**1.3**	**1.1**
Scenario 2 BCR @ -100%				
Western Sydney (CZ6)	0.2	0.2	0.3	0.2
Darwin (CZ1)	0.5	0.4	0.6	0.5
Brisbane (CZ2)	0.3	0.2	0.4	0.3
Adelaide (CZ5)	0.3	0.2	0.4	0.3
Hobart (CZ7)	0.1	0.1	0.1	0.1
Melbourne (CZ6)	0.1	0.1	0.2	0.2
Perth (CZ5)	0.2	0.2	0.3	0.3
Canberra (CZ7)	0.1	0.1	0.1	0.1
Average:	**0.2**	**0.2**	**0.3**	**0.2**

Source: pitt&sherry

3 Storey Office

Table A5.33 below shows the BCRs that are attained by the 3 storey office in Scenario 3; that is, with higher carbon prices and learning rates.

Table A5.33: 3 Storey Office: Revised Benefit Cost Ratios by Climate Zone, Year and Discount Rate: Scenario 2

Summary Table - 3 Storey Office	2015	2015	2020	2020
Real discount rate:	**5%**	**7%**	**5%**	**7%**
Scenario 2 BCR @ -40%				
Western Sydney (CZ6)	2.1	1.6	2.9	2.3
Darwin (CZ1)	2.0	1.6	2.8	2.2
Brisbane (CZ2)	2.1	1.6	2.8	2.3
Adelaide (CZ5)	2.4	1.9	3.3	2.6
Hobart (CZ7)	2.3	1.8	3.2	2.5
Melbourne (CZ6)	1.9	1.5	2.6	2.1
Perth (CZ5)	2.2	1.7	3.1	2.4
Canberra (CZ7)	1.9	1.5	2.7	2.1
Average:	**2.1**	**1.6**	**2.9**	**2.3**
Scenario 2 BCR @ -70%				
Western Sydney (CZ6)	2.0	1.6	2.8	2.2
Darwin (CZ1)	2.3	1.8	3.1	2.5
Brisbane (CZ2)	2.2	1.7	3.0	2.4
Adelaide (CZ5)	2.5	2.0	3.5	2.7
Hobart (CZ7)	2.2	1.7	3.1	2.4
Melbourne (CZ6)	2.0	1.6	2.8	2.2
Perth (CZ5)	2.3	1.8	3.2	2.5
Canberra (CZ7)	1.8	1.4	2.5	2.0
Average:	**2.2**	**1.7**	**3.0**	**2.4**
Scenario 2 BCR @ -100%				
Western Sydney (CZ6)	0.7	0.5	0.9	0.7
Darwin (CZ1)	0.7	0.5	1.0	0.8
Brisbane (CZ2)	0.7	0.6	1.0	0.8
Adelaide (CZ5)	0.8	0.6	1.1	0.9
Hobart (CZ7)	0.7	0.5	0.9	0.7
Scenario 2 BCR @ -100% (cont)				
Melbourne (CZ6)	0.7	0.5	0.9	0.7
Perth (CZ5)	0.7	0.6	1.0	0.8
Canberra (CZ7)	0.6	0.4	0.8	0.6
Average:	**0.7**	**0.5**	**0.9**	**0.8**

Source: pitt&sherry

Supermarket

Table A5.34 below shows the BCRs that are attained by the supermarket in Scenario 3; that is, with higher carbon prices and learning rates.

Table A5.34: Supermarket: Revised Benefit Cost Ratios by Climate Zone, Year and Discount Rate: Scenario 2

Summary Table - Supermarket	2015	2015	2020	2020
Real discount rate:	**5%**	**7%**	**5%**	**7%**
Scenario 2 BCR @ -40%				
Western Sydney (CZ6)	6.0	4.7	8.2	6.5
Darwin (CZ1)	8.1	6.3	11.2	8.9
Brisbane (CZ2)	7.6	6.0	10.3	8.2
Adelaide (CZ5)	6.7	5.3	9.1	7.2
Hobart (CZ7)	4.5	3.5	6.2	4.9
Melbourne (CZ6)	4.8	3.8	6.6	5.3
Perth (CZ5)	6.6	5.2	9.2	7.3
Canberra (CZ7)	4.3	3.3	5.8	4.7
Average:	**6.1**	**4.8**	**8.3**	**6.6**
Scenario 2 BCR @ -70%				
Western Sydney (CZ6)	2.2	1.8	3.1	2.4
Darwin (CZ1)	3.6	2.8	5.0	4.0
Brisbane (CZ2)	2.6	2.1	3.6	2.9
Adelaide (CZ5)	2.6	2.0	3.5	2.8
Hobart (CZ7)	2.0	1.5	2.7	2.1
Melbourne (CZ6)	2.0	1.6	2.8	2.2
Perth (CZ5)	2.5	2.0	3.5	2.8
Canberra (CZ7)	1.7	1.3	2.3	1.9
Average:	**2.4**	**1.9**	**3.3**	**2.6**
Scenario 2 BCR @ -100%				
Western Sydney (CZ6)	1.3	1.0	1.8	1.4
Darwin (CZ1)	1.4	1.1	2.0	1.6
Brisbane (CZ2)	1.6	1.2	2.1	1.7
Adelaide (CZ5)	1.5	1.2	2.1	1.7
Hobart (CZ7)	1.1	0.9	1.6	1.2
Melbourne (CZ6)	1.2	0.9	1.6	1.3
Perth (CZ5)	1.5	1.2	2.1	1.6
Canberra (CZ7)	1.0	0.8	1.3	1.1
Average:	**1.3**	**1.0**	**1.8**	**1.5**

Source: pitt&sherry

Healthcare Facility

Table A5.35 below shows the BCRs that are attained by the healthcare facility in Scenario 2; that is, with higher carbon prices and learning rates.

