Accelerating Net-Zero High-Rise Residential Buildings in Australia

Final Report

transport | community | mining | industrial | food & beverage | carbon & energy



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In association with:

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Executive Summary

Why this report?

With growing populations and rapid urbanisation, many cities – in Australia and elsewhere – are experiencing a burgeoning demand for high-rise residential apartment buildings. Yet these buildings are typically more energy-intensive than low-rise housing, and their height and form creates challenges for reducing their emissions footprint. Can we realise the twin imperative for compact *and* sustainable cities?

This Report examines the technical and economic feasibility of moving towards net-zero high-rise residential buildings in Australia and identifies pathways to accelerate their commercialisation. Net-zero is defined in this report as '*an energy efficient building where the delivered energy imported is less than or equal to the on-site renewable exported energy'.* This definition reflects the US Department of Energy approach, and essentially means that the building must generate as much energy as it uses over a year, but that it is free to import and export to the grid during the year.

The Report is designed to inspire Federal and State Government policy makers and the development industry to move rapidly toward buildings that go well beyond current requirements of BASIX (NSW) and the National Construction Code.

While it has been commissioned by the City of Sydney, with support from the Carbon Neutral Cities Alliance, many of the pathways to net-zero identified will require leadership and action by Federal and State Governments, as well as by the property and development industry.

Some of the immediate ways this report may be used include:

- Making the case for higher BASIX greenhouse gas targets.
- Informing the case for much stronger energy performance standards in the National Construction Code in the short term (2019), as well as for developing a longer term transition plan to achieve net-zero emissions in the built environment.
- Inspiring the development of the first net-zero residential high-rise buildings in Sydney and Melbourne.
- Assisting with broader understanding of what net-zero means for existing programs and policies.
- Encouraging better performance, greater comfort and utilisation of space, and lower running costs in new residential apartment buildings.
- Promoting efficient technologies and treatments that through commoditisation will bring down the costs for the Australian market, as has occurred overseas.
- Complementing work by the Australian Government and others to define Carbon Neutrality in Australian buildings by identifying the high potential possible to improve energy performance.

Rationale

Rising energy costs, rising demand for high-quality urban living, a preference for compact and 'liveable' cities and, perhaps above all, the need to combat rising greenhouse gas emissions, are the key drivers for net-zero high-rise residential buildings in Australia.

Australia is a signatory to the 2015 Paris Climate Agreement, which effectively commits every country to achieving near-zero emissions by mid-Century. All sectors will need to contribute to this outcome, including the built environment which is responsible for nearly a quarter of Australia's greenhouse emissions. At the same time, new highly energy efficient building technologies and design features are increasingly cost-effective, expanding the boundary of what is possible both technically and commercially.

With buildings having an economic life of 40 years or more, decisions must be made in the very short term if Australia is to get onto a path to net-zero emissions by mid-Century. Delay means cost. A wait-and-see approach would lead to higher costs for energy consumers, lower standards and competitiveness in industry and higher greenhouse gas abatement costs in future.

Key findings

There are four key findings from this project:

1. Net-zero high-rise residential buildings are technically feasible in Australia even today.
2. Net-zero high-rise residential buildings are highly cost effective from a societal perspective in Australia even today.
3. Commercial uptake of net-zero high-rise residential buildings in Australia will be slow due to significant gaps and weaknesses in our energy efficiency and climate policy framework.
4. A strategic and integrated approach, by industry and governments, could rapidly transform the market for net-zero high-rise residential buildings in Australia.

These points are briefly expanded upon below.

Net-zero high-rise residential buildings are technically feasible in Australia today

A combination of very high energy efficiency and building-integrated photovoltaic facades (BiPV) can deliver net-zero outcomes for high-rise residential buildings in Australia. Chapter 3 highlights many strategies that can be highly effective and cost-effective in reducing energy demand and emissions. We adopted a 'fabric first' approach – aiming to improve the performance of the thermal shell as much possible in order to largely eliminate heating and cooling demands – with key strategies including:

- Reduced window-to-wall ratios (to 50% in Sydney, 30% in Melbourne)
- High-performance glazing
- Improved insulation
- Air tight facade
- Mechanical ventilation with heat recovery
- High efficiency ceiling fans, appliances and lighting
- High COP heat pumps for domestic hot water and swimming pools
- Building integrated (and some rooftop) PV (550 kW in Sydney and 1 MW in Melbourne).

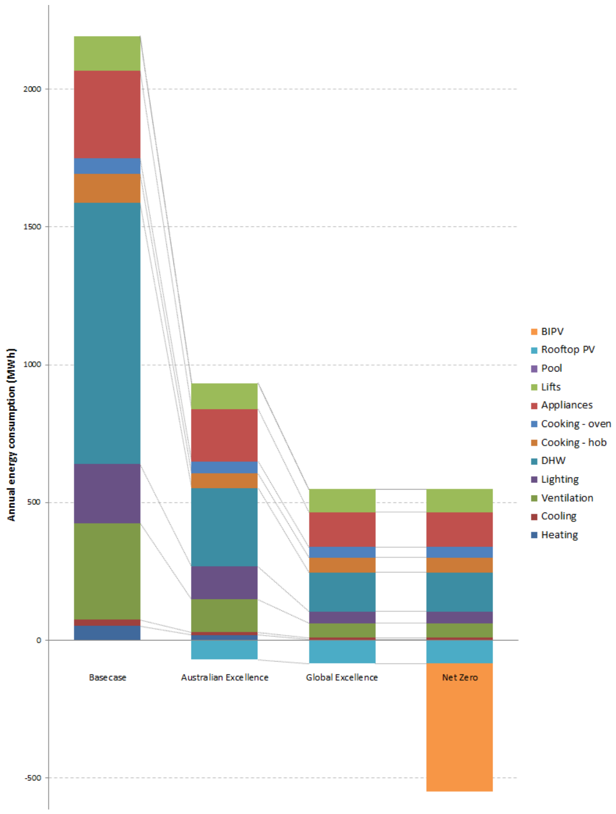
BiPV will not be suitable for all buildings due to over-shading risks, although these risks may be lessened through appropriate solar access protection. Also, BiPV might represent a higher cost, for the time being at least, than precinct or remote/utility-scale renewable energy generation. However, the relative willingness of consumers to pay for on-site vs off-site solutions in this context needs to be tested. It is possible that on-site may be perceived to have higher value, as well as higher cost.

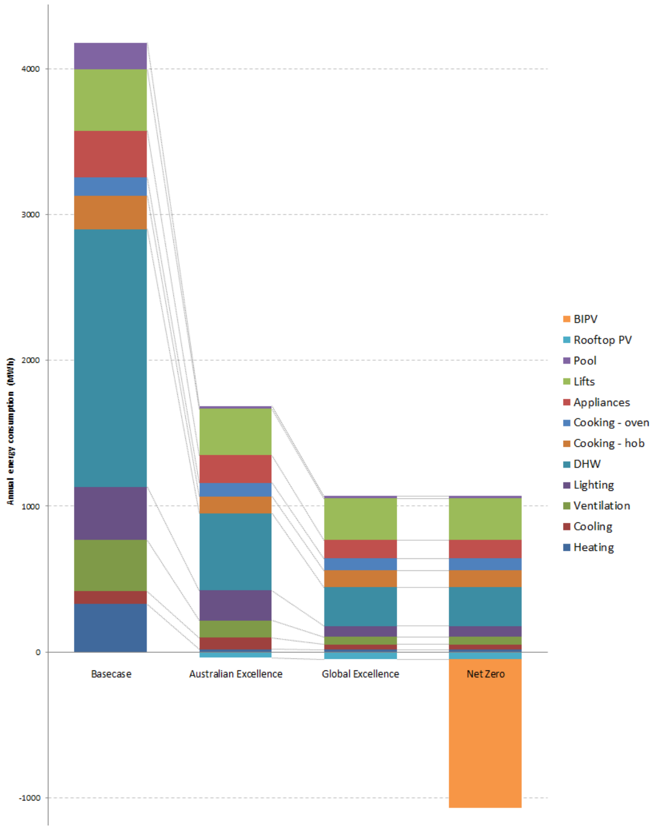
 

Sydney's Australia Tower II; Melbourne's EQ Tower (render)

Some of the energy efficiency options presented in this report – such as lower window-to-wall ratios (WWR) – may be controversial with the development community, as consumers are reputed to prefer expansive glass areas in apartment buildings. With lower WWRs, much higher performance (and more expensive) glazing can be used without impacting greatly on overall facade costs, as glazed area is lower. Achieving net zero with high WWRs may be feasible, but it would bring a significant cost penalty.

We note that the energy efficiency measures are extremely effective – our modelling indicates that average star ratings could be lifted dramatically from 4.4 to 9.2 in Sydney and from 6.5 to 9.3 in Melbourne.





Moving towards net-zero – Sydney... ...and Melbourne

Net-zero high-rise residential buildings are highly cost effective from a societal perspective in Australia today

We examined two (actual) buildings in detail and found that both would be highly cost effective from a societal perspective if they attained the net-zero performance level. The smaller (30 storey) Sydney building would generate a net social benefit of almost $6 million, while the larger (65 storey) Melbourne building would create a net social benefit of over $10 million, when compared to their 'as constructed' base cases.[1] These results represent attractive social benefit cost ratios in the 1.7 – 1.8 range, and social rates of return on investment of some 13% - 14%.

We found that *higher* social benefits are created by going to the net-zero performance level than would be the case for very high energy efficiency – here described as Australian excellence or global excellence. This is because more greenhouse gas emissions are avoided, and also because there are cost synergies at very high levels of thermal/facade performance, such as downsizing or even eliminating the need for expensive heating and cooling equipment. The results also suggests that a point is reached where renewable energy solutions become more cost effective at the margin than chasing diminishing returns through ever-higher levels of energy efficiency.

We also found that net-zero is already marginally cost effective (in Sydney) or nearly cost effective (in Melbourne) *on the basis of direct cost and benefits alone.* That is, the value of energy savings and avoided infrastructure costs approximately offsets the incremental construction costs – that is, even if we ignore wider social benefits such as greenhouse gas abatement and before taking into account any potential uplift in building value.

Summary results of the benefit cost analysis for net-zero are set out in Table 1 below. We acknowledge that there is uncertainty about some key values – such as incremental costs and consumer willingness to pay – as we are dealing with an emerging product in a rapidly evolving market place. Stakeholders have called for further research to be undertaken in these areas (see *Further work* below). It is important to note that this uncertainty includes upside risk – many stakeholders felt that our incremental cost estimates were too high, while the value of energy savings would increase if energy prices rise faster than expected and if carbon pricing is reintroduced, improving the return on investment.

Table 1: Benefit Cost Analysis: Summary Results: Net Zero Scenario

Parameter	Sydney	Melbourne
Incremental cost	$7.1m (7.8%)	$13.9m (8.2%)
Present value of energy savings	$6.1m	$10.6m
Present value of avoided infrastructure costs	$2.0m	$3.8m
Net present value (direct costs and benefits only)	$1.0m	$0.5m
Benefit cost ratio (direct costs and benefits only)	1.1	1
Internal rate of return (direct costs and benefits only)	8.3%	7.4%
Present value of avoided greenhouse gas emissions	$4.9m	$9.6m
Net social benefit	$5.9m	$10.2m
Social benefit cost ratio	1.8	1.7
Social return on investment	14%	13%

Note: Present values are calculated over the period 2017 – 2050 using a 7% real discount rate.

[1] The Melbourne building is still under construction – we have used its design-intent energy performance (average 6.5 star) as the basis for modelling.

Commercial uptake of net-zero high-rise residential buildings in Australia will be slow due to significant gaps and weaknesses in our energy efficiency and climate policy framework

Despite the benefit cost analysis results above, commercial uptake of net-zero is likely to be slow, at least in the absence of a strategic and integrated market transformation strategy. A range of gaps and weaknesses in Australia's energy efficiency and climate policy framework mask the true social benefits of net-zero. This makes it very difficult for investors and developers to monetise the benefits they are creating. In the absence of carbon pricing, for example, developers cannot earn a fair rate of return on investment in avoided greenhouse gas emissions.

With low minimum energy performance standards in Australia, the demand for (and therefore the supply of) high-performance solutions is limited, keeping those solutions trapped in niche, high-cost markets. As a result, high and net-zero energy performance is more costly than in should be. For example, we estimate incremental costs for net-zero in Australia today in the 7.8% to 8.2% range, while the City of London reports that the same performance can be achieved for a cost premium of just 1.5%.[2] Stakeholder feedback suggests these estimates are probably conservative, and lower values may well be able to be realised.

In addition to policy gaps, potential investors in and developers of net-zero high-rise buildings in Australia – and also the potential residents in those buildings – face a range of uncertainties and 'first of a kind' risks. What are the real incremental costs (on an optimised basis)? How quickly could those costs come down? Are consumers willing to pay the costs? Under what circumstances?

If we have no clear answers to these questions today, it is in part because we have taken only tentative steps down this path, with more research and market-testing to be done. Beyond this, however, we have limited direct experience with designing and constructing such high-performance buildings in Australia. There is no substitute for learning-by-doing and for discovering the answers to such questions in a real-world context. However, this will happen only slowly unless policy gaps, risks and uncertainties are consciously and strategically overcome.

A strategic and integrated approach, by industry and government, could rapidly transform the market

Australia's building market is large, complex and highly competitive. At the same time, it is a sector where performance regulation and also market demand for sustainability outcomes is relatively weak. As a result, innovation and excellence in energy performance tends to be restricted to particular market niches (such as CBD offices and higher-value homes), while much construction activity occurs at the mandatory minimum level of performance, at best.[3]

However supply chains, building technologies and building professionals are all linked, to varying degrees, to global markets and knowledge centres, and innovations can and do flow rapidly when policy and market conditions are right. As a result, there is a significant opportunity to accelerate the roll-out of very high performance buildings – including net-zero high-rises – in Australia, including by drawing on the lessons of other countries and markets that have already ventured down this path.

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[2] http://www.energyforlondon.org/major-london-housing-development-to-be-zero-carbon-from-october-2016/ - noting that this study covers a mix of low and high rise housing.

[3] The National Energy Efficient Buildings Project casts doubt on the extent to which mandatory minimum standards are in fact being enforced in Australia. Refer to https://www.sa.gov.au/topics/water-energy-and-environment/energy/government-energy-efficiency-initiatives/national-energy-efficient-building-project

No single policy or program will deliver the breadth and depth of innovation required for market transformation. Rather we highlight four integrated elements that together have the potential to accelerate the commercialisation of net-zero high-rise residential buildings in Australia.

1. *Incentives:* Incentives are fundamental to market behaviours. At present in Australia, energy performance standards are low. High standards are essential to high performance and in particular to driving the industry learning and innovation that will lead to high standards being met cost effectively. Incentives can also be market driven, but the high-rise residential sector currently lacks a whole-of-building rating tool that could be used to help focus and build these market incentives. Carbon pricing would place a monetary value on and therefore reward efforts to reduce greenhouse gas emissions in Australia. The absence of an effective scheme in Australia means that market incentives for high-performance and net-zero buildings are weaker than they should be.

2. *Transforming key markets:* Buildings are complex systems composed of a myriad of individual elements and components. Of these, some are key to achieving net-zero, both because of their technical performance but also because they can represent a cost barrier. We nominate high-performance glazing, facades and certain HVAC elements, such as mechanical ventilation with heat recovery, and building-integrated PV (BiPV), as key targets for co-ordinated market transformation strategies, with the aim of driving lower costs and greater uptake in the building market.

3. *Raising awareness.* Education and awareness-raising for consumers is critical to raising consumer demand for high-performance high-rise buildings, and also for using energy efficiently. Strategies could include new ratings tools, effective communication strategies linked to those, and use of new media and innovative approaches. As with the overarching market transformation strategy, integration, co-ordination, consistency and working to an overarching plan, are the key elements for success. Campaigns would focus on bottom line benefits, like ongoing cost savings and higher housing values, as well as on improved comfort and liveability, particularly in more severe weather conditions.

4. *Building capacity:* Building the capacity of a whole range of building industry professionals and trades is essential. This needs to be coordinated with the other strategies to ensure that quality outcomes and performance expectations are met in a cost-effective manner. Awareness, training and professional development strategies will be important, as will pilot and demonstration projects that enable professionals to learn from each other and understand real world challenges and solutions.

This approach is summarised in Figure 1 below.

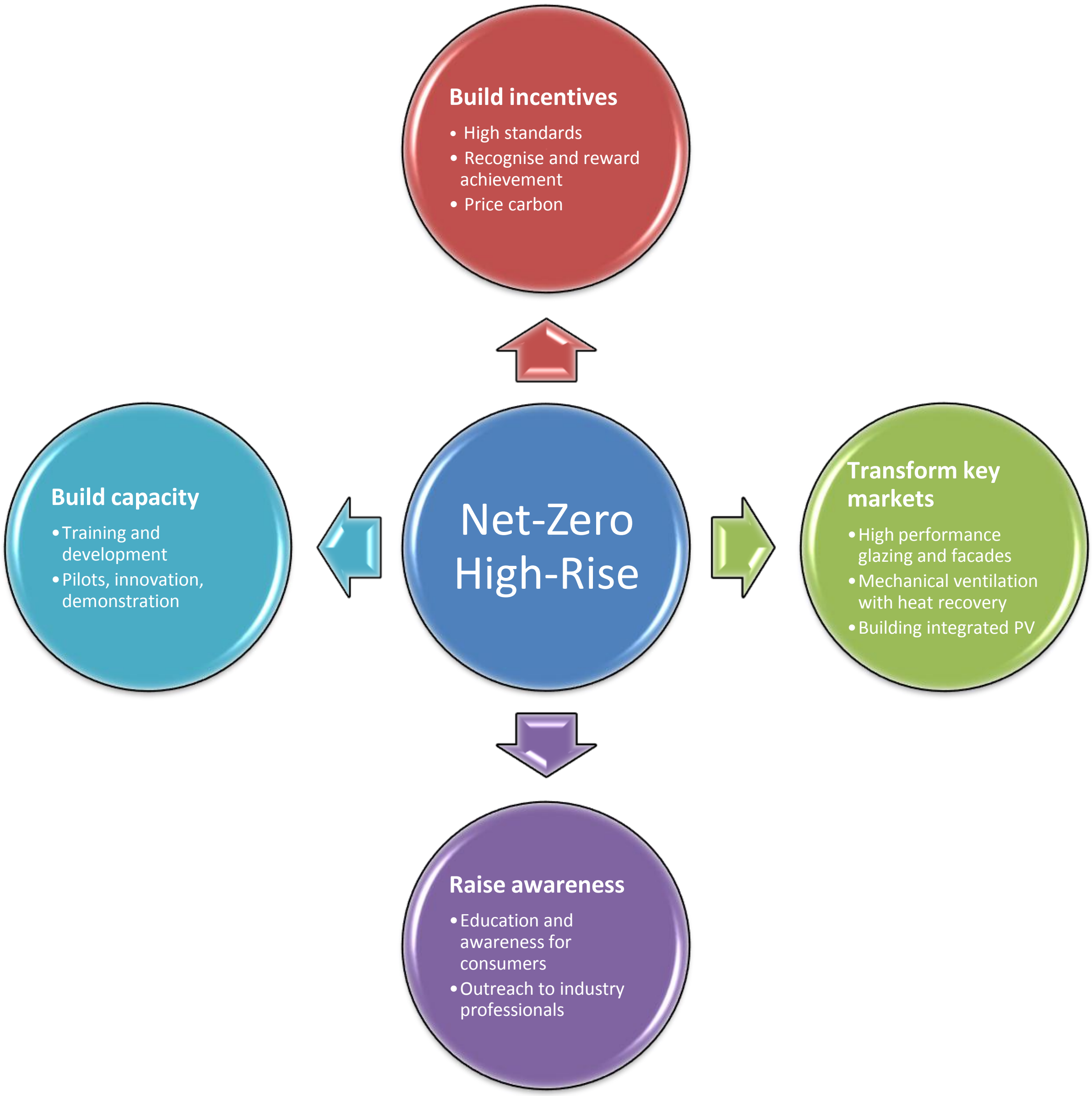

Figure 1: ***An Integrated, Strategic Approach for Market Transformation***

Different perspectives on net zero

During the course of this project, it became apparent that there are different stakeholder perspectives on net-zero. Investors and/or developers are the parties most exposed to the commercial risks associated with building performance – with the split of risks *between* these two groups dependent upon the nature of commercial contracts between them. Investors must finance any incremental costs associated with higher energy performance, and they therefore require confidence that they can earn a reasonable rate of return on such investments. Developers and others in the sales chain also need to be careful not to make performance claims for a building which may turn out, in retrospect, not to be warranted.

Of course, consumers also require confidence that performance claims are warranted and, in particular, that they justify the cost premiums that investors may be seeking. We note that both perspectives can be assisted by the availability of accurate, comprehensive and accredited ratings tools, while mandatory disclosure of actual building performance (using such tools) provides a key mechanism for apartment buyers to relate premiums to actual performance, and hence to make justified purchasing decisions. This in turn means that investors are more likely to receive a fair return on their investment.

We can summarise the potential benefits of net-zero as follows:

Table 2: Potential Benefits of Net-Zero

Investors	Developers	Residents	Society
Premium for apartment sales	Reputation and branding benefits – leadership position in the market	Savings on energy bills and body corporate fees	Reduced greenhouse gas emissions
Faster sales rate	Business growth	Higher apartment resale values	Reduced peak loads and infrastructure costs
Enhanced return on investment	Learning benefits (driving down costs)	Improved comfort, resilience to extreme weather conditions and health outcomes	
		Improve space utilisation, due to more comfortable perimeter zones	
		Psychological benefit of doing something tangible for the environment (may be important for 'willingness to pay')	

Other significant findings

During the course of this project, we made some observations that are relevant to the wider context of high-rise building energy performance in Australia.

First, this study appears to confirm other results that indicate that BASIX thermal performance requirements are lower than optimal from an economic perspective.[4] The average NatHERS (National House Energy Rating Scheme) star rating of the Sydney apartments modelled in this project was 4.4, compared to 6.5 in Melbourne (noting that the City of Melbourne applies planning policies that call for an additional star or 10% improvement in thermal performance over mandatory minimums, and also that Sydney's mild climate means that the Sydney building uses less energy, at a given star rating, than does the Melbourne building). At the same time, BASIX includes other elements, like appliance efficiency, that NatHERS does not. There is also evidence that energy performance standards under the National Construction Code are also well short of economic optimums.[5] Both should be revised upwards urgently based on evidence of what is optimal from a societal perspective.

Second, there appears to be wide stakeholder support for a 'fabric first' approach to building design and regulation. That is, we should focus our efforts, in the first instance, on ensuring that the basic design and

[4] A 2013 RIS by ACIL Allen indicated that households may be as much as $3,200 better off if standards were lifted – see http://www.acilallen.com.au/cms_files/Allen_Benefit_Cost_Analysis_2013.pdf, p. xi.

[5] See pitt&sherry, *Pathway to 2020 for Increased Stringency in New Building Energy Efficiency Standards: Benefit Cost Analysis: 2016 Update for Residential Buildings*, May 2016, available from http://www.nathers.gov.au/sites/prod.nathers/files/u20/Pathways%20update%20report%20-%20final.pdf

construction of residential buildings – high- or low-rise – features solar passive or 'passivhaus' approaches, including high-performance facades, glazing and shading; air-tight construction with mechanical or hybrid ventilation with heat recovery; and optimal use of thermal mass and natural lighting. We should ensure that the basic 'thermal shell' of buildings is as energy efficient as economically justifiable, again based on evidence rather than intuition. Building shells may have an economic life of 40 years or more while, during that time, the appliance set, occupancy patterns and occupant behaviours will vary widely. Shell design and construction is particularly important when climate change is taken into account, with the prospect that buildings built today will need to withstand increasingly harsh climate conditions while delivering comfort, amenity and safety to their occupants at an affordable cost.

Moving forward

Given the complexity and diversity of the Australian building industry, where governance is split between local, state and national tiers of government, only a collaborative and integrated approach – fully supported if not championed by industry – is likely to succeed.

Industry leadership is critical, because net-zero high-rise will not come about by regulation. It will only come about when consumers demand this product, when industry embraces the challenge, and when policy and planning conditions are right.

Policy and planning is of course the domain of government, so government has an equally important role to play. A critical step for national and state governments is to correct policy gaps and shortcomings, such as unpriced greenhouse gas emissions, low standards for new building work, ensuring compliance with existing and future energy performance standards, the lack of comprehensive ratings tools for this building class, and consumer information gaps including mandatory disclosure of housing performance. Many of these policy domains are shared responsibilities between the national and state governments, reinforcing the need for leadership and a collaborative approach around a common plan.

With building product markets being national and international, it is the national government that has greatest scope to lead market transformation initiatives – to drive down the cost of high performance building elements such as glazing, air-tight facades, mechanical ventilation with heat recovery, high performance lighting, building-integrated PV and others. That said, states can facilitate the market transformation process by adapting existing measures such as white certificates schemes (eg, VEET in Victoria and the Energy Savings Scheme in NSW), and ratings/compliance schemes such as NABERS and BASIX. States also determine stamp duty policies, which represent a potential lever to encourage high-performance and net-zero housing.

Local government is, in many ways, closest to the buildings coal-face through its critical role in planning and development approval. While there are differing degrees of freedom held by local councils around Australia, many have the opportunity to induce above-mandatory-minimum performance levels, to undertake master planning at the precinct level, to use fees and charges or 'fast track' approval processes and local design competitions to influence the quality of development that occurs in their regions. A 'net zero challenge', for example, could provide a tangible reward, as well as recognition, to developers willing to undertake the risks associated with a first-of-a-kind net-zero high rise development in Australian cities. Stakeholders noted that relaxation of certain planning provisions, such as minimum floor-to-floor heights (eg, *SEPP65* in NSW), and total building height/floor restrictions, could go a long way towards offsetting the incremental costs of net-zero. Equally, it is vital that occupant amenity is not traded away, otherwise consumers will not be willing to pay premiums for high-energy performance.

Further work

Our recommendations for further work are as follows:

1. Further investigate the incremental costs associated with attaining net-zero performance, and establish cost-optimised pathways, showing incremental energy savings and costs for different treatments. There is no single or unique pathway, and the relative costs and savings of particular design, construction and fit-out treatments will always be context- and path-dependent. Realistically, a case study approach on a wider range of building forms and climate zones is called for. The study should include cost assessment by qualified quantity surveyors, but should also seek input from developers, product suppliers and a range of building industry professionals. This study could also consider the question of how quickly incremental costs are expected to fall through time (the 'learning rate') and which building elements would be expected to offer the greatest return on investment in market transformation initiatives, for better policy targeting.
2. Undertake market and consumer research to quantify the willingness of consumers (including targeted consumer segments in relevant markets) to pay premiums for net-zero performance. We note that such research may need to include an element of consumer education, including the bottom line financial benefits, as 'net-zero' may not convey meaning to all consumers. This study could be linked to the first study above by exploring consumer responses to the prospect of declining cost premiums through time. This study should explore the question of whether and how consumer willingness to pay is correlated with on-site or off-site renewables, including precinct or utility-scale/remote renewables, and potentially with other competing solutions such as Green Power and carbon offsets.

1. Introduction

1.1 Objectives

The purpose of this project is to identify the costs, benefits and key opportunities for accelerating market transformation to net-zero high-rise residential buildings in Australia. We illustrate the story with two in-depth analyses of actual buildings: one in Sydney and one in Melbourne.

The project is majority-funded by the Carbon Neutral City Alliance (CNCA), an international grouping of cities that are targeting at least 85% reduction in their greenhouse gas emissions by 2050. In Australia Sydney, Melbourne and recently Adelaide are members. Their respective GHG reduction targets are:

- Sydney is committed to achieving 70% reduction in GHG emissions by 2030;
- Melbourne is committed to become carbon-neutral by 2020 – the most progressive of all CNCA city targets;
- Adelaide is committed to carbon neutral by 2025 or sooner.

1.2 Context

Along with many other countries, Australia is facing the challenge of sustainably housing a growing population. Already, some 66% of Australians live in capital cities, and many cities are consciously pursuing strategies aimed at increasing population density in our traditionally low-density cities. Many Australians are responding positively to the opportunities presented by urban living, and as a result, high-rise apartment buildings are the fastest growing building segment in Australia. In Sydney and Melbourne in particular, but also in Adelaide, Brisbane, Perth and elsewhere, Class 2 (apartment) buildings are increasingly replacing low-rise residential buildings, disused/repurposed industrial buildings and older office buildings. This market is also being driven by significant investment from other countries, with secure investment being a key investment driver.

Given the global climate agreement reached in Paris in 2015, there is now a clear need for all countries, including Australia, to move to a position of near-zero net greenhouse gas emissions by around the middle of this Century – a timeframe well within the average lifespan of a new apartment building built today. The mathematics of the global carbon budget means that essentially all sectors of Australia's economy, including the high-rise residential sector, need to transition as rapidly as possible and as far as possible towards net zero emissions. At the same time, different sectors will face unique challenges and differing costs during this transition, and it may be economically optimal for some sectors to reduce emissions faster and some a little slower.

Taller residential buildings present some unique and sometimes inherent challenges. Energy performance standards for Class 2 buildings in Australia are relatively low, and the energy intensity of these buildings is generally higher than for Class 1 (single dwelling) buildings.[6] This creates the risk that greenhouse gas emissions will tend to rise as a result of the trend towards high-rise living. There may be some greenhouse gas savings associated with avoided transport emissions in more compact cities, but this is not certain – it depends on travel needs and behaviours, transport infrastructure decisions and other factors.

[6] See *Pathway to 2020 for Increased Stringency in New Building Energy Efficiency Standards: Benefit Cost Analysis*, pitt&sherry, 2012, p. 49-50.

The aspect ratio of these buildings is generally tall and narrow, providing limited roof area for solar technologies. Their facade area is much larger than their roof area, but wind pressures at higher elevations, risks of partial overshading by other buildings, and the currently higher costs of building-integrated PV (BiPV) pose further challenges in this area. Similarly, height can create challenges for shade structures on facades and for strategies commonly used in shorter buildings, such as passive ventilation. Taller buildings require lifts for vertical people transportation and are much more likely to be centrally conditioned than stand-alone dwellings. Passive or hybrid ventilation strategies, suitable for lower buildings, can be challenging in taller buildings, primarily due to excessive wind pressures and related noise and safety concerns. When compared to traditional (Class 1) houses, individual apartments in high-rise buildings may also have reduced and uneven access to light. There is also growing concern about the quality of housing outcomes being achieved in these buildings (see for example *Better Apartments – Minister's Forum Context Report*, July 2015).

It is also important to consider the nature of the markets for high-rise residential buildings. The majority of high-rise residential buildings in Australia have a form of ownership known as strata title, in which residents own and manage their own apartments, and an owners corporation (a collective of the apartment owners) owns and manages common areas and plant. This can create particular challenges for decision-making and investment, which can impact on the energy performance of these buildings. Residents of high-rise residential buildings are as diverse as the Australian population itself, including wealthy professionals, retirees, large and small families, and students on strictly limited budgets. Also, as we consider in Section 3 and again in Chapter 6 in more detail, the differing interests of investors, developers and communities must be considered.

Overall, the challenge is not only to describe a pathway to net zero emissions high-rise residential buildings in Australia, but also to ensure that the pathway is technically feasible, commercially sound and that it contributes to our wider desire for resilient, dynamic and highly liveable cities that are more equitable and socially inclusive. At the same time, new opportunities are being opened up by advances in the performance and reductions in the cost of high-performance building elements, including high-performance glazing and facade systems, LED lighting, photovoltaic (PV) systems and many more.

1.3 International Experience

In setting out on this pathway, Australia can benefit from the experience of many nations that have already made significant progress. This section reviews the leading programs and strategies adopted by various countries to achieve low or net zero performance in buildings. Policies and programs are also supplemented by the case studies of exemplar buildings where such standards are achieved. The key objective of this section is to show what is possible and how other countries have gone about the change process.

1.3.1 The European Union

Energy efficient buildings are the key part of the EU's climate change policy. To enable transition to energy efficient buildings, in 2002 it introduced the European Commission's Energy Performance of Buildings Directive (EPBD), which was updated in 2010 to reflect the developments in construction technologies and practices. EPBD has three key strategies[7]:

[7] https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings

• *Setting mid-range national targets for "nearly zero energy buildings"*[8] *by 2020, with public institutions leading the way by 2018.*

• *Ensuring immediate and ongoing improvement in minimum energy performance standards by making all cost optimal measures required by code for new construction and major renovation.*

• *Accelerating market transformation for energy efficiency and ensuring ongoing data collection to track progress through the issuance of energy performance certificates (energy labelling).*

Some of the targets set by the EU countries in response to EPBD are shown below:

Table 3: Targets set for the performance of new buildings in EU countries

Country	Target	Target year
France	Energy Positive Building	2020
UK	Zero Carbon Emissions Buildings	2016
Brussels (Belgium)	Passive House equivalent (45 kWh/m^2/year)	2015
Luxembourg	Passive House equivalent	2020
Denmark	20 kWh/m^2 limit for heating, cooling, ventilation and hot water	2020

1.3.2 UK Zero Net Carbon by 2016

In December 2006 the Labour Government published a consultation document setting out plans to move towards zero carbon in new housing using three main 'policy levers': the planning system; the Code for Sustainable Homes; and the Building Regulations. Code for Sustainable Homes, a voluntary set of standards for assessing new homes, whose highest level (6) requires zero carbon, was published at the same time.[9]

In 2011, however, the *Plan for Growth* said that the Government would introduce "more realistic solutions" for carbon reductions and allow for off-site reductions, stating that these proposals would "ensure that it remains viable to build new houses". In August 2013, the Government launched the *Next steps to zero carbon homes: allowable solutions consultation*.[10] In July 2014 the Government published its response to the consultation, in which it explained its decision to set an onsite standard as being equivalent to Level 4 of the Code for Sustainable Homes (the original intention was for it to be set at Level 6). This would represent "an improvement on current Building Regulations' requirements of approximately 20% across the new homes build mix."

Finally in July 2015 the UK government announced that it would not proceed with the zero carbon allowable solutions, instead it would keep the energy efficiency standards under review. It justified its decision by the high costs associated with zero-carbon homes and an excessive pressure on developers.

[8] Each member state is left to set its own operational definition of net zero.
[9] HC Deb 1 March 2010, c960W and CLG, Code for Sustainable Homes: A step-change in sustainable home building practice, December 2006
[10] CLG, Next steps to zero carbon homes: allowable solutions, August 2013

Just six months later[11], however, WElink Energy and China National Building Materials (CNBM) announced that they would develop 8,000 zero-carbon homes in the UK. The apartment buildings will be zero-carbon, zero-waste and water-efficient buildings; and have rooftop solar panels, energy storage and waste-to-energy technologies. This is viewed by many as evidence that zero-carbon homes are cost-effective and have a sustainable business model.

1.3.3 London Zero Net Carbon

In contrast to the UK Government, on the 18th of November 2015, the Mayor of London announced that Zero Carbon Homes would still be implemented in London. This decision was backed up by the analysis of London development carried out in 2015 which concluded that extra cost associated with moving to zero carbon standard would add between 1 and 1.4% of base cost.[12] The Mayor of London further highlighted that such a cost differential does not represent a significant determinant in the viability and the deliverability of housing development in London.

1.3.4 Passivhaus

The Passivhaus Concept

The 'Passivhaus' (Passive House in English) principles were devised in Germany in 1991 by Dr Wolfgang Fiest. The passive house concept is based on achieving energy use reduction in the building sector by making optimal use of natural energy flows. There are five principles underpinning the passive house concept:

- *thermal bridge free design*
- *excellent thermal insulation and use of thermal mass*
- *passive house windows (low thermal bridge coefficients and very low u-values)*
- *ventilation that includes heat recovery*
- *airtight construction*[13].

A passive house is a concept aimed to reach comfortable indoor temperatures without, or at least minimising, external heating or cooling. Critical to this outcome is appropriate solar gain, use of thermal mass, and heat recovery ventilation systems (see Chapter 3 for details). This has been expressed as "...reducing peak loads to the point at which the building can be heated and/or cooled with the fresh air that must, in any case, be brought in to provide for good air quality".[14]

Passive houses may have external heating units – including heat pumps integrated with the mechanical ventilation heat recovery units – but these will only be used in more extreme weather conditions.[15] The demands for a Mid-European Passive House are that the annual space heating demand should be less than 15 kWh/m^2.a and that the combined primary energy consumption (space heating, domestic hot water and household electricity) must not exceed 120 kWh/m^2.a.

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[11] 15th January 2016

[12] http://www.energyforlondon.org/major-london-housing-development-to-be-zero-carbon-from-october-2016/ - noting that this study covers a mix of low and high rise housing.

[13] Liana Muller, Thomas Berker, 2013, *Passive House at the crossroads: The past and the present of a voluntary standard that managed to bridge the energy efficiency gas*.

[14] *Active for more comfort: Passive House – information for property developers, contractors and clients*, International Passive House Institute, Second Edition 2014, p. 1, available online at *www.passivehouse-international.org*

[15] *Ibid*.

More than 80,000 passive houses are understood to exist in Europe.[16] Progressively, however, the concept is being applied around the world in hot, mild and cold climates alike.[17] While the principles remain the same, regardless of climate – as does building physics – optimal solutions must be adapted to the local climate and also building culture.[18]

While the passivhaus standard was first applied to single dwellings, it is increasingly being applied to high-rise buildings, residential and commercial. Figure 2 shows the tallest high-rise residential building that is targeting Passivhaus certification at the time of writing - although clearly records are made to be broken.

Figure 2: 26-storey residential apartments designed for Passivhaus certification - Cornell Tech, Roosevelt Island, New York © Handel Architects

Swedish Passive House Classification

In Sweden, due to colder climate, as compared to several other European countries, an adapted passive house solution is called for. The harsh temperatures, especially during winter, make it necessary to have thicker envelope wall insulation to reduce the heat losses, as compared to what is needed in the southern European countries. This, however, means that the house will stay relatively cool during the summer as well. The passivhaus standard (EN ISO 7730:2006, 2009) makes it clear how thermal comfort should be calculated. This accounts for parameters like draught (unwanted local cooling of the body caused by air movement), too cold supply air, extreme air change rates and noisy ventilation units.

The Passive House Planning Package

The Passive House Planning Package (PHPP) is a tool for modelling and simulating passive house performances. It has a spreadsheet design and is a modified excel document. PHPP has lately become widely adopted as one of the most common tool for classifying passive houses according to the European passive house classification. One of the reasons why PHPP is widely chosen is because of its transparency, in that all calculations and implementation pathways are fully displayed.[19] The package also allows for verified, accredited outcomes and rigorous testing against other modelling tools.

[16] http://www.thefifthestate.com.au/columns/spinifex/the-passive-house-pilgrims-of-darmstadt/81994.
[17] *Active for more comfort: Passive House – information for property developers, contractors and clients*, International Passive House Institute, Second Edition 2014, available online at *www.passivehouse-international.org*
[18] *Ibid*, p. 11, *Adapting to local conditions*
[19] Moran, et al., 2013.

PHPP is built around different data sheets, where each sheet contains a specific data input segment. These sheets include parts of the building such as the building areas, the U-values, the Windows, the ventilation, the climate data, the verification results and many more. PHPP is made so that each sheet is built with calculations linking your input data to other relevant calculations. When all the received input data is defined in PHPP, the passive house classification parameters results will be listed under the verification sheet.

Brussels Passive House Levels

The City of Brussels has mandated that all new social and public buildings must meet Passive House levels from 2013, while all new buildings have to meet these norms since 1 January 2015.[20]

For the City of Brussels, the Passivhaus standard requires fulfilment of the following requirements:

- The building must be designed to have an annual heating and cooling demand as calculated with the Passivhaus Planning Package of not more than 15 kWh/m² per year (4746 btu/ft² per year) in heating and 15 kWh/m² per year cooling energy or to be designed with a peak heat load of 10W/m².
- Total primary energy (source energy for electricity, etc.) consumption (primary energy for heating, hot water and electricity) must not be more than 120 kWh/m² per year (37900 btu/ft² per year).
- The building must not leak more air than 0.6 times the house volume per hour (n50 ≤ 0.6 / hour) at 50 Pa (N/m²) as tested by a blower door.
- Internal temperatures may not exceed 25 degrees Celcius for more than 5% of the hours in any year.

This is one of the most far-reaching examples of implementation of passive house standards to date.[21]

1.3.5 Hong Kong Zero Carbon Partnership

The Hong Kong Zero Carbon Partnership[22] is a research initiative funded by the Construction Industry Council (CIC) and led by The University of Hong Kong (HKU) with support from a number of organisations. The Partnership aims to function as a mechanism to bridge the links between the public and many stakeholder groups in Hong Kong and beyond, and provide a platform to support the transition of the buildings and the built environment in Hong Kong towards zero carbon and sustainability.

The Hong Kong Housing Authority (HKHA) has outlined carbon reduction and energy saving initiatives, which include:

- passive design
- reducing consumption of lighting systems
- reducing consumption of lift installations
- reducing consumption of water pump installations
- utilising solar energy
- implementing carbon emission estimation (CEE) and
- implementing ISO 50001 Energy Management System (EnMS).

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[20] Moniteur Belge, 2011; BE, 2012; CSTC, 2012 (http://www.ejustice.just.fgov.be/cgi/article.pl?language=fr&caller=summary&pub_date=2011-09-14&numac=2011031430 (In French)

[21] http://nypassivehouse.org/wp-content/uploads/2014/12/Brussels-INFO-SHEET-on-2015-Passive-House-Implementation.pdf

[22] Hong Kong Zero Carbon Partnership for Enhancing Public and Stakeholder Engagement, 2015, Zero Carbon Buildings: International Practice and Stakeholder Engagement Seminar Proceedings. Namely, Carbon Reduction for High Rise Residential Development: Myth or Reality?

The HKHA has also emphasised the importance of raising public awareness of saving energy. Ms Ada Fung, Deputy Director, Hong Kong Housing Authority noted: "*It is a long journey to arrive at 'Zero Carbon Building. for high-rise buildings. Nevertheless, it will be a target for all of us*." She also suggested "*To achieve this target, we require: technology advancement in energy saving facilities and clean energy source, low embodied carbon building materials, green construction technology, public awareness on energy saving, and stakeholders' collaboration from building industry*".

1.3.6 China's Zaishuiyifang Project

China has been pursuing a pilot of passive low-energy residential buildings that include energy-efficient envelope features. The Zaishuiyifang project, a Sino-German collaboration on a residential high-rise building (18 storeys, 6,500 m^2) was completed in 2012, and energy consumption was monitored in two apartment units. The project is in a heating-dominated climate, in Qinhuangdao City, Hebei Province, so a key objective was to reduce heating energy consumption. The test results showed that energy consumption for heating was ≤ 17 kWh/m^2 per year, while maintaining high levels of comfort that were demonstrated by comfort requirements being satisfied over 90% of the time. The regular municipal heating supply was not utilised. The units also had small variations in indoor temperatures (≤ 3˚C). Energy consumption for cooling was also low, at ≤ 15 kWh/m^2 per year. Overall, the passive low-energy building consumed less than one-third the energy of a building-code-compliant structure. The price premium for the high-performance building was estimated at USD 165/m^2.

The following key energy-efficient building envelope measures were implemented:

- energy-efficient wall and roof insulation, including exterior insulation (25 cm EPS) with U-values of approximately 0.15 W/m^2K;
- highly insulating windows with triple-glazed, low-e glass, and low-conductive frames, with an overall U-value of approximately 0.9 W/m^2K, and G-value (SHGC) > 0.5;
- low air infiltration through air sealing with leakage measured at below 0.6 ACH at 50 Pa; and
- heat recovery (75%) from exhaust ventilation air that reduced the heating penalty associated with ventilation air, while maintaining high air quality (CO_2 concentration ≤ 1000 parts per million).

1.3.7 Energiesprong – UK and The Netherlands - retrofits

Energiesprong is a new program approach, pioneered initially in The Netherlands, to retrofit houses existing houses to a zero energy standard. The developers of Energiesprong are now exploring whether this successful model for retrofitting homes can work elsewhere and they have established a working group of construction companies and social housing providers to examine the practicalities of Energiesprong working in the UK. The group is focusing on two main areas: how the technology can be applied to UK housing stock, and what financial model will succeed in making the solution viable for both the industry and the housing providers.

The ambition of Energiesprong UK is to change the market conditions to make net zero energy housing a reality. Energiesprong UK are taking a market transformation approach, which delivers fully integrated refurbishment packages with a long term guarantee that makes the solution commercially financeable and scalable. The retrofit is non-intrusive and can usually be completed within one week and without the resident needing to move out. The finished result is a warm and affordable home that is modern and attractive with a long term quality guarantee. The Energiesprong philosophy is "to create what is needed" rather than "to do what is possible". It aims to refurbish up to 111,000 homes in the UK.

Current offers for Net Zero Energy (E=0) *refurbishments* – if they exist at all – are indicated to not be compelling to homeowners, whether private, commercial or (semi-) public. The building sector doesn't offer them because the current price point is too high to attract significant demand; local and central government regulations are not conducive to E=0 solutions and existing financial arrangements for home owners do not work. To get out of this vicious circle, an intensive innovation process focused on cost reduction, hassle-free installation and performance warrantied solutions is needed. This in turn requires implementation at scale. Energiesprong UK plans to facilitate financiers and government to tune their financing products and regulations towards this new product. Energiesprong has developed prototypes for terraced housing, 4-storey houses and multi-apartment blocks, and is currently scaling up its approach for even larger residential buildings.

1.4 Exemplar Buildings

The policy models and measure above are not the only opportunities for Australia to find guidance and experience in our quest for net-zero high-rise buildings. The following examples of buildings from around the world highlight the potential for very high performance residential high-rise (and some mixed use) buildings. The case studies draw attention to key features that assist the energy performance of these buildings, and also provide links for further information.

160 m Highrise Living-Tower, Germany

A 100% glazed façade with triple insulated glazing for each apartment will maximize daylight allowing the sun to be utilised for heat in winter, with balconies designed to shade those facades during summer.

Heating and cooling is achieved by radiant surfaces, combining sunlight in winter with an absorption chiller for the cooling source in summer. Apartments are mainly naturally ventilated but mechanical ventilation is possible via air supply elements, individually controlled and equipped with convectors to pre-heat the supplied air. Exhaust systems are equipped with a centralized heat recovery system.

The balconies provide shade during the summer and also double as windscreens. Each balcony will also come equipped with solar panels to supply energy to operate the building. The building's glass envelope will allow the sun to act as a free heating source to maximize warmth in the winter.

Use:	Residential
Size:	47 storey, 340 apartments
Features:	Designed to be energy positive. Passive heating and cooling, PVs on balconies
Links:	http://blog.transsolar.com/post/87579602749/160-m-highrise-living-tower-in-frankfurt-as

Pertamina Energy Tower, Indonesia

Pertamina Energy Tower is the world's first supertall tower for which energy is the primary design driver. The tower opens up at the crown, revealing a 'wind funnel' that will take advantage of the prevailing winds and increased wind speeds at the upper floors to generate energy.

Precisely calibrated for Jakarta's proximity to the equator, the tower's curved facade will mitigate solar heat gain throughout the year. Exterior sun shades will dramatically improve the workplace environment and save energy by reducing the need for artificial lighting in the office interiors.
The building will have a self-contained central power facility and will utilize geo-thermal energy to supplement wind and solar energy systems located on the roof. Overall, the development is targeting net zero energy.

Anticipated Completion: 2020.

Use: Mixed Use – commercial, office and residential
Size: 557,379 m^2, 99 stories with a height of 523 m.
Features: First supertall project targeting net zero. Wind, solar and geothermal energy sources
Links: http://www.som.com/projects/pertamina_energy_tower#sthash.kDdoFJW9.dpuf

Trump Tower at City Center White Plains, USA

Energy costs for tenants at Trump Tower at City Center were twice as high as originally predicted by developers when the building was built in 2006. An energy audit pointed to three major issues for energy consumption: lighting, hot water heaters, and temperature controls.

Six solutions were identified:

- Cogeneration (combined heat and power) to supplement hot water heating With CHP, the building could generate some of its own electricity and use the excess heat for the building.
- Energy-efficient lighting upgrades in common areas and parking garages, as well as exterior lighting
- Controls, including motion sensors and timers in hallways and stairwells
- Improved boiler and temperature controls (timers for dryer exhaust fans)
- Installation of pool covers to reduce the cost of heating
- Integration of an energy management system

Partly funded through a New York State Energy Research and Development Authority program, the building now saves more than $400,000 a year.

Use: Residential
Size: 102,193m^2, 35 storey, 212 apartments
Features: Building retrofit, energy use halved though improvements to controls, lighting and use of cogeneration
Links: http://www.habitatmag.com/Publication-Content/Building-Operations/2012/2012-December/Steps-by-Condo-Cut-Electric-Bill
http://hrf.uberflip.com/i/393415-october-2014

The Printworks Clapham, UK

Printworks is part of a major initiative to increase the supply of affordable housing in London. The 168 plot scheme of 1, 2 and 3 bedroom apartments has a high performance building envelope and gas communal heating system.

Comprising 4 interconnected buildings the design reduces energy demand by improving building fabric performance, centralised low NOx gas-fired boiler for hot water and space heating and photovoltaic panels supply 10% of the required power.

The development will ensure that the central plant system usage is measurable and manageable from commencement as well as ensuring future connections are possible.

Use: Residential
Size: 168 apartments
Features: Modular gas boiler system for space heating and hot water, roof PV system
Links: http://www.zerocarbonhub.org/printworks

TEDA MSD H2 Low Carbon Building, China

Located at Tianjin TEDA Modern Service District, H2 low carbon building was conceived as a demonstration project and research platform for green building technologies. The top floor and roof garden of the 9 storey building is designated as a showcase for low carbon building technologies, while the remaining floors for the slab tower are office spaces.

The 2 storey podium will be occupied by retail shops, bank, restaurants and main lobby. Parking lots, MEP equipment and auxiliary facilities are located in the 2 storey basement.

An array of photovoltaic cells is positioned in front of a double-skinned facade on the south elevation, while the north facade utilizes triple-glazing curtain wall panels. The design incorporates rainwater harvesting. H2 low carbon building has been accredited the first office building in the world with 4 green certification; China 3 Stars, CASBEE, BREEAM and LEED.

Use: Mixed Use – Office, hotel and commercial
Size: 21,158m^2, 9 storey
Features: First office building in the world with 4 green certification; China 3 Stars, CASBEE, BREEAM and LEED
Links: http://www.atkinsglobal.com/en-GB/projects/teda-msd-h2-low-carbon-building

Goldtex Apartments Philadelphia, USA

Redevelopment of an existing building. Sustainable features include an entirely new building envelope, which creates an insulating thermal barrier utilizing its original shell as a heat sink. Post Brothers also installed a variety of light-spreading and non-light-transmitting windows with heat-blocking coatings, maximizing the building's energy consumption and retention.

Each apartment in the 13-story multifamily community is equipped with Energy Star-rated appliances and efficient LED light fixtures. Energy Star rated appliances, LEED compliant fixtures, and LED and CFL lightbulbs are used throughout.

Heat energy, drained from the building from bathroom and common hallway exhaust fans, is extracted to generate power before the air is released into the atmosphere.,

Goldtex, runs on 100 percent wind-generated power.

Use: Mixed Use – Office, hotel and commercial
Size: 13 storey
Features: High rise retrofit, 100% wind generated power
Links: https://www.multihousingnews.com/post/philly-gets-first-zero-carbon-footprint-residential-building/

One Brighton, United Kingdom

Completed in 2009, the 172-unit scheme aimed to set a benchmark for sustainable living and design. Its construction included Britain's greenest concrete frame (post-tensioned with 50% cement GGBS replacement, 100% recycled aggregate) and also made use of sustainable construction materials such as natural clay blocks and wood fibre insulation. An on-site biomass boiler and PV panels provide approximately 50% of energy requirements, the remainder is wind energy generated off-site

The developers were able to remove the requirement for on-site car parking, saving the project approximately £2 million, and released low-value car-parking space for higher value residential living space.

Use: Mixed use – residential, offices and shops
Size: 0.39-hectare site containing 172 apartments and 2,000 m^2 commercial space.
Features: Car free with car sharing. The development achieved a LEED1 platinum-equivalent efficiency rating. Designs achieved the EcoHomes2 'excellent' rating, extensive use of recycled materials.
Links: http://www.building.co.uk/one-brighton-five-years-on/5069541.article

Herman Teirlinch building, Belgium

The building will accommodate approximately 2,600 civil servants for the Flemish Government in Brussels. the building will also include a large kitchen, two auditoriums, a multi-functional room; a library; a large meeting-room complex; underground archive space and underground parking will be available for 310 cars. The project is due for completion in 2017.

The project is designed to meet the strict criteria defined by the Brussels regional government to receive a passive certification label and also to be BREEM compliant. T5 tubes will be used for lighting with central control and automation for light intensity and occupancy. Heating and cooling of the office spaces will be achieved using Concrete Core Activation (CCA) with dynamic loads managed by VAV boxes equipped with air quality and temperature sensors.

Use: Mixed use – offices and retail

Size: 66.500 m2

Features: Over 90% of all primary energy demand within the building provided by groundwater and associated heat pump systems. High levels of HVAC automation

Links: http://www.neutelings-riedijk.com/index.php?id=10,659,0,0,1,0
http://www.boydens.be/en/references/office/herman_teirlinck_building_%26_8211%3B_passive_building_for_the_administration_of_the_flemish_government_in_brussels-876.html

Hanover Olympic, Los Angeles, United States

This 7 storey, net-zero, mid-rise building features 20 eco-apartments that use onsite solar panels to achieve net zero performance. Developed by the Hanover Company, the building allows residents to monitor solar energy generation and useable in real time via an iPad app, and also view credits on their monthly utility bills. In total, 65.5 kW of solar panels are installed, or around 3 kW per apartment.

The building's energy efficiency features include EnergyStar rated appliances, LED lighting.

Use: Residential

Size: Not stated

Features: Rooftop solar, high efficiency lighting and appliances, smart app tracking.

Links: http://www.digitaltrends.com/home/net-zero-apartment-hanover-olympic-los-angeles/
http://www.builderonline.com/newsletter/la-gets-its-first-net-zero-apartment-community_c

1.5 Market Transformation

The key approach that has enabled many other countries to make the progress they have towards very high performance residential buildings – but which is little known in Australia – is called *market transformation*.

The market transformation model has been successfully applied in Europe, US, Japan and other countries for at least two decades.[23] The American Council for an Energy Efficient Economy (ACEEE) defines market transformation as *"...the strategic process of intervening in a market to create lasting change in market behaviour by removing identified barriers or exploiting opportunities to accelerate the adoption of all cost-effective energy efficiency as a matter of standard practice*." It describes market transformation as the process of getting new, high performance products or designs to be taken up in the mainstream, without the need for ongoing support or cost.

This is a more sophisticated and subtle policy model than generally seen in Australia, despite its widespread use in other OECD countries. It requires excellent knowledge of technical potentials for performance improvement, of the potential for cost reductions (including industry learning), and of market structures and behaviours (including the extent of competition, domestically and internationally). These insights are used to structure a policy package that leverages permanent change via a set of temporary interventions. The end goal is to change both producer and consumer behaviours and preferences, and local production processes/plant, such that older, inefficient components and practices are completely replaced by newer, more efficient ones; realising economies of scale for what are currently niche products, and significantly reducing their cost in the process.

A wide range of strategies can be used to achieve market transformation, from mandatory codes and performance based standards, to financial incentives, information measures and more. There is no unique solution for any given product – rather, the measures must be tailored to the unique circumstance of each product market.

While this work has been commissioned by the City of Sydney with funding through the Carbon Neutral Cities Alliance, the actions highlighted in this report to accelerate net-zero buildings in Australia will require action by the Australian and State Governments, as well as the development industry, to realise the economic, social and environmental benefits. With building product markets being national and international, it is the national government that has the greatest opportunity to offer leadership in this area.

We note that single policy instruments are less likely to be effective in achieving market transformation – that is unless strong regulation is used, such as when Australia became the first country in the world to ban the sale of most incandescent globes. This led to an effective market transformation, including the rapid reduction in the price of more efficient technologies such as compact fluorescent lamps. The timing of that measure was critical, as it was able to take advantage of existing market trends towards better technical performance/user acceptability and also cost reductions (due in large part to Chinese manufacturing). This illustrates the importance, for market transformation, of understanding and working with and reinforcing market trends. In some cases, this may not be possible (at a given point in time), in which case that product would not be a good candidate for a market transformation approach.

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[23] An early overview of the approach is contained in *Creating Markets for Energy Technologies*, International Energy Agency, 2003.

Around the world, commonly-cited examples of market transformation at work include the commercialisation of compact fluorescent lamps as replacement for incandescent lamps, refrigeration (US), air conditioners (Japan), the commercialisation of high-performance glazing, LED lighting and solar panels. In California, the UK and Europe, mandatory standards for high-performance glazing have led to the virtual elimination of glazing strategies that are ubiquitous in Australia (single glazing, uninsulated frames), while economies of scale led to significant cost reductions[24]. Some successful international examples of enabling market transformation in built environment are: Energiesprong in The Netherlands and the UK; Zero Carbon Homes in the UK and Passivhaus concept. Generally market transformation initiative or strategy involves the key steps outlined in Figure 3.

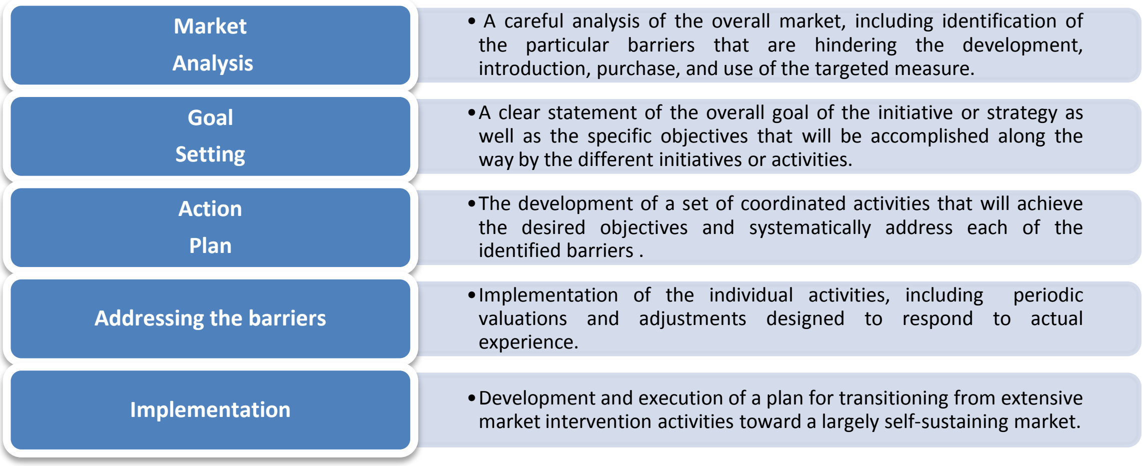

Figure 3: Market Transformation Approach

This report could be considered the 'Market Analysis' stage. Our hope is that it will contribute to appropriate goal setting and subsequent actions by the Australian and State Governments such as establishing more ambitious building codes.

What the market transformation approach highlights is the need for a comprehensive and fully integrated approach to policy design; informed by industry and market perspectives, potentials and cost/benefit considerations; but also aware of the differing incentive structures created by specific policy instruments. This approach offers the opportunity to transform building practice and productivity in Australia, working with rather than against markets, to achieve self-sustaining outcomes. It demands a 'continuous improvement' – based on evidence, research and market feedback – rather than a 'set and forget' approach to policy.

[24] Zero carbon Hub, Cost Analysis of Meeting Zero Carbon Standard, 2014, http://www.zerocarbonhub.org/sites/default/files/resources/reports/Cost_Analysis-Meeting_the_Zero_Carbon_Standard.pdf

2. Key Terms and Definitions

Chapter 2 provides the background and key definitions and concepts that are directly relevant to the scope of the project. It begins with defining the net-zero concept, and provides examples of what different countries define as net-zero. It then moves on to outline boundaries and scopes, types of emissions and buildings including high-rise residential apartments, performance levels, building codes and concludes with best-practice examples.

2.1 Net-Zero

There is a range definitions and interpretations of 'net-zero' in use around the world, including whether 'net zero' refers to operational energy, lifecycle energy, greenhouse gas emissions or something else. The choice of definition has important consequences for policy and also building design and construction. In this report we follow the US Department of Energy (DoE) definition:

> ***'Net zero means an energy efficient building where the delivered energy imported is less than or equal to the on-site renewable exported energy over a year'.***

The Carbon Neutral Cities alliance, for example, focuses on greenhouse gas emissions and notes that carbon neutrality or zero net emissions is reached when the net greenhouse gas emissions associated with a city (or organization or facility) is zero.[25]

The European Commission definition also focuses on energy, but provides greater leeway in allowing 'nearly zero' energy and also the use of renewable 'on site or nearby'. In particular, the Energy Performance of Buildings Directive (EPBD) specifies that where a building has a very high energy performance, energy requirements for a 'near-zero building' should be covered to a very significant extent by energy from renewable sources *including energy from renewable sources produced on-site or nearby* (EPBD Article 2).[26] Comparison of EPBD2 with the United Kingdom's Fabric Energy Efficiency Standard (FEES) indicates that FEES broadly meets the EPBD2 requirements for zero-energy buildings.[27]

The US Department of Energy defines a Zero Energy Building (ZEB) as *An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy*.[28] This is an energy-based definition, which specifies that the building must be energy efficient, where net-zero energy can only be achieved by improving energy efficiency and by generating renewable energy on-site.

Neither the US nor EU definitions allow for the use of purchased offsets.

The *Living Building Challenge* is "...a building certification program, advocacy tool and philosophy that defines the most advanced measure of sustainability in the built environment possible today and acts to rapidly diminish the gap between current limits and the end-game positive solutions we seek." The *Living Building Challenge* defines a fundamental requirement for net-zero as "One hundred percent of the

[25] Carbon Neutral Cities Alliance, 2015. *Framework for Long-Term Deep Carbon Reduction Planning*. Developed for the Carbon Neutral Cities Alliance by the Innovation Network for Communities, December 2015.
[26] 'Directive 2010/31/EU of the European Parliament and of the Council
[27] Zero Carbon Hub, 2011. *Energy Performance of Buildings Directive – Introductory Guide to the Recast EPBD-2.* Prepared by Cutland Consulting for Zero Carbon Hub.
[28] USDOE/National Institute of Building Sciences, *A Common Definition for Zero Energy Buildings*, September 2015.

project's energy needs must be supplied by on-site renewable energy on a net annual basis, without the use of on-site combustion."[29] This is effectively the same definition as US DoE.

Another concept is Net Zero Energy Cost. This means that the building has an energy utility bill of $0 over the course of a year. It enables building owners or operators may take advantage of selling Renewable Energy Credits (RECs) from on-site renewable generation.[30]

In Australia, the NSW Office of Environment & Heritage NABERS program and the Green Building Council of Australia are currently working with the Australian Government Department of the Environment to develop a methodology that is intended to become a national standard for carbon neutral buildings in Australia, as an element of the National Carbon Offset Standard (NCOS). NCOS is also developing carbon neutral standards for precincts and for cities. Noting that this is an ongoing process, there is as yet no firm and agreed definition of net zero. That said, there appears to be an emerging consensus that the standard will be based on the general NCOS definition of net zero carbon/greenhouse gas emissions: *"…a situation where the net emissions associated with an organisation's activities, product, service or event are equal to zero because the organisation has reduced its emissions, and acquired and cancelled offset units to fully account for its remaining emissions"*.[31] It is expected that NCOS certified carbon neutral buildings will be developed based on background knowledge and IP from both Green Star and NABERS with appropriate deviations to account for the particular nature of multi unit and mixed use buildings[32].

As with any carbon accounting process, such a definition must be accompanied by information about the system boundary, the scope of emissions considered, what are eligible offsets, etc, and these dimensions are currently under discussion. We note that under the proposed NCOS approach, renewable energy onsite must either be from systems that are not eligible for certificates under the national Renewable Energy Target scheme (nRET) or else, more realistically, the certificates must be held or surrendered and not on-sold. Off-site generation from renewable energy is allowed, provided the electricity is purchased under a GreenPower contract or, as above, an equivalent amount of nRET certificates are retired.[33]

The NCOS approach is consistent with its general focus on offsets as a pathway for achieving net zero emissions. However, this appears out of line with international practice, and raises the question of whether offsets could or should be relied upon, in all circumstances, to certify a building as carbon neutral. For example, the owner of a very energy inefficient building, with inherently high energy and emissions intensity, could purchase sufficient offsets to meet the above condition, and the building could be declared carbon neutral. The question arises whether this would be accepted as credible by the public, or whether allowing such solutions could be perceived to damage the 'brand' of carbon neutrality. For this reason, the Scoping Paper released by NCOS in 2015 notes that "It must be demonstrated that the asset has reduced emissions as much as possible through energy efficiency and other measures, prior to the use of offset units". The exact translation of this condition into a clear set of rules or standards remains a work-in-progress.

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[29] https://living-future.org/net-zero/requirements

[30] Torcellini, P., Pless, S., Deru, M. and Crawley D., 2006. *Zero Energy Buildings: A Critical Look at the Definition*. Conference Paper NREL/CP-550-39833 June 2006

[31] NCOS/OEH/GBCA, *NCOS Buildings Scoping Paper: starting the conversation on a national standard for carbon neutral buildings in Australia*, April 2016, p. 7.

[32] Office of Environment and Heritage NSW, 2016. *Carbon Neutral Buildings Workshop Agenda*. April 29 2016.

[33] ibid, pp 10 – 11.

From this discussion we can conclude that 'net zero energy' is a tougher test to meet than 'net zero emissions', because the latter allows for the purchase of offsets. In both the US and EU cases, the definitions specify that the building must be energy efficient, but in practice such a phrase is only meaningful when defined using particular metrics and benchmarks. For example in Australia, the energy efficiency or intensity of a building is generally defined in $MJ/m^2.a$, and an efficiency benchmark would need to be set with reference to the specific building class. For some classes, a NABERS rating (without Green Power) could be used for this purpose (eg, 5 or more stars), while for others, unique benchmarks would need to be derived, perhaps based on lowest decile performance within a class/climate zone, for example.

While there may be market reasons for allowing offsets to be used to claim carbon neutrality for buildings in the short term, a definition that focuses on the energy performance of the building, and on-site renewable, may be more robust and credible over the medium and longer term. This is because, as noted, the global perspective is that all countries and sectors must work towards carbon neutrality, while offsets (as distinct from sequestration) merely trade abatement between one party and another. This implies a diminishing role for offsets as all countries move towards carbon neutrality.

There may be a case, particularly for precincts, to allow renewable energy 'nearby' to reduce a building's net (annual) energy consumption to zero, as per the European definition, but this approach assumes a particular precinct-style development that is not yet common across Australia. There may also be issues in the consistency of this solution with National Energy Market rules. Similarly, it may be possible to allow offsite renewable, secured remotely via a contract, to reduce onsite energy consumption to net zero. However, this approach suffers from a lack of transparency and long term security. If it were to be adopted, considerable attention would need to be paid to transparency and security mechanisms. For example, a public register of certified net zero buildings could be created (online) showing the offset/RE contract status, as well as energy efficiency in $MJ/m^2.a$, of every certified building.

For this Report, we adopt the US definition for working purposes: that is, *an energy efficient building where the delivered energy imported is less than or equal to the on-site renewable exported energy*. As discussed in Section 3, this is a challenging but feasible standard for high-rise buildings to meet.

2.2 Boundaries/Scopes

The developing NCOS buildings framework notes that the emissions system boundary can be thought of as comprising both the base building (owner controlled) and the tenant energy use. However, the practicality of treating the entire building as one asset, and issues such as access to energy consumption data, are still being considered.

Potential emissions source include:[34]

- Energy consumed by the asset (all sources)
- Refrigerant gases, and
- The upstream extraction, production and transmission components of the Scope 1 and Scope 2 energy used.[35]

[34] Office of Environment and Heritage NSW, 2016. *Carbon Neutral Buildings Workshop Agenda*. April 29 2016.
[35] Factors as per National Greenhouse Accounts Factors. August 2015.

Underlying emissions drivers include heating, cooling, ventilation, domestic hot water, indoor and outdoor lighting, plug loads, process energy, elevators and conveying systems.[36] Transport-related emissions may be considered Scope 3, but the extent to which these emissions are attributable to a building, as distinct from the transport decisions of its occupants, is arguable.

From first principles, Scope 1 (direct) and Scope 2 (electricity consumption) emissions should be included in the assessment of any high rise project. As in many carbon accounting systems, however, it is the Scope 3 emissions that are more problematic, as they require judgements about degrees of attribution, responsibility/accountability and also reliable data availability. Scope 3 emissions are a key component of NCOS and the draft NCOS buildings framework. However, it is yet to be determined which Scope 3 sources might be included, with grey areas including emissions from building occupants commuting, potable water, waste water and waste from operations. It should be noted though that the draft UNEP *Protocol for Measuring Energy Use and Reporting Greenhouse Gas Emissions from Building Operations* does not currently provide a means of identifying or calculating Scope 3 sources, nor are these described in detail in the Metric & Protocol.[37] Scope 3 electricity and gas emissions include those attributable to system losses upstream from the point of consumption, and these should be included as they represent an actual emissions source attributable to the consumption activity.

2.3 Operational vs Embodied Energy/Emissions

The NCOS, US and European definitions of 'net zero' all explicitly or implicitly relate to operational rather than embodied energy or emissions. Embodied energy/emissions are the energy used, or emissions created, in the construction materials and construction process of a building.

Embodied energy is a major component of lifetime energy requirements for high-rise buildings, with one study in Australia suggesting that they might have up to 60% more embodied energy per unit gross floor area than low-rise buildings.[38] This is primarily explained by their greater need for high-strength structural materials including steel and reinforced concrete. However it should be noted that when compared on a per person basis, high rise may actually be more efficient than low rise, due to a higher density of residents.[39] Further, it is often observed that the share of a buildings lifecycle emissions that are embodied, rather than operational, almost inevitably rises as the energy efficiency of the building increases. This suggests that, over the longer term, inclusion of embodied energy or emissions in the 'net zero' definition will become important.

The NCOS 2013 guidelines do allow for inclusion of embodied energy in Life Cycle Assessment as part of green house gas inventory calculation. Assessment of embodied energy would necessitate further specific boundary definition to delineate included supply chains. Inconsistent boundary definition has been shown to result in major differences in assessment outcomes.[40] Although many rating systems enable inclusion of

[36] National Institute of Building Sciences, 2015. *A Common Definition for Zero Energy Buildings*. Prepared for the U.S. Department of Energy by the National Institute of Building Sciences, September 2015.
[37] UNEP, 2010. *Common Carbon Metric – Protocol for Measuring Energy Use and Reporting Greenhouse Gas Emissions from Building Operations*. Draft for Pilot Testing.
[38] Treloar G.J., R. Fay R., Ilozor B., Love P.E.D., 2001. *An analysis of the embodied energy of office buildings by height*. Facilities 19(5/6), pp 204-214, 2001.
[39] Oldfield P., *Embodied Carbon and High-Rise*. CTBUH 9th World Congress Shanghai 2012 Proceedings, pp 614-622, 2012.
[40] Bawden, K., and Wiliams, E., 2015. *Hybrid Life Cycle Assessment of Low, Mid and High Rise Multi-Family Dwellings. Challenges*, 6 pp 98 – 116; April 2015.

the environmental impact of building materials, a lack of a matured and agreed database for building materials has been an issue for practical application.[41] While the inclusion of embodied energy or emissions could be a long term goal, it is unlikely to be feasible in the short term and we have not covered this aspect in this Report.

2.4 High-Rise

The term high-rise does not have an internationally-agreed definition and has been variously defined as follows:

- The Building Sustainability Index (BASIX), which applied in New South Wales, defines residential high rise as 6 storeys or more.[42]
- Australian Bureau of Statistics defines high rise units as flats or apartments in four or more storey blocks.[43]
- The US National Fire Protection Association 101 Life Safety Code defines high rise as a building where the floor of an occupied story is greater than 75 ft (23 m) above.[44] This equates to approximately 7 storeys.

In an Australian context and for the purpose of this report, the definition provided in BASIX is considered the most relevant.

The term 'super high-rise', although less clearly defined, has been used to describe very tall multi-storey buildings 300 meters in height[45] or over 40 storeys.[46] We note that the UK Knight Frank report, *Tall Towers 2012*, finds that construction costs increase significantly after about 25 storeys. They observed a 43% uplift in construction cost per unit area between the 10th and 50th floor in London's residential towers, for example.[47]

2.5 Building Use Classification

This report focuses on high rise residential buildings, but many such buildings have areas – in some cases, significant areas – that do not have a residential function. Such buildings are generally referred to as 'mixed use'. Under the National Construction Code, performance requirements (including energy performance requirements) are imposed according to the function of specific building areas. Therefore, when a residential building also includes offices and retail, for example, different energy standards apply to each functional area. Relatedly, the Australian Bureau of Statistics buildings classification system is based on 'primary purpose', which corresponds to the function that is associated with the largest share of the total floor area. Therefore a 'residential' building, in the context of this report, is a building where the greatest share of the floor area is classified residential (Class 2). Appendix A summaries the building classes as per the National Construction Code.

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[41] Berggren, B., Wall, M. and Hall, M., 2013. *LCE analysis of buildings – Taking the step towards Net Zero Energy Buildings*. Energy and Buildings 62 pp. 381–391, 2013.
[42] NSW Department of Planning, 2011. 2006-09 Multi-Dwelling Outcomes BASIX Ongoing Monitoring Program.
[43] Australian Bureau of Statistics (ABS), 2013. *Article 4102.0 - Australian Social Trends*, April 2013.
[44] Cote, R. ed., NFPA 101 Life Safety Code Handbook, 8th ed., National Fire Protection Association, Quincy, 2000.
[45] Council on Tall Buildings and Urban Habitat http://www.ctbuh.org/TallBuildings/HeightStatistics/Criteria/tabid/446/language/en-US/Default.aspx Accessed 13/05/2016.
[46]Government of Singapore https://www.scdf.gov.sg/content/scdf_internet/en/community-and-volunteers/community-preparedness/what-to-do-if-a-fire-breaks-out-in-a-super-high-rise--building.html
[47] Knight Frank, *Tall Towers 2012: London's high-rise residential developments*, 2012.

2.6 New vs Existing

The focus on this study is primarily on new buildings. This is because there are much greater, and generally more cost effective, opportunities to improve the energy performance of new as compared to existing buildings. Also, given the long life of buildings, the sooner net zero principles are applied to new buildings, the sooner savings will be realised. Solar access/overshading issues are critical for both new and existing buildings.

That said, and although the renewal rate for the existing building stock is relatively low, significant energy efficiency benefits can be realised during upgrades or retrofit of existing buildings. A good example is the Energiesprong program in The Netherlands. Leading edge technologies and solutions that can deliver energy savings of 90% or more are available in some applications (like lighting or ventilation in areas that are currently over-serviced (eg, where natural lighting or ventilation is available).[48]

Market factors indicate that the number of high rise projects is likely to increase in urban Australia in the coming years. Ideally, promotion of net-zero high rise would be targeted at both new projects and existing building stock (via upgrades and retrofits), however the pathways to achieving this could differ significantly.

2.7 Performance Levels

2.7.1 Minimum Compliance

In Australia, 'minimum compliance' varies from one jurisdiction to the next. In most states, the energy performance requirements are set out in the National Construction Code (Part 3.12 for residential (Class 1) buildings and Section J for Class 2 – 9 buildings) - . Note that for high rise residential buildings, this means that energy performance requirements are split, with the residential areas generally required to attain 6 stars, on average, as rated under the National House Energy Rating Scheme (NatHERS) scheme, while common areas of the building will need to comply with Section J. As noted in Section 2.5, where there are other functional areas within a mixed use, residential building, these areas may need to comply with performance requirements specific to those functions.

A further complication arises in that while there is an Inter Governmental Agreement that commits all states and territories to apply the Code on a consistent basis, this agreement is not legally binding and jurisdictions do make significant variations and in some cases additions to the agreed Code. For example, a 3.5 star rating (and not 6 star) applies to Class 2 dwellings in the Northern Territory, based on the 2009 version of the Building Code of Australia.[49] Also, in New South Wales, Part 3.12 is replaced by the BASIX scheme (see below).