Table A5.35: Healthcare Facility: Benefit Cost Ratios by Climate Zone, Year and Discount Rate: Scenario 2

Summary Table - Health	**2015**	**2015**	**2020**	**2020**
Real discount rate:	**5%**	**7%**	**5%**	**7%**
Scenario 2 BCR @ -40%				
Western Sydney (CZ6)	2.9	2.3	4.1	3.2
Darwin (CZ1)	4.9	3.8	6.9	5.4
Brisbane (CZ2)	4.0	3.1	5.5	4.3
Adelaide (CZ5)	3.7	2.9	5.2	4.1
Hobart (CZ7)	3.2	2.5	4.6	3.6
Melbourne (CZ6)	3.1	2.4	4.4	3.5
Perth (CZ5)	3.8	3.0	5.4	4.2
Canberra (CZ7)	3.0	2.3	4.3	3.3
Average:	**3.6**	**2.8**	**5.0**	**4.0**
Scenario 2 BCR @ -70%				
Western Sydney (CZ6)	1.4	1.1	1.8	1.4
Darwin (CZ1)	1.9	1.5	2.6	2.1
Brisbane (CZ2)	1.5	1.2	2.0	1.6
Adelaide (CZ5)	1.8	1.5	2.4	2.0
Hobart (CZ7)	1.3	1.0	1.7	1.3
Melbourne (CZ6)	1.1	0.9	1.4	1.2
Perth (CZ5)	1.6	1.2	2.2	1.7
Canberra (CZ7)	1.0	0.8	1.3	1.0
Average:	**1.4**	**1.1**	**1.9**	**1.5**
Scenario 2 BCR @ -100%				
Western Sydney (CZ6)	0.3	0.3	0.4	0.4
Darwin (CZ1)	1.0	0.8	1.3	1.1
Brisbane (CZ2)	0.5	0.4	0.6	0.5
Adelaide (CZ5)	0.6	0.5	0.8	0.7
Hobart (CZ7)	0.3	0.2	0.4	0.3
Melbourne (CZ6)	0.4	0.3	0.5	0.4
Perth (CZ5)	0.5	0.4	0.6	0.5
Canberra (CZ7)	0.2	0.2	0.3	0.2
Average:	**0.5**	**0.4**	**0.6**	**0.5**

Source: pitt&sherry

Benefit-Cost Analysis of PV in Commercial Buildings

PV is cost effective in all but one climate zone at a 5% real discount rate, and in Darwin, Adelaide and Perth at a 7% real discount rate. For these climate zones, it is possible that the break even levels of energy savings are influenced by the cost-effective availability of PV; however, this is not certain. If energy savings options were available with the same or similar benefit cost ratios, and PV were not available, then the break even savings level would not change: instead, the energy savings options would substitute for PV at the same cost. Only in the circumstance where no such similarly-priced savings options were available, and therefore PV determined the cost at the margin in the break even solution, could we say that the break even savings level is sensitive to PV. To quantify these relationships, it would be necessary to construct a full marginal energy savings cost curve for commercial buildings; a research project in its own right.

Table A5.36: Benefit Cost Ratios for PV: Commercial Buildings: Scenario 2

	2015		**2020**	
Real discount rate:	@ 5%	@ 7%	@ 5%	@ 7%
Western Sydney (CZ6)	0.88	0.70	1.10	0.93
Darwin (CZ1)	0.92	0.75	1.17	1.02
Brisbane (CZ2)	0.89	0.73	1.10	0.95
Adelaide (CZ5)	1.07	0.87	1.35	1.17
Hobart (CZ7)	0.78	0.64	1.03	0.89
Melbourne (CZ6)	0.81	0.65	1.04	0.87
Perth (CZ5)	1.10	0.87	1.66	1.39
Canberra (CZ7)	0.67	0.53	0.85	0.71

Source: pitt&sherry

1.2.3 Benefit Cost Ratio = 1.2

Tables A5.37 – A5.39 show the comparison of energy savings for commercial buildings relative to BCA2010 that are achieved at BCR = 1 and BCR = 1.2, for each climate zones for the main results as well as scenarios 1 and 2, at a 7% real discount rate.