2.7.1.1 National Construction Code (NCC)

BCA section J0.2 requires that the sole occupancy units (dwelling areas) of a Class 2 building must collectively achieve an average of not less than a 6 Star rating, while each individual unit must achieve a rating of not less than 5 stars, as determined under the *Nationwide House Energy Rating Scheme* (NatHERS). BCA construction requirements for thermal breaks, insulation and building sealing for the sole occupancy units must also be complied with. The remainder of the building (common areas passageways,

[48] pitt&sherry, 2014. *Energy Efficiency Master Plan – Foundation Report*. Prepared for City of Sydney, 2014.
[49] Australian Building Codes Board, *National Construction Code Series Volume Two*, 2015, p. 376.

plant rooms etc.) and services provisions must comply with the relevant provisions of Part J.[50] Stakeholders noted that there is a range of uncertainties around ratings tools – under both NatHERS and BASIX – and also related issues such as degrees of compliance with stated ratings and a lack of audit-based evidence. pitt&sherry has previously investigated these issues in detail, and further information may be found in the Phase 1 Report from the *National Energy Efficient Buildings Project*.[51]

We note that energy performance requirements under the National Construction Code have not been updated since being agreed by the Council of Australian Governments (COAG) in 2009, nor are there plans to potentially update them before 2019. A process is currently underway to review the standards, but no targets or intended outcomes have yet been announced.

2.7.1.2 BASIX

The Building Sustainability Index (BASIX) was introduced in July 2004 by the NSW Government as a sustainable planning measure. BASIX aims to deliver equitable, effective water and greenhouse gas reductions across NSW. It is implemented under the NSW *Environmental Planning and Assessment Act 1979* and applies to all residential dwelling types as part of the development application process in NSW.

BASIX sets sustainability targets for water and greenhouse gas emissions as well as minimum performance levels for the thermal comfort of a proposed development. The targets are calculated based on NSW average benchmarks from 2002-03, and have not been updated significantly ever since. The BASIX assessment tool assesses a project based on these benchmarks – taking into account regional variations such as soil type, climate, rainfall and evaporation rates. The targets for energy are:

- up to a 40% reduction in greenhouse gas emissions, depending upon the building type and location;
- BASIX also sets minimum performance levels for the thermal comfort of the dwelling.

Sustainability, energy efficiency and thermal comfort features that are rewarded by BASIX are summarised in Table 4 and in Figure 4 below.

Table 4: Thermal Comfort and Energy Measures encouraged by BASIX

Energy measures encouraged by BASIX	Thermal comfort measures encouraged by BASIX
- Light shelves for improved natural lighting	- Passive solar orientation
- Solar hot water system	- Insulation in ceiling and walls
- Natural light in kitchen and bathroom areas	- Cross ventilation allowing air to flow through units, reducing the need for air conditioning
- Compact fluorescent and LED lights with timers in common area lighting	- High performance glass
- Energy efficient appliances such as refrigerators	- Roof overhang, window eaves, pergolas and louvres to reduce sun's heat.
- Ceiling fans for cooling	- Consideration of thermal mass optimisation.
- Carbon monoxide monitoring to regulate carpark ventilation	
- Insulated hot water pipe	

[50] Victorian Building Authority, *Practice Note 2014-55: Residential Sustainability Measures*, July 2014, p. 2.

[51] pitt&sherry and Swinburne University of Technology, National Energy Efficient Buildings Project – Phase 1 Report, 2014, available from https://www.sa.gov.au/topics/water-energy-and-environment/energy/government-energy-efficiency-initiatives/national-energy-efficient-building-project

Energy measures encouraged by BASIX		Thermal comfort measures encouraged by BASIX
-	Energy efficient pool and spa heating	
-	Clothes line on louvred balcony to reduce need for electric drying	
-	On-site electricity and heat generation (cogeneration system).	

The BASIX benchmark for energy is the average NSW annual greenhouse gas emissions from the residential sector on a per capita basis. The benchmarks are calculated from pre-2002-03 NSW average residential electricity and gas consumption data collected from state-wide energy utilities, with the benchmark expressed in terms of greenhouse gas emissions equal to 3,292 kg of CO_2 per person per year. For example, a 25% greenhouse gas reduction would mean that a dwelling will be designed to enable each occupant to reduce their greenhouse emissions to no greater that 2,469 kg of CO_2 per person per year.

BASIX applies to all new multiple home developments. The BASIX assessment tool multi-dwelling section is specifically designed to suit larger residential developments, especially for unit blocks with common areas such as car parks, lifts and shared gardens which can require significant amounts of water and energy, but also has limitations in modelling very large buildings, eg, with more than 100 apartments.

Sustainable multi-unit features encouraged by BASIX

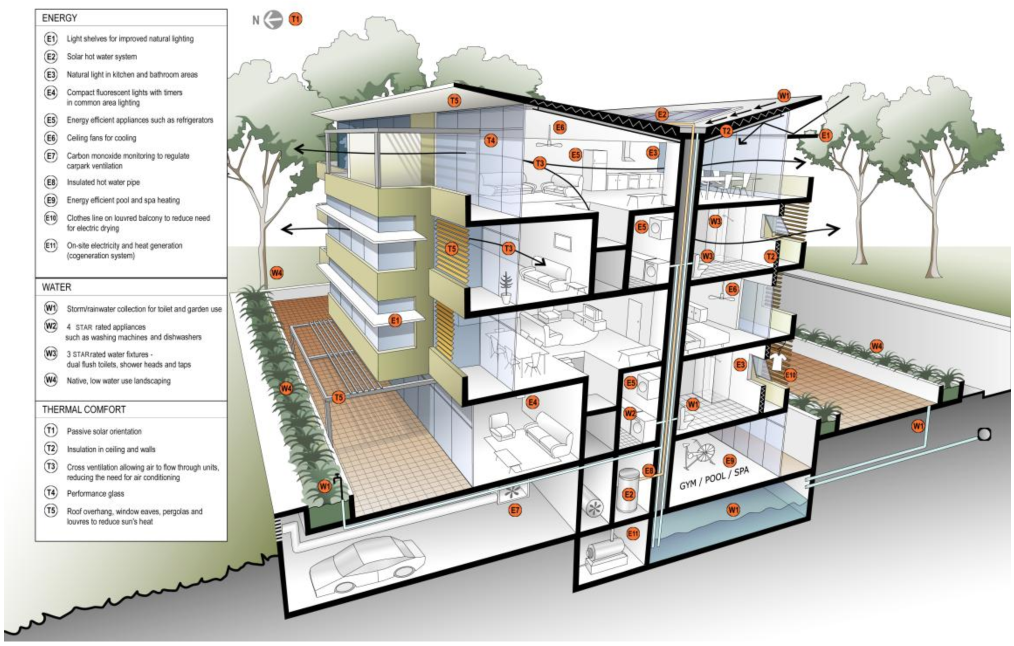

Figure 4: Sustainable multi-features encouraged by BASIX

Stakeholder feedback, including from NSW state government agencies, noted that there are some advantages to BASIX that are not shared by the NCC. In particular, BASIX includes ‘plug load’ (non-fixed appliances) efficiency measures and water efficiency measures, in addition to the thermal load and fixed appliance parameters disciplined by the Code. It also includes separate summer cooling and winter heating load limits, unlike the single averaged value of the Code, and this is widely considered to be an advance. There is also greater discoverability of BASIX ratings than for NatHERS, although the extent of this appears to vary by local government area.

While we acknowledge these strengths, the primary concern with BASIX is that its performance targets are – even more so than those in the NCC – long since overdue for a major review and uplift. They appear to have fallen well behind those applying in other states – when, as noted, those standards themselves (in other states) are also well out of date. With every passing year, a legacy is being created of buildings that could and should have much higher energy performance and yet will be expensive to retrofit with features that could have been incorporated much more cost effectively during the building's initial design and construction.

There are concerns about the flexibility and transparency of the BASIX calculator tool and the extent to which the calculator has kept up to date with current building technologies. There have been changes made to the tool recently that enable larger/taller buildings to be modelled more efficiently (up to 600 apartments). At the same time, there are concerns with the NatHERS family of tools. In the National Energy Efficient Buildings Project, referred to above, we were told that at least 70% of thermal modelling under BASIX is done by NatHERS accredited tools in any case, and also that compliance issues were similar in NSW and in other states.

Both BASIX and NatHERS tools are criticised for not covering all common area energy consumption in Class 2 buildings (or any, in NatHERS's case). Finally, BASIX uses an unusual metric, greenhouse gas emissions per capita, which is hard to validate against other more commonly-available metrics, and which is affected by factors unrelated by building performance such as changes in household composition and in the greenhouse gas intensity of electricity supply.

Overall, the criticisms of BASIX are relatively mild and could readily be addressed via a conventional policy review process, which should include consultation with a wide range of building industry professionals and consumer and environmental representatives. This should also extend to a commitment to a regular review/upgrade process for BASIX, for example in parallel with the NCC's 3-year cycle, so that similar issues do not re-emerge in future.

2.7.2 Australian Excellence

Australian excellence in this report is used to characterise the best and most effective strategies to improve energy performance that are locally available at the present time. It represents exemplar performance that could be achieved by a new build today. The actual performance benchmark, relative to base case, varies by climate zone and will also change over time, but it exceeds a 50% improvement in both Sydney and Melbourne.

2.7.3 Global Excellence

Global excellence builds on Australian excellence by incorporating façade performance and energy outcomes comparable with global passive design standards. For key building elements, like lighting and glazing for example, we assume that current trends towards higher performance and lower cost continue, and the scenario demonstrates outcomes likely to be achieved over the next 5 years. Of course, the global excellence benchmark will also shift through time, but in this report it represents around a 75% improvement over the base case.

Detailed information on each of these specifications is provided in Sections 4.6 – 4.8.

3. Design Considerations and Abatement Opportunities

High-rise residential buildings are becoming more common as cities re-develop and increase in density. For example, by 2030 the population of Sydney is forecast to be 45% larger than it was in 2011.[52] It has been further estimated that by then approximately 80% of residents will be living in apartments and at least 90% of the new dwellings built will be high-rise buildings.[53] This sub-sector therefore has the potential to play a leading role in achieving future climate change targets. Equally, growth in this sector will place additional pressure on emissions if we do not see movement towards best energy practices, and ultimately net-zero.

3.1 Design Considerations

High-rise buildings are, on average, more energy intensive than lower rise buildings. It has been found previously that high rise buildings in Sydney consume around 38% more energy per square metre than low-mid rise, and the high rise buildings are typically much larger.[54] This may be attributed to the higher level of centralised energy services often found in such buildings, which may include centralised air conditioning, lifts, underground car-parks, swimming pools and spas, and perhaps other facilities such as laundries and cafes. Up to 90% of high rise dwellings will have centralised HVAC systems, while up to 50% of them may have a swimming pool. These effects may be offset to a degree by the lower surface area to volume ratio generally found in large, as compared to smaller, buildings. This can mean that less energy is required to maintain internal temperature stability per unit of building volume.

In addition, high-rise buildings present particular challenges when incorporating passive ventilation, thermal improvements, use of photovoltaics (PV) and other energy efficiency mechanisms that would be considered for lower rise projects. A technical challenge for tall buildings is that they have limited roof area compared to their volume, and those roofs are often crowded with plant and equipment, and perhaps telephone base station, reducing the available roof area for PV systems.[55] Advancements in building-integrated PV (BiPV) technology and also battery storage will assist in this area. Other challenges may include:

- Potential over-shadowing by adjacent buildings/structures, and/or the risk of future over-shadowing;
- Requirements for car park (number per unit; outdoor vs. underground) and the implications of this for energy consumption for lighting and ventilation;
- Energy required from lifts to transport people vertically;
- The diverse range of attributes, size and form found in high-rise residential apartments;
- Aspect ratio;
- Window-to-wall ratios;
- High wind loadings particularly at the upper levels of tall towers, which may create challenges for shade structures, passive ventilation and solar panel installation;
- Standardised designs (like highly glazed curtain wall buildings) being used in climate zones where this solution may not be optimal.

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[52] Residential apartments sustainability plan, City of Sydney, http://www.cityofsydney.nsw.gov.au/__data/assets/pdf_file/0005/241538/FINAL-Residential-Apartments-Sustainability-Plan_2015.pdf

[53] Ibid.

[54] pitt&sherry, 2014. *Energy Efficiency Master Plan – Foundation Report*. Prepared for City of Sydney, 2014.

[55] So, A., Katz, D., and Wacks, K., 2014. Towards *Zero Net Energy (ZNE) Super High-Rise Commercial Buildings*. CABA White Paper, June 2014.

Conventional design and construction practices for high-rise multi-unit residential buildings present a number of constraints with regard to achieving high levels of energy performance. Increased energy performance (e.g. minimisation of glazing areas; improvement of glazing and opaque thermal performance; reduction of air leakage; installation of higher efficiency mechanical and electrical systems) has to be balanced with achieving acceptable commercial outcomes which typically include:

- Maximising glass area to enhance marketability, daylight and views;
- Provision of access to outdoors via balconies;
- The need for Code-mandated combustibility and life safety requirements;
- A preference for building systems to minimise exterior construction access and streamlined construction sequencing;
- The adoption of increased structural load requirements; and
- Minimisation of capital costs.[56]

In addition to technical challenges highlighted above, there is a number of economic and commercial considerations that have to be addressed in order to achieve successful market transformation to net-zero high rise residential apartments, as summarised in Figure 5 below.

Knowledge barriers	• Lack of knowledge about sustainability; • Lack of guidance and clarity; • Mixed messages.
Low standards	• Energy performance requirements for Class 2 (apartment buildings) are relatively low.
Return on investment	• High costs associated with non-standard solutions, at least initially; • Perception that costs of low-carbon solutions outweigh the benefits.
Ownership	• Strata title ownership - issues associated with multiple stakeholders; • Split incentives between owner-occupiers, tenant and investor.

Figure 5: Commercial and Economic Barriers Associated with High-Rise Residential Buildings[57]

3.2 Abatement Opportunities

Achieving very high energy performance in high-rise residential buildings is a complex process. Optimum solutions will require early stakeholder involvement and development of technically feasible, cost-effective and robust solutions tailored to this building class. Such solutions require a thorough understanding of specific opportunities that exist to date both locally and internationally in order for the clear pathways to be developed.

A solid conceptual framework for understanding the opportunities for high-rise residential buildings is offered by Faithful & Gould's *Carbon Cost Hierarchy Pyramid* (see Figure 6 below). This hierarchy indicates that, as a rule, active elements like solar PV, wind turbines, tri-generation, etc (sometimes disparagingly referred to as 'eco-bling'), typically have higher costs while delivering less savings than passive elements

[56] Cianfrone et al., Holistic approach to achieving low-energy, high-rise residential buildings, Building Physics, 2016

[57] Reference to Figure 1 - Strata title is a form of ownership devised for multi-level apartment blocks and horizontal subdivisions with shared areas.

such as building form and orientation (including its design). The philosophy is sometimes known as 'fabric first', referring to the desirability of getting the basic building design, orientation and shell right, from an energy efficiency perspective, before calling on more active elements like renewable energy. In between are opportunities such as better metering, controls, occupant engagement and energy efficient services.

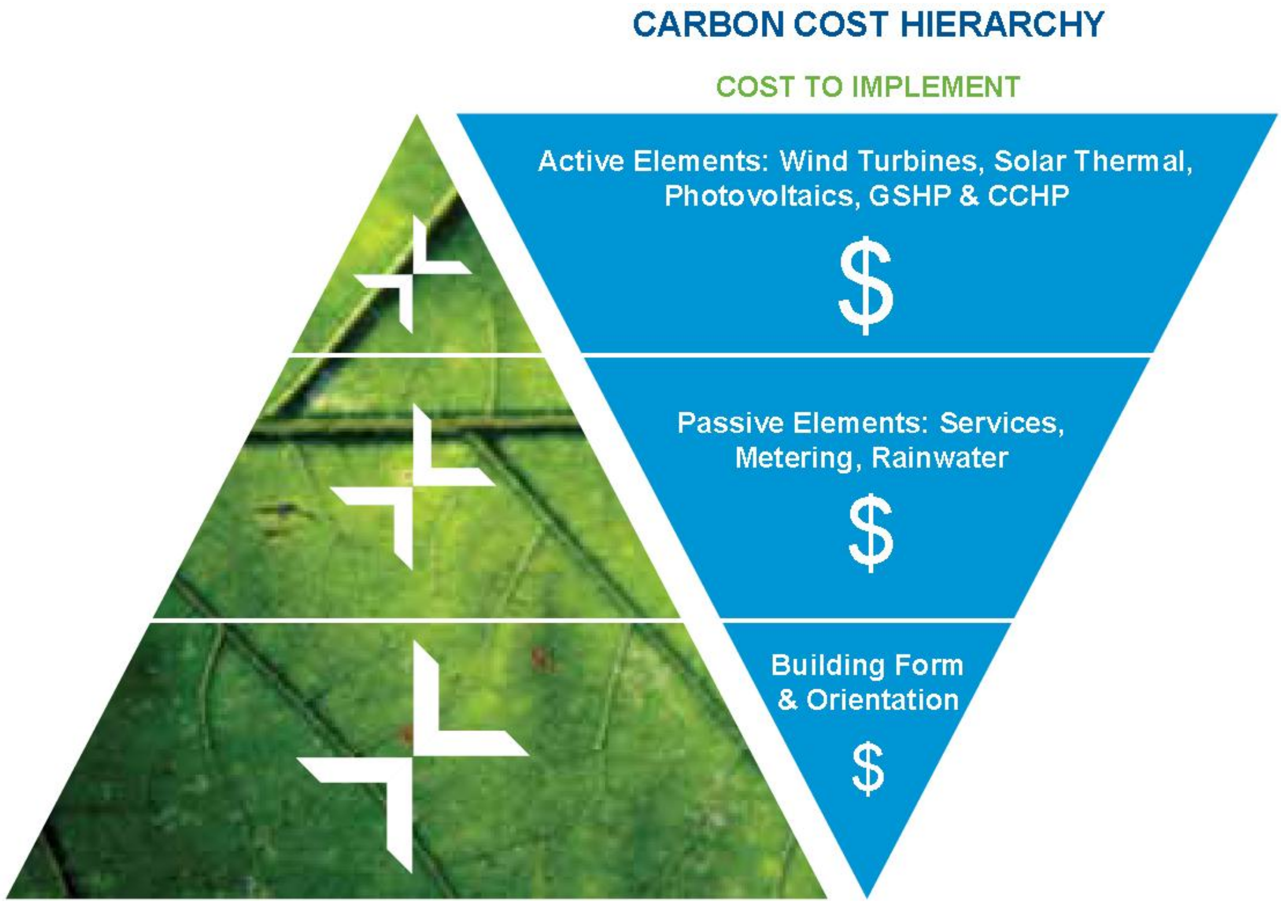


Figure 6 – Carbon Cost Pyramid (Source: Faithful+Gould)

This approach is consistent with both the European and American net-zero definitions, which call for the building to first be energy efficient. It is also consistent with the solar passive design philosophy, which seeks to make optimal use of natural energy flows through passive elements like design, shading, facade performance, thermal mass and insulation.

The remainder of this chapter is devoted to the detailed analysis of specific opportunities and design initiatives and evaluates them in relation to the following attributes:

- *Energy saving potential*
- *Ease of implementation in new-build and retrofit including spatial implications*
- *Policy context, drivers/barriers and marketability*
- *Capital, operational and maintenance costs, return on investment and learning rates.*

Table 5 provides a summary in the form of a matrix to facilitate quick comparison of relevant attributes. Attributes are ranked on a scale of 1 (red) to 5 (green) with 5 representing the most desirable/positive outcome. Designers and policymakers should give particular consideration to those initiatives having significantly differing ease of implementation between new-build and retrofit stages.

A low marketability ranking represents initiatives with limited likelihood that inclusion would influence decision to purchase or that the developer would be able to recover some form of market premium, planning or CSR advantage, based on current levels of awareness of benefits associated with this particular initiative. However an overall 'green premium' or advantage may be realised based on provision of a suite of measures adding up to a holistic benchmark or certification, such as a NatHERS, Green Star, Carbon Neutral or Net-Zero Energy.

Table 5 Energy efficiency initiatives – quick comparison

Initiative	Energy saving potential	Ease of implementation - new build	Ease of implementation - retrofit	Marketability	Cost impacts	Overall rating
Envelope/fabric						
High-performance glazing	4	5	2	3	3	3.6
50% window-wall ratio	4	5	1	2	4	3.8
30% window-wall ratio	5	4	1	1	3	3.4
Translucent walls	5	3	1	3	1	3.1
Thermal bridging	3	2	1	1	2	2.0
Exposed thermal mass	2	4	2	3	5	3.2
Apartment air-tightness	4	2	1	1	1	2.1
Trickle ventilators	1	4	3	4	3	2.3
HVAC & Hydraulics						
Heat-recovery ventilation	3	3	1	1	4	2.7
Variable speed drives	5	5	4	1	5	3.4
Low-velocity air distribution	5	3	1	1	4	3.4
High-efficiency air-conditioning	4	5	4	3	3	3.1
Ceiling fans	4	4	3	4	3	3.3
Naturally ventilated car park	4	2	1	2	3	2.8
Ultra-low flow shower heads	4	5	4	2	4	3.1
Shower drain heat recovery	3	3	1	2	2	2.5
Pool blankets	4	4	2	3	3	3.3
Renewables						
Rooftop PV	1	4	1	3	3	2.6
Building integrated PV	4	2	1	4	1	2.8
Solar hot water generation	2	3	2	3	3	2.4
Regenerative motor lifts	3	5	4	2	4	2.7
Lighting						
LED apartment lighting	5	5	4	4	5	4.1
LED carpark lighting	5	5	4	4	4	3.9
Whitened car park surfaces	3	4	3	5	2	3.0
Appliances						
Induction cooktops	2	5	4	5	3	2.9
Low-energy dishwashers	3	5	5	4	3	2.7
Occupant behaviour						
Apartment kill-switches	3	4	1	5	3	3.7
Real-time submeter monitoring	2	3	1	3	2	2.4
Average rating	3.5	3.9	2.3	2.8	3.1	3.0

Opportunities Case Study

The *City of Sydney Energy Efficiency Master Plan, Improving Energy Productivity 2015 – 2030*, August 2015 (Master Plan), provides an excellent local example of energy efficiency opportunity assessment. The Plan, prepared by the City of Sydney in 2015, provides performance measures for high-rise multi-unit dwellings (Figure 7).

Minimum performance standards

- Minimum Energy Performance Standards (MEPS).
- NSW Building Sustainability Index (BASIX).
- National Construction Code (NCC).

Information and incentive programs

- Commercial Building Disclosure (CBD).
- Green Star.
- National Australian Built Environment Rating Scheme (NABERS).
- NSW Energy Savings Scheme (ESS).

Targets and strategies

- NSW Government Resource Efficiency Policy (GREP).
- Australian greenhouse gas emissions target(s).
- Australian and State Governments Energy Efficiency Strategy.

City of Sydney programs

- Better Buildings Partnership (BBP).
- CitySwitch Green Office.
- Smart Green Business.

Figure 7: City of Sydney Measures for high-rise multi-unit dwellings

It notes that if the existing policies and programs are simply maintained, a mix of market-based mechanisms, partnerships, rating tools, information programs and regulation, modelling predicts they would reduce total energy by 10 per cent below 2006 levels for all buildings across the local government area by 2030. Without these programs total energy would increase by 26 per cent over the period.

There is a significant future role for building codes, minimum energy performance standards for appliances, building rating tools and voluntary programs at current levels. However, there is uncertainty surrounding levels of compliance with codes and whether buildings perform as well as designed and intended.

In addition to ensuring that existing policies and programs are working, there is scope to increase codes and standards beyond current levels for greater efficiency while still being cost-effective.

New policies and programs scenarios modelled for the Master Plan include:

- Building retrofits and tune-ups
- Improved compliance and targets for existing building codes
- Mandatory disclosure of energy performance of buildings.

These have been identified as ready opportunities that are based on already established and accepted frameworks. Together with existing policies and programs the savings would be 31 per cent below 2006 levels by 2030.

Refer to http://www.cityofsydney.nsw.gov.au/vision/towards-2030/sustainability/carbon-reduction/energy-efficiency

Table 5 also shows that envelope and fabric initiatives such as high-performance glazing, window to wall ratios and trickle ventilators tend to have highest energy saving potential and tend to cost less. This is also true for LED Lighting measures which are also characterised by the relative ease of implementation and high marketability. Renewables tend to be comparatively more costly per unit of abatement, although costs are falling rapidly in this area.

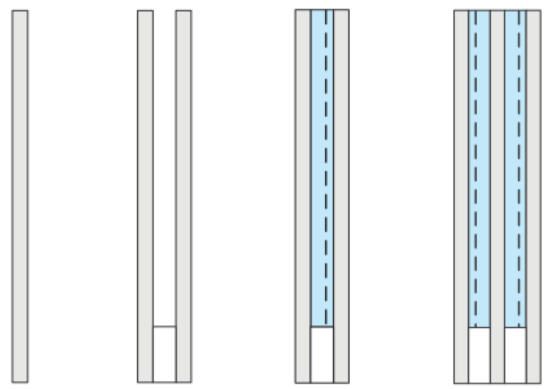
3.3 Envelopes/Fabric

3.3.1 High-Performance Glazing

Energy saving potential

In thermal performance terms, windows are the weak point of a building envelope. Standard practice windows typically have 5 to 10 times the conduction loss of standard practice walls. This ratio remains true even when applying global best-practice standards such as Passivhaus or Minergie-P. The energy saving potential of higher performance glazing is substantial. The difference in thermal conduction performance between minimum standard windows (untreated single-glazed, standard aluminium frames) and best-available can approach ten-fold as illustrated in Table 6.

Table 6: Comparison of glazing composition, performance and internal surface temperature at -10°C (adapted from PHI)[58]



Type of glazing	Single glazing	Air-filled double glazing	Double glazing with gas-filled spaces and selective coating	Triple glazing with two gas-filled spaces and two selective coatings
Spacer	none	Stainless steel	Warm edge spacer	Warm edge spacer
U_w value in [W/m^{2}K]	5.60	2.80	1.20	0.65
Internal surface temperature* [°C]	–1.8	9.1	15.3	17.5
g value [–]	0.92	0.80	0.62	0.48

Passivhaus standard windows are often referred to as 'warm windows' and require system U-values (including frame) below 0.85W/m^{2}K for cool temperate climate regions. For warm temperate climates such as Melbourne and Sydney a maximum Uw-value of 1.25W/m^{2}K with a Ug of 1.2W/m^{2}K is the minimum performance for Passivhaus certification. This is achieved with double-glazed, ultra-low emissivity glass with inert gas cavity fill in combination with premium thermally-broken frames.

[58] The Passivhaus Designer's Manual, Hope & McLeod 2015.

A rule-of-thumb equation can be used to provide an initial guide as to whether the glazing properties of the window are sufficient to achieve a positive energy balance[59]:

$$U_g - (S \cdot g) < 0$$

where:

Ug is the glazing U-value,

S is the annual solar transmission coefficient

g is the solar heat gain coefficient (SHGC)

If this condition is fulfilled, more useful solar energy can be gained during the heating period than the window actually loses as heat to the outside.

Taking a Ug value of 1.2W/m²K and a representative value of S as 3.2W/m²K for a warm temperate climate provides a minimum g value of 0.4.

Ease of implementation

There are few implementation challenges associated with incorporating high-performance glazing in new-build construction. Double-glazing using low-emissivity glass with SHGCs of 0.20 – 0.35 are typical of that supplied to code-compliant high-rise apartments in Melbourne. Thermally-improved frames and argon gas fill are frequently required for developments with a high proportion of vision glazing. Low-emissivity glass is not manufactured in Australia. Ultra-high-rise residential apartments typically incorporate curtain walling[60], which is also not fabricated in Australia but is readily procurable.

Drivers and marketability

The average performance of glazing in Australia is considerably lower than in northern Europe where code compliance is more demanding. Higher performance windows are crucial for buildings aspiring to be energy –efficient.

Better thermal performance leads to greater comfort for occupants close to glazing (e.g. reduced condensation risk, downdraught or radiant temperature asymmetry) and often better acoustic performance. Near-neutral internal glass temperatures are particularly important in order to minimise discomfort for occupants, which in turn could trigger a demand for heating or cooling. If occupants are exposed to radiant temperature asymmetry greater than 5°C it can lead to feelings of thermal discomfort.[61] In this way high-performance glazing increases useable floor area by making the room façade perimeter occupiable. This is particularly important in high-rise apartments where dwelling floor area is constrained and typically below 50m² for 1 bedroom apartments.

Relative humidity levels in dwellings are typically higher than other uses due to moisture generation from washing, drying and cooking activities. Toxic mould can grow on substrates where surface relative humidity is above 80%. For Passivhaus certification windows must meet a corresponding hygiene criterion. The high-performance double-glazing standard nominated for warm-temperate climates creates a minimum internal glass surface temperature of 14°C when external temperature is 5°C. This is intended to eliminate condensation on the windows.

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[59] The Passivhaus Designer's Manual, Hopfe & McLeod 2015

[60] Where the facade or outer covering of a building is non-structural, but rather hung like a curtain from the floorplates.

[61] BS EN ISO 7730:2005

Costs

Indicative overall costs are presented in Table 7, indicating that good practice glazing typically costs at least 40% more than typical standard practice glazing, but potentially higher in some cases. It should be noted that overseas experience shows that prices fall substantially as high performance glazing becomes standard practice.[62] Note that we experienced difficulty receiving quotes from suppliers to establish baseline costs for the different performance levels noted below. We attribute this to the relatively immature market for high-performance glazing in Australia.

Table 7: Glazing make-up comparison

Window performance	Glass panes	Low-emissivity coating	Cavity	Cavity closer	Frame type	Typical Frame Uf	Typical System Uw
Minimum	1	None	None	-	Non-thermally broken	8	5 - 7
Standard	2	Single coat	Air	Aluminium	Thermally improved	5	3 - 5
Good-practice	2	Double coat	Argon	Polyamide	Thermally broken	2	1.5 - 3
Excellence	3	Triple coat	Krypton	Polyamide	Thermally broken	1	0.7-1.2

Indicative cost ranges of elemental upgrades:

- Low emissivity coatings add $10/m² to uncoated IGU costs and can improve U-values by 30%
- Double low-e coatings add $15/m² to uncoated IGU costs and can improve U-values by 40%
- Argon cavity fill adds $2/m² over air and can improve U-values by 8%
- Window frames typically comprise 60% of window cost, before installation
- Thermally-broken frames typically cost more than traditional aluminium frames.

The cost of high-performance glazing is a function of the spread of supply and demand in the market. Whilst a market for single-glazing and basic double glazing remains, high-performance glazing is likely to attract premium pricing associated with low-volumes or absence of commoditisation. This highlights the opportunity for market transformation initiatives in this area.

3.3.2 Window to Wall Ratios

Energy saving potential

A typical new-build high-rise residential development in Australia has an overall window to wall ratio (WWR) exceeding two-thirds. At these levels windows are responsible for around 95% of conduction losses through the façade of high-rise apartments, when using typical current glazing and wall specifications. Reducing this ratio in conjunction with improved glazing performance and insulation levels is crucial to delivering a cost-effective high performance façade. Glazing performance improvements in this instance should combine higher thermal efficiency with improved light transmission.

Energy savings realisable due to reduced WWRs are substantial.

In studies of Dutch office buildings, the least energy use was observed at window-to-wall ratios (WWR) of about 30% for north (i.e. facing away from equator), while at 20% WWR for south, east, and west

[62] A good treatment of market transformation, including for glazing, is offered in International Energy Agency, *Creating Markets for Energy Technologies*, 2003.

orientations[63]. Comparable numbers emerge for Passivhaus studies. A rule-of thumb for initial planning for passive performance is to target total glazing area (excluding frame) of 15-20% of treated floor area.[64]

Figure 8: Example of Low Window-to-Wall Ratio Design Apartment Building: Icon Building, St Kilda, Victoria

Drivers and marketability

A relatively static regulatory environment combined with increasingly energy efficient façade products has avoided any downward pressure on WWRs. This contrasts with the high-rise office sector where incentives to achieve best-practice NABERS ratings have moderated WWRs for new-builds.

There are two potential disincentives associated with reducing WWRs towards optimal energy performance levels: 1. current market expectations in Australia for extent of outlook from apartments; and 2. providing appropriate levels of daylight amenity within key zones of the apartment.

Daylight amenity & perceptions

Typical new residential towers in Australia incorporate glass with a visible light transmission (VLT) of 30-40%. Comparable daylight admission can be achieved through smaller windows with clearer glazing, which may have a VLT up to 70%.

[63] Ochoa et al., 2012 referenced in The Passivhaus Designer's Manual, Hope & McLeod 2015.
[64] How to build Passivhaus: Rules of thumb, Passivhaus Trust 2015.

Figure 9 indicates that 1 & 2 bedroom apartments (40-60m²) typically incorporate 9-15m² of glazing. The reference ultra-high rise tower apartments have a range of glazing extents from 12m² to 29m² for dual-aspect corner apartments.

Figure 9: Zone area to glazing area relationship in Australia (Source: Sustainability Victoria)

Figure 10 indicates that glazing performance increases have lead to increased glazing ratios, in the absence of continuously evolving residential energy rating standards.

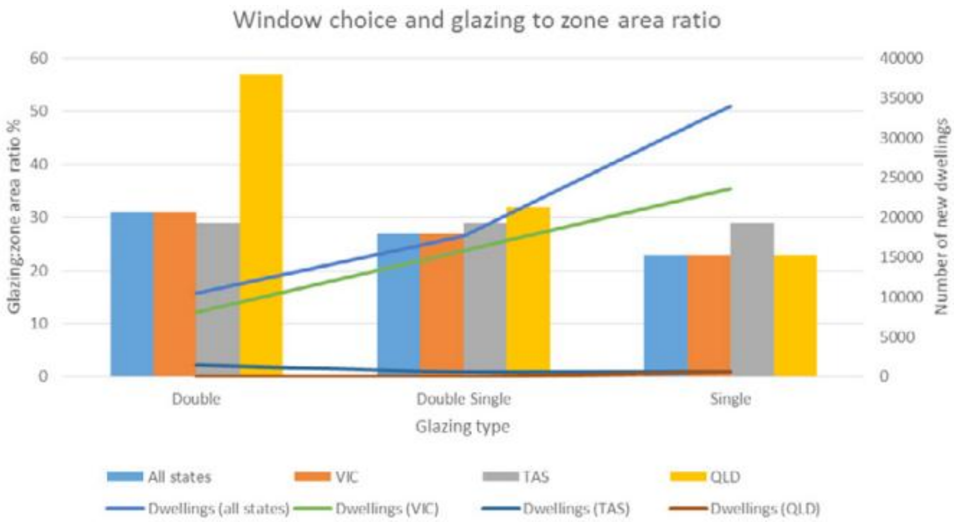


Figure 10: Window types and glazing ratio relationship in Australia (Source: Sustainability Victoria)

Expansive façade glazing frequently reduces visual comfort by increasing glare contrast between windows and what then appears to be relatively gloomy apartment surfaces. Our eyes are unable to successfully adapt via pupil dilation due to the resulting poor uniformity of light levels. Glare sensitivity also increases with age.

For northwards orientations light shelves can be a very effective way of improving daylight uniformity by reflecting light deeper into the apartments whilst moderating light levels closer to the glazing.

A more typical intervention to overcome the contrast and glare associated with extensive glazing is use of blinds. The dynamic nature of sunlight makes effective manual adjustment onerous, whilst automated systems are expensive and rarely successful in long-term use. As human nature acts in response to discomfort rather than comfort manually adjusted blinds tend to remain in a dropped position, obviating the benefits of daylight and view presumed at planning stage.

This behaviour is well illustrated by towers with high WWRs exhibiting fully dropped blinds – see an example in Figure 11. It is particularly noteworthy that the majority of blinds remain in position throughout dull overcast days as residents appear to have conceded the struggle to balance visual comfort with views.

Figure 11: Highly glazed high-rise residential towers in Sydney (Green Square) exhibiting prevalence of dropped blinds and shutter (Source: City of Sydney)

A 2011 study of over-glazing of office buildings by the University of Auckland found that optimum WWR rarely exceeds 50% and is more commonly in the range of 30 to 40%. It concluded that such proportions of glazing could have increased occupant appreciation, increased productivity and decreased energy consumption.[65]

Optimal WWRs within a floor plate will vary by façade orientation, with below average WWRs being important for north-facing glazing to avoid overheating in a passive design context.

Totally homogeneous light distribution is known to generate uninteresting spaces without shades.[66]

It is important that reductions in WWR from current Australian apartment trends be accompanied by an increase in the visible light transmission (VLT) of the remaining glass to minimise extent of daylight reduction. It is possible for daylight amenity to be increased through judicious integration of ultra high-performance translucent wall panels (see Section 3.3.4).

A key design strategy is prioritising daylight quality over daylight quantity. Daylight factor modelling has traditionally been used as a compliance tool, but effectively rewards excessively bright areas and ignores orientation and sunlight variability. More recently developed metrics such as useful daylight illuminance (UDI) are better suited to optimizing visual comfort of daylight, in conjunction with moderating cooling and

[65] http://anzasca.net/wp-content/uploads/2014/02/32P2.pdf
[66] The Passivhaus Designer's Manual, Hopfe & McLeod 2015

artificial lighting loads. There is some preliminary evidence that UDI may act also act as a proxy for the daylight glare probability (DGP) metric.[67]

Exterior view

An obvious challenge in significantly reducing WWRs from current Australian trends is that of constrained outlook, which is particularly relevant to high-rise apartments where views may be considered a key attribute/compensation for other lifestyle compromises.

According to the German standard DIN 5034-1:2011, the following criteria should be fulfilled to provide a reasonable view to the exterior:

- Sum of all window widths should be 55% of total façade width.
- Glazed area should be at least 10 % of floor area and 30 % of façade area.
- Rooms with depth less than 5m, should have minimum glazing area of 1.25 m^2; or 1.5m^2 with larger depths
- Base of glazing should be a maximum of 0.95m above floor level.
- Top of glazing should be at least 2.2m above floor level.

For ultra-high rise applications it is reasonable to selectively incorporate full-height glazing to facilitate downwards views. It should be noted that glazing below 0.7m above floor level will not contribute useful daylight to the working plane and tends to worsen daylight uniformity through the room.

In the context of low WWR it is interesting to note recent research supporting our ability to 'fill in the blind spots'. In other words, we see not only with our eyes, but with our brain too.[68,69] Figure 12 below shows a triangle that it actually not there but suggested by the position of the black dots – that suggested triangle is there thanks to the focus of brain activity shown at the right of the figure. Creative façade designs could further exploit this aspect of physiology.

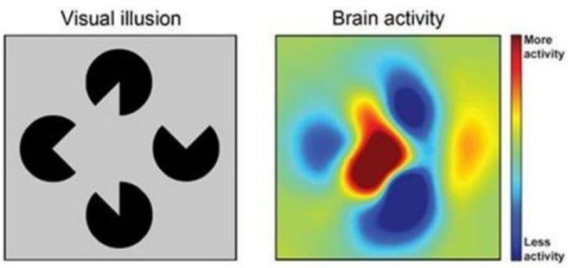


Figure 12 – A Visual illusion produced by brain activity (Source: Science Daily and Radboud University**)**

Achieving net zero high rise buildings requires paradigm shifts including re-imagining planning or design norms and future occupant behaviours and norms. Such shifts are apparent in the success of voluntary near-zero-energy standards such as Passivhaus, Minergie-P and the Living Building Challenge. These approaches embrace the lean-mean-green design hierarchy, which begins with efficient façade materials and effective façade composition.

[67] http://www.ibpsa-england.org/resources/files/bso-2012/3B1.pdf
[68] https://www.sciencedaily.com/releases/2014/06/140627094551.htm
[69] http://phys.org/news/2011-04-eyes-brain.html

Stakeholder feedback on the draft report included scepticism about the marketability of low window-wall ratios, generally from a developer/owner perspective – where we do see a preference for high WWRs – but some also expressing concern about adequate access to light and related amenity issues. We feel that the substantive points are covered above, but we acknowledge that there is both buyer and industry resistance in this area, and realising change in this area could require outreach to many elements of the building industry – including real estate agents, for example – as well as public information campaigns.

Costs

Decreasing WWRs in isolation delivers lower cost facades as windows cost more than opaque wall construction. Proportionally increasing thermal performance of the remaining glass therefore becomes viable. Reduced glazing extents also makes utilisation of clear glass viable. Clear glass is produced in large volumes and is typically cheaper than tinted glass.

3.3.3 High-Performance Glazing + Lower WWRs

Energy saving potential

The energy saving potential of an efficient tower façade combining high-performance glazing, high levels of wall insulation and reduced WWRs is the most compelling of all initiatives that could be considered. This combination of measures is essential to approach passive design conditions relevant to net-zero emissions in high-rise developments where renewable energy opportunities are constrained.

These measures have considerably longer life spans than building systems initiatives and are not well-suited to retrofit in a high-rise context.

To illustrate the potential for energy savings, three façade performance scenarios were modelled:

- Base-case using façade composition and performance representative of that used to achieve compliance with current regulations and planning policies
- An 'Australian Excellence' standard representing exemplar performance whilst remaining within the realms of a currently viable outcome.
- A 'Global Excellence' standard representing façade performance and energy outcomes comparable with global passive design standards.

While the detailed results are presented in Chapter 4, here we note that through a combination of reducing WWRs to 30%, adding insulation and utilising high-performance glazing, average star ratings could be lifted dramatically from 4.4 to 9.2 in Sydney and from 6.5 to 9.3 in Melbourne.

Singapore residential facade metric (RETV)

It is interesting to consider the compliance approach used in Singapore, where the majority of residential provision in Singapore is high-rise[70]. For residential developments without mandatory Green Mark prerequisites current building code deemed-to-satisfy compliance can be achieved with WWR < 30% with SHGC < 0.6, or WWR<40% with SHGC < 0.44 for unshaded glass.

Building regulations define the weighted performance of windows and walls averaged over the whole building envelope area as the Residential Envelope Transmittance Value (RETV), calculated as follows:

[70] https://www.researchgate.net/publication/222648100_Romancing_the_high-rise_in_Singapore_Cities_221_3-13

$$RETV = 3.4(1-WWR)U_w + 1.3(WWR)U_f + 58.6(WWR)(CF)(SC)$$

where

RETV	:	residential envelope transmittance value (W/m^2)
WWR	:	window-to-wall ratio (fenestration area/gross area of exterior wall)
U_w	:	thermal transmittance of opaque wall ($W/m^2 K$)
U_f	:	thermal transmittance of fenestration ($W/m^2 K$)
CF	:	correction factor for solar heat gain through fenestration
SC	:	shading coefficients of fenestration

For Green Mark rated residential developments a prerequisite is that RETV be less than $22W/m^2$ (Gold Plus rated developments) or $20W/m^2$ (Platinum rated developments) with rating points available for reductions below these levels. These Green Mark ratings are mandatory within strategic city areas.

The concept of summarising residential envelope performance in a single value used as a compliance threshold has much merit in the context of accelerating progress towards net-zero standards. Optimal RETV weightings and target thresholds will vary for Australian capital city climates.

Ancillary savings

It is often overlooked that as façade performance improves significant consequential savings may be realised elsewhere. For example, significantly reduced air-conditioning plant capacities result in:

- Cost reductions in air-conditioning system supply and installation, and associated design fees, commissioning, O&M costs and ongoing energy consumption costs.
- Spatial reduction in extent of condenser banks. Ultra-high rise towers may include around half of a mid-rise floor for VRF system condenser banks due to height separation constraints. This area would be equal to that required for four 2-bedroom apartments. The saleable value of this plant area if it were halved through reduced building fabric loads would be over $1M.
- Reduction in substation size, capital cost and connection cost. Associated reduction in switchgear and power cabling infrastructure throughout tower.
- Reduction in cooling tower water infrastructure resulting in reduced pumping costs, connection charges, and associated water consumption.

Outcomes from international pathfinder sustainability projects found reductions of 75% in mechanical plant capacities and 50% in electrical capacities resulting in up to 15% extra net lettable area.[71]

3.3.4 Translucent Walls

Energy saving potential

Translucent walls transmit diffuse light but have energy performance comparable with insulated external walls. They have energy saving potential where used to supplement daylight penetration in high-performance facades requiring low WWRs. There are a number of products produced internationally with a remarkable range of heat and light transmission properties (Table 8).

[71] Detail Engineering 2: Building Design at Arup – Chris Twinn 2013

Table 8: Comparison of translucent wall product characteristics

Product	Pane composition	Cavity fill	Depth *mm*	U-value	R-value	SHGC	VLT	Rw *dB*	Origin	Non-captive product cost	Install cost
Okagel	Double-glazing	Aerogel	60	0.3	3.3	0.54	45%	52	Germany	$1500-$1800/m²	$1000/m²
Solera + Lumira	Double-glazing	Aerogel	76	0.31	3.2	0.07-0.30	7-32%	52	Canada		
				0.21							
GlassX	Quadruple glazing	Inert gas, PCM	52-72	0.48	2.1	0.33-0.37	4-55%	47	Switzerland	$840/m²	
Kalwall	-	FRP + Aerogel	70	0.28	3.6	0.13-0.18	12-15%	34	USA	$820/m² incl. TB frames	$300/m²
Rodeca	12 layer polycarbonate sheeting		60	0.71-0.77	1.3	0.37-0.43	30-41%	27	Germany	$180/m² supply incl. TB frames	$120/m²

Insulating performance of these products exceed that of wall constructions commonly utilised for NCC compliance in Australian dwellings. One product range incorporates semi-transparent phase-change material (PCM) which offers additional energy-saving potential.

Ease of implementation

Translucent wall products made from fibre-reinforced plastic (FRP) were first established in the 1950s but still represent a niche market product. The majority of products are installed in thermally-broken frames making implementation similar to glazing installation procedures. These high performance products are imported and not commonly specified in Australia therefore additional design co-ordination effort will be required.

Drivers and marketability

Whilst high-performance translucent wall products may be considered relatively high-tech products they are a passive product (in contrast to electro-chromic glass), which may offer greater longevity and have insulating properties unachievable with solely glazed solutions. The diffuse light provided can be an asset if carefully applied. Creating a successful internal and external aesthetic will be a key a design challenge when combining glass and translucent walls in a tower apartment format. This is particularly true where phase-change material is incorporated due to its unconventional and dynamically changing appearance.

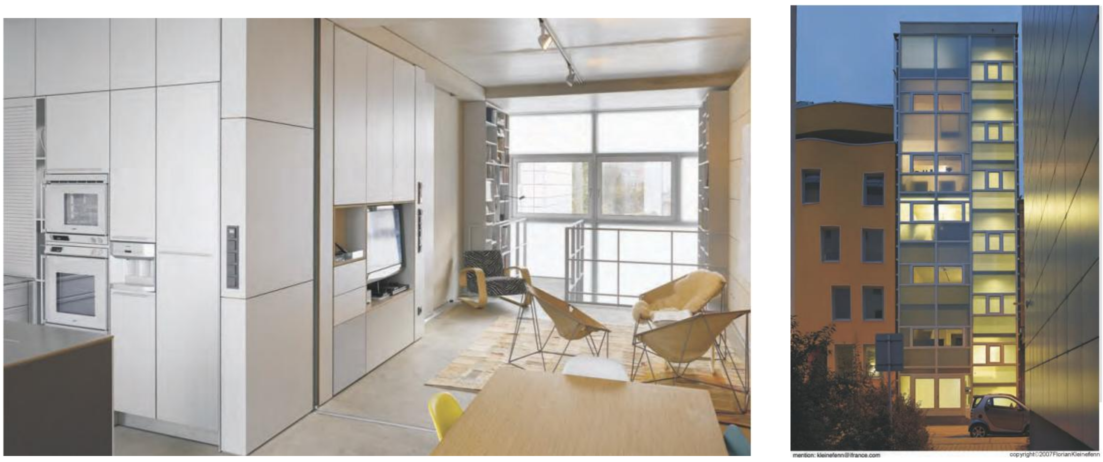


Figure 13: Residential apartments, Berlin (© GlassX)

Figure 14: Lumira Aerogel glazing sections within high-rise apartments in Chelsea, New York(© Solera)

Figure 15: Kalwall + Lumira aerogel at Tintern Middle School, Melbourne(© Kalwall)

Costs

The costs of translucent walls vary considerably. For Australian warm-temperate climates these costs are likely to be prohibitive currently but these products may have a useful role in resolving daylight concerns for specific challenging instances, particularly as energy targets become more stringent.

3.3.5 Exposed Thermal Mass

Energy saving potential

When used correctly, thermal mass can significantly increase comfort and reduce energy consumption in dwellings. High-rise developments typically incorporate lightweight external walls and plasterboard ceilings. Exposed thermal mass in apartments is most readily achieved via exposed concrete soffits and tiled floors. Exposed thermal mass moderates internal temperature swings which reduce instantaneous peak loads. Figure 16 demonstrates that exposed thermal mass has the potential to reduce temperatures by up to 6-8°C. This in turn reduces peak plant capacities required.

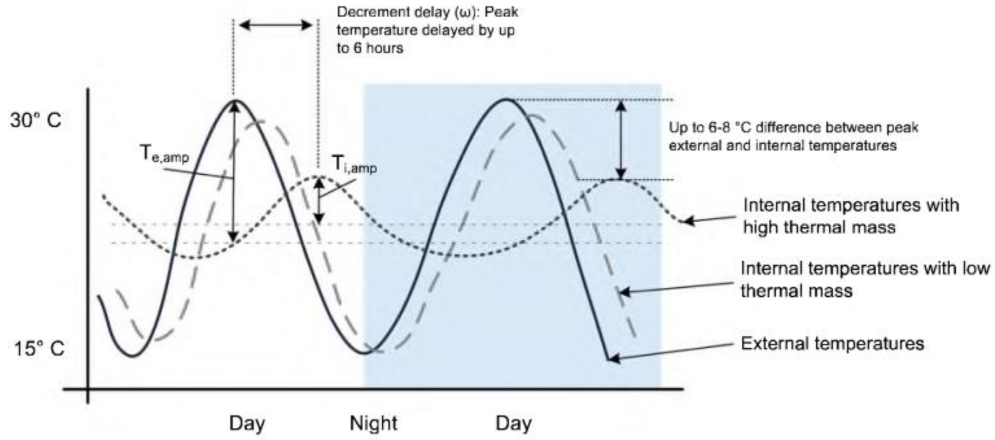


Figure 16: Effect of thermal mass on internal temperature swings and delayed peaks[72]

Moderated peak temperatures can significantly increase the number of hours within which ceiling fans or evaporative cooling can be employed in lieu of active air-conditioning. Use of ceiling fans is considered further in Section 3.9.

For thermal mass to be effective in passive design as a comfort and energy moderator it must be reasonably matched to solar gains by constraining glazing extents (Figure 17). This horizontal axis of this figure indicates that optimal amounts of thermal mass storage vary by climate, and generally rise as a function of climate variability. Hobart's cooler climate, for example, means that more thermal mass storage will be beneficial than in Darwin, for example, where temperature variability in lower. The vertical axis indicates that more north-facing glazing would be required in Hobart, for example, to capture the requisite amount of thermal energy, than would be the case in Darwin. By implication, this figure also indicates that there is a danger of over-glazing, particularly on northern and western facades, leading to excessive heat gain in summer.

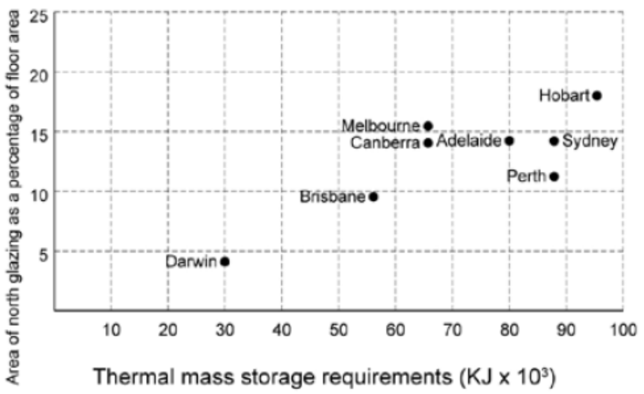


Figure 17: Recommended glass to thermal mass ratios for Australian cities[73]

Some stakeholder feedback suggested that the importance of thermal mass can be overstated. Our view is that all solutions must be adapted for the local climate conditions, building designs and intended uses. Too little or too much exposed thermal mass, in the wrong locations, poorly insulated from the external

[72] The Passivhaus Designer's Manual, Hopfe & McLeod 2015

[73] Baggs, D and Mortensen, N. 2006. Thermal mass in building design. Environment design guide, DES 4. Australian Institute of Architects, Melbourne.

environment, or poorly integrated into the overall design (in particular, with inappropriate amounts of insolation and/or shading throughout the seasons), or in the wrong climate zone, could lead to this solution being ineffective or even counter-productive. When appropriately integrated and managed, however, exposed thermal mass can be an important component of a low or zero carbon building, contributing radiant heat and coolth for comfort and thermal inertia (storage) for climate resilience. In very hot climates, light-weight structures with low thermal mass may be preferred. However, even in some hot climates (eg, hot, inland locations), there may be opportunities to take advantage of a high diurnal range to actively or passively cool thermal mass at night, in order to carry that coolth into the succeeding day.

Ease of implementation

For exposed concrete soffits to be presentable lighting or other ceiling fixtures or conduits may be marshalled into bulkheads or rafts, requiring more design and installation co-ordination. Concrete formwork must be of reasonable quality to provide desired soffit finishes.

The uppermost apartment floor will require insulation to be installed above a concrete slab, which also requires a little more design effort.

Phase change materials (PCMs)

Adding mass increases column sizes which is a particular challenge for the viability of ultra-high-rise towers. Space is also at a premium. In this context there are opportunities associated with phase-change materials (PCMs) as a lightweight substitute for thermal mass. PCMs such as paraffin wax with a melting point between 25°-35°C can be useful for storing internal solar gains. PCM impregnated plasterboard can have properties comparable to a masonry wall but has different fire resistance characteristics to standard plasterboard (may be more flammable) and is not currently cost-effective enough to be considered other than in niche instances.

PCM salts such as calcium chloride can also be incorporated into semi-translucent glazing products creating windows with comparable thermal mass to masonry walls. Transparency varies with changing phase of the salts (Figure 18).

Figure 18: PCM salts embedded within glazing change translucency during phase-change whilst absorbing significant thermal loads © CrystalX

Drivers and marketability

Exposed concrete soffits provide a different, more studio-like aesthetic compared to conventional plasterboard ceilings in apartments, which may inform branding of the development.

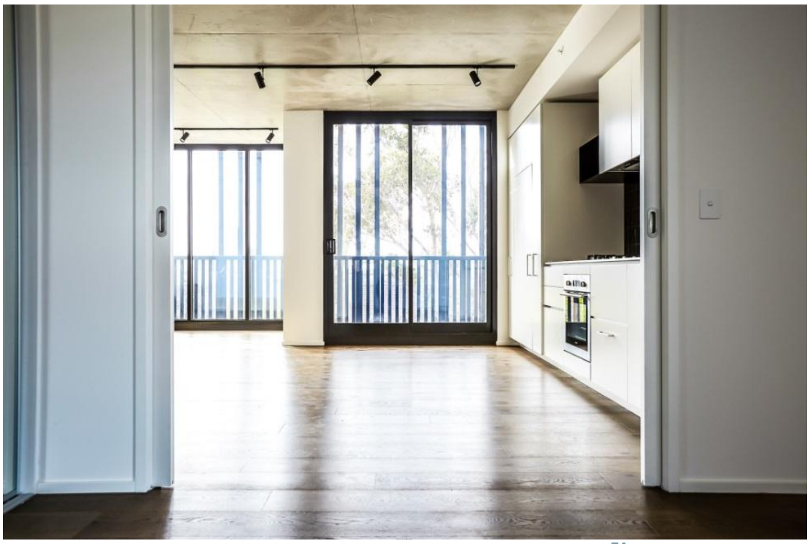


Figure 19: Exposed concrete soffits in apartment development in Prahran, Melbourne[74]

Tiled floors are typically provided to kitchen and bathroom areas as standard, based on consumer preferences, whilst bedrooms are typically carpeted. Thermal mass is less important for bedroom areas as delaying peak temperature gains may be less beneficial.

Demand-response management

A much more recent additional motivation for exposed thermal mass in dwellings is the emergence of demand-response management (DRM) ready, or demand-response enabled devices (DREDs). This technology allows network operators to remotely turn down the capacity of enabled devices in order to manage peak grid demand. In return, consumers enjoy a low-cost power tariff. Peak-grid demand is typically associated with peak air-conditioning demand on the grid at the hottest times of day/year. Thermal mass reduces the peak demand and delays it for several hours significantly lessening the impact of capacity turn-down.

Most new residential air-conditioning units can be supplied with this technology at no additional cost.

Costs

Exposed concrete soffits save the construction time and cost of installing plasterboard ceiling. Some of this saving may be offset by the increased co-ordination required for ceiling services. For high-rise developments far higher value may be leveraged through the potential to reduce floor-to-floor heights, saving on façade area and potentially incorporating additional floors.

3.3.6 Thermal Bridging and Breaks

Energy saving potential

Thermal bridging refers to design and construction elements that facilitate the passage of heat/coolth through a building's facades, while thermal 'breaks' do the opposite – prevent or slow the passage of heat. For example, uninsulated concrete slabs that extend to balconies – exposed to large external temperature variations – will transmit those heat variations inside the building unless an insulation barrier or thermal break is put in place (see Figure 20 below). Other key causes of thermal bridging are aluminium window frames (aluminium in an excellent conductor of heat) and any metal-to-metal fixings, as when corrugated iron is fixed to steel beams.

[74] http://www.projectgroup.com.au/project-1/york-apartments-1

The relatively low level of insulation required for building regulation compliance has made thermal bridging a minor consideration in the Australian construction sector. The energy saving potential of minimising thermal bridging, by increased use of thermal breaks, is currently relatively low but will rise in significance as the required levels of insulation and airtightness increase. The high-performance building envelopes required for net-zero energy buildings means that the relative impact of thermal bridging becomes significant enough to warrant the effort required for effective mitigation. For Passivhaus standards this means wherever a thermal transmittance coefficient exceeds 0.01 W/mK, the additional specific heat losses must be considered.

Ease of implementation

Thermal bridging is a relatively challenging aspect of design and construction to tackle. This is linked to low awareness and the difficulties of solution associated with methods of construction that have become standardised and cost-effective in Australia. The hardest form of thermal bridging to tackle is that associated with superstructure and substructure. A significant common instance in high-rise residential occurs at balconies formed as extensions of apartment floor slabs. The exposed external balcony slab acts like a heat-sink fin sucking heat out of the building via the structure. The same is true for vertical blade walls.

Figure 20: Load-bearing thermal-break element preventing cold-bridging from exposed balcony slab into apartment © Schöck

Figure 20 shows a proprietary solution for concrete construction. Allowance must be made for the fact that such products are imported and custom-designed for each application and/or load. As with air-tight barrier considerations it is crucial there is architectural clarity around an unbroken thermal insulation line throughout façade sections. These products have started being used in Australian residential developments (mainly double and triple-storey private residences between Sydney and Melbourne) and are now being specified in residential developments up to 10 storeys in height. Timber-framed buildings have inherently lower potential for significant thermal bridging through structure. There is growing interest in high-rise residential timber-framed construction in Australia following the 2013 completion of the 10-storey Forte development in Melbourne's Docklands, and subsequent changes to the Building Code. A 14-storey residential building is currently being erected in Bergen, Norway, whilst proposals have been published for an 80-storey timber skyscraper in London.[75]

[75] http://www.bdonline.co.uk/plp-plans-80-storey-%E2%80%98timber-tower%E2%80%99-for-barbican/5081146.article

Drivers and marketability

Like air-infiltration, thermal bridging is largely an invisible problem. Being invisible and outside the scope of certification, thermal bridging is not uppermost in the minds of developers, designers, constructors or purchasers. Industry awareness would improve with stringent regulations, or scoring incentives within ratings tools.

Measures included in the current version of the National Construction Code are minimal and not quantified in any form. Within the Australian residential sector, the dominant thermal bridge consideration currently is in connection to risk of condensation. Reducing thermal bridging is one of the strategies available to reduce condensation, in addition to improving the energy performance of the envelope.

Thermography is one technique used to locate air-leakage paths as part of air-tightness testing, and also to uncover thermal bridging, for example due to missing insulation panels. There is some prospect of market awareness levels improving with the recent emergence of affordable consumer level thermographic devices and apps for smart phones (Figure 21).

Figure 21: Thermographic camera attachment for smart phones may enhance user awareness of façade performance and deficiencies. Image © Flir

As residential design moves towards best-practice energy performance, the capacity (or indeed presence) of heating/cooling systems reduces and the effects of thermal bridging and air-leakage will become more apparent and relevant to consumers.

Costs

As with most initiatives, costs are highly context-sensitive. Based on Passivhaus projects commissioned in Australia over recent years, a proprietary fully load-bearing thermally-broken solution for cantilevered concrete slab balcony construction has typically costed around $250-$300 per lineal metre of thermally-broken load lines.[76] This would largely represent an additional cost, although a small volume of standard concrete would be displaced by the product (Figure 22).

[76] Source: LAROS Technologies based on use of Schöck 'IsoKorb' product from Germany

Figure 22: Applications for Schöck 'IsoKorb' Product from Germany

3.4 Air-Tight Facades

Energy saving potential

High-rise towers are highly exposed to prevailing winds and wind speeds rise with height. For large cities with tall buildings horizontal wind speeds at a height of 50 storeys are typically double that at 3 storey level. This in turn means ambient air pressure difference across tower facades at the 50th storey is 4 times that across the façade at 3 storey level. The energy saving potential of air-tight facades at these heights is therefore quadruple that at low rise heights within cities.

There is currently very little data on air-tightness of either existing or new Australian buildings. A 2011 ANU study[77] of office buildings concluded that that air leakage rates in Australia are much higher than those reported in Europe and USA. For the residential apartment sector a conservative estimate of air permeability may be gained from research following the introduction of air-tightness requirements to the UK building regulations in 2002[78]. Figure 23 shows a spread of performance centred around the compliance point of 10m³/hr per m² of façade area at a test pressure of 50Pa.

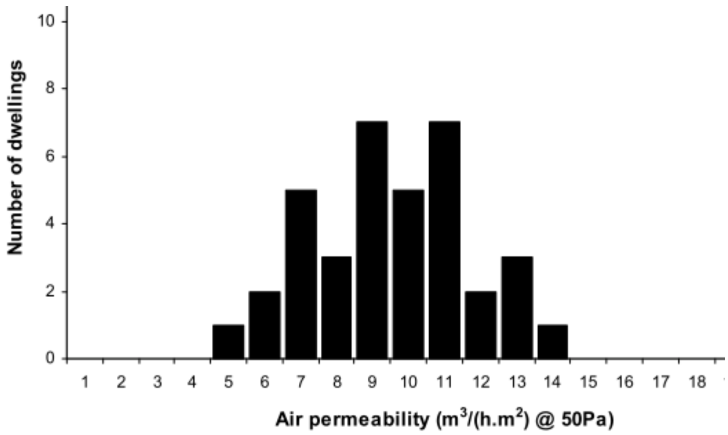


Figure 23: Air permeability of low-rise UK apartments built after introduction of requirements

[77] http://www.airah.org.au/imis15_prod/Content_Files/EcoLibrium/2012/March%202012/2012_03_01.pdf
[78] http://www.leedsbeckett.ac.uk/as/cebe/projects/airtight/airtight_final_report.pdf

The UK good practice air tightness for dwellings is 3m³/h/m² @ 50Pa, whilst performance required for compliance with near zero energy standards such as Passivhaus is 0.6 ach (air changes per hour) @ 50Pa. The US-based International Energy Conservation Code set an initial standard of 7ach in 2009, which was upgraded in 2012 to 3ach @ 50Pa for most US climate zones. The potential savings under various air-tightness levels are shown below.

ACH_{50}	Natural air change/hr	Ranking	% of cost	Potential saving from improved air sealing	Ventilation requirements
0.6	0.03	Aspirational Passivhaus*	1–2%*	No further sealing possible	Constant energy recovery ventilation
1.5	0.075	Best practice	2%	None: leakage costs minimal	Constant energy recovery ventilation
3.5	0.18	Excellent	6%	1–3%	Occasional forced ventilation
5	0.25	Better	10%	2–4%	Occasional
7	0.35	Good	14%	2–5%	Small
10	0.50	Fair	20%	3–10%	Rare
20	1.0	Poor	40%	5–10%	None — open vented

Figure 24: Air-tightness benchmarks in Australia with indicative savings potential[79]

A business-as-usual Australian apartment performance (assumed as 10ach@50Pa) would result in a leakage rate of 350l/s at 50Pa test pressure, or 17.5l/s at typical breeze exposure. For a typical high rise situation this may double to 35l/s. Annual energy impact of this leakage depends on climate, occupancy profile, HVAC system efficiency and set-points etc. For the two climates being considered in this report, the annual infiltration thermal loads are given in Table 9.

Table 9: Comparison of annual thermal loads due to business-as-usual air infiltration in high-rise apartments

	Heating *kWh pa*	Cooling *kWh pa*	Total *kWh pa*
Sydney	1344	181	1525
Melbourne	2425	180	2605

Achieving a net-zero best-practice target of around 1 ach @ 50Pa would reduce this thermal load on the apartment air-conditioning system by 90%.

Ease of implementation

The National Construction Code does not require buildings to be designed to minimise leakage of building envelopes under typical wind conditions. Subsequently there is no requirement for testing of air tightness.

This means that there is currently very limited experience within the design professions of appropriate air-tight standard construction details. There is also limited experience within construction teams of practical methodologies suitable for reliably building to these standards. However UK experience demonstrates that industry is able to develop expertise and good practice relatively quickly from a similar base once requirements are mandated.

[79] http://www.yourhome.gov.au/passive-design/sealing-your-home

Architects must nominate air-barrier lines through façade section. A key recommendation is to require head contractors nominate an air-barrier manager or 'air-tightness champion' responsible for maintaining integrity of the air tight barrier throughout the build, liaising with both design team and trades.

A study of mid and high-rise buildings in the US showed that air leakage sites identified during building testing were almost all due to detailing at corners, penetrations and joints.[80]

As apartments become more air-tight the need for controlled ventilation increases. Trickle ventilators can provide a controlled substitute for adventitious background ventilation, but they must be appropriately designed and installed. Adventitious air leakage has traditionally limited indoor air quality problems such as the build-up of moisture, which can cause condensation or mould on cold surfaces such as thermal bridges in the building envelope. If utilised in high-rise applications trickle vents should incorporate an internal flap that self-closes under high wind pressures.

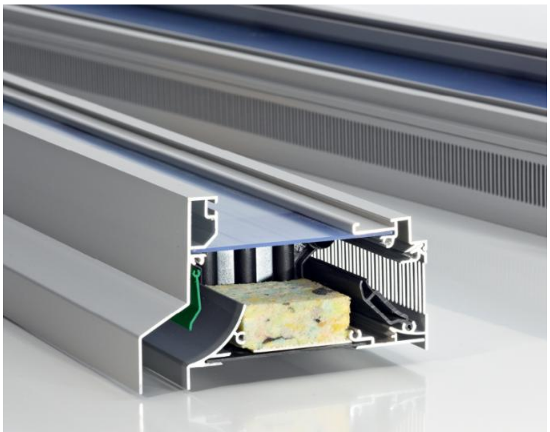


Figure 25: Section through high-performance trickle ventilator incorporating both manual and self-regulating flaps, thermal-breaks and acoustic insulation © Duco

Drivers and marketability

Incorporation of air-tightness standards for new buildings within national or state-based codes, alongside mandatory compliance testing, is key to establishing cost-effective best-practice.

Currently, rating tools such as Green Star offer some incentive through provision of Innovation points within rating tools. Current Green Star provision provides a point for carrying out an air-tightness test regardless of the result, provided test reports are passed back to the GBCA for future dissemination of understanding. Further points are obtained if performance meets international good or best-practice levels.

Localised air infiltration and draughts can greatly affect occupants' perception of thermal comfort.[81] Air-tight facades in high-rise towers increases useable floor area by making the room façade perimeter occupiable. This is particularly important in high-rise apartments where dwelling floor area is constrained and typically below 50m² for 1 bedroom apartments. There is an emerging international market for trickle warranted for use in ultra high-rise applications.

[80] http://web.ornl.gov/sci/buildings/2016/2013%20B12%20papers/186-Brennan.pdf

[81] BS EN ISO 7730:2005

Costs

Overseas experience demonstrates that air tight construction does not have to cost any more than leaky construction. This is because success is largely a matter of design detailing and construction discipline, which quickly become routine once requirements are mandated.

The most basic trickle ventilation units start from below $10 each, whilst premium high-acoustic performance self-regulating vents suitable for high-rise exposure can cost over $200 each.

Testing

Testing is typically achieved using a portable blower door test-rig (Figure 26).

A cost effective way of demonstrating air-tightness within high-rise residential buildings would be to test whole floors at a time, since inter-apartment air permeability has minimal energy impost. Testing of random selection of representative floors would determine whether sample results are meeting the specified performance level and extent of further testing required. If sample testing is undertaken the average results of those tested in each type group must be better than the design air permeability specification to provide a degree of confidence that the untested units will meet design. For each floor / apartment tested that fails an additional unit should be tested.

A representative cost of testing a complete tower floor of 10 apartments would be of the order of $10,000 allowing for a subsequent retest. Representative sampling of floors should cover 20% of apartment envelope area (ATTMA). The costs of rectifying leaks would be additional to this.

Figure 26: Air permeability testing using a typical blower door rig

3.5 Hot Water

Energy saving potential

Domestic hot water (DHW) heating loads can represent up to half of the energy consumption of high-rise residential towers, depending on usage. We note that while some apartment buildings have individual apartment hot water systems, this is unusual for high- and ultra-high-rise. In this report, we assume that both reference buildings have centralised DHW systems.

Natural gas when available has traditionally been used in NSW and Victoria for DHW generation, via a non-condensing gas-fired boiler of efficiency between 70% (current minimum MEPS standard) to 85%. Energy savings of up to 85% can be achieved through use of an electric heat-pump with an annual CoP of 3.0 or more. This relatively low CoP is due to the high condenser temperature required to deliver hot water at a temperature high enough to prevent legionella propagation. Figure 27 illustrates variation in domestic air-source heat pump (ASHP) CoPs with temperature rise. As shown, COPs can rise to 5 or 6 in ideal conditions.

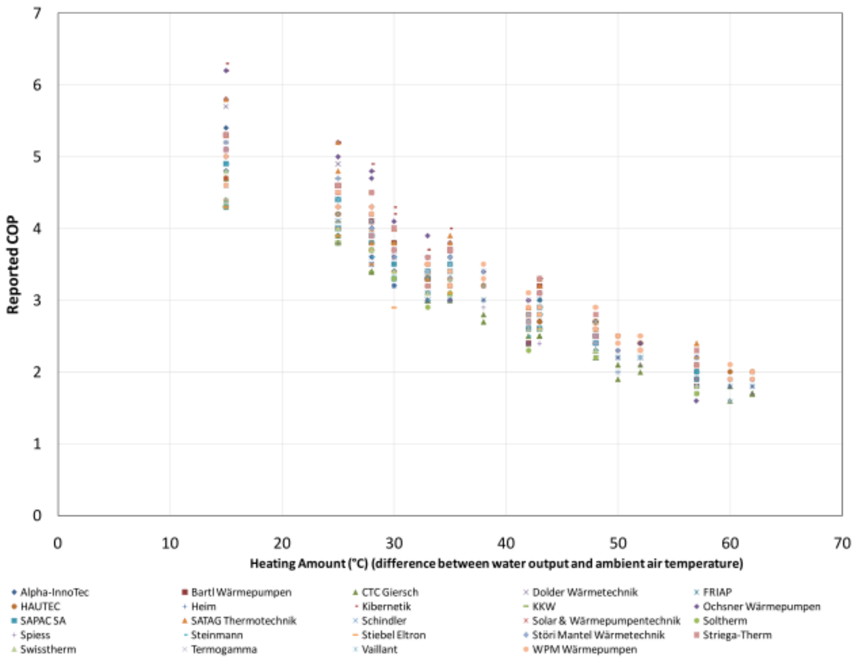


Figure 27: Published ASHP CoPs versus temperature rise.

Efficiencies will be higher in Sydney than Melbourne due to higher average ambient air temperatures and humidities. Efficiency in Brisbane would be higher again. For residential applications, peak DHW load occurs early in the morning and in the evenings when ambient temperatures are well below daily peak. This impact on efficiencies can be considerably mitigated by locating system evaporator units within a basement car-park where temperatures are relatively stable throughout the day. In this way the thermal mass of the basement and surrounding ground is harnessed, combined with indirect heat-recovery from car engines/bodies. We note that some older heat pump models still have a heating element which is used to warm the operating fluid in very cold conditions, and therefore reduce the COP somewhat. Newer models typically have no heating element and increasingly use CO_2 as a refrigerant, which performs much better in cold conditions. In all cases and conditions, COPs for heat pump DHW systems exceed 1 and therefore offer a more efficient solution than gas or electric resistance.

The carbon intensity of both grid electricity and natural gas varies between NSW and Victoria, and from year to year with changing generation mix. In NSW the ratio of grid to gas emissions (kgCO2/kWh) is currently 4:1 whilst in Victoria it is 6:1 due to a high proportion of brown-coal fired generation. This means that even a good DHW heat pump system has higher carbon emissions than a gas-fired system in both NSW and Victoria. However this situation is unlikely to prevail for the majority of the life of the tower. The generation mix in Victoria and NSW will be progressively decarbonised towards 2050 as renewables replace old fossil fuel power stations. Victoria has committed to 40% renewables generation by 2025. It is therefore reasonable to assume that DHW heat-pumps will represent the lowest carbon form of generation in both states within 10 years.

Further significant reductions in standing and distribution heat losses are realisable by increasing levels of insulation for both storage cylinders and circulation pipework from minimum levels specified within the NCC. Studies have shown that as little as 10% of energy supplied to a storage hot water heater is actually used as useful hot water, with general figures between 25-60%.[82] Numerous other aspects affect this such as choice of circulation system controls, distribution system design and pipe-sizing, which have considerable impact on wasted hot water draw-off.

Ultra-low-flow shower heads are available (Figure 28) with flow-rates as low as 5 litres/minute compared to standard best practice of 7.5 - 9 litres/minute. These will produce commensurate savings in DHW consumption of 33-45%.

Figure 28: SatinJet ultra-low flow showerhead © Methven

Solar hot water

Solar hot water systems have the potential to decrease heating consumption by up to 70%. Gas boosted solar systems are widely used on low-rise residential buildings in Sydney, for example. The challenge for high-rise towers is the competition for available roof space from other roof-top fixtures. These can include solar PV panels, which have the potential to produce greater energy and carbon savings for the same space take and at lower capital, operating and maintenance costs, when DHW is generated using electric heat pumps. Relatedly, for larger buildings with centralised DHW systems, there may not be sufficient collector area to capture a useful amount of solar energy. That said, architectural innovation could find ways to integrating collectors into the rooftops of covered walkways or even facades, at least for new or renovated buildings.

Shower drain water heat-recovery

Showers consume around two-thirds of the hot water in apartments. [83] Shower waste-water is typically as warm as 35°C. Some of this lost heat can be recovered by passing through a heat-exchange tube that pre-heats incoming cold water supply.

[82] http://www.waterrating.gov.au/resource/background-research-project-consideration-hot-water-circulators-inclusion-wels-scheme

[83] Based on WELS ratings 3* for shower heads and 5* for basin and sink taps, and usage profiles from GBCA Green Star methodology.

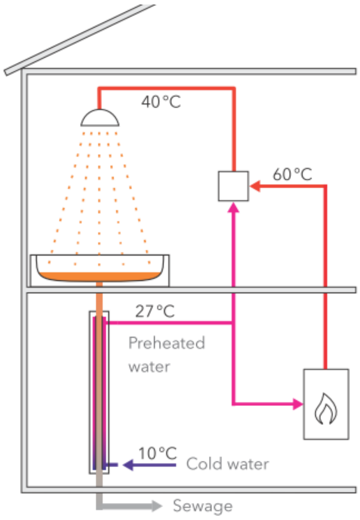


Figure 29: Operating principle of shower drain water heat recovery tube © Wagner Solar

Vertical devices are the most efficient but require installing within the floor below. Horizontal devices can be integrated within shower trays. It can take up to 2½ minutes for the device to reach steady state temperature and peak efficiencies of 54-66% heat recovery.[84] Overall recovery efficiency will therefore be reduced relative to shower time.

Figure 30: Shower Tray heat recovery © Wagner Solar

Ease of implementation

Gas-boosted solar is a quasi-conventional DHW solution in apartment buildings, with the key physical constraint being sufficient roof area for solar collectors. As noted, innovative architects are finding ways to integrate solar collectors into building facades are other structures, and not only roofs.

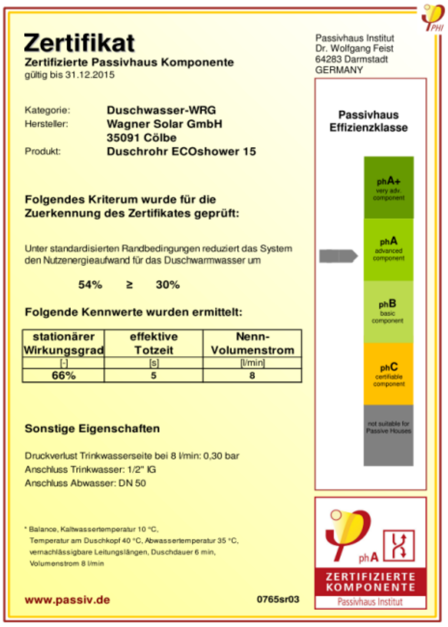
Heat-pump based DHW systems are also well known to the industry and have few implementation issues. The key requirement is that their heat exchangers are not situated in enclosed spaces (see more on this issue in Section 3.7.1).