Table A5.37: Comparison of % Energy Savings at BCR =1 and BCR = 1.2, Base Case

Base Case	**2015 (BCR 1)**	**2015 (BCR 1.2)**	**2020 (BCR 1)**	**2020 (BCR 1.2)**
Sydney (CZ5)	58%	46%	68%	58%
Darwin (CZ1)	74%	66%	80%	74%
Brisbane (CZ2)	70%	61%	77%	70%
Adelaide (CZ5)	67%	57%	76%	68%
Hobart (CZ7)	49%	37%	61%	51%
Melbourne (CZ6)	52%	38%	63%	53%
Perth (CZ5)	66%	56%	75%	67%
Canberra (CZ7)	41%	27%	54%	43%
Weighted average	**58%**	**47%**	**68%**	**59%**

Source: pitt&sherry

Table A5.38: Comparison of % Energy Savings at BCR =1 and BCR = 1.2, Scenario 1

Scenario 1	2015	2015	2020	2020
	(BCR 1)	(BCR 1.2)	(BCR 1)	(BCR 1.2)
Sydney (CZ5)	41%	26%	43%	29%
Darwin (CZ1)	66%	57%	66%	57%
Brisbane (CZ2)	58%	47%	59%	49%
Adelaide (CZ5)	54%	41%	56%	43%
Hobart (CZ7)	31%	15%	34%	18%
Melbourne (CZ6)	33%	12%	35%	15%
Perth (CZ5)	52%	40%	54%	42%
Canberra (CZ7)	18%	0%	21%	4%
Weighted average	**42%**	**27%**	**44%**	**29%**

Source: pitt&sherry

Table A5.39: Comparison of % Energy Reduction at BCR =1 and BCR = 1.2, Scenario 2

Scenario 2	2015 (BCR 1)	2015 (BCR 1.2)	2020 (BCR 1)	2020 (BCR 1.2)
Sydney (CZ5)	67%	58%	80%	73%
Darwin (CZ1)	84%	78%	93%	88%
Brisbane (CZ2)	76%	69%	86%	81%
Adelaide (CZ5)	74%	66%	86%	80%
Hobart (CZ7)	60%	49%	74%	67%
Melbourne (CZ6)	62%	52%	76%	71%
Perth (CZ5)	73%	65%	85%	79%
Canberra (CZ7)	54%	43%	70%	62%
Weighted average	**68%**	**59%**	**80%**	**74%**

Source: *pitt&sherry*

Apart from Canberra in Scenario 1, the reduction in energy savings that result from the change in BCR for all climate zones ranges between about 7 - 12 percentage points for a 20 percent change in BCR. As noted in Chapter 3, the present values of energy savings and costs for all the commercial buildings studied are related by linear functions. As a result, changes in energy savings are not highly sensitive to changes in benefit cost ratios.

The change in energy savings rate is greater for Canberra in Scenario 1 as this climate zone shows the lowest level of cost effective energy savings at BCR = 1. As noted in Chapter 5, this is because commercial buildings use – and in this scenario save – mostly natural gas. Gas is generally valued at around one third of electricity per megajoule, and Canberra has the lowest gas prices of all states. Therefore, energy savings in Canberra have a relatively low value, particularly in Scenario 1, and the break even savings rate is low and sensitive to erosion at the higher investment hurdle rate.

1.3 Residential Building Sensitivity Analysis: Passive Solar Re-design

Overview

The main part of this study was undertaken with the assumption that the predominant response from industry to higher residential building shell performance standards would be to generally favour re-specification rather than re-design as the primary means of compliance. Experience from the introduction of the 5 star energy standard in Victoria suggests that mostly designers responded to those regulations using the re-specify approach (see ACIL – Tasman report "Evaluation of the Victorian 5 star building standard" ACIL-Tasman, 2008).

Re-design options can however offer low cost pathways or even zero cost pathways to cost effective increases in building shell thermal performance. Primarily, the design changes examined in this sensitivity analysis were changes intended to improve solar heat gain during the heating season and or reduce solar heat gain during the cooling season - the application of *passive solar design principles*. These principles were adapted to the existing representative designs utilized in this study to deliver zero cost "passive" design improvements – "passive" to reflect that the changes undertaken were not a complete and comprehensive approach to re-design, and zero cost to allow direct comparison of results of the benefit cost modelling.

Further, although the impact of PV was included in the model, there is no discussion results with PV included as the purpose of the "passive" design changes is to examine costless efficiency improvements. As in the main study, the inclusion of PV would dominate the results.

Sample Modelled

Passive design improvements were applied to the medium and large dwellings built in brick veneer (BV) and cavity brick (CB) with concrete slab on ground (CSOG). While BV is the predominant form of wall construction in Australia, by also including CB constructions, the characteristics of construction in both WA (90% of detached dwellings are CB) and NT (50% of detached dwellings are CB) are better covered. The dwelling types selected for this sensitivity analysis represent 60-80% of dwellings in all jurisdictions. Neither lightweight wall construction nor suspended timber floor construction was included as both are inherently less sensitive to improvement via passive solar design and occupy significantly lower shares of construction types in dwellings.

Redesign Improvement Measures Modelled

In order to make a fair comparison between a pathway with and without the application of passive design principles, the basic designs for the sample dwellings were retained in each case. In the case of the passive solar pathway a number of changes to window and/or room positions were then applied. Basically, window and room positions were adjusted to provide the best star rating at zero net cost. The repositioning of windows and rooms took solar orientation into account, as well as the accounting for relative window areas in day-time and night-time occupied spaces in the dwelling. Building code requirements were respected and professional architectural expertise and commonsense applied to adjustments in window and room positions. The redesigns included net zero changes in window areas[35] and floor areas and should result in a net zero change in building costs except possibly for the additional costs associated with re-design.