Shower drain heat recovery is relatively simple to install in new-build, albeit much less well-known. Non-duplex apartments would require the shower tray version in most instances. Such systems are much more challenging to retrofit successfully.

84 http://passipedia.org/planning/building_services/heating_and_dhw/experience_with_drain_water_heat_recovery/available_systems_example_application_and_analysis

Drivers and marketability

DHW generation is largely invisible to residents, even if residents will generally be paying a share of centralised DHW system costs, and therefore it can hard to market improved energy or greenhouse performance in this area. Low-flow showers would often be considered a marketing disadvantage. Shower drain water heat recovery devices can be certified by the Passivhaus Institute, which has an energy labelling scheme that makes efficiency claims more legible and verifiable.



Zertifikat

Zertifizierte Passivhaus Komponente
gültig bis 31.12.2015

Passivhaus Institut
Dr. Wolfgang Feist
64283 Darmstadt
GERMANY

Kategorie: **Duschwasser-WRG**
Hersteller: **Wagner Solar GmbH**
35091 Cölbe
Produkt: **Duschrohr ECOshower 15**

Folgendes Kriterum wurde für die Zuerkennung des Zertifikates geprüft:

Unter standardisierten Randbedingungen reduziert das System den Nutzenergieaufwand für das Duschwarmwasser um

54% ≥ 30%

Folgende Kennwerte wurden ermittelt:

stationärer Wirkungsgrad	effektive Totzeit	Nenn-Volumenstrom
[-]	[s]	[l/min]
66%	5	8

Sonstige Eigenschaften

Druckverlust Trinkwasserseite bei 8 l/min: 0,30 bar
Anschluss Trinkwasser: 1/2" IG
Anschluss Abwasser: DN 50

* Balance, Kaltwassertemperatur 10 °C, Temperatur am Duschkopf 40 °C, Abwassertemperatur 35 °C, vernachlässigbare Leitungslängen, Duschdauer 6 min, Volumenstrom 8 l/min

www.passiv.de
0765sr03

Figure 31: Passivhaus Institute certification of shower drain water heat-recovery performance

Costs

Typical cost of shower drain water heat recovery devices are around $500.

3.6 Swimming Pools

Energy saving potential

Pool energy consumption can represent up to 10% of the energy consumption of high-rise residential towers.

Natural gas when available has traditionally been used in NSW and Victoria for pool heating, via a non-condensing gas-fired boiler of efficiency between 70% (current minimum MEPS standard) to 85%. A condensing boiler, which recovers heat from flue gases is ideally suited to pool heating due to the low circuit return temperatures that promote condensation of flue gases. Condensing boilers are not common in Australia. If heat is taken from a centralised hot water system a titanium plate-heat exchanger must be used.

Much more significantly, energy savings of up to 85% can be achieved through use of an electric heat-pump with an annual CoP of up to 6. This relatively high CoP is due to the low condenser temperature required to deliver typical pool temperatures of around 30°C, and makes annual running costs cheaper than gas at current fuel price differentials.

The carbon intensity of both grid electricity and natural gas varies between NSW and Victoria, and from year to year with changing generation mix. In NSW the ratio of grid to gas emissions (kgCO2/kWh) is currently 4:1 whilst in Victoria it is 6:1 due to a high proportion of brown coal-fired generation. This means that a best-practice pool heat pump system also has lower carbon emissions than a gas-fired system, even in Victoria.

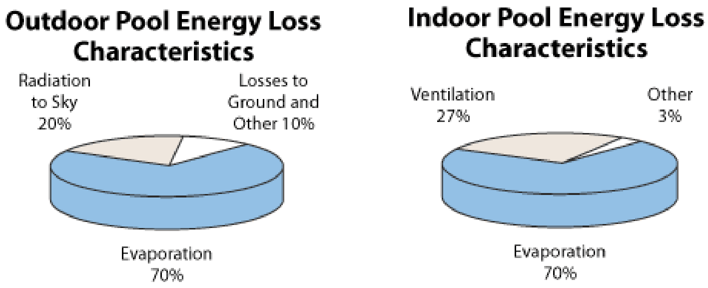


Figure 32: Indoor vs outdoor pool energy loss ratios[85]

Pool heat loss by conduction can be reduced by increasing insulation levels around the sides and base of the pool. Pools are typically provided at tower podium levels, frequently above unheated car-park spaces. Poor design co-ordination means it is not uncommon for slab–to–slab heights to have been squeezed to the point where insulation specified to the soffit of pool bases cannot be installed due to height restrictions within car-parks. Note that losses from outdoor pools greatly exceed those from indoor pools, as they are exposed to wider temperature variation and wind effects.

Heat pumps

We note that air-water heat pumps are increasingly being used for pool heating, as they offer high coefficients of performance but also the opportunity to cover their electrical load with renewable energy, thus offering a zero emissions solutions. In other work, we have found this solution to be cost-effective in some situations, and not cost effective in others, as gas boilers are very low cost and gas in cheaper, per unit energy delivered, than electricity. However, since heat pump efficiency continues to improve, and with an increasing focus on zero emissions pathways through time, we do expect this to become the dominant solution over time.

Pool blankets

Pool blankets reduce both convection and evaporative heat losses from both outdoor and indoor pools by up to 50-70%. If utilised for 8 hours a day this would result in a 23% reduction in heating load.

For unmanned communal residential pools it is important to have simple motorised operation of the pool blanket to maximise convenience of pool blanket re-instatement after usage.

[85] http://energy.gov/energysaver/swimming-pool-covers

Figure 33: Integrated pool blanket © Remco

Ease of implementation

Electric heat-pumps are simple to implement in new-build developments. Integrated pool blankets are also simple to implement in new-builds but very difficult to retrofit. Above ground pool blankets are relatively easy to retrofit but are undesirable in terms of pool hall aesthetics.

Drivers and marketability

Pool heating costs are passed on to residents through owners corporation communal energy fees but are generally invisible in terms of usage breakdowns.

A high-quality integrated pool blanket can enhance the safety and image of the pool hall and reduced pool maintenance and pool chemical costs.

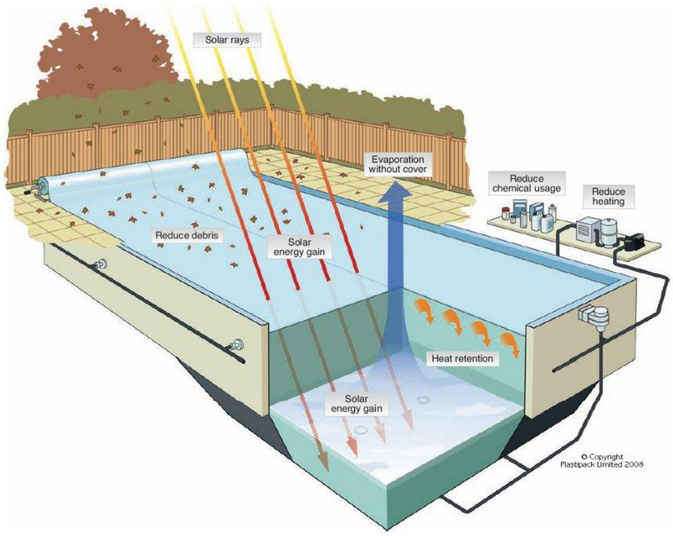


Figure 34: Pool blanket attributes

Costs

Heat-pump plant is around triple the cost of a dedicated gas-boiler, adding around $20,000. Typical cost of an integrated pool blanket for a 25 metre 2-lane lap pool would be $50,000.

3.7 HVAC/Hydraulic Systems

3.7.1 High-efficiency air-conditioning

Energy saving potential

The energy saving potential of high-efficiency air-conditioning systems is significant. Residential air-conditioners have been subject to Minimum Energy Performance Standards (MEPS) since 2004. Figure 35 demonstrates a clear relationship between rising MEPS standards and installed efficiencies. It also shows that current best-available units are around 60% more efficient than the minimum permissible level.

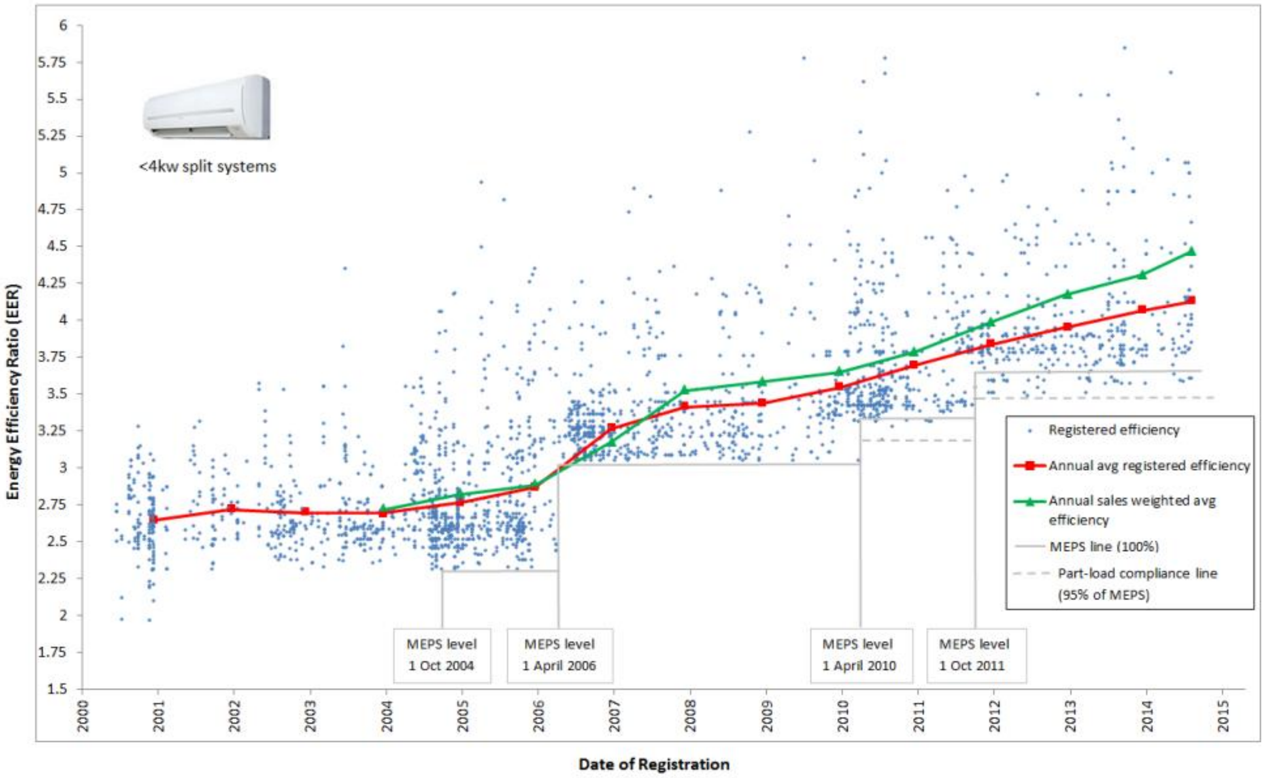


Figure 35: Energy efficiency ratings – Australian air conditioners less than 4 kW capacity, 2000 -2014[86]

Figure 35 relates to split system units where the outdoor unit (condenser) is connected to one (or more) units within a single dwelling. The outdoor unit typically sits on an apartment balcony, and the whole system selected by the developer becomes individually owned by the purchaser.

Air-conditioning units in residential apartments are reverse-cycle heat-pumps meaning they can provide either heating or cooling with comparable efficiency.

For larger (or premium) residential developments centralised systems are utilised with units linked to a large common condenser bank typically located at rooftop level. This technology is called VRF (variable refrigerant flow) and is owned and operated by the owners corporation who also provide billing. VRF system efficiency is not covered by mandatory energy performance labelling.

It is described by heating and cooling efficiency figures (Coefficient of Performance (CoP) and Energy Efficiency Rating (EER) respectively) published by manufacturers, often to Japanese standards and climatic conditions. Such ratings describe performance efficiency at peak heating and cooling loads. This is

[86] http://www.energyrating.gov.au/document/consultation-regulation-impact-statement-air-conditioners-and-chillers

unfortunately not a reliable indicator of annual power consumption as units very rarely operate at peak capacity. Seasonal energy efficiency ratings (SEERs) are much more reliable metrics.

AS/NZS 3823.4 takes account of part-load performance in relation to prevailing Australian climatic conditions. Unfortunately adoption of this SEER standard is not mandatory and as a result no manufacturers have published SEER performance data in accordance with this standard since publication in 2014.

Ground sourced heat pumps

Ground sourced heat pumps offer the potential for higher efficiencies than air-to-air heat pumps, by utilising the ground as a heat source rather than ambient air. Particularly in winter, the temperature of the earth two or three metres below ground could be ten degrees or more warmer than that of the air. In summer, the below ground temperature will be similar to that in winter; that is, much cooler than the ambient air temperature, improving the efficiency of heat rejection. In effect, access to the thermal inertia of the ground improves the co-efficient of performance of a heat pump, as illustrated in this image from the Alternative Technology Association:[87]

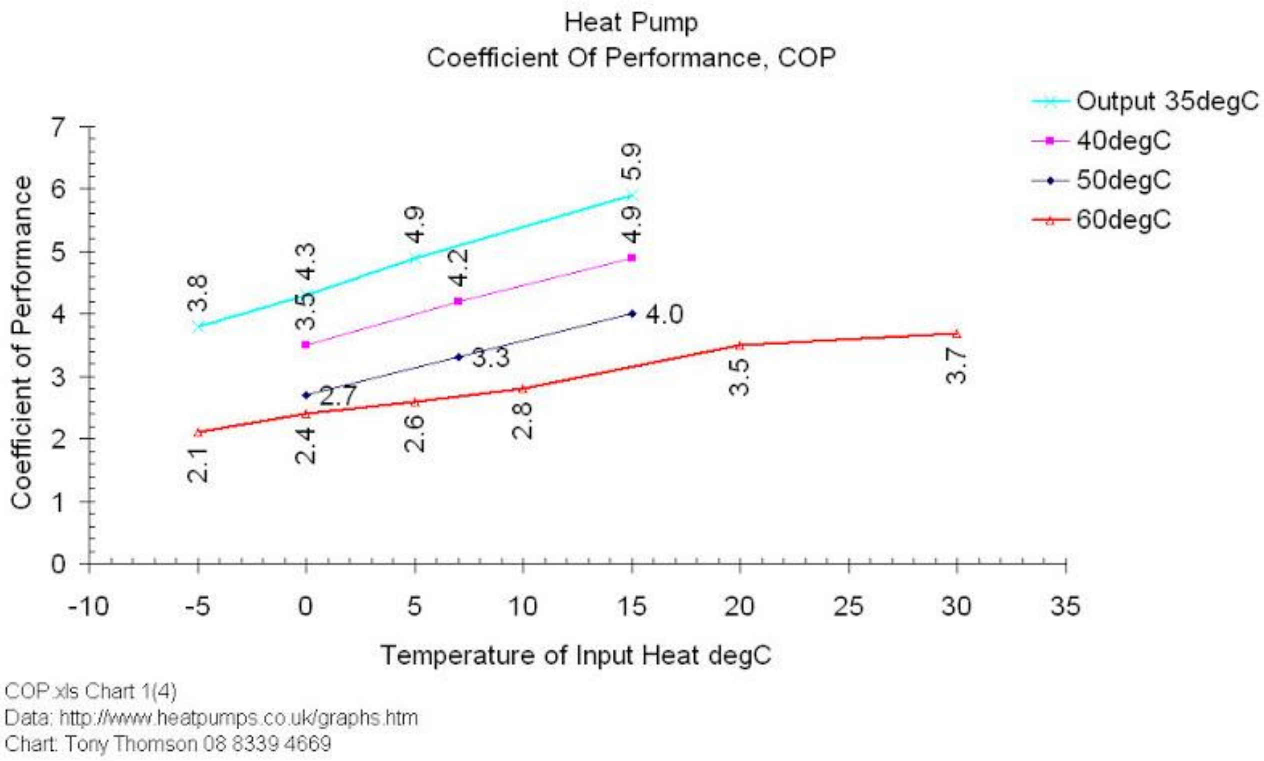


Figure 36: Heat Pump Co-efficient of Performance related to Temperature of Input Heat

The primary barriers are that ground loops typically need to be installed during the construction phase, as they are generally buried underneath a building or its grounds/carparks, and secondly, cost. Industry estimates suggest that 25% - 35% of the total cost of a ground-sourced heat pump system is associated with drilling or digging holes. There are some examples of heat exchangers being incorporated into pile

[87] http://www.ata.org.au/forums/topic/4384

foundations during the construction process, in order to install ground sourced heat pumps at low marginal cost.[88] However, this is not yet a widespread practice in the Australian construction industry.

Standby power

A CSIRO study[89] of residential air-conditioners installed in three Australian cities in 2014 found that energy consumed, simply by leaving an air conditioner to switch on and off automatically, can account for 17% of a home's heating and cooling energy in Adelaide, 25% in Melbourne and 31% in Queensland. Remarkably standby power is not regulated within the Australian MEPS program.

Such data on parasitic energy losses reinforces the maxim that the most efficient (and cheapest) systems are those that are designed out. This is critical understanding for achieving net-zero energy certification which is based on measured consumption in use rather than simulation modelling.

Ease of implementation

High-efficiency split unit condensers, often mounted on balconies, typically run quieter due to more efficient fans and compressors. High-efficiency VRF system condensers (rooftop outdoor units) may require more footprint space than compacted format standard units, but have reduced power infrastructure requirements.

Industry feedback noted that the developer is generally the decision-maker with respect to which model of heat pump is installed in apartments, and we note that this may also extend to other appliances. From this perspective, we note that whole building ratings/disclosure schemes, that include at least fixed if not all appliance consumption, create the right incentives for developers. Otherwise it was noted that architectural design constraints, such as available ceiling space and outdoor locating space, may dominate considerations. It was also noted that locating space considerations for split systems can impact on the length and efficiency of pipe runs, while requirements to enclose air-cooled units can have a negative impact on the efficiency of these unit.

Specific issues raised included a trend towards enclosed balustrades – partly due to rising safety concerns for children, but also due to an architectural trend towards clear glass balustrades to improve views. These trends, and potentially also local council requirements to hide air conditioning units from street view, can lead to the outside units of split systems being located in enclosed spaces where their efficiency and performance can suffer due to higher ambient temperatures around the heat exchanger (Figure 37).

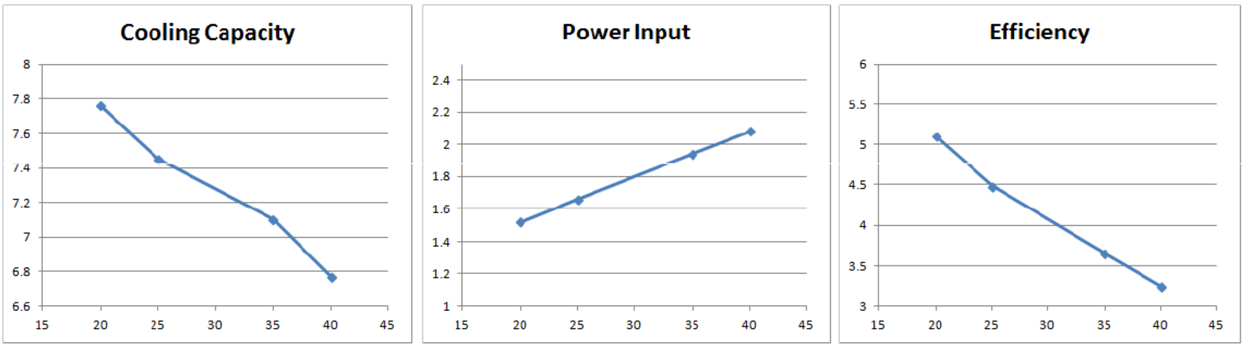


Figure 37: Split System Air Conditioner Capacity, Power Input and Efficiency related to Ambient Temperature (Source: Daikin Australia Pty Ltd)

88 http://australiangeomechanics.org/admin/wp-content/uploads/2015/03/46_4_9.pdf
89 https://www.airah.org.au/imis15_prod/Content_Files/EcoLibrium/2014/November14/11-14-Eco-003.pdf

VRF systems can only operate with a height difference between indoor and outdoor units of 60-90m. Beyond this water-cooled variable refrigerant flow (VRF) systems are typically used. These can have higher efficiency when paired with energy-efficient cooling towers, at the expense of water consumption and more onerous maintenance.

Omission of active heating and cooling systems becomes possible when façade energy performance reaches levels considered as global best-practice as modelled within Section **Error! Reference source not found.**. In such instance physiological cooling can be provided by ceiling fans or low-energy techniques such as evaporative cooling.

Drivers and marketability

Unitary residential air-conditioners incorporate mandatory energy star rating labelling allowing consumers to better understand performance.

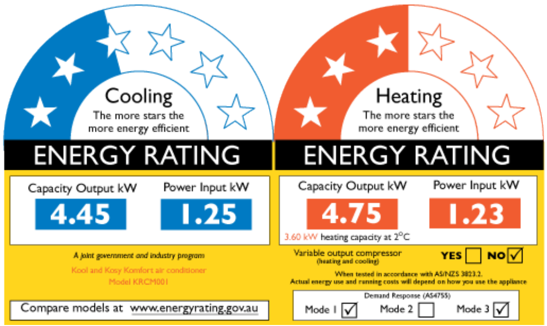


Figure 38: Example of air-conditioner energy rating labels

Such information is rarely included in sales documentation. Communal systems such as VRF do not have mandatory labelling systems.

Planning drivers

Without planning policy triggers, residential developers have minimal incentive to install high-performance units.

In Melbourne, metropolitan councils often require air-conditioning units to be within 1 star of best-available. This measure cannot be applied to communal systems as they do not have star ratings. Most manufacturers produce a high-CoP range, although they report low sales take-up in Australia.

Within the BASIX tool an EER of 4.0 is the highest recognised, and it is possible to be in the 2nd highest scoring band using a unit below the current minimum energy performance standard allowable (3.66).

Enforcement of such policy measures in both cities is highly variable. Interviews with consent authority staff in NSW confirm that it is common for homeowners to be very detached from commitments that the building designer makes on their behalf – i.e. a lack of consumer engagement concerning the detail of BASIX commitments is common.[90] In Victoria, indeed across Australia, compliance activity directly related to the energy efficiency aspects of the NCC is uncommon. Given the technical nature of the NCC, it is likely that consumers outside NSW are even less engaged with the detail of energy efficiency requirements for residential buildings.

[90] https://www.basix.nsw.gov.au/basixcms/images/BASIX%20%20COMPLIANCE%20AUDIT%20April%202013.pdf

Costs

High-efficiency VRF units are less commonly specified currently and cost up to 20% more than standard ranges which often incorporate identical compressor and condenser components in a more space-efficient i.e. cramped casing that impedes efficient air flow.

3.8 Ventilation

Adequate ventilation is fundamental to good building design and critical for occupant well-being.

To date, most Australian buildings have been built either deliberately or inadvertently with high air leakage rates – in part because energy performance (and some argue construction) standards are low, but in part because of a view that air leakage is an appropriate strategy to combat condensation and mould growth, which can lead to serious health impacts for building occupants as well as the potential for structural damage to the buildings themselves.

Setting aside whether a 'leaky building' approach is in fact an adequate and effective response to such health and safety concerns, it is the case that as we strive for higher energy performance and greater thermal comfort in our buildings, and also as the climate changes and becomes more severe, it will be critical that we improve the air-tightness of our buildings, to at least bring them into line with similar buildings in Europe and North America. To do this requires not only attention to gap sealing and overall construction quality, but also adequate natural ('passive'), mechanical or 'hybrid' ventilation (a mix of the two).

For the most part, residential buildings in Australia rely on natural ventilation, although many newer high-rise apartment buildings offer centralised HVAC services. For example, a NCC deemed-to-satisfy solution for Section F (4.6 – *Natural Ventilation*) is that habitable rooms must have permanent openings (window, doors or other devices) that can be opened, with an aggregate openable area not less than 5% of the floor area to be ventilated (subject to further conditions). But such requirements are implicitly based on behavioural assumptions, including that people will and do open doors and windows sufficiently to achieve adequate ventilation. In reality, concerns about noise, personal safety, outdoor air pollution or other factors may discourage such behaviours.

From a health as well as a sustainability perspective, more sophisticated and more effective ventilation strategies are called for in future. These may include a mix of passive approaches (not simply openable facade areas, but appropriately designed buildings and structures like thermal chimneys) and mechanical ventilation, the relative contributions of which might vary according to weather and season, as well as occupant preferences. Where there is mechanical ventilation, good practice requires that outgoing heat/coolth is captured and passed back to the fresh intake air, thus ensuring a balance of good indoor air quality and high energy performance. It is an unfortunate but common myth in the Australian building industry that these two outcomes represent trade-offs: in fact, both are essential and neither should be traded away.

Industry feedback on the draft report strongly supported the importance of ventilation. It was noted that there remains work to do to define acceptable/pragmatic design conditions for comfort across Australia's diverse climate zones, including factors such as internal temperature stability during the day/night diurnal range; acceptable fresh air supply rates and the operability of mixed mode or hybrid solutions with adaptive comfort scales.

We support these conclusions and urge industry to seek solutions that do not trade-off energy performance. A number of studies have noted, for example, that the nature of controls offered to occupants can be critical to influencing energy-use behaviours.[91] If HVAC systems only offer an 'on/off' or 'set and forget' control strategy, most people will indeed do as encouraged and leave it on/forget. However, where more behaviourally-adapted control strategies are offered – including manual on/automatic off, timers, sensors, intelligent software mixing active and passive HVAC strategies, individual unit/room control options and many more – then many people will respond in more adapted ways. At the same time, such control strategies enable those who desire (or require) high comfort standards to achieve this while limiting the spillover effects for other building users (eg, through inefficient use of centralised building service systems) and without excessive energy consumption and emissions.

Energy saving potential

Significant energy saving potential exists through deployment of: variable speed drives with electrically-commutated motors for fans; reduced system pressure drops through increased cross-sectional area of ductwork and air-handling units; and heat recovery. These are considered below in turn.

Variable speed drives

Variable speed drive (VSD) fans can easily halve energy consumption in fresh-air ventilation systems using occupancy based sensing devices. When using VSDs a relatively small reduction in flow can produce a disproportionately large reduction in motor input power (Figure 39).

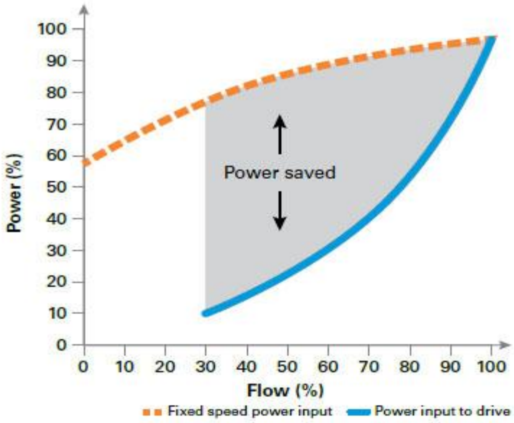


Figure 39: Energy savings characteristic of variable speed drives for fans and pumps

Reduced system pressure drop

System pressure drop in commercial buildings is typically split around 50:50 between distribution system and air-handling plant. This ratio can be more heavily weighted towards distribution system pressure drop in ultra-high-rise buildings, where there are long runs within constrained risers. Increasing cross-sectional area of ductwork and air-handling units also produces disproportionately large savings in fan power. A 20% increase in duct area reduces:

- air-speed by 20%,
- system pressure drops by 36%
- motor power requirement by almost 50%.

Reduced system pressures also reduces air-leakage from ductwork, which can be a significant source of energy loss. Ductwork leakage can be further reduced by requiring ductwork air-leakage testing to be carried out before ventilation system commissioning.

[91] See http://www.lrc.rpi.edu/researchAreas/reducingBarriers/autoShutOffBarriers.asp for example, or http://www.lutron.com/TechnicalDocumentLibrary/3683273_Code_Compliance_Commercial_Application_Guide.pdf

Heat recovery

Heat-recovery between fresh air intake and exhaust air streams can recover 60% - 95% of energy associated with conditioning of room air, depending on device type and quality. For both Melbourne and Sydney climates the heating savings achievable are considerably higher than those in cooling mode. Figure 40 illustrates that the annual heat energy saving potential in Melbourne's climate is 80% higher than in Sydney's climate due to its longer and colder heating season. The annual cooling energy saving potential is almost identical for both cities.

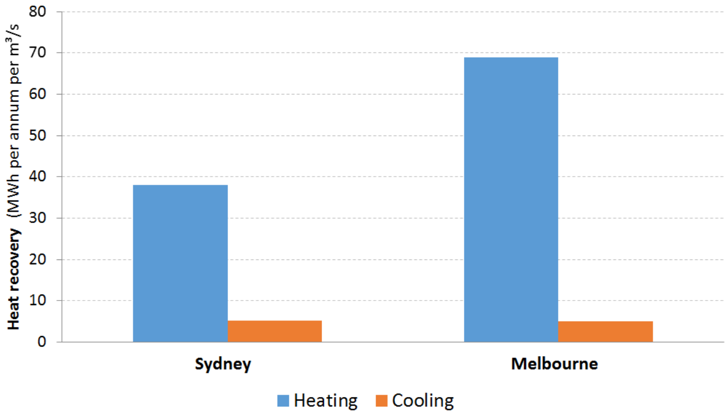


Figure 40: Comparison of energy saving potential of heat-recovery for Sydney and Melbourne climates

Ease of implementation

Variable speed drives are simple to implement, taking up negligible space. The most common form of heat-recovery device in ventilation systems is the cross-flow plate-heat exchanger (Figure 41). These are typically the most cost-effective to install and operate.

Façade wind-pressures on ultra-high-rise towers may limit use of individual apartment mechanical ventilation heat recover (MVHR) systems. An alternative arrangement would be to connect individual apartment systems to common intake and discharge plenums shared between multiple floors. Spatial allowance must be made for heat-recovery within communal systems.

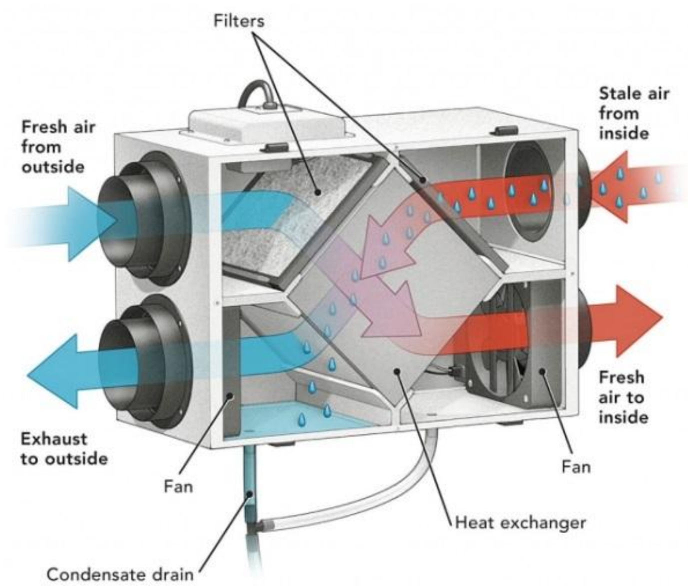


Figure 41: Air-to-air plate heat exchanger

Drivers and marketability

None of the initiatives listed are mandatory or directly incentivised in Australia. Whilst the initiatives listed have considerable impact on energy consumption, they often are invisible to users and hence unmarketable in isolation. Marketability is achievable only when a package of such invisible measure adds up to an improved rating that is advertisable e.g. NatHERS, Green Star, Net-Zero Energy, Carbon Neutral etc. While there may be costs associated with such ratings, there is also evidence that can be very effective in influencing both consumer and building owner behaviour, particularly when there is mandatory disclosure of rated performance.[92]

Reduced system air velocities may deliver a slight reduction in perceivable air system noise, depending on design configuration.

VSDs make the task of initial system commissioning and subsequent tuning more cost-effective.

Costs

Capital costs associated with these measures will typically produce good return on investment for owner-occupier developers. VSDs are frequently retrofitted. High-efficiency heat-exchangers are relatively expensive when imported into Australia. Making such measures mandatory would significantly increase market size in Australia with associated cost-efficiencies for the supply chain.

3.9 Ceiling Fans

Energy saving potential

Ceiling fans have the potential to save considerable energy where they are used to reduce reliance on air-conditioning system operation i.e. in mixed-mode ventilation application. Ceiling fans can provide physiological cooling of 3°-4°C with airspeed of 1m/s, which means that they can considerably delay the point at which air-conditioning needs to be turned on. Unlike air-conditioning they can be effectively used in conjunction with natural ventilation.

Best-practice ceiling fans can be up to 10 times more efficient than current Energy Star minimum efficiency requirements (0.02 W/l/s at medium speed).

Incorporating ceiling fans in typical high-rise apartments can improve NatHERS ratings by up to 0.5 stars.

Ease of implementation

Ceiling fans are simple to install. Ceiling heights in high-rise residential apartments are typically only 2.7m in living rooms and 2.4m in bedrooms, increasing to 2.8m if there is an exposed soffit. It is therefore important to use low-profile fans that can be mounted within 300mm of soffit/ceiling. Industry feedback noted that fans may be more effective when combined with large, openable doors or windows. However, they do offer a 'perceived comfort' effect in the absence of these features (which can be problematic at high elevations due to wind pressure and noise effects).

Drivers and marketability

Ceiling fans are currently not commonly provided in apartments in the mild temperate climates of Melbourne and Sydney. Ceiling fans have traditionally been manufactured with inefficient multiple-pole AC motors and non-aerodynamic blades making them noisy and obtrusive in operation.

[92] See, for example, Australian Government (Department of the Environment, Water, Heritage & the Arts), *Energy Efficiency Rating and House Price in the ACT*, National Framework for Energy Efficiency, 2006.

Figure 42: Ultra-low-energy ceiling fan suitable for low ceiling application © Aeratron

Best-practice fans incorporate DC motors with efficient variable speed controllers and high turn-down ratios. As with access to openable windows for natural ventilation, adaptive comfort principles also apply to ceiling fans; i.e., greater comfort can be ascribed where user control of air speed is facilitated. In addition to proprietary control devices, remote control can increasingly be achieved using generic apps on smartphones, offering greater convenience to users.

It is important that users understand that ceiling fans cannot cool rooms, and can only cool occupants skin when they are exposed to appropriate air speeds.

Costs

The cost of best-in-class ceiling fans is of the order of $300 each when bought in commercial quantities.

3.10 Car-Park Ventilation

Energy saving potential

Car parks need ventilation due to vehicle exhaust gas emission. If the car park is not configured to allow effective cross-ventilation e.g. within basements or podiums with adjacent structures, a mechanical ventilation system must be provided. This can impose a significant energy load on the building.

Ventilation energy consumption can be reduced by any of the following measures:

- *CO monitoring*
    - Good-practice design utilises variable-speed drives on fans linked to carbon monoxide sensors, to minimise unnecessary power consumption.
- *Ventilation system configuration*
    - Impulse/jet-style shunt fans are less energy intensive than ducted systems
- *Reducing emissions duration and intensity:*
    - Multi-level car parks increase the average time taken to park and the amount of emissions generated through rising levels
    - Improve traffic management to minimise queuing of cars waiting to exit car-park, particularly at peak times.

- Allocate specific car spaces to minimise hunting for car spaces

- *Incentivising greener transport*
  - Offset car-parking extent with provision of motorbike, scooter and cycle spaces, small car spaces and electric vehicle usage e.g. through free charging from roof-top PV. Such measures are typically rewarded through rating systems such as Green Star.
- *Car-stacker systems*
  - Car-stackers minimise time spent with engines running. However resulting fan energy savings will be countered by power required to drive the stacking hydraulics. Further research in this area would be beneficial.
- *Exemplar passive ventilation*
  - High-rise buildings can generate significant suction draw through incorporation of vertical ventilation shafts. The pressure that can be generated is proportional to height of shaft and temperature difference between intake and exhaust points. Temperature difference can be enhanced through solar admission. It is quite feasible that adequate ventilation could be provided through a well-engineered configuration.
  - Manitoba Hydro Place in Winnipeg, Canada (Figure 43) is a prominent example of a high-rise commercial building where a solar chimney has been used to draw ventilation air through office spaces. The additional height of chimney beyond roof level required for this purpose would not be necessary for basement ventilation.

Figure 43: 115m high solar chimney providing passive ventilation whilst making an iconic design statement

Ease of implementation

Controls based on carbon monoxide sensing are simple to implement and common as base-case provision in new-build.

Impulse fans are generally easier and cheaper to implement than ductwork based systems due to reduced co-ordination, materials and labour requirements. Relevant code standards in Australia are evolving.

Drivers and marketability

Small car parking spaces (max. 5.0 x 2.3m) promote use of smaller vehicles with lower emission rates and are incentivised through tools such as Green Star. Small car spaces are less readily implemented in car-stacker systems, though the inherently cramped nature of typical systems may be considered an inducement to utilise smaller vehicles.

Provision of electric vehicle share (EV) cars for exclusive use of residents is currently being offered by some developers. It is also common to provide free EV charging points powered by roof-top solar panels. Energy associated with this provision is conventionally excluded from overall net-zero calculations.

Provision of shared cargo bikes (electrified or otherwise) further assists reliance on cars for transport of groceries or toddlers.

In zero car urban developments such as the Commons in Melbourne (Figure 44) it is common to provide one bike space per apartment, or 1 per bedroom.