These adjustments were all effectively made on the drawing board with no change to the overall size or spatial provisions of the dwelling, the assumption being that these are zero cost improvements. Some might argue that for those that adopt the re-design approach, additional design costs might add to the cost of the dwelling, however there are reasons why this is unlikely to be the case:

- The added design costs would in many cases be defrayed over a large number of dwellings constructed to the new design.
- Where the price point is critical the rational volume builder adopting the re-design approach will have determined that this represents a lower cost pathway to compliance compared to the simple re-specification pathway.
- Given that re-design is generally undertaken periodically by volume builders, re-design to address new thermal performance stringencies would likely not involve additional costs.
- For individually designed dwellings (such as those produced by architects) the point is moot because at least in theory each new dwelling is designed from scratch. It is recognised however that such individually designed dwellings represent only a minor portion of the market.

The adjustments did not take block constraints into consideration, eg size and proportion of the block, orientation to the street, location of driveways and garages etc. Potentially more significant issues with this passive re-design approach relate to the realities of suburban development. Such issues include:

- Relocating of a key window or a key room (e.g. living space) may work perfectly well in an internal planning sense but could compromise the external aspect of that room. For instance, if the street frontage of the dwelling faces north, in most climates it will be most beneficial to have all the main living areas facing the street (north) however this could limit the scope for direct linkages between living spaces and private

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[35] a minor decrease in west facing window area was used in the 2-storey large detached dwelling as a means of achieving significant improvements, particularly in hotter climates.

outdoor open spaces. Such limitations can impact on consumer perceptions and the market value of the finished product.

- Where a northerly aspect is towards a side boundary solar access may be significantly compromised by overshadowing from adjoining properties, particularly on smaller (narrower) blocks where the scope for offsetting away from the overshadowing neighbour will be limited. To some extent the capacity of designer to take advantage of passive solar design principles will depend upon the rules for subdivision.

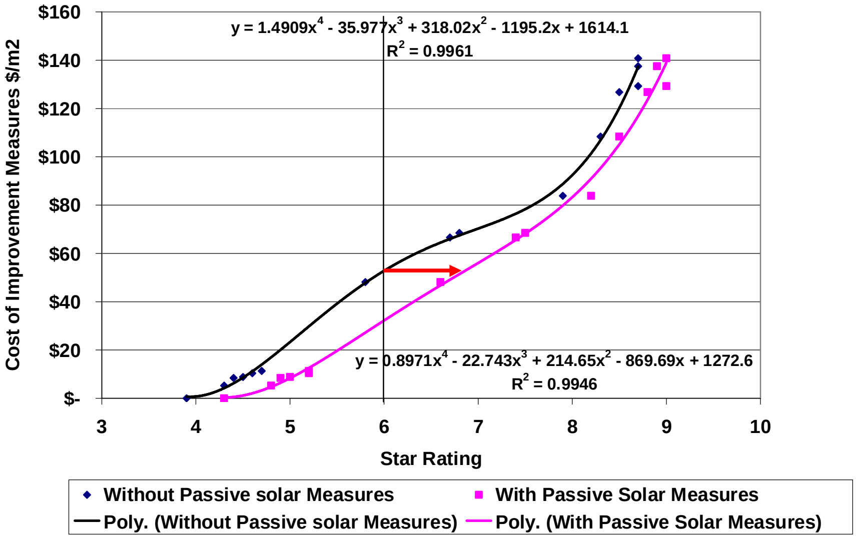
For this sensitivity analysis the passive solar improvement measures applied to the two detached dwelling types are detailed in Annex A.

Method

The method undertaken for this sensitivity analysis was identical to that undertaken for the main part of the study using AccuRate simulations of each dwelling type examined in each climate zone. Improvement measures were added progressively to each dwelling using a least cost approach. In the case of the passive solar pathway, the re-design measures noted above were deemed to have no cost and were therefore always adopted first. Following the application of these no cost measures the re-specification measures were then added in the same order as undertaken in the main study[36].

As in the main study, the results comparing cost of aggregate improvements with achieved star rating were plotted against each other and a polynomial curve fitted to each set of points to allow interpolation and extrapolation of results (average fit for polynomials was better than 0.99) (see figure A5.2). As expected, the cost benefit curves for the passive solar pathway (pink line) were offset to the right of those for the non passive solar pathway (black line) indicating a lower cost for the same level of improvement. The red arrow indicates the level of improvement above the 6 star Base Case due to the application of the passive solar measures. The case shown in Figure represents one of the most significant improvements observed. The improvement levels observed ranged from 0.1 star up to 0.9 star. The average level of improvement was around 0.5 star (see Table A5.40). It can be seen that “passive” design considerations provide good efficiency benefits, particularly for cavity brick/CSOG construction, in some climates.

Figure A5.2: Cost benefit curves medium sized BV in Perth



Source: Energy Efficient Strategies

36 In theory the application of the passive solar design measures as a first step could have subtly affected the order in which the re-specification measures can be most cost effectively applied. In reality the order of application of the re-specification measures is unlikely to be significantly affected by the initial application of the passive design measures.

Table A5.40 Performance Improvement from "Passive" Re-Design (AccuRate Stars)

Location/AccuRate Zone	Medium Detached, BV Walls, CSOG	Large Detached, BV Walls, CSOG	Medium Detached, CB Walls, CSOG	Large Detached, CB Walls, CSOG
Sydney (CZ6)	0.4	0.5	0.7	0.5
Darwin (CZ1)	0.3	0.2	0.2	0.3
Brisbane (CZ2)	0.2	0.4	0.4	0.8
Adelaide (CZ5)	0.5	0.4	0.6	0.7
Hobart (CZ7)	0.3	0.1	0.4	0.5
Melbourne (CZ6)	0.3	0.3	0.4	0.4
Perth (C5)	0.8	0.4	0.9	0.9
Canberra (CZ7)	0.4	0.4	0.5	0.6
Weighted Average	0.4	0.4	0.6	0.6

Source: Energy Efficient Strategies

It should be noted, however, that the increase in star rating (above 6 stars) at which the breakeven point was then reached for the "passive design pathway" case was typically more than that attributable to the passive solar design measures alone (i.e. more than indicated in Table A5.40). Details are provided in the economic modelling results section below. This is because without the passive solar measures the cost of the initial set of re-specification improvements (i.e. non zero cost improvements) is simply compared to the benefits arising from those measures alone. Whereas, in the case of the "with passive solar measures" the cost of the initial set of re-specification improvements (non zero cost) is compared to the benefits arising from those measures plus the benefits arising from the passive solar measures (zero cost).

For example, in the without passive solar measures case, the first measure, say an increase in ceiling insulation levels, may deliver 0.3 stars of improvement (i.e. total = 6.3 stars) at a certain cost. In the "with passive solar measures" case, the same improvement may also deliver 0.3 stars improvement but this will be in addition to the around 0.5 stars of improvement (on average) due to the passive solar measures already applied, giving a total improvement of 0.8 stars (i.e. total = 6.8 stars). This means that the "with passive solar measures" case delivers 6.8 stars performance for the same cost that the "without passive solar measures" case delivers only 6.3 star performance. If the benefit cost threshold is met only at or above an improvement of say 0.4 stars for the cost associated with the increase in ceiling insulation levels then this measure will be considered cost effective (and therefore included) in the "with passive solar measures" case but not in the "without passive solar measures" case. Effectively the passive solar design measures are cross subsidising some of the re-specification measures that would otherwise fail to meet the cost effective threshold.

Benefit Cost Modelling and Results at Break Even

The benefit/cost modelling was done in the same way as before. To highlight the impact of the "passive" design approach, however, the focus of the results will be only the Base Case Scenario and Scenario 2 for construction in 2015 and 2020 at 7% discount rate. The model was set up to allow before and after modelling using the original distribution and restructured dwelling distributions containing only medium and large dwellings with BV and CB walls on CSOG and semi-detached and Class 2 dwellings or containing only medium and large dwellings with BV and CB walls on CSOG.

Table A5.41 shows the energy savings at breakeven compared to BCA2010 from benefit cost modelling for the original distribution of buildings in each climate (all buildings and original distributions), and for hypothetical distributions of only medium and large detached dwellings in which the whole stock is improved (the distributions were scaled up from the original distributions of M/BV/CSOG, M/CB/CSOG, L/BV/CSOG and L/CB/CSOG). Irrespective of the building stock model, the results shown in Table A5.40 provide a consistent pattern of improved benefit/cost ratios at breakeven as a consequence of the improved passive designs (i.e. the difference between the respective Improvement and No Improvement lines). For the original distribution, the improvements in breakeven percentages are minor for the milder and warmer climates (Sydney, Brisbane, Adelaide, Perth, Darwin) and better for colder climates (Melbourne, Hobart, Canberra). This pattern is repeated for the hypothetical building distribution in which the performance of every building is improved, and reflects previous observations that colder climates are more likely to result in economic justification for higher energy standards.

Table A5.41 Comparison of Breakeven Energy Savings Relative to BCA2010 with Improved Designs (%) at 7% Discount Rate

Stock		Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
All (Original)	Base Case	2015	9%	3%	7%	11%	18%	14%	3%	4%
		2020	14%	7%	7%	11%	32%	17%	3%	7%
	Scen 2	2015	14%	4%	7%	11%	26%	16%	3%	7%
		2020	19%	25%	22%	22%	32%	25%	15%	29%
All (Improved)	Base Case	2015	12%	11%	8%	16%	22%	21%	7%	18%
		2020	16%	16%	8%	16%	36%	23%	7%	26%
	Scen 2	2015	17%	13%	8%	16%	30%	22%	7%	25%
		2020	22%	31%	23%	29%	36%	30%	18%	43%
M+L Only (No Improvement)	Base Case	2015	7%	1%	9%	11%	18%	12%	3%	3%
		2020	14%	5%	7%	11%	31%	14%	3%	5%
	Scen 2	2015	14%	2%	7%	11%	26%	13%	3%	5%
		2020	19%	23%	22%	21%	31%	23%	17%	27%
M+L Only (Improvement)	Base Case	2015	12%	14%	9%	17%	23%	23%	8%	19%
		2020	17%	19%	8%	18%	37%	26%	10%	27%
	Scen 2	2015	17%	17%	9%	18%	31%	25%	10%	26%
		2020	23%	33%	24%	31%	37%	33%	22%	43%

Source: Energy Efficient Strategies

A more specific focus on the impact of the described "passive" design improvements can be obtained from the modelling results which identify the building shell star rating at breakeven. Tables A5.42 – A5.45 illustrate the results for the four relevant improved building types. In each table the star rating at breakeven is shown for the original dwelling and for the dwelling with the "passive" improvement.