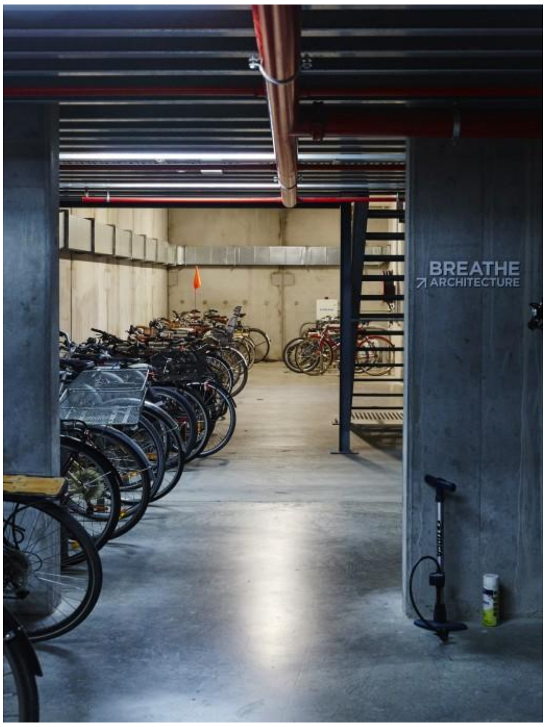


Figure 44: Fully utilised bike storage at the Commons, Melbourne where no car parking is provided

Costs

Electric vehicles require charging infrastructure with a typical cost of $3,000 per car-space, representing 3% of sale price. Cycle spaces, scooter spaces and even small car spaces cost less to provide than car spaces. Smaller parking spaces result in proportionally reduced lighting installation.

3.11 Lighting

Energy saving potential - Apartment lighting

New-build apartments in Australia typically incorporate LED downlights as their primary artificial light source. Relatively inefficient LED products (e.g. standard domestic LED downlights of around 40-60 lumens per watt) are up to 3-4 times more efficient than the minimal permissible in Australia (15 lumens per watt). However current best-practice downlight products exceed 100 lumens per watt.

Figure 45: Current LED downlight

Two-way light switching (whereby a lighting circuit can be switched on/off at two different switch points) and apartment master switches improve user convenience resulting in decreased energy consumption and increased lamp life.

Lighting control systems

Automatic control systems can include occupancy sensing, personal-dimming, daylight harvesting, high-output trim, or any combination of these approaches. Such controls are particularly well suited to LED technology and have been shown to provide energy savings of as much as 20 to 60%, depending on the application and use-case.[93]

- Occupancy/vacancy sensing 20-60%
- Personal dimming controls 10-20%
- Daylight harvesting 25-60%

Energy saving potential - Car-park lighting

Current best-practice luminaire efficiencies for car-park lighting products is over 130 lumens per watt.

Fluorescent light tubes have reduced efficiency when operated within cool car park ambient temperatures. Additionally car-park soffit heights are low with the result that light distribution from traditional luminaire results in inefficient bright patches under luminaires. LEDs are inherently more directional so lighting distribution efficacy can be enhanced when combined with very wide beam optics. Combining these attributes can deliver car-park lighting solutions below $1W/m^2/100$ lux, around half that of traditional fluorescent systems.

[93] http://www.energy.gov/sites/prod/files/2015/02/f19/biery_controls_sanfrancisco2015.pdf

Figure 46: LED luminaire system specifically optimised for car-park application © Philips

Further significant savings can be achieved through whitened car-park soffits, walls and floor surfaces. Typically these would be exposed concrete surfaces with a reflectance of 27%. For representative lighting modelling purposes a maintenance factor of 0.6 may be used to account for a gradual build-up of exhaust residues and tyre marks on floor surfaces between cleaning cycles which would reduce reflectances and overall lighting performance.

When the same car-park is modelled using the same maintenance factor but with improved initial reflectances of 70% for soffits and walls and 50% for floors the number of luminaire lamps required to achieve the same average illumination level of 50 lux is halved. This represents a halving of both energy consumption and a significant reduction in the cost of the lighting system. This capital cost saving would be used to offset the cost of providing the whitened car park surfaces.

Further savings are attainable by reducing lighting levels over parking bays relative to aisles and ramps.

Future LED efficiency gains

Recent and projected rate of improvement of luminaire efficiencies (Figure 47) demonstrate that LED products have overtaken best-in-class traditional luminaire products over the last 3 years or so. [94]

[94] http://energy.gov/eere/ssl/downloads/solid-state-lighting-2016-rd-plan

Figure 47: Comparison of LED and Incumbent Light Source Efficacies (Source: US Dept of Energy) (DOE in this Figure refers to the Department of Energy and is intended to illustrate the expected impact of DOE research in driving higher LED efficiencies.)

Best-practice industrial luminaire products delivering 180 or 200 lumens per watt (luminaire efficiency) are already commercially available.[95, 96]

In 2014 a current world-record of 303 lumens per watt lamp efficiency was achieved by Cree.[97] Colour-mixed LED technologies have the potential to achieve 330 lumens per watt (lamp efficiency).[98]

Luminaire product ranges that effectively exploit LED lamp characteristics are now growing, with LED luminaires accounting for the majority of sales of Europe's largest luminaire manufacturer (Zumtobel).

Ease of implementation

Since LED lamps produce more directional light it is important that lighting designers select luminaire products that utilise this light distribution efficiently, and understand differences between lamp efficiency and luminaire efficiency.

Drivers and marketability

The energy-efficiency of LED lighting over incandescents is generally well understood by consumers and therefore marketable. What is less well understood is the wide range of efficiencies of current LED lighting products, noting that poorly selected LED luminaires can be less efficient than best-in-class alternative technologies. Raising the current minimum energy performance standard from 15 lumens per watt could be considered at federal, state, or council levels.

The large difference in efficiency between incandescents and even poor-efficiency LEDs can produce a behavioural 'rebound' effect where occupants may be tempted to leave LED lighting operational for longer periods. This risk reduces as inefficient lamps become obsolete. Sales of incandescent lamps in all

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95 http://www.veko.com/nw-25242-7-3613990/nieuws/180_lumens_per_watt.html
96 http://www.philips.com/consumerfiles/newscenter/main/design/resources/pdf/Inside-Innovation-Backgrounder-Lumens-per-Watt.pdf
97 http://www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier
98 http://energy.gov/eere/ssl/downloads/solid-state-lighting-2016-rd-plan

European Union member states were phased out in 2012, whilst China has plans to phase out incandescents by 2016.

White car-park surfaces create a less oppressive environment and are recommended as a crime-prevention measure by NSW government guidelines[99]. A high-reflectance low-VOC epoxy resin floor coating would cost around \$20/m² for a double-coat application including diamond-grinding preparation. A beneficial by-product is reduced tyre-squeal.

Costs

Whilst efficiency has improved significantly over recent years the costs of LED lighting has come down even more dramatically and this trend is set to continue (Figure 48).[100] It is important to note that the price scale on the graph is logarithmic, indicating a halving in price every couple of years or so.

The significant potential energy savings due to best-practice lighting and controls will produce upstream savings in larger developments due to reduced associated electrical infrastructure provision.

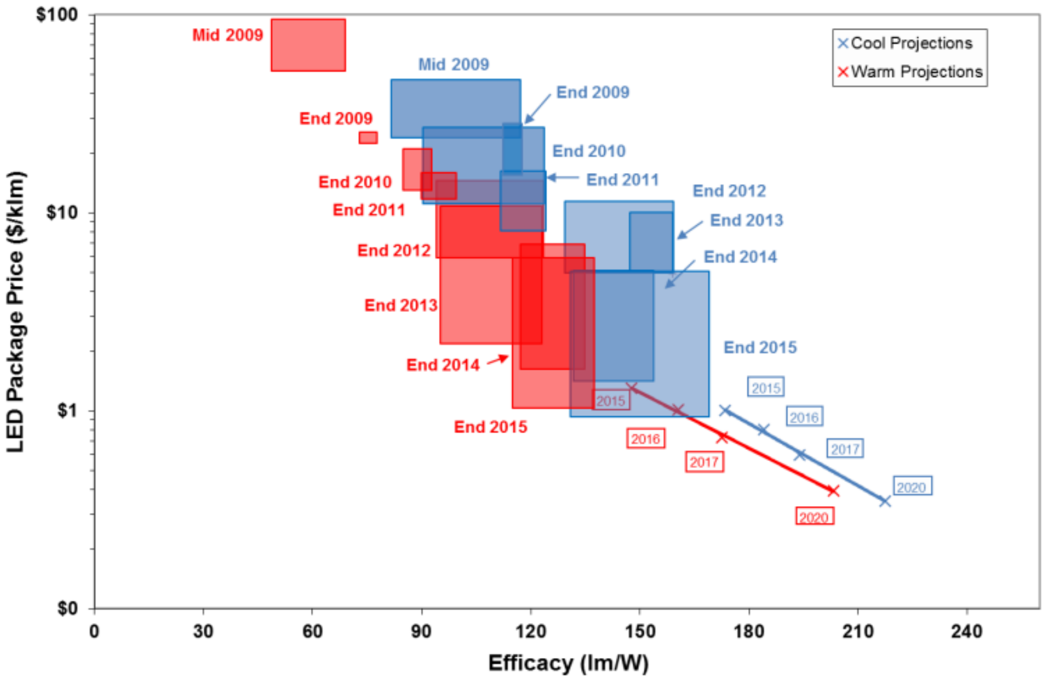

Figure 48: LED package price/efficacy status and projections

3.12 Appliances and User Behaviours

An important but challenging area of residential building energy use is the influence that building occupants have on energy consumption. It is clear that occupant behaviours have an enormous influence on actual energy consumption in dwellings. A recent study from the Michigan State University, for example, showed that more than 50% of potential energy savings from energy efficient homes could be lost if users don't know how to use the buildings properly.[101] The counter-part to such observations is that 50% or more of energy use could be saved, at very little cost, if consumers a) have access to an enabling environment (appropriate technologies and controls) and b) have access to the information they need to use that environment well.

[99] http://www.crimeprevention.nsw.gov.au/Documents/car_park_guidelines.pdf
[100] http://energy.gov/eere/ssl/downloads/solid-state-lighting-2016-rd-plan
[101] http://www.thefifthestate.com.au/energy-lead/energy/green-homes-are-only-as-green-as-their-users/82764

Most high-rise residential buildings in Australia are strata-titled, meaning that occupants purchase the apartments or dwelling units, while an owners co-operative or body corporate manages the common areas and services. This means that, in the first place, the apartment owners are sovereign with respect to their choice of at least mobile appliances (but sometimes also fixed appliances like cooking, space conditioning, etc). Second, it means that decisions about common areas and plant (which can include key plant such as centralised hot water or space conditioning services, as well as lighting to common areas and carparks, are complicated and potentially slow.

Notwithstanding these challenges, there is an increasing array of opportunities to engage with and influence occupant choices and behaviours, without excessively constraining their sovereignty or freedom to choose. This can begin with overall marketing and positioning: a 'green' or very high energy performance building is likely to attract occupants who are more interested in and willing to engage with advanced energy management strategies than might otherwise be the case. New controls, meters, software tools and 'human interface' strategies (eg, moving on from in-house displays to web-based tools and phone apps) all offer new opportunities. Other approaches – such as offering financial incentives, non-financial incentives and rewards, and community-based social market approaches – all offer additional engagement strategies.

3.12.1 High-Efficiency Appliances

Energy saving potential

Appliances including cooking usage incur almost one third of total residential energy consumption in Australia (Figure 49).

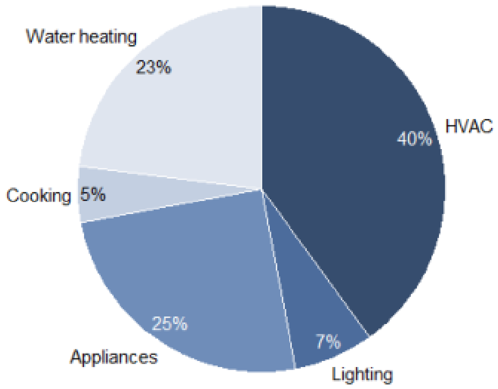

Figure 49: Residential energy consumption in Australia by end use[102]

This proportion is likely to be higher in a typical apartment context due to limited exposed dwelling envelope, although we are unaware of existing research in this area. The largest and fastest rising component of household energy use is electrical appliances (Figure 50).

[102] http://apo.org.au/files/Resource/low-carbon-high-performance-full-report-asbec-2016.pdf

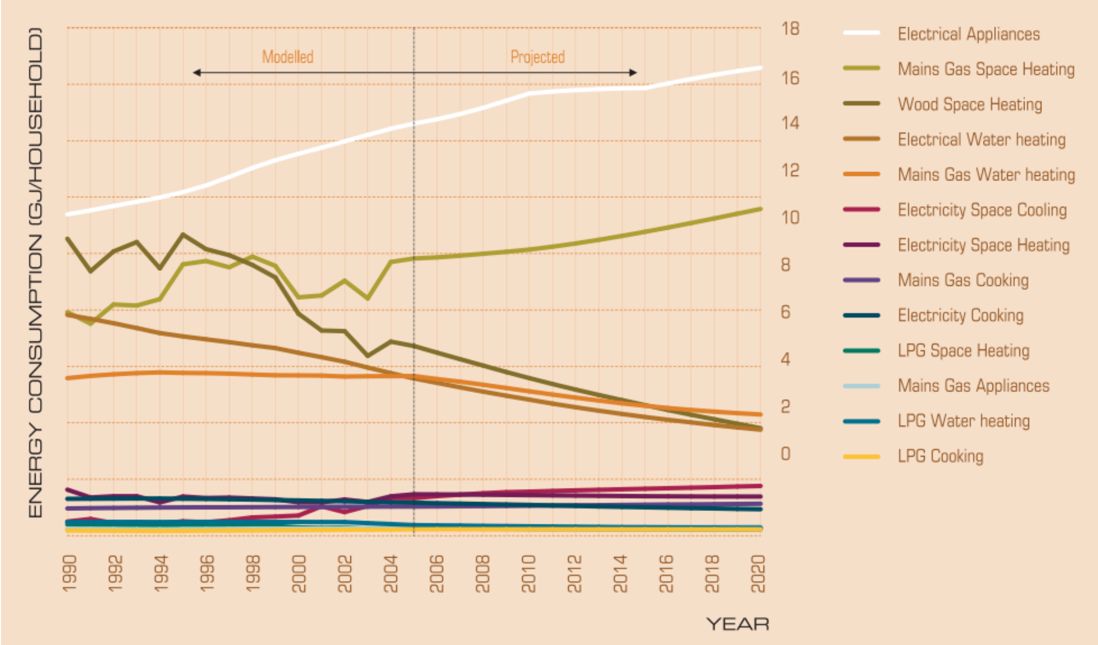

Figure 50: Trends in major end-use energy per household – Australia[103]

Appliances most commonly provided by developers as default kitchenware are:

- Cooktops
- Ovens
- Dishwashers
- Washing machines.

Induction hobs

The vast majority of new build apartments in Sydney and Melbourne are provided with gas hobs. Induction cooktops are approximately 50% more efficient at heating a pot/pan than gas and 10% more efficient than standard electric cooktops.[104] Induction hobs also overcome many of the controllability issues associated with standard electric cooktops by heating pans directly (Figure 51).

Figure 51: Induction hobs heat the pan directly

[103] http://www.energyrating.gov.au/document/report-energy-use-australian-residential-sector-1986-2020

[104] http://media.bze.org.au/bp/bze_buildings_plan.pdf

While electricity is more carbon intensive than natural gas in NSW and Victoria, substantial grid decarbonisation must be expected to happen well within the lifetime of new high-rise buildings. Retrofitting electrical infrastructure for induction cooktops after gas is likely to be challenging given the relatively high peak power draw across the building.

Induction hobs can slightly worsen power factor within the building but this can be counteracted with power factor correction. Penalisation of poor power factors is currently not common within Victorian network businesses, but this is also set to change.

Ovens

Although electric ovens are around twice as efficient as gas ovens, they are often only 14% efficient and there are significant opportunities for improving efficiency to as much as 24%. Key opportunities are decreased thermal mass, increased insulation, enhanced glazing performance and convection fans.[105]

Dishwashers

Recently developed dishwashers, like clothes washers can gain significant energy rating improvement through integration of heat-pump technology. The highest performing dishwasher available in Australia utilises this technology resulting in a 6 star energy rating. The next closest product is 4½ stars.

Washing machines/dryers

Washing machine efficiency has improved dramatically over the last decade or so, primarily due to popularisation of front-loading machines, use of cold water (including better detergents), increased capacities, increased spin speeds and durations (leading to less drying energy being required) and direct drive motors. Dryers are already available using condensing techniques and heat pumps, and the cost premiums associated with these technologies appear to be falling. In research labs, new washing technologies are being developed for the future that may utilise ultrasonic technology for cleaning purposes, or use carbon dioxide as a solvent (as is already used in dry cleaning). However, these products are not yet available in the general consumer market.

Ease of implementation

Installation of induction cooktops in lieu of gas hobs provides considerable savings in gas pipework, metering and associated safety infrastructure, although this may be offset to some degree by additional electrical cabling and potentially other costs. The extent of these additional electrical costs will depend upon the overall load profile of the building and not only on the choice of cooktops.

Drivers and marketability

The Green Star Multi-Unit Residential rating tool incentivises developers to provide appliances with energy ratings within 1 star of best-available within the same capacity band. This can readily be established using the Equipment Energy Efficiency online tool: http://reg.energyrating.gov.au/comparator/product_types/

Costs

Induction cooktops have come down substantially in cost in Australia with the arrival of low-cost options, such as Ikea models priced at around $450 compared to around $300 for gas cooktops of comparable quality. Heat-pump dishwashers are currently only produced by one Swiss manufacturer and cost around $4,000.

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[105] http://media.bze.org.au/bp/bze_buildings_plan.pd

3.12.2 Apartment Power 'kill-switches'

Energy saving potential

Master switches or 'kill' switches operate in a similar fashion to hotel card keys by isolating non-essential power and lighting circuits. This provides residents with a convenient way to switch off all non-essential power demand when exiting the apartment.

Average householder standby power consumption is around 10% of total residential energy[106], i.e. around one third of total appliance consumption.

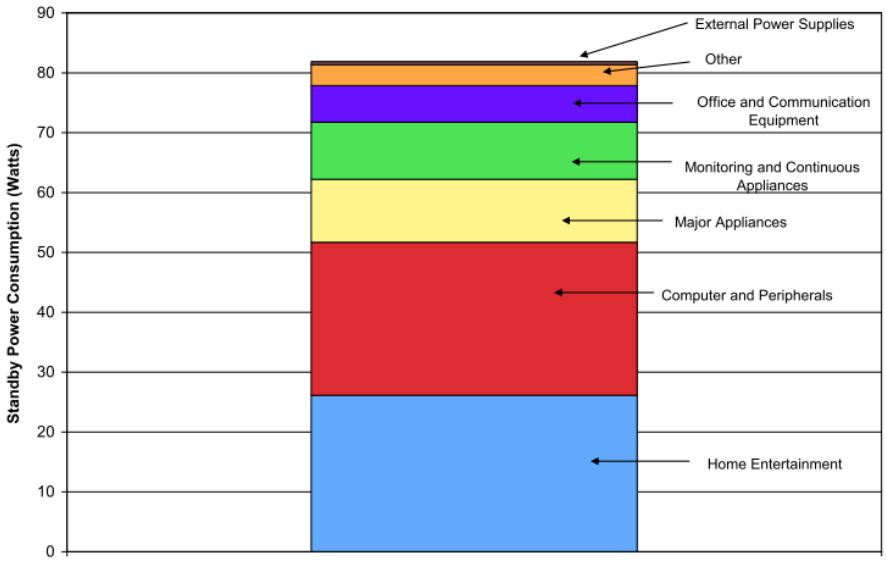

Figure 52: Comparative standby power consumption of appliance groups[107]

Kill switches can eliminate the majority of standby power consumption plus extraneous consumption of lighting and air-conditioning and IT or entertainment devices that may otherwise be left on when leaving the apartment.

Ease of implementation

Implementation requires separation of essential (e.g. refrigerator power) and non-essential circuitry and power sockets in apartments.

Drivers and marketability

Appliance and equipment numbers have grown from 46 per household (on average) in 2000 to 67 per household in 2010. Average standby power consumption in Australia in 2010 was 82 watts per household, equating to 717 kWh per year or on average $136 for each household. [108]

Apartment kill switches for lighting and air-conditioning circuits are incentivised by the Green Star Multi-Unit Residential rating tool. They are typically familiar to consumers from hotel card key equivalents. In

[106] http://energyrating.gov.au/document/report-third-survey-residential-standby-power-consumption-australian-homes-2010

[107] http://energyrating.gov.au/document/report-third-survey-residential-standby-power-consumption-australian-homes-2010

[108] http://www.energyrating.gov.au/document/report-third-survey-residential-standby-power-consumption-australian-homes-2010

Canada occupants are encouraged to use the kill switch, along with other switches, via the Flick Off campaign (Figure 53).

Figure 53: FLICK OFF campaign logo[109]

Costs

Typical cost of implementing kill-switch functionality is around $200 per apartment for a lighting or power circuit master-switch and up to $500 to include an air-conditioning power shut-off that includes an interface to allow controlled shut-down of the device.

3.12.3 Vertical Transportation

Energy saving potential

Without lifts high-rise buildings would not be possible. The least efficient lift type incorporates a hydraulic ram and is therefore not suited to high-rise buildings. A typical new ultra-high rise development in Australia would incorporate lifts with a gearless traction AC motor with a counterweight and travel speeds of 5 to 7m/s. New lift cars typically incorporate LED lighting. Energy consumption of high-speed lifts due to drag can be reduced using more aerodynamic lift car profiles. Energy savings of 20-25% can be achieved using regenerative motor drives, which allow lifts to be retarded by running the lift motor in reverse as a generator feeding power back into the building, as opposed to being dissipated in heat banks which impose a cooling load.

For high-rise applications the relative significance of lift standby power consumption is less than in low-rise applications where it can be as high as 70-80%.[110] Standby consumption can be reduced by disabling lift car lights and fan once parked. Traction lifts traditionally utilise steel rope. For ultra-high-rise buildings the weight of cable being moved is considerably higher than the weight of the lift car, passengers and counterweight combined. Manufacturers have recently developed stronger lighter alternatives made of aramid fibres, or a carbon-fibre cored belt. For a 300m high lift this means a reduction in cable weight of 33% from 18 tonnes to 12 tonnes. This technology is currently being installed in the bank of 13 lifts being installed in Australia 108 (Figure 54) in Melbourne, the only building in the southern hemisphere over 100 storeys.

[109] By Source, Fair use, https://en.wikipedia.org/w/index.php?curid=10938163
[110] http://cdn.kone.com/www.kone.us/images/eco-efficiency-faq.pdf?v=2

Figure 54: Energy-efficient lightweight composite lift rope utilised on Australia 108 tower lifts, Melbourne

Ease of implementation

More efficient lifts are easily implemented, having smaller motors requiring less auxiliary cooling installation and reduced plant space. Smaller lift motors also require smaller emergency power generation sets where lifts are used to reduce egress times as part of fire-evacuation strategy.

Destination control where users nominate a destination floor and are directed to a lift with compatible passengers is not well-suited to residential application where there is not a clearly defined peak arrival time.

Drivers and marketability

Lifts with slower speeds and slower acceleration rates consume less energy at the expense of travel and wait times. The minimum speed likely to be considered acceptable for ultra-high-rise is 5m/s. Longer lift travel and wait times may be made more tolerable using engaging screen displays within lift-lobby and lift cars.

The various measures designers can employ to encourage stair usage are much less relevant to high-rise residential applications.

Energy efficiency certificates for lifts exist (Figure 55) but are not mandated in Australia.

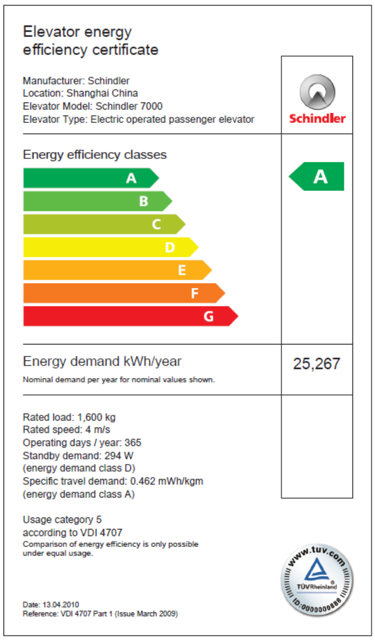

Figure 55: Lift energy efficiency class label

Even if not displayed within the lift car, an efficiency label makes energy use visible. Every manufacturer who uses the label increases awareness of the availability and value of energy-efficient elevators.[111]

Costs

Slower lift speeds require smaller motors with considerable direct cost savings. A 5m/s lift covering 60 storeys costs 20% less (or $200,000 less per lift) than a 6m/s lift. The cost of regenerative motor drives is around $10k per lift.

3.13 Renewables

3.13.1 Rooftop photovoltaic array

Energy saving potential

Energy saving potential is limited by area of roof relative to gross floor area, which is inherently constrained in high-rise typographies. Available roof area is typically constrained by extent and nature of roof-top plant and self-shadowing of roof by staircore, lift overruns or plant screens. This can be overcome by incorporation of a steel grating platform over-sailing such obstructions.

Overshadowing from adjacent structures is typically less of a concern of high-rise buildings. The Australian PV Institute (APVI) has developed an online Solar Potential Tool for quick estimation of the potential for electricity generation from PV on building roofs in Australian cities using a 3D city building database.

The theoretical optimum tilt of panels to maximise annual energy production is around 30° in Sydney. However installation at this angle increases wind loads and reduces the number of panel rows that can be installed on a given area without incurring self-shadowing. To maximise energy contribution from available roofspace PV modules should be installed at a maximum tilt of 10°. Whilst this reduces total annual solar flux per panel this is more than offset by the increased number of panels which can be accommodated.

[111] http://kms.energyefficiencycentre.org/sites/default/files/a1501.pdf

Figure 56 indicates variation in annual output with respect to tilt and azimuth for a notional 10kW array for a selection of Australian capital cities.

In Sydney, annual reduction in energy production due to a reduction in tilt from 30° to 10° would be a maximum of 6% for northwards orientation, dropping below 1% where oriented 45° off north. At 10° tilt panels will drain water at reasonable self-cleansing velocity. For ultra-high-rise towers this tilt could be further reduced due to scouring effect of prevailing winds at roof level.

Perth														
Azimuth		-90	-75	-60	-45	-30	-15	0	15	30	45	60	75	90
	5	14.7	14.9	15	15.1	15.3	15.4	15.5	15.5	15.5	15.4	15.4	15.3	15.1
	10	14.5	14.8	15.1	15.3	15.6	15.8	15.9	16	15.9	15.9	15.7	15.5	15.2
Tilt angle	15	14.2	14.6	15	15.4	15.7	16	16.2	16.3	16.3	16.2	15.9	15.6	15.2
	20	13.9	14.4	14.9	15.4	15.8	16.2	16.4	16.6	16.5	16.4	16.1	15.6	15.1
	30	13.2	13.9	14.6	15.2	15.8	16.2	16.6	16.7	16.7	16.5	16.1	15.5	14.8

Brisbane														
Azimuth		-90	-75	-60	-45	-30	-15	0	15	30	45	60	75	90
	5	14.1	14.2	14.3	14.4	14.5	14.5	14.5	14.5	14.4	14.4	14.3	14.2	14
	10	14	14.2	14.4	14.6	14.7	14.8	14.8	14.8	14.7	14.5	14.4	14.1	13.9
Tilt angle	15	13.9	14.2	14.5	14.7	14.9	15	15.1	15	14.9	14.6	14.3	14	13.7
	20	13.6	14.1	14.5	14.8	15	15.2	15.2	15.1	14.9	14.6	14.3	13.9	13.5
	30	13	13.6	14.2	14.6	14.9	15.1	15.2	15.1	14.8	14.4	13.9	13.4	12.8

Sydney														
Azimuth		-90	-75	-60	-45	-30	-15	0	15	30	45	60	75	90
	5	12.4	12.5	12.7	12.8	12.9	12.9	13	13	13	12.9	12.9	12.7	12.6
	10	12.3	12.51	12.8	13	13.2	13.3	13.4	13.4	13.4	13.3	13.1	12.9	12.6
Tilt angle	15	12	12.4	12.8	13.1	13.4	13.6	13.7	13.8	13.6	13.5	13.3	12.9	12.6
	20	11.8	12.3	12.8	13.1	13.5	13.8	14	14	13.9	13.7	13.3	12.9	12.4
	30	11.2	11.9	12.5	13.1	13.6	13.9	14.2	14.2	14.1	13.8	13.3	12.7	12

Melbourne														
Azimuth		-90	-75	-60	-45	-30	-15	0	15	30	45	60	75	90
	5	12.2	12.3	12.4	12.6	12.7	12.7	12.8	12.8	12.7	12.7	12.6	12.5	12.3
	10	12	12.3	12.6	12.8	13	13.1	13.2	13.2	13.1	13	12.8	12.5	12.3
Tilt angle	15	11.9	12.2	12.6	12.9	13.2	13.4	13.5	13.5	13.4	13.2	13	12.6	12.3
	20	11.7	12.1	12.6	13	13.3	13.6	13.7	13.7	13.6	13.4	13	12.6	12.1
	30	11.1	11.8	12.4	13	13.4	13.8	14	14	13.8	13.5	13	12.4	11.8

Figure 56: Variation in output (MWh per annum) with respect to tilt and azimuth for a notional 10kW PV array

The annual output of a 50kWp PV array could be expected to offset the energy consumption of around 20 standard NCC compliant apartments.

Ease of implementation

Effective solar arrays are relatively easy to implement at town planning or schematic design stage whilst there is some flexibility in location of roof plant and before selection of an embedded network provider.

Significant retrofit to high-rise buildings is considerably more challenging both spatially in terms of finding contiguous unshadowed space, and for the need for structural engineering input.

As a minimum short-term measure new-builds should incorporate spatial reservation and fixing and electrical switchboard provision for simple future installation. Provision of a 'solar-ready-roof' is awarded points within the current pilot update of the Green Mark building rating system.

There are also significant regulatory and tax implication hurdles to overcome in retrofit scenarios which the City of Sydney is currently investing resources in.[112]

[112] http://www.abc.net.au/news/2016-01-23/landmark-trial-sees-sydney-apartment-block-adopt/7109336

Drivers and marketability

Output from renewable energy installations counts towards scoring systems such as Green Star, BASIX (NSW) and BESS (Victoria). These are used to benchmark acceptable ESD credentials of development applications against planning policy objectives and measures.

City of Melbourne Eco-City strategy for new-builds states that 'Designers are encouraged to incorporate roof forms with suitable structure, orientation, inclination and solar access in plans for new developments.' Up until 2015 council rebates of up to $4,000 were available for 10-30kW systems.

The presence of environmental features such as solar panels is often included in marketing literature. The popularity of PV in Australia is evidenced by the highest rate of residential rooftop PV penetration in the world at 15% in 2015 (followed by Belgium at 7%).[113]

Whilst PV output in apartments typically offsets communal energy demand an 86 apartment development in Perth provides 2kW of PV directly wired to each apartment.[114] The developer claims "overwhelming buyer support for projects incorporating renewable energy technologies, not only because of cost-saving benefits, but also because people recognise this is the way of the future."[115]

Rooftop solar installations are also gaining prominence through increased public familiarity with satellite mapping and navigation tools such as Google Maps (Figure 57).

Figure 57: Aesthetically arranged solar thermal array on roof of 1 Bligh Street, Sydney

Electric vehicle (EV) charge points within apartments are not currently common but will become important as the global EV market grows. EV charging has strong symbiosis with on-site renewable energy. In a 2015 survey commissioned by Ford, 83% of EV drivers said they had solar panels at home already or would consider installing them in order to get a true zero-emission driving experience.[116] However, as there can

[113] http://www.pv-magazine.com/news/details/beitrag/australia-leads-world-in-residential-solar-penetration_100021291/#axzz48o5NJ6GE

[114] http://onestepoffthegrid.com.au/rooftop-solar-for-apartments-how-one-developer-is-making-it-happen/

[115] http://reneweconomy.com.au/2015/wa-residential-complex-installs-2kw-of-solar-for-each-apartment-24669

[116] http://cleantechnica.com/2015/08/09/ct-exclusive-interview-10000-ev-drivers-cant-wrong-can-different/

be a mismatch between the times of renewable energy generation and EV charging times, synergies with the emerging market in energy storage (batteries), combined with PV, may be even stronger. Batteries enable surplus energy from PV systems to be stored during the day and then drawn down, including for EV charging, overnight.

3.13.2 Other Solar Technologies

Solar thermal technologies, that capture the sun's heat directly, are most widely seen in solar hot water applications, which were described in Section 3.5 above. Other solar thermal technologies, like solar troughs or dishes, will generally experience the same issues as solar PV, and that is lack of suitable, unshaded roof-space. In Australia, this technology is at a relatively early stage of development, with two utility scale developments at Kogan Creek (Qld) and Liddell (NSW) power stations. Heat pumps are sometimes considered a form of renewable energy technology, and these are discussed under Section 3.7 above. Overall PV panels offer both the lowest cost and most reliable solar energy solution for most buildings, with their zero-noise and near-zero maintenance requirements being seen as major advantages.

Costs

The average price of 30-50kW commercial PV systems in Australia after federal government incentives is currently $1.20 per Watt, representing a drop of 20% over the last 2 years.[117]

Last year a major manufacturer forecast cost of solar PV modules to fall 25% in the next three years by improvements in cell efficiency and scale of output. They have been able to increase cell efficiency at 0.5% per year over the past five years, and expect this to continue, or even accelerate.[118]

Basic polycrystalline PV panels have a module efficiency of around 15% (250Wp). Current commercially available best-practice mono-crystalline panels have module efficiencies of up to 20% (330Wp).

The installation cost component within a high-rise context will be higher. Fixing to steel roof structures is cheaper than direct fixing to concrete roofs where panels require ballasted support racks.

Return on investment is dependent on tariff rates/structure and charges set by electricity retailers and local network service providers (LNSPs). There are 8 LNSPs in Victoria and NSW alone. Feed-in-tariffs for new installations are typically net at a rate of around 5¢/kWh. Typical payback periods can vary from 3 years in Western Australia to over 10 years in Melbourne.

Although solar power is typically the most cost-effective renewable in the built environment it is nevertheless still a higher cost strategy for energy and carbon savings compared with some of the other design and energy efficiency initiatives considered here.

3.14 Building Integrated PV (BiPV)

While conventional PV roof modules (Building added PV, or BaPV) dominate the current grid-connected market globally, they miss the opportunity of displacing conventional building materials. By substituting rather than overlapping standard building elements, building integrated PV (BiPV) offers a potential solution that can completely replace building skin components, maintain the mechanical resistance, thermal insulation, weatherproofing requirements and provide operational energy for the building.

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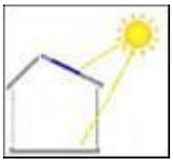
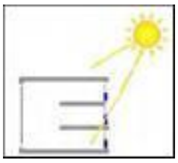
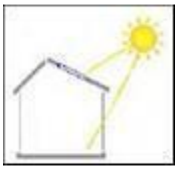
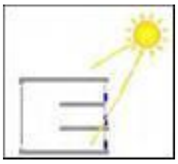
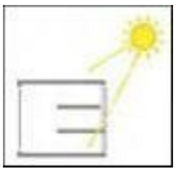
[117] Derived from http://www.solarchoice.net.au/blog/news/commercial-solar-pv-system-prices-march-2016-300316
[118] http://reneweconomy.com.au/2015/solar-pv-costs-to-fall-another-25-per-cent-in-three-years-32854

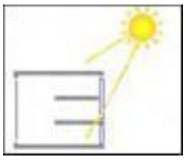
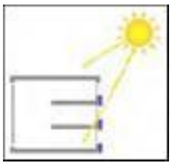
We have not been able to undertake a detailed assessment of the state of the BiPV market in Australia in the context of this study. Stakeholder feedback indicates that there has been consolidation in this sector globally in recent years, and some manufacturers are reported to have closed their BiPV production facilities. This could create difficulties for procuring product that complies with relevant IEC standards.

That said, we note that there is a current proposal for a 60 storey BiPV clad apartment/mixed-use building, the Sol Invictus ("invincible sun") Tower, at 42-48 Morey Street near the West Gate Freeway in Melbourne. The building is set to feature 3000 sqm of BiPV and 300 sqm of rooftop PV. The PV systems, which are expected to supply at least 50% of the tower's base load power, will be imported from China because "...Chinese regulations required similar high-tech, energy-generating buildings".[119]

Table 10: BiPV Examples

Type of product	Integration mode	Sketch	Examples
Opaque rigid PV Modules or PV tiles	Sloped roof covered with discontinuous element		 
PV foils Flexible PV foils	Flat roof or curved roof covered with continuous or discontinuous element		 
Semi-transparent and translucent PV	Skylight Atrium Veranda		 
Opaque PV cladding	Opaque part of a Curtain wall		 
Transparent PV glass	Windows or External part of a glass double skin wall		 

119 http://www.smh.com.au/business/property/first-solarpowered-apartment-skyscraper-to-rise-in-melbourne-20160819-gqwv76.html

Type of product	Integration mode	Sketch	Examples
Opaque PV Modules	Light wall made of BIPV modules (PV modules replace the wall itself)		
Opaque PV modules	Sun shade : Awnings Fastenings		 

Source: Dr Mark Snow

There are three main types of BiPV:

- Rigid (opaque) products
- Flexible products
- Transparent/semi-transparent products.

Rigid BiPV has typically used mono or poly crystalline silicon wafers to build customised building cladding structures. Tiles with PV can be designed to interlace with conventional roofing tiles or cladding materials. Flush mounted panels that overlay conventional roofing are not truly an integrated building material.

Flexible BiPV laminates are designed to be glued onto existing building materials such as metal roofing. Flexible shingles can also interlace with conventional asphalt shingles. PV cells deposited directly on building materials is a growing area of BIPV investment but use newer PV materials which are less well developed than rigid crystalline silicon.

Transparent BiPV are often categorised by the glass industry within a group called 'smart windows' and include electrochromic windows that have active electronics to control the translucent properties of the glazing. This is done by passing a voltage through the glass to change the glass properties to opaque and even reflective or transparent. Glass technologies have already achieved a level of sophistication and maturity that lend themselves to PV applications. Amorphous silicon and CIGS thin films are showing real prospect as the PV absorber materials with transparent conductors to compete with electrochromic glass windows. Customised BIPV glass is still in its infancy with varying success of performance yields and profitability. However, the prospects are encouraging as demand drives higher volumes and facilitates manufacturing and cost efficiencies.

Opportunity

Vertical PV façades produce relatively more power in winter and less in summer, and more in the early and late hours of the day, when the sun is lower in the sky. Typically a building will have at least two, but often three, exposed façades, and each will produce at maximum power at different hours of the day. This effect will lead to a widening of the peak of power production through the day and year, which allows a better adjustment to the load profile, thus enabling significant savings regarding electricity storage and/or fossil fuel based backup power reduction. In Australia in particular, Western orientated solar can produce useful energy during late afternoon summer air-conditioning peaks.