Table A5.42 Medium Detached Dwelling BV/CSOB, Star Rating at Breakeven

Scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Not Improved									
Base Case	2015	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
	2020	6.0	6.0	6.0	6.0	6.0	6.2	6.0	6.0
Scen 2	2015	6.0	6.0	6.0	6.0	6.0	6.1	6.0	6.0
	2020	6.0	6.7	6.0	6.0	6.0	6.7	6.8	7.1
Improved									
Base Case	2015	6.4	6.6	6.3	6.6	7.0	6.7	6.5	7.0
	2020	6.5	6.8	6.3	6.7	7.0	6.9	6.6	7.4
Scen 2	2015	6.5	6.8	6.3	6.7	7.0	6.8	6.6	7.3
	2020	6.6	7.4	6.3	7.1	7.2	7.2	7.1	8.1

Source: Energy Efficient Strategies

Table A5.43: Large Detached Dwelling BV/CSOB Star Rating at Breakeven

Scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Not Improved									
Base Case	2015	6.0	6.0	6.0	6.0	6.0	6.3	6.0	6.0
	2020	6.0	6.0	6.0	6.0	6.0	6.4	6.0	6.0
Scen 2	2015	6.0	6.0	6.0	6.0	6.0	6.4	6.0	6.0
	2020	6.0	6.8	6.0	6.0	6.0	6.6	7.0	6.8
Improved									
Base Case	2015	6.5	6.7	6.5	6.4	6.5	6.5	6.4	6.8
	2020	6.5	6.8	6.5	6.5	6.5	6.7	6.5	7.0
Scen 2	2015	6.5	6.8	6.5	6.4	6.5	6.7	6.5	7.0
	2020	6.6	7.1	6.5	6.5	6.6	7.0	6.9	7.6

Source: Energy Efficient Strategies

Table A5.44: Medium Detached Dwelling CB/CSOB Star Rating at Breakeven

	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Not Improved									
Base Case	2015	6.0	6.0	6.0	6.0	6.0	6.0	6.0	-
	2020	6.0	6.4	6.0	6.0	6.0	6.1	6.0	-
Scen 2	2015	6.0	6.4	6.0	6.0	6.0	6.1	6.0	-
	2020	6.0	7.3	6.0	6.0	6.0	6.8	6.1	-
Improved									
Base Case	2015	6.9	7.3	6.5	6.8	7.0	7.0	6.3	-
	2020	6.9	7.5	6.5	6.9	7.1	7.2	6.4	-
Scen 2	2015	6.9	7.5	6.5	6.9	7.1	7.1	6.4	-
	2020	7.1	8.1	6.6	7.2	7.2	7.6	6.7	-

Source: Energy Efficient Strategies

Table A5.45: Large Detached Dwelling CB/CSOB Star Rating at Breakeven

Scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Not Improved									
Base Case	2015	6.0	6.0	6.0	6.0	6.0	6.0	6.0	-
	2020	6.0	6.2	6.0	6.0	6.0	6.0	6.0	-
Scen 2	2015	6.0	6.2	6.0	6.0	6.0	6.0	6.0	-
	2020	6.0	7.0	6.0	6.0	6.0	6.1	6.7	-
Improved									
Base Case	2015	6.6	6.8	6.9	6.9	7.0	6.9	6.5	-
	2020	6.6	7.0	6.9	6.9	7.0	7.0	6.6	-
Scen 2	2015	6.6	7.1	6.9	6.9	7.0	7.0	6.6	-
	2020	6.7	7.4	7.0	7.1	7.1	7.3	7.1	-

Source: Energy Efficient Strategies

As previously noted, the improvement in star rating at breakeven is greater than the star rating improvement due to the "passive" improvements alone. In the economic modelling, the benefit cost calculation proceeds from the new starting point, with same cost ranking of improvements that had previously been determined for the un-improved dwelling. The energy efficiency benefits of "passive" options (i.e. reduced energy cost) then provide a free "bonus" benefit in each successive benefit cost calculation on the way to reaching breakeven, so that the star rating at the new breakeven point is higher than the star rating at the original breakeven point plus the "passive" star rating addition.

This result is illustrated in Table A5.46, which involves a combination of the results from Tables A5.42 – A5.45 and Table A5.40, such that the "passive" benefit is subtracted from the difference between the star rating with improvements at breakeven and the star rating without improvements at breakeven. The anomalous result for Darwin for the Large BV dwelling occurs because the optimal improvements path for the un-improved dwelling is different from that for the improved dwelling. There are no results for Canberra for cavity brick dwellings because this building type has a very low representation in the Canberra stock.

The results in Table A5.46 reflect previous conclusions that building shell efficiency gains beyond the 6-star are not cost effective in milder/warmer climates, with significant benefits beyond "passive" design improvements in Melbourne, Hobart and Canberra.

Table A5.46: Star Rating Improvement at Breakeven in addition to "Passive" Benefit

Dwelling	Scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Medium BV	Base Case	2015	0.0	0.3	0.1	0.1	0.2	0.4	0.2	0.6
		2020	0.1	0.5	0.1	0.2	0.2	0.4	0.3	1.0
	Scen 2	2015	0.1	0.5	0.1	0.2	0.2	0.4	0.3	0.9
		2020	0.2	0.4	0.1	0.6	0.4	0.2	0	0.6
Large BV	Base Case	2015	0	0.4	0.1	0	0.1	0.1	0.2	0.4
		2020	0	0.5	0.1	0.1	0.1	0.2	0.3	0.6
	Scen 2	2015	0	0.5	0.1	0	0.1	0.2	0.3	0.6
		2020	0.1	0	0.1	0.1	0.2	0.3	-0.3	0.4
Medium CB	Base Case	2015	0.2	0.9	0.1	0.2	0.1	0.6	0.1	
		2020	0.2	0.7	0.1	0.3	0.2	0.7	0.2	
	Scen 2	2015	0.2	0.7	0.1	0.3	0.2	0.6	0.2	
		2020	0.4	0.4	0.2	0.6	0.3	0.4	0.4	
Large CB	Base Case	2015	0.1	0.4	0.1	0.2	0.1	0.4	0.2	
		2020	0.1	0.4	0.1	0.2	0.1	0.5	0.3	
	Scen 2	2015	0.1	0.5	0.1	0.2	0.1	0.5	0.3	
		2020	0.2	0.0	0.2	0.4	0.2	0.7	0.1	

Source: Energy Efficient Strategies

Detailed Design Changes

The following is a brief description of the design changes undertaken to improve the performance of the dwellings that were the subject of this sensitivity analysis.

Medium Detached Dwelling

- North was set to the side boundary of the dwelling as shown in the plan below except in the case of Darwin where North was set in the opposite direction (i.e. rotated 180°). In the following dot points references to specific orientations should be read as the opposite orientation (i.e. rotated 180°) in the case of Darwin.
- One of the bedrooms (bed 4) and the laundry (immediately to its West) were both shifted from the north side of the dwelling to the south. In this arrangement Bed 4 retained a window facing to the east
- The space on the north side that was formerly occupied by bed 4 and the laundry was replaced with the rumpus room that was formerly positioned on the south east corner. This was designed to allow for improved access to passive solar heating (except in Darwin).

- The two windows to the rumpus room (W10 and W11) that were formerly located on the south and east facades were shifted to the north façade.
- Both of the living room windows (W1 and W2) formerly facing west was relocated to the north façade
- Both of the Bed 1 windows (W16 and W17) formerly facing west was relocated to the north facade

Figure A5.3: Medium Detached Dwelling - Floor Plan

Source: Energy Efficient Strategies

Large Detached Dwelling

- North was set to the rear boundary of the dwelling as shown in the plan below except in the case of Darwin where North was set in the opposite direction (i.e. rotated 180°). In the following dot points references to specific orientations should be read as the opposite orientation (i.e. rotated 180°) in the case of Darwin.