In BiPV applications, it may be justifiable to trade-off optimum tilt and orientation with other design considerations. For instance, on a large building with a BiPV façade, the cost, aesthetic and maintenance benefits of a standard vertical façade may offset the energy lost by not having an optimum tilt. Similarly, buildings which purchase electricity with a time of use tariff may also consider orienting PV to generate electricity at times of peak cost, to reduce the amount of electricity that the building needs to purchase at the peak prices (Snow & Prasad, 2011).

The emissions embodied in building fabric represent up to 15% of building lifecycle greenhouse gas emissions (Ramesh *et al.*, 2010; Thiel *et al*, 2013) and present a significant opportunity for carbon reduction. The building fabric is currently a problem in carbon footprint terms, but innovative use of fabric materials and design provides a significant opportunity for incorporating passive and active renewable energy solutions.

Costs

Globally, the BIPV market suffers from a lack of standardisation and modularity, while very few systems have been installed in Australia. Most of the systems are custom-made and, hence, do not entirely meet the functional, technical, and economical requirements of the architects and engineering consultants, installers, owners and end users.

By their very nature, PV materials are smart building elements and consequently attract a price premium. The price of conventional PV products has fallen to the point where the focus on reducing costs is now on the balance of systems and reducing the installation costs of PV. While BIPV subsidies have been able to provide the market confidence for industry to invest in PV building applications especially in Italy and France, there is a clear knowledge gap in understanding the true value proposition of BIPV.

BIPV however, have the disadvantage of being at least 10% more expensive that BAPV options. Upfront capital outlay is therefore a barrier for uptake; however, leasing arrangements over a longer-term plan can internalise these costs into the building asset value. Considerations of the cost of the existing building skin will affect the payback on BIPV.

From a high-rise residential building perspective, there is the prospect that BIPV will not only deliver a cost effective zero energy building solution for new buildings, it also has the ability to offer similar solutions for the retrofit market. Thermally stressed buildings can use BIPV to ameliorate these conditions, reduce the mechanical cooling and improve the overall indoor conditions that can impact on worker productivity. This is before considering the marketing value of a green building in attracting future tenants or the value onsite power generation can assist in reducing grid network demand and consequently, defer infrastructure augmentation.

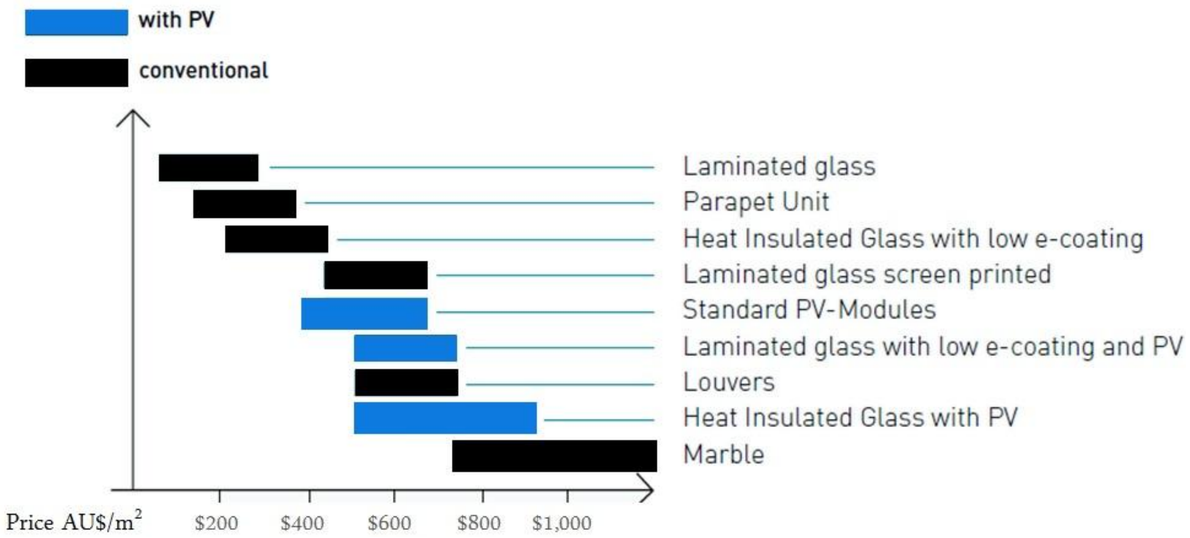


Figure 58 – PV building elements versus conventional building product costs

Source: Updated and adapted from Ingo Hagemann (2007)

While roof tiles and flexible BIPV products will continue to grow, the major BIPV market player is projected to be BIPV glazing systems (Figure 59) as smart window technology and its mature and sophisticated fabrication processes are coupled with improved PV technologies. Given glazing is a large component of commercial building façades and already commands a premium price for sunlight and thermally responsive products the progression to BIPV glass is a less ambiguous one compared to other PV building element options such as opaque BIPV (Quesada *et al.,* 2012).

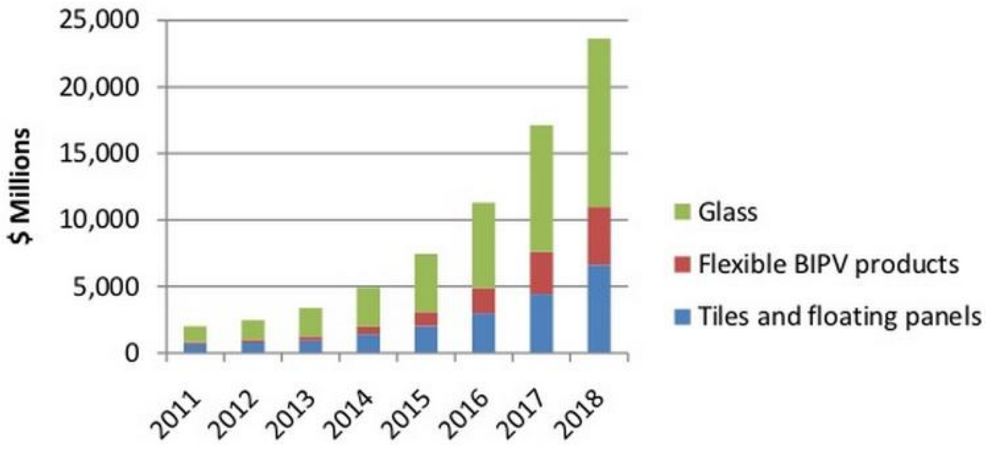


Figure 59 – Projected growth of rigid, flexible and glazing BIPV

Source: Nanomarkets, 2011

Marketability

In terms of future uptake of BiPV, there is a need for product manufacturers to persuade building developers that the products will continue to perform well over long periods of time, not only in terms of PV output, but also in terms of the integrity of the facade. Any new facade product faces a similar challenge, when compared to perhaps lower performance but well-known and reliable solutions. BiPV may be a suitable subject for market transformation initiatives, for example with applied independent research into durability testing leading to greater confidence and therefore uptake. Some but not all major city

Councils in Australia have various forms of planning controls to preserve solar access. For buildings relying on solar panels to achieve targeted performance levels, a guarantee of continued solar access within planning schemes will be critical.

The gridded dark-blue or black appearance of conventional solar cells can be aesthetically restrictive. Recent technological innovation (launched in 2014) has allowed selective light filters to be applied to heterojunction crystalline silicon solar modules to create uniform white and coloured panel effects. Such advancements facilitate BIPV integration across a much broader range of architectural intent (Figure 60 and Figure 61).

An ongoing aesthetic consideration will be constraints around commercially viable panel sizes.

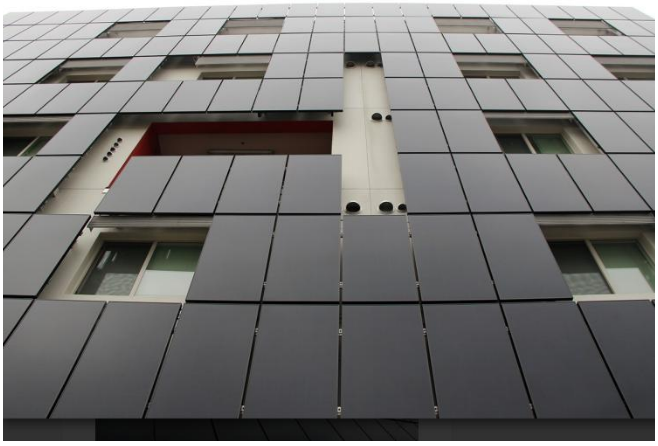


Figure 60: Residential building facade in Los Angeles overclad with mono-crystalline PV modules © KoningEizenberg

Figure 61: Commercial building clad in pioneering white PV modules, Neuchatel, Switzerland © Solaxess

Being more reflective, the inherent efficiency of these white PV modules is lower (currently around 70-90% that of conventional crystalline silicon modules), though comparable to dark-hued thin-film technology. Lower efficiencies in turn mean that proportionally greater areas would be required for equivalent yield.

4. Applied Modelling

4.1 Introduction

This section illustrates, with reference to two specific buildings ('reference developments') in Australia, the overall potential for moving towards net-zero, at least in the short term. We compare and contrast the energy performance levels that could be achieved by two building forms (in two climate zones) and in four performance levels (these terms are defined in Chapter 2):

- Base case
- Australian excellence
- Global excellence
- Net zero.

At the outset we need to state clearly that there are literally thousands of design, construction, plant and equipment, fit-out, commissioning, function, occupancy and climate zone variables, each one of which has the potential to have a material impact on the energy performance of a given building in a given location. When these elements are combined in differing ways and degrees, the specific performance outcomes that could be expected are almost infinite in number. There is simply a limited extent to which it is possible or valid to generalise about the energy performance potentials of specific building forms. In particular, the two building forms presented below are used to illustrate efficiency potentials in a general way, and no warranty is provided about the specific performance outcomes for these or other particular buildings.

Further, we note that real-world building projects will expend many hundreds or thousands of hours on building design, modelling and performance simulation. Such efforts have been well beyond the scope of this project. Therefore the results below reflect the professional experience and judgement of the authors and are intended to present plausible solutions at each of three performance levels targeted.

However, even with these disclaimers, it is important that the results of this study have been informed by real buildings and real-world project costings. Overall we find that the results are favourable, indicating that net-zero high-rise residential buildings are both technically and economically viable.

4.2 Context

4.2.1 Design context comparison

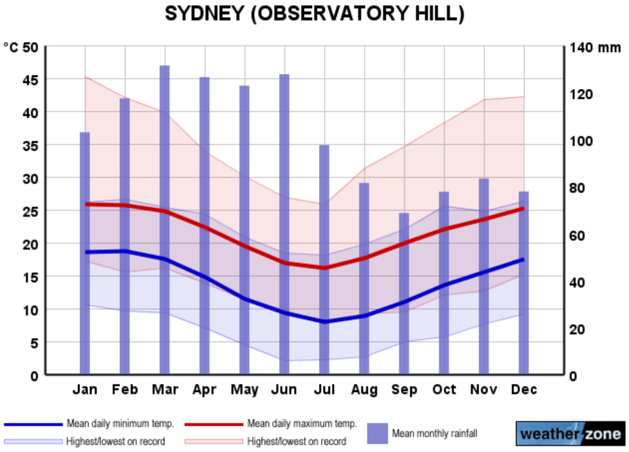
Whilst building regulations are nationally aligned, apartment design requirements vary as a function of:

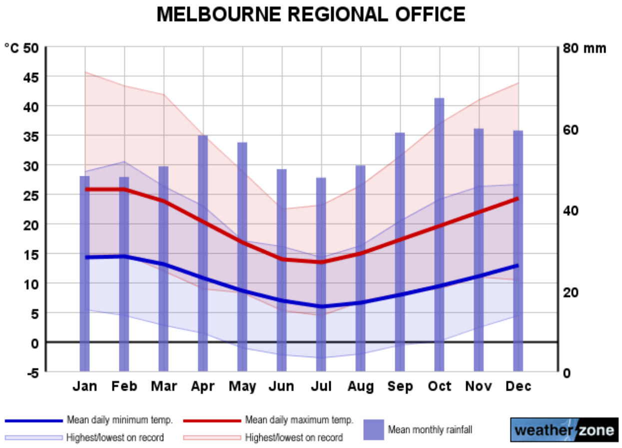
- Climate
- Apartment design guidance
- Compliance tools for sustainability rating.

Also, in New South Wales (NSW), the BASIX scheme operates in the place of the normal Code requirements for residential buildings.

Climate

Both climates may be classified as warm-temperate, though significant differences exist. Melbourne experiences more changeable weather, with more extreme summer and winter design conditions.





Climatic differences account for differing energy performances associated with NatHERS (the National House Energy Rating System) star ratings (Figure 62). Sydney is one of the mildest climates in Australia, meaning that thermal loads on buildings are more modest than in Melbourne's cooler climate.

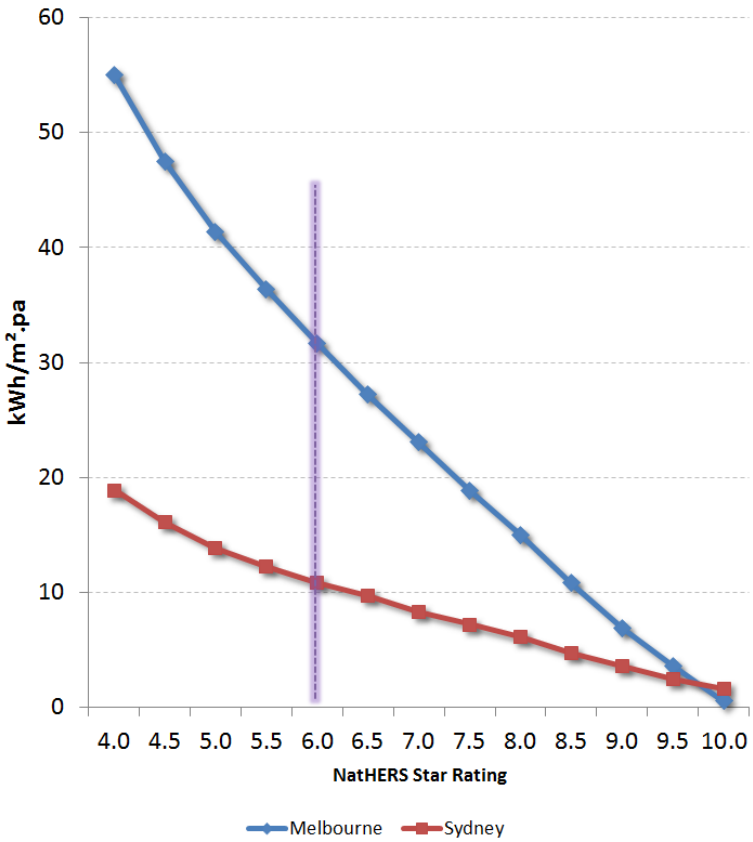


Figure 62: NatHERS star rating scales for Sydney and Melbourne relative to NCC minimum

Planning constraints

In 2002 the NSW Government introduced State Environmental Planning Policy No 65 (SEPP 65), named Design Quality of Residential Apartment Development, with its accompanying "Apartment Design Guide," formerly the "Residential Flat Design Code". As a result, NSW apartments are commonly bigger than their Victorian counterparts, with higher ceilings and greater access to daylight and natural ventilation.

The Victorian Government is currently drafting standards for better apartment design expected to be released for discussion in 2016.

Sustainability compliance tools

Compliance with the National Construction Code's energy performance requirements in Victoria, like all other states except NSW, can be assessed with reference to designs achieving the minimum allowed NatHERS ratings. In addition most Melbourne inner councils utilise either the Sustainable Tools for Environmental Performance Strategy (STEPS), introduced in 2005, or the newer Built Environment Sustainability Scorecard (BESS), introduced in 2016, as online rating tools to assess planning applications for best-practice sustainability compliance.

NSW utilises the BASIX compliance tool, introduced in 2004. BASIX allows apartment envelope minimum compliance based on maximum annual heating and cooling loads assessed using NatHERS energy modelling software. BASIX compliance requires achievement of overall emissions and water scores based on a variety of attributes of the development. As a result development compliance is commonly achieved without the building envelope meeting the nationally mandated 6 stars (average) and 5 stars (minimum) performance. It has recently been reported that 53% of new 2014 NSW dwellings did not achieve NCC compliant energy ratings.[120]

A graphical representation of the distribution of certified NatHERS ratings for all apartments in each of the reference developments is given for Sydney in Figure 63 and Melbourne in Figure 64.

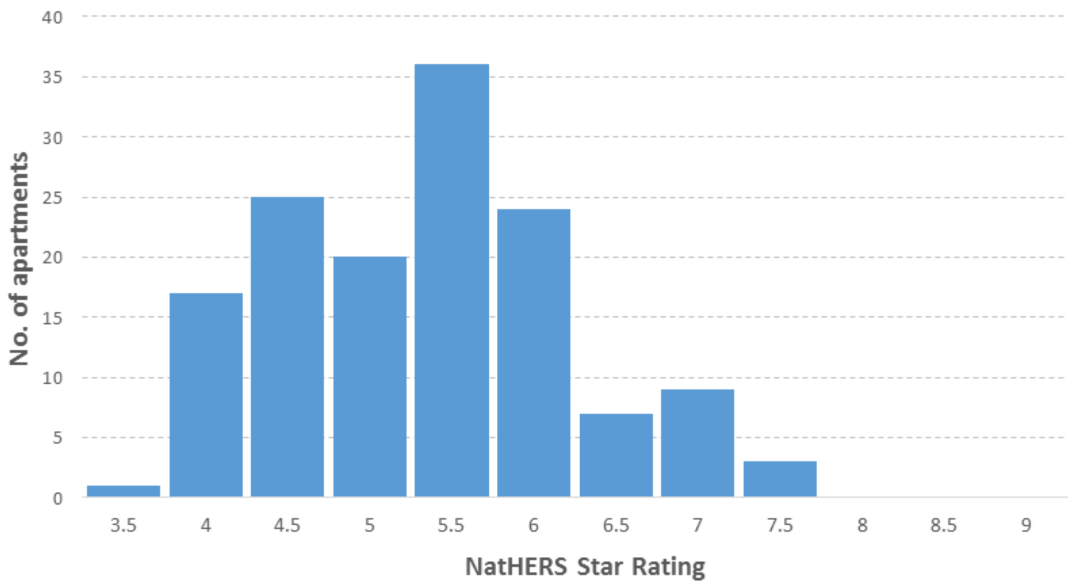


Figure 63: Certified NatHERS star rating distribution for Australia Towers II – Sydney[121]

Key statistics reported for the Sydney high-rise development are as follows:

- Average energy rating: 5.3 star (i.e. 15% worse than NCC minimum average requirement)
- BASIX score: 20 (complies with minimum requirements in NSW)
- Best-performing apartments: 7.5 star
- Worst performing apartment: 3.5 star (i.e. 60% worse than NCC absolute minimum requirement)
- %age apartments below 6 star: 70%

[120] http://www.thefifthestate.com.au/spinifex/basix-social-equity-and-innovation/82391

[121] Note that certification for this project was obtained using approved software which rounds to the nearest half-star.

This means the worst performing apartment will use over 3 times as much energy as best-performers to maintain comfort conditions.

As noted earlier in this section, compliance with NatHERS ratings is not mandatory in NSW. Compliance is achieved through a BASIX energy score equal to the minimum compliance of 20. This score is heavily influenced by parameters other than building envelope performance e.g. appliances and lighting and ventilation switching.

We also note that the claim of 5.3 star average performance differs from the results achieved in detailed modelling undertaken for this project, which generated a result of 4.4 star. Possible explanations for this discrepancy include that the representative floor modelled for this project may differ from the whole of building average; differences in modelling assumptions; and/or the base building may have under-complied with the claimed rating. pitt&sherry's *National Energy Efficiency Building Project* report (December 2014) examined the compliance issue and found that the vast majority of industry stakeholders believe that under-compliance with Code energy performance requirements is commonplace, right around Australia. However, that report did not include careful compliance audits (although it did call for state regulators to undertake such audits), and we do not suggest here any under-compliance for this particular building, as there could be a number of explanations of the results noted.

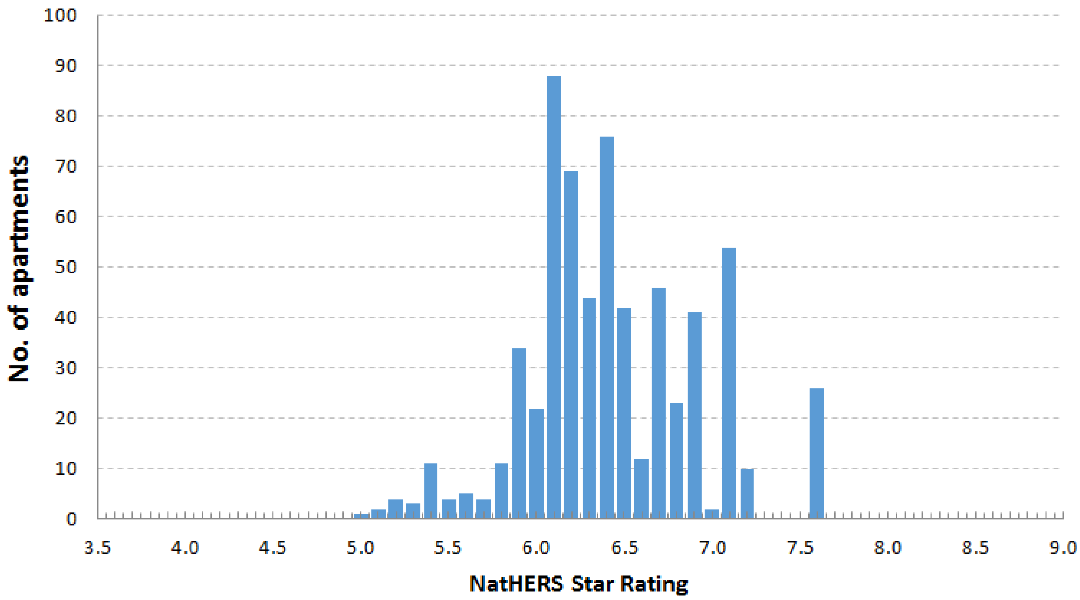


Figure 64: Certified NatHERS star rating distribution for Eq.Tower – Melbourne

Key statistics for the Melbourne ultra-high-rise development are as follows:

- Average energy rating: 6.4* (i.e. 10% better than NCC minimum average requirement).
- Best-performing apartments: 7.6*
- Worst performing apartment: 5.0* (i.e. NCC absolute minimum requirement)
- %age of apartments below 6*: 13%

This means the worst performing apartment will use almost 2½ times as much energy as best-performers to maintain comfort conditions. Note that our modelling showed the average energy rating as slightly higher than claimed, at 6.5 star.

Drivers and marketability

The number of new apartment projects winning approval from local councils nationally almost doubled from 2012-13 to 105,000 new dwellings over the 2013-2014 financial year. Apartments accounted for 95 per cent of the growth in housing construction in that period.[122]

Currently, foreign and domestic investor buyers comprise about 70 per cent of the residential unit market.[123] This has the potential to create split-incentives between landlords and tenants for energy-efficient design.

Additionally, the majority of apartments are sold off-plan at a stage when individual apartment energy ratings are not available. Purchasing a relatively energy-efficient apartment is therefore a matter of luck. Consumer awareness is further diminished by the absence of mandatory disclosure of energy performance within the established housing market.

Reference projects used in this report as the basis for modelling scenarios are compliant with relevant local planning policies and applicable building codes.

4.3 Sydney High-Rise Reference Building

The reference building that was modelled is representative of high rise developments within the inner suburbs of Sydney. Australia Towers is a development combining a 24 storey and a 30 storey tower over a common 2 storey podium base. It is located at 1 Australia Avenue within Sydney Olympic Park, 17km from the CBD. Images are provided below.

The development includes a podium garden with entertaining spaces on Level 3, supplemented by a rooftop common room and a terrace.

The Sydney tower floor plate modelled comprises 11 apartments on a mid-floor of a 25 storey tower (Australia Towers II) comprising:

- 3-bedroom apartments - 2
- 2 bedroom apartments – 5
- 1 bedroom apartments – 4

The average apartment size for this floorplate is 74m².

[122] http://www.theaustralian.com.au/business/economics/chinas-6bn-thirst-for-apartments-fuels-economy/news-story/815d10c2fffc58334a574d53b980b6d9
[123] http://www.theaustralian.com.au/business/property/apartments-market-warning-from-real-estate-analysts/news-story/7956e54e94de3cf772a74a5a181d04d7

Figure 65: Australia Towers – external upper levels

Figure 66: Australia Towers – street view

Figure 67: Australia Towers – wide view

Figure 68: Australia Towers – Living area and balcony

Figure 69: Australia Towers - Kitchen & living area

Figure 70: Representative 11-apartment floor plate of high-rise tower – Sydney

Australia Towers II is the 2nd of 3 phases. It comprises 287 apartments – ranging from one to four bedrooms. It was completed in 2014 under BCA 2010/BASIX.

It has 95 one-bedroom apartments ranging from $450,000 to $595,000 and from 54 to 71 square metres internally, 132 two-bedroom apartments with between 77 square metres and 122 square metres of internal space and priced between $585,000 and $1,085,000, 26 three-bedroom apartments of between 103 and 159 square metres each ranging from $900,000 and $1,565,000 and 14 four-bedroom units, which will range from between $995,000 and $1.76 million and between 141 and 181 square metres internally.

Every apartment has at least one car space.[124]

The developer Ecove estimated that strata levies would be low – due to the sport and recreational facilities offered in Sydney Olympic Park - estimating them to be $600 to $750 for a one-bedroom, $800 to $1,000 for a two-bedroom, and $1,200 to $1,500 for a three of four-bedroom apartment, per quarter. The building has a small gym but no pool.

4.4 Melbourne Ultra-High-Rise Reference Building

The reference building that was modelled for Melbourne is representative of ultra-high rise developments currently in detailed design or construction phases. Eq. Tower is located in A'Beckett Street within the CBD, an area close to extensive retail, commercial and university facilities.

The project has 65 storeys with 634 apartments comprising the following mix:

- 34% one-bedroom
- 13% one-bedroom with study
- 37% 2 bedroom, 1 bathroom
- 14% 2 bedroom, 2 bathroom
- 3% 3-bedroom, 2 bathroom

At upper levels balconies give way to winter-gardens (fully enclosed 'greenhouse' spaces) in response to wind-exposure.

The development incorporates a 7 storey podium containing ground floor retail premises, and residents' communal facilities at level 8 including an open deck, pool and gymnasium. Communal facilities on level 7, include an outdoor area with 25-metre pool, spa and sauna, and grassed relaxation areas. Indoor areas include a gym, private cinema, communal kitchen and dining room, lounge and karaoke suites. On level 33, a private dining room seating up to 20 guests, a lounge and a games room with billiards, poker and mahjong tables.

The development has one basement level providing racks for 200 cycles. Levels 1 to 7 incorporate car-parking and podium liner apartments.

Apartments have an average energy rating 10% better than mandated by the National Construction Code, which is 6 stars NatHERS on average, and a minimum rating of 5 stars. The project is also benchmarked against the Green Star multi-residential sustainability rating tool.

Planning approval was granted in early 2014, with construction commencing early 2015. The development is due for completion in mid-2017.

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124 http://www.propertyobserver.com.au/finding/residential-investment/new-developments/16407-about-40-of-olympic-parks-atii-tower-sold-soon-after-marketing-starting-gun-sounds.html

Advertised sales prices for one bedroom apartments, from 40 to 54 square metres, started from $359,000, with two-bedroom apartments spanning 53 to 71 square metres from $489,000. Three bedroom penthouses, at 81 square metres, start from $891,000.[125] Residential car park spaces in Melbourne CBD currently retail between $75,000 and $100,000.

Marketing stage renders for the development are shown in the figures below (© Elenberg Fraser).

Figure 71: Eq. Tower external render – wide view

Figure 72: Eq. Tower external render - close view

[125] http://www.propertyobserver.com.au/finding/residential-investment/new-developments/29728-eq-tower-melbourne-icd-property.html

Figure 73: Eq. Tower apartment renders – bedroom

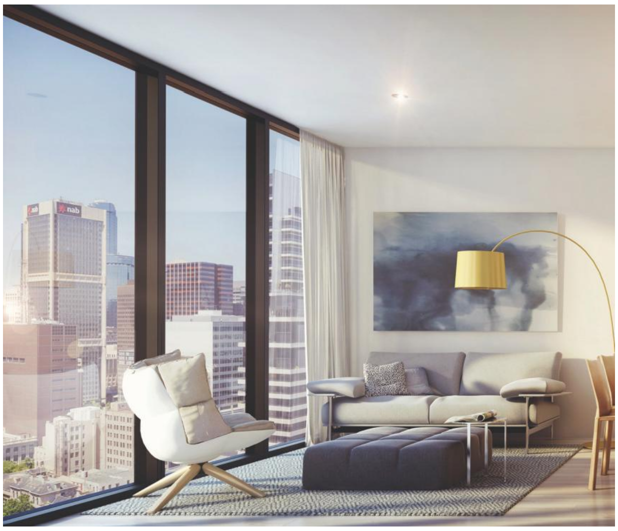

Figure 74: Eq. Tower apartment render - living room

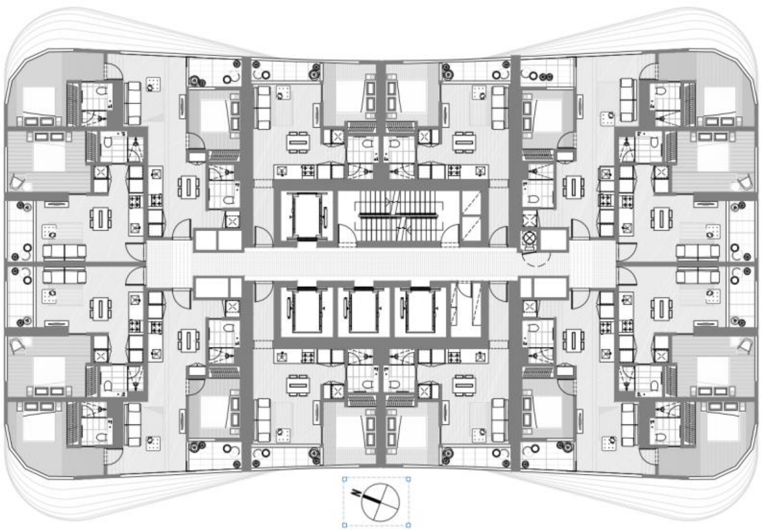

Figure 75: Representative 12-apartment floor plate of ultra high-rise tower - Melbourne

4.5 Thermal Modelling Specifications and Results

This section presents the key assumptions that were made about the specifications of each of the Sydney and Melbourne buildings in each of their four performance guises: base case, Australian Excellence, Global Excellence and Net-Zero. It then shows the result of our thermal simulation modelling. We place particular emphasis on the performance of the façades in each of the base case, Australian Excellence and Global Excellence/Net-Zero (the façade/efficiency solutions for these two guises are identical), to demonstrate the effectiveness and cost effectiveness of reducing window-to-wall ratios, utilising high performance glazing and adding insulation.

Modelling Limitations

Building energy modelling is based on a wide range of data, assumptions and methodologies developed by industry largely over the last decade or so. It must be noted that many current assumptions have not been extensively validated in the context of new high-rise residential developments in Australian cities. Large and detailed data sets are required to draw reliable conclusions from empirical performance studies.

Building energy modelling tends to under-predict energy consumption as it cannot readily predict the vast range of efficiency reductions associated with sub-optimal design, procurement, installation, commissioning, operation and maintenance. Even where most of these factors can be aligned, as was the case with parallel rows of terraced passive housing in the landmark BedZED project in London, the variance in energy consumption between best and worst performing households monitored was more than five-fold due to variation in occupancy density, patterns, preferences and behaviours.

It should therefore be considered that energy consumption associated with each of the four scenarios underestimates likely performance-in-use, and will also be subject to large 'random' contextual variation.

For these reasons building energy modelling is most reliable where used to test relative performance impacts of initiative options, rather than predicting absolute overall performance as is required for net-zero energy design.

4.5.1 Sydney Building

Base-case:

Under the base case, the dominant energy consumption predicted is associated with domestic hot water (DHW) generation. This assumes gas-fired generation with a non-condensing boiler of efficiency 85%. Note that efficiencies as low as 70% are permissible under current MEPS standards in Australia. The same applies to pool heating boilers typically supplied separately.

DHW usage modelling is based on an assumed occupancy density of two persons per one bedroom apartment, three per two-bedroom apartment and four per three-bedroom apartment. It is further assumed that each resident has one eight-minute shower per day, and uses a wash hand basin seven times a day and a sink tap four times a day. Cooking loads assume an apartment energy consumption of 237kWh pa for an electric oven and 444kWh for gas hobs.

Lighting is the next highest load predicted, after DHW. Commercial LED downlights are assumed throughout new-build apartments and T5 fluorescent lamps throughout car-park areas. Note that the NCC currently permits lighting densities around double those assumed.

- Façade fabric comprises:

- Windows: Clear single glazing with non-thermally-improved aluminium frames. Curtain wall system fixed and awning windows. Traditional sliding doors. Values typify a weighted average performance of window types (fixed, awning, sliding door).
    - Walls: 75mm bulk-fill insulation as non-vision glazing spandrel panels
- Results highlight typical Sydney climate outcomes where apartments will experience heating deficit for around three-quarters of the year but at around two-thirds of the level of a typical Melbourne apartment. Typical installed air-conditioning unit sizes will range from 2-4kW, based on sub-contractor modelling including design safety margins using basic load sizing software.

Australian Excellence case:

- Façade fabric comprises:
    - Windows: Double low-e coated, light tint double glazing with argon fill, thermally-broken frames. Values typify a weighted average performance of window types (fixed, awning, sliding door).
    - Walls: 90mm bulk-fill insulation as non-vision glazing spandrel panels.
- Results show fabric loads reduced to one-third that of the base-case.
- Heating & Cooling:
    - 43% façade heat load reduction in accordance with NatHERS ratings associated with 60% WWR and improved wall and window performance
    - 38% façade cooling load reduction in accordance with NatHERS ratings associated with 60% WWR and improved wall and window performance
    - 33% reduction in corresponding air-conditioner plant consumption due to specification of current best-in-class VRF systems (seasonal CoPs and EERs increased from 4 to 6). Slightly reduced energy reduction applicable to cooling loads (small) due to addition of ultra-low-energy ceiling fans.
    - Façade cost increase of 10% - increased glazing costs offset by reduced glazing extents.
    - Air-conditioning system cost increase zero – high-efficiency plant cost and incorporation of ceiling fans offset by decreased plant capacity and associated infrastructure.
- Energy consumption reductions and cost increases are predicted based on the following considerations:[126]
    - 33% reduction in corresponding air-conditioner plant consumption due to specification of current best-in-class VRF systems (seasonal CoPs and EERs increased from 4 to 6). Slightly reduced energy reduction applicable to cooling loads (small) due to addition of ultra-low-energy ceiling fans.
    - Façade cost increase of 10% - increased glazing costs offset by reduced glazing extents.
    - Air-conditioning system cost increase zero – high-efficiency plant cost and incorporation of ceiling fans offset by decreased plant capacity and associated infrastructure.
- Ventilation:
    - 51% decrease in fan motor loads due to 20% increase in cross-sectional area of ductwork, filters and coils as per Section 3.8
    - 25% decrease in fan motor loads due to more extensive implementation of VSDs.

[126] All percentage energy reductions and cost increases taken relative to base-case scenario.

- Ductwork and AHU cost increase of 10% due to 10% increase in linear dimensions.
- Loss of NSA due to increase in riser and plant room areas of 20% offset by decreased plant spatial requirements associated with heating & cooling load reductions above.
- Fan controls cost increase of 25%

- Lighting:
  - 40% decrease in lighting consumption due to increase in average LED/fluorescent efficacy from 66 lumens per watt to 100 lumens per watt.
  - 10% decrease in lighting consumption due to improved extent of presence/absence detection and daylight dimming controls.
  - Lighting system supply cost increase (in the short term) by a factor of 3 to 7 due to the premium niche-market nature of the above measures currently. Installation cost increase of 10%.
- Domestic hot water:
  - 66% decrease in DHW generation energy due to switch from 85% efficient non-condensing gas-fired boilers to electric heat pump generation with seasonal coefficient of performance of 2.5.
  - 20% reduction in standing storage and distribution system heat losses due to improved cylinder lagging and pipework insulation thicknesses.
  - Heat pump plant costs triple that of boiler plant and gas infrastructure system cost.
  - DHW system insulation cost increase of 20%.
- Cooking
  - Gas hob loads (444kWh) reduced by 50% due to replacement by induction hobs.
  - Electric oven loads reduced by 20% through a combination of more efficient oven and increased utilisation of microwave oven. Electric oven usage decrease of 5% assumed due to behavioural change stimulated by enhanced awareness of apartment power consumption sub-metering data enabled via app/web browser access to real-time energy consumption infographics.
  - Induction hob extra-over cost of $200 per apartment, but likely to be recovered within apartment sale cost therefore no net additional cost to developer.
- Appliances
  - 40% appliance load reduction due to installation of best-in-class dishwashers, fridges and washer/dryers.
  - Additional costs of up to $2,000 per apartment depending on extent of developer provision, likely to be partially recoverable in sales cost.
- Lifts
  - 25% through use of regenerative motor drives, avoidance of premium lift speeds and improved standby power regulation.
  - Cost increase of energy-regulating features offset by reduction in lift motor size and associated infrastructure.

- Pool
    - 85% reduction in pool heat generation consumption due to switch from 85% efficient non-condensing boilers by pool contractor or 80% efficient titanium LTHW heat-exchanger to heat-pump with seasonal CoP of 5.5.
    - 25% reduction in pool heat losses due to incorporation of integrated motorised pool blanket.
    - 50% reduction in pool pump circulation consumption due to improved pump-efficiency, VSD, pump operation times and 20% increase in cross-sectional area of filter cartridges.
    - Heat-pump plant around triple the cost of an integrated boiler or titanium LTHW heat-exchanger (add $20,000).
    - Integrated pool blankets for typical 25 meter 2-lane lap pool add $50,000.
- Rooftop PV
    - Provision of 200 standard PV panels (50kWp) on horizontal steel grating platform over central roof, generating 70MWh of renewable energy per annum. Cost addition of $100,000.

Global Excellence case:

The Global Excellence scenario predicts a further 57% potential energy consumption reduction over the Australian Excellence scenario for both buildings. It is considered to be particularly viable in around 5 years' time since certain initiatives such as LED efficacies incorporate anticipated technological improvements in component efficiencies, cost efficiencies, learning rates and associated market and supply chain evolution within that timeframe.