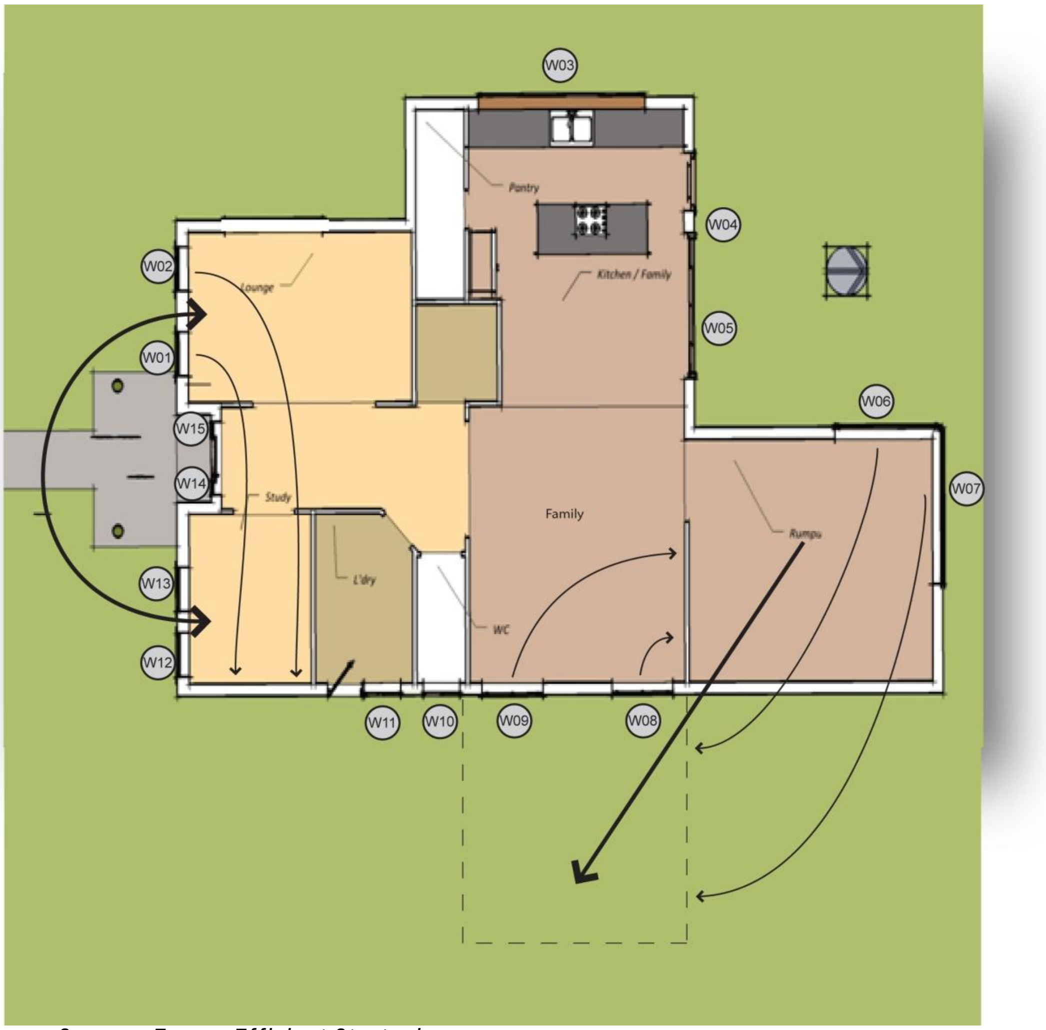
GROUND FLOOR

- The lounge (currently on the West side) was swapped with the study and laundry on the East side and its windows (W1 and W2) relocated to the East.
- The Rumpus room was relocated to the East side of the building to allow the family room windows (W8 and W9) to be relocated to a northerly aspect. In addition the rumpus room windows W6 and W7 were both located on the North side of the relocated Rumpus room.
- Window W3, a highly exposed windowin the west façade, was removed

UPPER FLOOR

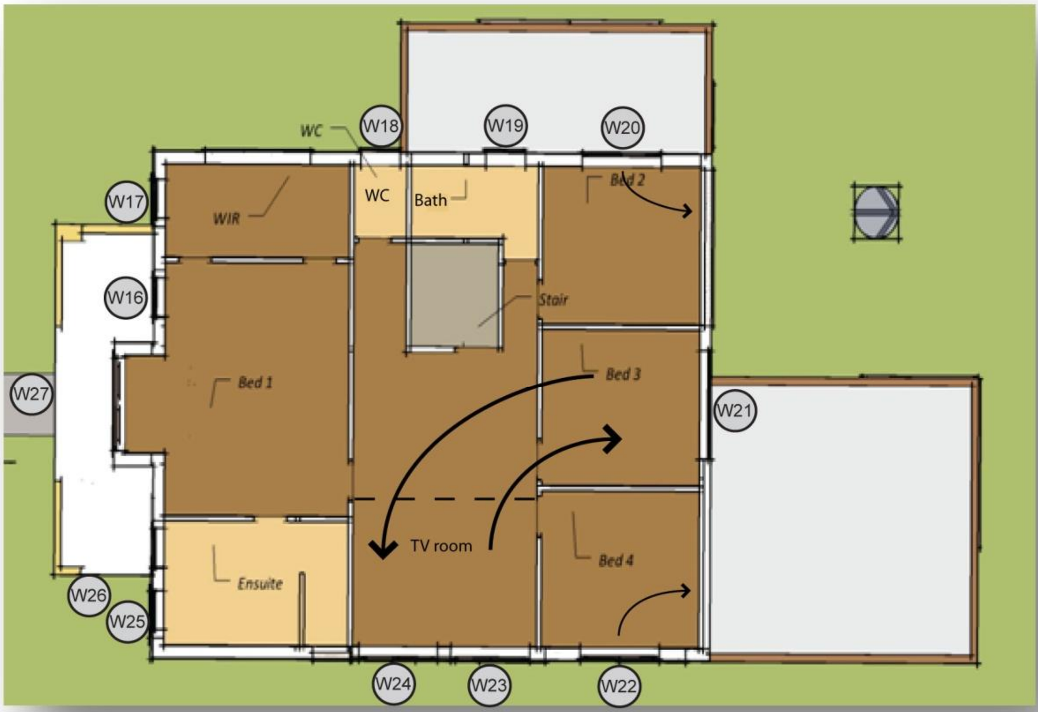
- W 20 in bedroom 2 was relocated from the West façade to the North.
- Bedroom 3 and the TV rooms were swapped giving the TV room windows (W23 and W24) a northerly aspect.
- W 22 in bedroom 4 was relocated from the East façade to the North.

Figure A5.4: Large Detached Dwelling - Lower floor Plan



Source: Energy Efficient Strategies

Figure A5.5: Large Detached Dwelling - Upper Floor Plan



Source: Energy Efficient Strategies

transport infrastructure | community infrastructure | industrial infrastructure | climate change

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