This case highlights the fact that certain loads such as heating, cooling and to some extent mechanical ventilation can be largely eliminated through adoption of established passive design principles. Other components have significant energy usage that cannot be viably recovered within the realms of advancement considered plausible over the next couple of decades. This is typically the case where high-grade energy such as electricity or gas converts to distributed low-grade heat.

Sequential energy consumption reductions and cost impacts are predicted based on the following considerations, whilst incorporating 5 years of anticipated technological improvements in component efficiencies, cost efficiencies and associated market and supply chain evolution:[127]

- Façade fabric comprises:
    - Windows: Double low-e coated, neutral hue double glazing with argon/krypton fill, premium (imported) thermally-broken frames (U_f<1.2W/m²K).
    - Walls: up to 90mm rigid phenolic foam insulation as non-vision glazing spandrel panels.
    - Reduced infiltration due to air-tight construction (with mechanical ventilation and heat recovery).
- Apartments incorporate a ceiling fan in the living room and bedrooms further reducing need for air-conditioning.
- Results show total fabric loads around 10% of base-case with more equalised heating and cooling loads. Most significantly loads reduce to a level where conventional air-conditioning units and associated infrastructure could be avoidable. Internal heat gains would offset remaining heat

[127] All percentage energy reductions and cost increases taken relative to base-case scenario.

losses, and cooling loads offset by ceiling fans, evaporative cooling, and adaptive comfort principles.

- Heating & Cooling:
  - 91% façade heat load reduction in accordance with NatHERS ratings associated with 50% WWR and improved wall and window performance.
  - 62% façade cooling load reduction in accordance with NatHERS ratings associated with 50% WWR and improved wall and window performance.
  - 95% reduction in heating requirements due to omission of VRF air-conditioning system. Heated towel rails with thermostats would be used in bathrooms. Remaining cooling consumption associated with ultra-low-energy ceiling fans. Potential for introduction of evaporative cooling into fresh air systems.
  - Façade cost increase of 20% - increased glazing costs offset by reduced glazing extents.
  - VRF system cost and space omitted.
    - This performance is comparable with Passivhaus standards for warm-temperate climates.
- Ventilation:
  - 76% decrease in fan motor loads due to 30% increase in cross-sectional area of ductwork, filters and coils as per Section 3.8.
  - 40% decrease in fan motor loads due to full implementation of VSDs.
  - Ductwork and AHU cost increase of 14% due to 14% increase in linear dimensions (to achieve 30% increase in cross-sectional area).
  - Loss of NSA due to increase in ductwork risers of 30% and plant room areas of 15% more than offset by decreased plant spatial requirements associated with heating & cooling load reductions above.
  - Fan controls cost increase of 40%.
- Lighting:
  - 67% decrease in lighting consumption due to increase in average LED/fluorescent luminaire efficacy from 66 lumens per watt to 200 lumens per watt. Note such efficacies are not commercially available in 2016 but predicted by the US DoE to be available at or below current prices from 2020 onwards (see Section 3.11).
  - 35% decrease in lighting consumption due to full implementation of daylight dimming control and presence/absence detection.
  - Lighting system supply cost for ultra-high-efficiency luminaires will be significantly higher than current typical pricing in the short-term but is predicted by the US DoE to normalise from 2020 onwards.
- Domestic hot water:
  - 72% decrease in DHW generation energy due to switch from 85% efficient non-condensing gas-fired boilers to electric heat pump generation with seasonal coefficient of performance of 3.0.
  - 30% reduction in standing storage and distribution system heat losses due to improved cylinder lagging and pipework insulation thicknesses.
  - 20% reduction in DHW load due to incorporation of drain water heat-exchangers for showers.

- 10% potential reduction in DHW usage due to incorporation of shower-timers with auto-shut-off and/or reduced flow showerheads (beyond 3* WELS rating).
    - Heat pump plant cost triple that of boiler plant and gas infrastructure system cost.
    - DHW system insulation cost increase of 20%.
- Cooking
    - Gas hob loads (444kWh) reduced by 50% due to replacement by induction hobs.
    - Electric oven loads reduced by 25% through a combination of maximum efficiency oven and increased utilisation of microwave oven. Electric oven usage decrease of 10% assumed due to behavioural change stimulated by enhanced awareness of apartment power consumption sub-metering data enabled via app/web browser access to real-time energy consumption infographics.
    - Induction hob extra-over cost of $200 per apartment, but likely to be recovered within apartment sale cost therefore no net additional cost to developer.
- Appliances
    - 50% appliance load reduction due to installation of best-in-class dishwashers, fridges and washer/dryers.
    - Additional costs of up to $2,000 per apartment depending on extent of developer provision, likely to be partially recoverable in sales cost.
- Lifts
    - 33% through use of regenerative motor drives, improved standby power regulation, and reduction in number of lift shafts utilised based on extended waiting times.
    - Cost increase of energy-regulating features more than offset by reduction in lift provision and associated infrastructure.
- Pool
    - 85% reduction in pool heat generation consumption due to switch from 85% efficient non-condensing boilers by pool contractor or 80% efficient titanium LTHW heat-exchanger to heat-pump with seasonal CoP of 5.5.
    - 25% reduction in pool heat losses due to incorporation of integrated motorised pool blanket.
    - 50% reduction in pool pump circulation consumption due to improved pump-efficiency, VSD, pump operation times and 20% increase in cross-sectional area of filter cartridges.
    - Heat-pump plant around triple the cost of an integrated boiler or titanium LTHW heat-exchanger (add $20,000).
    - Integrated pool blankets for typical 25 metre 2-lane lap pool add $50,000.
- Rooftop PV
    - Provision of 200 ultra-high-efficiency PV panels (50kWp) on horizontal steel grating platform over central roof generating 84MWh of renewable energy per annum. Cost addition of $140,000.

Façade performance - Sydney

Energy performance results of the three façade scenarios for this floorplate are presented in Table 11.

Table 11: Effect on energy ratings of higher-performance glazing and insulation using lower WWRs - Sydney

Façade performance	Glazing ratio WWR	Windows U	Walls R	SHGC	VLT	Average star rating	Total MJ/m²	Heating MJ/m²	Cooling MJ/m²	Apartment NatHERS star ratings 1	2	3	4	5	6	7	8	9	10	11
Typical new-build (SYD)	70%	6.0	1.5	0.60	75%	**4.4**	112.1	22.4	13.9	4.4	5.1	4.6	4.1	3.9	3.7	4.3	4.9	4.4	4.4	4.4
Australian excellence	60%	2.2	2.0	0.40	50%	**6.7**	43.2	30.7	12.5	6.9	7.8	7.4	5.7	7.3	7.4	6.9	5.6	6	5.1	7
Global excellence	50%	1.1	4.0	0.50	70%	**9.2**	12.5	4.8	7.7	8.9	9.5	9.7	8.6	9.1	9.2	9.2	8.9	9.4	8.8	9.5

Results as modelled for this project, which may differ from project documentation. SHGC = solar heat gain co-efficient (as defined in the National Construction Code). U and R values measure thermal resistance, with U being the inverse of R – that, is low U values are better than high ones, while high R values are better than low ones.

As WWR decreases the benefits of increased wall insulation become more significant. However at a WWR of 50%, insulation levels beyond R=3 to 4m²K/W (U=0.33 to 0.25W/m²K) for apartment facades in a Sydney climate deliver fractional returns relative to cost, while also taking up additional space.

The milder climate of Sydney has meant that energy performance above 9 stars is achievable without resorting to WWRs below 50%, which would be expected to be harder to market than in a Melbourne climate. This decision however necessitates more extensive use of particularly expensive imported high-performance double-glazing, amplified by the longer facades associated with larger apartment expectations in NSW.

Modelling Net Zero

For the Sydney high-rise case, a larger roof combined with considerably reduced storeys (compared with the Melbourne building) results in conventional rooftop PV being able to represent a solid portion of the building consumption. The persistent energy consumption of the global excellence scenario is 462MWh. To cover this demand we propose:

- Vertically mounted panels on north, east and west facing facades in Sydney also provide an average yield of 0.84MWh/kWp.
- This requires 550kWp of non-south-facing BIPV achievable using 1,800m² of high-efficiency (300Wp) 60-cell PV modules.
- Length of façade suitably oriented for PV for typical floor plate perimeter is 100m giving a total façade area of 300m². Of this 50% is vision glazing leaving 150m² of viable BIPV area per floor.
- Net-zero energy therefore requires the top 12 stories (roughly half) of tower height to be clad in BIPV (three façades).

A cost of up to $1M is estimated for this extent of BIPV.

4.5.2 Melbourne Building

Base-case

As per the Sydney building, the dominant energy consumption in the base case is domestic hot water (DHW) generation. We assume gas-fired generation with a non-condensing boiler of efficiency 85%. The same applies to pool heating boilers typically supplied separately.

DHW usage modelling is based on an assumed occupancy density of two persons per one bedroom apartment, three per two-bedroom apartment and four per three-bedroom apartment. The actual average densities within the City of Melbourne are 1.2 persons per bedroom, with 99.4% living in apartments.[128] It is further assumed that each resident has one eight-minute shower per day, and uses a wash hand basin seven times a day and a sink tap four times a day. This usage profile may also not be representative of the very young demographic of Melbourne - with a median age of 28 years compared with the national average of 37, and 41% lone-person households relative to the national average of 24%.

Cooking loads assume an apartment energy consumption of 237kWh pa for an electric oven and 444kWh for gas hobs.

Lighting is again the next highest load predicted. Commercial LED downlights are assumed throughout new-build apartments and T5 fluorescent lamps throughout car-park areas.

- Façade fabric comprises:
    - Windows: Single low-e coated, heavy tint double glazing with air fill, non-thermally-improved aluminium curtain wall frames. Values typify a weighted average performance of window types (fixed, awning, sliding door).
    - Walls: 70mm bulk-fill insulation as non-vision glazing spandrel panels
- Results highlight typical Melbourne climate outcomes where apartments will experience heating deficit for around three quarters of the year. Typical installed air-conditioning unit sizes will range from 3-5kW, based on sub-contractor modelling including design safety margins using basic load sizing software.

Australian Excellence case

- Façade fabric comprises:
    - Windows: Double low-e coated, light tint double glazing with argon-filled, thermally-broken frames. Values typify a weighted average performance of window types (fixed, awning, sliding door).
    - Walls (non-vision spandrel glazed curtain wall): 70mm rigid phenolic foam insulation as non-vision glazing spandrel panels
- Results show fabric loads reduced to almost half that of the base-case.
- Heating & Cooling:
    - 50% façade heat load reduction in accordance with NatHERS ratings associated with 50% WWR and improved wall and window performance
    - 13% façade cooling load reduction in accordance with NatHERS ratings associated with 50% WWR and improved wall and window performance
    - 33% reduction in corresponding air-conditioner plant consumption due to specification of current best-in-class VRF systems (seasonal CoPs and EERs increased from 4 to 6). Slightly reduced energy reduction applicable to cooling loads (small) due to addition of ultra-low-energy ceiling fans.
    - Façade cost increase of 10% - increased glazing costs offset by reduced glazing extents.

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128 http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/quickstat/SSC20867?opendocument&navpos=220

- Air-conditioning system cost increase zero – high-efficiency plant cost and incorporation of ceiling fans offset by decreased plant capacity and associated infrastructure.

- Energy consumption reductions and cost increases are predicted based on the following considerations:[129]
    - 33% reduction in corresponding air-conditioner plant consumption due to specification of current best-in-class VRF systems (seasonal CoPs and EERs increased from 4 to 6). Slightly reduced energy reduction applicable to cooling loads (small) due to addition of ultra-low-energy ceiling fans.
    - Façade cost increase of 10% - increased glazing costs offset by reduced glazing extents.
    - Air-conditioning system cost increase zero – high-efficiency plant cost and incorporation of ceiling fans offset by decreased plant capacity and associated infrastructure.
- Ventilation:
    - 51% decrease in fan motor loads due to 20% increase in cross-sectional area of ductwork, filters and coils as per Section 3.8.
    - 25% decrease in fan motor loads due to more extensive implementation of VSDs.
    - Ductwork and AHU cost increase of 10% due to 10% increase in linear dimensions.
    - Loss of NSA due to increase in riser and plant room areas of 20% offset by decreased plant spatial requirements associated with heating & cooling load reductions above.
    - Fan controls cost increase of 25%
- Lighting:
    - 40% decrease in lighting consumption due to increase in average LED/fluorescent efficacy from 66 lumens per watt to 100 lumens per watt.
    - 10% decrease in lighting consumption due to improved extent of presence/absence detection and daylight dimming controls.
    - Lighting system supply cost increase (in the short term) by a factor of 3 to 7 due to the premium niche-market nature of the above measures currently. Installation cost increase of 10%.
- Domestic hot water:
    - 66% decrease in DHW generation energy due to switch from 85% efficient non-condensing gas-fired boilers to electric heat pump generation with seasonal coefficient of performance of 2.5.
    - 20% reduction in standing storage and distribution system heat losses due to improved cylinder lagging and pipework insulation thicknesses.
    - Heat pump plant costs triple that of boiler plant and gas infrastructure system cost.
    - DHW system insulation cost increase of 20%.
- Cooking
    - Gas hob loads (444kWh) reduced by 50% due to replacement by induction hobs.
    - Electric oven loads reduced by 20% through a combination of more efficient oven and increased utilisation of microwave oven. Electric oven usage decrease of 5% assumed due to behavioural change stimulated by enhanced awareness of apartment power consumption sub-metering data enabled via app/web browser access to real-time energy consumption infographics.

[129] All percentage energy reductions and cost increases taken relative to base-case scenario.

- Induction hob extra-over cost of $200 per apartment, but likely to be recovered within apartment sale cost therefore no net additional cost to developer.

- Appliances
    - 40% appliance load reduction due to installation of best-in-class dishwashers, fridges and washer/dryers.
    - Additional costs of up to $2,000 per apartment depending on extent of developer provision, likely to be partially recoverable in sales cost.
- Lifts
    - 25% through use of regenerative motor drives, avoidance of premium lift speeds and improved standby power regulation.
    - Cost increase of energy-regulating features offset by reduction in lift motor size and associated infrastructure.
- Pool
    - 85% reduction in pool heat generation consumption due to switch from 85% efficient non-condensing boilers by pool contractor or 80% efficient titanium LTHW heat-exchanger to heat-pump with seasonal CoP of 5.5.
    - 25% reduction in pool heat losses due to incorporation of integrated motorised pool blanket.
    - 50% reduction in pool pump circulation consumption due to improved pump-efficiency, VSD, pump operation times and 20% increase in cross-sectional area of filter cartridges.
    - Heat-pump plant around triple the cost of an integrated boiler or titanium LTHW heat-exchanger (add $20,000).
    - Integrated pool blankets for typical 25 meter 2-lane lap pool add $50,000.
- Rooftop PV
    - Provision of 120 standard PV panels (30kWp) on horizontal steel grating platform over central roof generating 40MWh of renewable energy per annum. Cost addition of $60,000.

Global Excellence case

- Façade fabric comprises:
    - Windows: Double low-e coated, neutral hue double glazing with argon/krypton fill, premium (imported) thermally-broken frames (U_f<1.2W/m²K).
    - Walls: up to 120mm rigid phenolic foam insulation as non-vision glazing spandrel panels.
    - Reduced infiltration due to air-tight construction (trickle ventilation is assumed).
- Apartments incorporate a ceiling fan in the living room and bedrooms further reducing need for air-conditioning.
- Results show total fabric loads below 20% of base-case with more equalised heating and cooling loads. Most significantly loads reduce to a level where conventional air-conditioning units and associated infrastructure could be avoidable. Internal heat gains would offset remaining heat losses, and cooling loads offset by ceiling fans, evaporative cooling, and adaptive comfort principles.

- Heating & Cooling:
    - 94% façade heat load reduction in accordance with NatHERS ratings associated with 30% WWR and improved wall and window performance.
    - 28% façade cooling load reduction in accordance with NatHERS ratings associated with 30% WWR and improved wall and window performance.
    - 95% reduction in heating requirements due to omission of VRF air-conditioning system. Heated towel rails with thermostats would be used in bathrooms. Remaining cooling consumption associated with ultra-low-energy ceiling fans. Potential for introduction of evaporative cooling into fresh air systems.
    - Façade cost increase of 20% - increased glazing costs offset by reduced glazing extents.
    - VRF system cost and space omitted.
        - This performance is comparable with Passivhaus standards for warm-temperate climates.
- Ventilation:
    - 76% decrease in fan motor loads due to 30% increase in cross-sectional area of ductwork, filters and coils as per Section 3.8.
    - 40% decrease in fan motor loads due to full implementation of VSDs.
    - Ductwork and AHU cost increase of 14% due to 14% increase in linear dimensions (to achieve 30% increase in cross-sectional area).
    - Loss of NSA due to increase in ductwork risers of 30% and plant room areas of 15% more than offset by decreased plant spatial requirements associated with heating & cooling load reductions above.
    - Fan controls cost increase of 40%.
- Lighting:
    - 67% decrease in lighting consumption due to increase in average LED/fluorescent luminaire efficacy from 66 lumens per watt to 200 lumens per watt. Note such efficacies are not commercially available in 2016 but predicted by the US DoE to be available at or below current prices from 2020 onwards (see Section 3.11).
    - 35% decrease in lighting consumption due to full implementation of daylight dimming control and presence/absence detection.
    - Lighting system supply cost for ultra-high-efficiency luminaires will be significantly higher than current typical pricing in the short-term but is predicted by the US DoE to normalise from 2020 onwards.
- Domestic hot water:
    - 72% decrease in DHW generation energy due to switch from 85% efficient non-condensing gas-fired boilers to electric heat pump generation with seasonal coefficient of performance of 3.0.
    - 30% reduction in standing storage and distribution system heat losses due to improved cylinder lagging and pipework insulation thicknesses.
    - 20% reduction in DHW load due to incorporation of drain water heat-exchangers for showers.
    - 10% potential reduction in DHW usage due to incorporation of shower-timers with auto-shut-off and/or reduced flow showerheads (beyond 3* WELS rating).

- Heat pump plant cost triple that of boiler plant and gas infrastructure system cost.
    - DHW system insulation cost increase of 20%.
- Cooking
    - Gas hob loads (444kWh) reduced by 50% due to replacement by induction hobs.
    - Electric oven loads reduced by 25% through a combination of maximum efficiency oven and increased utilisation of microwave oven. Electric oven usage decrease of 10% assumed due to behavioural change stimulated by enhanced awareness of apartment power consumption sub-metering data enabled via app/web browser access to real-time energy consumption infographics.
    - Induction hob extra-over cost of $200 per apartment, but likely to be recovered within apartment sale cost therefore no net additional cost to developer.
- Appliances
    - 50% appliance load reduction due to installation of best-in-class dishwashers, fridges and washer/dryers.
    - Additional costs of up to $2,000 per apartment depending on extent of developer provision, likely to be partially recoverable in sales cost.
- Lifts
    - 33% through use of regenerative motor drives, improved standby power regulation, and reduction in number of lift shafts utilised based on extended waiting times.
    - Cost increase of energy-regulating features more than offset by reduction in lift provision and associated infrastructure.
- Pool
    - 85% reduction in pool heat generation consumption due to switch from 85% efficient non-condensing boilers by pool contractor or 80% efficient titanium LTHW heat-exchanger to heat-pump with seasonal CoP of 5.5.
    - 25% reduction in pool heat losses due to incorporation of integrated motorised pool blanket.
    - 50% reduction in pool pump circulation consumption due to improved pump-efficiency, VSD, pump operation times and 20% increase in cross-sectional area of filter cartridges.
    - Heat-pump plant around triple the cost of an integrated boiler or titanium LTHW heat-exchanger (add $20,000).
    - Integrated pool blankets for typical 25 metre 2-lane lap pool add $50,000.
- Rooftop PV
    - Provision of 120 ultra-high efficiency PV panels (38kWp) on horizontal steel grating platform over central roof generating 50MWh of renewable energy per annum. Cost addition of $85,000.

Façade Performance - Melbourne

Energy performance results of the three façade scenarios for the Melbourne building are presented in

Table 12. It can be seen that this 'fabric first' approach alone could lift the average star rating of the apartments from 6.5 to 9.3, representing a remarkable 81% reduction in thermal loads.

Table 12: Effect on energy ratings of higher-performance glazing and insulation using lower WWRs - Melbourne

Façade performance	Glazing ratio	Windows	Walls	SHGC	VLT	Average star rating	Total	Heating	Cooling	Apartment NatHERS star ratings											
	WWR	*U*	*R*				*MJ/m²*	*MJ/m²*	*MJ/m²*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Typical new-build (MEL)	70%	2.9	2.0	0.25	35%	**6.5**	96.7	79.2	17.5	6.3	6.2	6.5	6.5	6.1	6.7	6.6	6.7	7.1	6.9	6.7	6.2
Australian excellence	50%	2.2	4.0	0.40	50%	**8.0**	54.9	39.7	15.2	7.4	7.8	8.1	8	7.8	7.7	7.7	8.3	8.6	8.4	8.3	7.4
Global excellence	30%	1.1	6.0	0.50	70%	**9.3**	17.7	5.1	12.6	9.2	9.2	9.2	9.2	9.3	9.4	9.4	9.4	9.3	9.3	9.4	9.2

Results as modelled for this project, which may differ from project documentation.

It can also be seen that as WWR decreases, the benefits of increased wall insulation become more significant. However at a WWR of 30% insulation levels beyond R=5 to 6m²K/W (U=0.20 to 0.17W/m²K) for apartment facades in a Melbourne climate delivers fractional returns relative to cost and space-take.

Table 13 highlights the relative contribution of windows and walls to façade conduction performance in each of the 3 performance scenarios. It illustrates that even at 30% WWR with ultra-high performance glazing, windows still account for three quarters of all fabric conduction losses and gains. It also highlights how the cost balance of the façade shifts alongside consequential factors.

Table 13: Effect on costs of decreasing window-wall ratio whilst improving glazing performance

`	Windows	Walls	SHGC	VLT	Window conduction losses	Wall conduction losses	Window conduction losses ratio	Wall cost	Window cost	Apartment façade cost
WWR	*U*	*R*			*W/K*	*W/K*		*$*	*$*	*$*
70%	2.9	2.0	0.25	35%	60.9	4.5	93%	$5,400	$19,950	**$25,350**
50%	2.2	4.0	0.40	50%	33.0	3.8	90%	$10,500	$17,250	**$27,750**
30%	1.1	6.0	0.50	70%	9.9	3.5	74%	$16,800	$12,150	**$28,950**

NB: cost estimates are indicative only, with market testing revealing wide variation in quotes.

Modelling Net Zero

For the Melbourne ultra-high-rise the Global Excellence scenario predicts a persistent energy consumption of some 1100MWh. The only plausible way to offset this consumption on-site would be through integration of building-integrated photovoltaics (BIPV) onto the building façade. BIPV modules would replace curtain wall as the weathering surface. This is particularly challenging in a high-rise context due to wind-loads and maintenance constraints. However it is technically feasible as follows:

- Vertically mounted panels on north, east and west facing facades in Melbourne provide an average yield of 0.84MWh/kWp.
- This requires 1.0MWp of non-south-facing BIPV achievable using 5,300m² of high-efficiency (300Wp) 60-cell PV modules.
- Typical floor plate perimeter is 120m giving a total façade area of 360m². Half of this is facing away from the equator leaving 180m² available. Of this 30% is vision glazing leaving 120m² of viable BIPV area per floor.
- Net-zero energy therefore requires the top 44 stories (roughly three-quarters) of tower height to be clad in BIPV (three facades).

A cost of $2-3M or around 1 to 1.5% of total construction cost may be appropriate for this extent of BIPV.

Viability would be contingent on no significant current or future overshadowing of the façade down to this height from nearby tower structures. Cladding the whole tower height in this manner would provide a 25%

allowance for this factor, which is likely to be sufficient in the immediate CBD context but would be at risk in the event of significant further high-rise development particularly to the north.

There is some rectitude in the 'fully-clad' BIPV outcome for higher latitude cities such as Melbourne in that the facades of ultra-high rise buildings inevitably cast long shadows over swathes of adjacent rooftops therefore diminishing their neighbours' potential for solar harvesting, and net-zero energy status attainment.

4.5.3 Summary of Results

The elemental contribution to high rise building energy consumption in the Base Case and the reductions modelled under the Australian Excellence and Global Excellence cases for the Sydney and Melbourne buildings are shown in Figure 76 and 78.

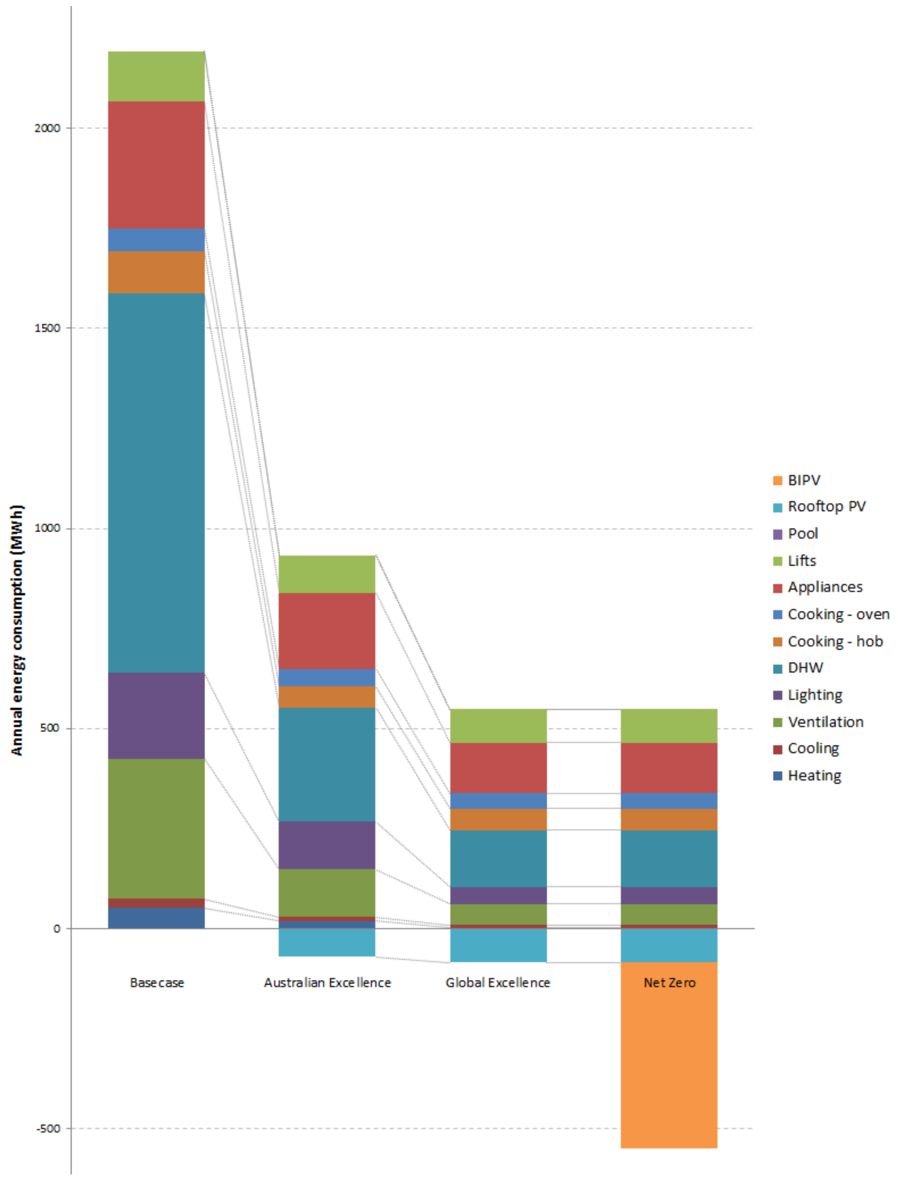

Figure 76: Shares of energy use and savings by performance scenario – SYDNEY

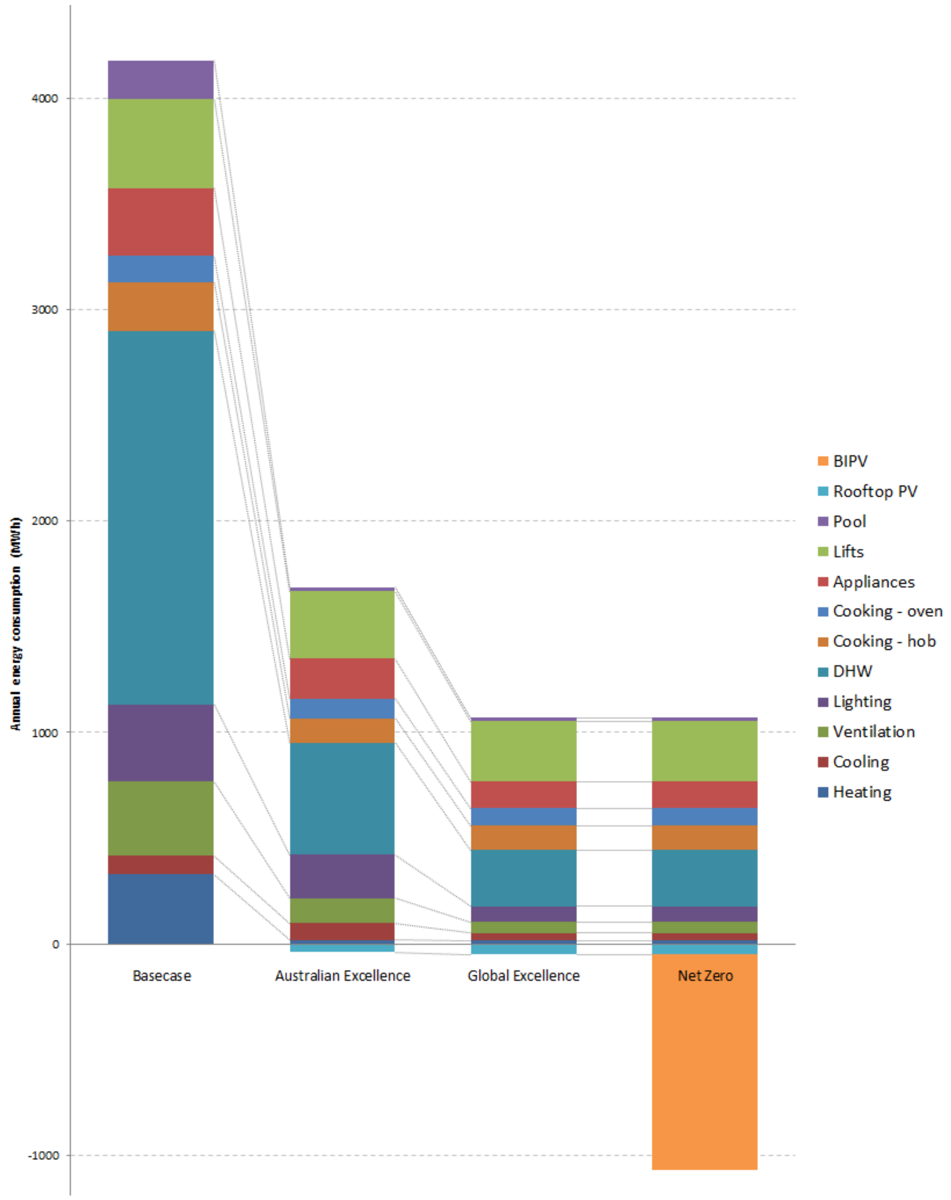

Figure 77 - Shares of energy use and savings by performance scenario – MELBOURNE

While it has not been possible to undertake an item-by-item cost-effectiveness analysis within the scope of this project, the key savings areas (for the Melbourne building) are set out in Table 14 below:

Table 14: Key Savings by End-Use: Melbourne Building

End-use	Base case (MWh/y)	Net zero (MWh/y)	% reduction
Heating	328	16	95%
Pool	182	18	90%
Ventilation	349	52	85%
DHW	1769	265	85%
Lighting	366	73	80%
Appliances	319	128	60%
Cooling	89	36	60%
Cooking - hob	231	116	50%
Cooking - oven	123	83	33%
Lifts	425	284	33%

These results reflect the ‘fabric first’ design philosophy, with key treatments being:

- Reduced window-to-wall ratios (to 50% in Sydney, 30% in Melbourne)
- High-performance glazing
- Improved insulation
- Air tight facade
- Mechanical ventilation with heat recovery
- High efficiency ceiling fans, appliances and lighting
- High COP heat pumps for domestic hot water and swimming pools
- Building integrated (and some rooftop) PV (550 kW in Sydney and 1 MW in Melbourne).

4.5.4 Alternatives to BiPV?

- ***Precinct Scale Solutions***

BiPV is not the only solution for a net zero building or precinct. First, the UK/EU definition of net zero allows for ‘nearby’ renewable energy installations, and these can offer some advantages over BiPV such as:

- Ground based installations at lower cost, including ongoing maintenance/repair costs;
- Optimal siting, within a precinct, to avoid overshading issues or to take advantage of wind corridors, etc;
- Allowing for a wider range of renewable energy technologies to be used, potentially at lower cost than PV, subject of course to planning and noise considerations;
- Within the set of PV solutions, allowing for flat plate panels with higher efficiencies than BiPV, optimal tilt and orientation, and also potentially for tracking technologies;
- Freeing up facade design and construction details for architectural purposes.

When compared to ‘remote’ renewable (discussed below), precinct scale systems are likely to share with BiPV ready consumer acceptance and credibility, due to the tangibility of the solution: the future resident of a precinct can see the system, and as a resident may even receive financial and/or output updates via smart phone apps.

The key barrier to precinct-scale renewable energy solutions is the National Energy Market (NEM) rules. These rules were designed with utility scale power systems in mind, and were developed with an explicit agenda of separating the then vertically-integrated and largely state-owned power system. Such a context is now long behind us, yet the NEM design has failed to keep pace with social and technological trends such as those that enable and create demand for precinct-scale renewable energy solutions. Precinct systems require direct relationships between generators and consumers, or indeed the two parties may be one ‘pro-sumer’. That is, the local consumers may own the precinct scale renewable facility through an owners corporation, with only limited scale transactions with the surrounding distribution network, even though these transactions may be important from an energy security perspective.

- ***Remote Renewables***

Another potential solution is to cover the residual energy demand of a highly energy efficient building with renewable energy generated at a remote site. The key advantage of this approach is that it frees the developer from local planning and site-specific considerations, and instead allows the market to identify the least-cost renewable energy solution, regardless of where the installation is located. Wind power economics, in particular, are strongly influenced by site-specific factors such as average wind speeds. It makes no sense at all to locate wind turbines in low wind areas. Solar technologies are less site dependent than wind, as a general rule, but still overshading risks, the higher cost and lower availability of urban land and other factors will come into play. The key question for remote renewable, then, is not an economic one, as remote generation will almost always be cheaper than local. Rather, the question is one of marketability: will purchasers of net-zero apartments accept that an offsite solution is permanent, and therefore be willing the pay the same premium as they might for a more tangible and local solution, even if that local solution may cost more? Schemes such as Green Power and the national Renewable Energy Target (nRET) scheme have operated for decades now and provide a ready-made solution to certifying the 'renewableness' of power supply. However, nRET is a mandatory scheme which has been affected by political interventions from time to time, while Green Power has only ever experienced limited market take-up, and less in recent times. This suggests that consumers do not value such solutions as highly as more tangible ones, like roof-top PV, which have experienced explosive growth in consumer take-up in recent years, including after generous subsidies were removed.

Clearly, more work would be required to tease out all the issues in this area, and we encourage governments and industry to approach this work with a consumer perspective in mind. Ultimately, the net-zero value proposition will be judged by consumers, and it will fail if consumers are not persuaded by the claims made by government and/or developers. Section 5 below notes that building rating, accreditation and mandatory performance disclosure schemes – along with industry and consumer education, and initiatives like LJ Hookers' *17 Things*[130] – can all help to build the consumers' willingness to pay.

4.5.5 What happens to gas?

Natural gas has traditionally been used in NSW and Victoria for domestic hot water, pool heating and cook-tops due to historic price differentials relative to electric resistance heating and greater controllability of gas cooktops relative to electric resistance hobs. Gas cooktops are generally unmetered within apartments – particularly in Victoria – and an average cost is built into owners corporation fees, reducing incentives for conservation. Stakeholder feedback indicates that many customers in high-rise residential buildings in NSW have on-market hot water meters that apportion gas usage (for all purposes) based on the proxy of metered hot water consumption.

Energy consumption of these applications can be reduced by 50 to 85% through switching from gas combustion to 'smart' (non-resistive) electrical heating technologies such as heat-pumps and induction hobs. This is important when considering current and future carbon intensities associated with grid power generation mix. The share of renewable energy for each of the Australian states in 2014 is shown in Figure 78. The peak load implications of induction hobs and heat pumps is discussed in Section 5.1 and taken into account in our modelling.

[130] http://www.ljhooker.com.au/17things

Figure 78: Comparison of renewable generation mix in Australia in 2014

Best-practice pool heat pumps should demonstrate carbon emissions savings in both NSW & Victoria based on current grid carbon intensities. DHW heat pumps should demonstrate carbon-emissions savings over their useful life in both states. Life-cycle carbon considerations are linked to grid decarbonisation trajectories, for example Victoria has just committed to 40% renewable energy generation by 2025. Retrofitting electrical infrastructure in the event of future heat-pump changeover may be challenging.

Note that on-site combustion of gas is not permitted in net-zero energy certified schemes such as the Living Building Challenge.

5. Benefit Cost Analysis

5.1 Methodology and Assumptions

This section presents the results of benefit cost analysis that we have undertaken on both the Sydney and Melbourne buildings. We begin by describing our methodology and key assumptions, and then present the results for each of the buildings.

The two buildings are modelled as if constructed during 2016 and commencing operational life from 2017 and running out to 2050. Each building is modelled in four specifications, as detailed above:

- Base case (NCC +10%, for EQ Tower, and BASIX for Australia Towers C)
- Australian excellence
- Global excellence
- Net zero.

The technical assumptions for each building in each guise are detailed in 4.6 – 4.8, and 4.10 for net zero, above. More detailed modelling assumptions are set out for the Sydney building in Table 15 and for the Melbourne building in Table 16.

Table 15: Sydney Building: Key Modelling Parameters

Parameter	Units	Value
Base case (BASIX)		
Energy consumption	MWh/y	2200
GFA	sqm	28,448
Total energy intensity	MJ/m2.a	278
Total energy intensity	kWh/m2.a	77.2
Construction cost	$/sqm	$3,200
Electricity share of enduse:	%	80%
Stated building value	$m	$180
Australian excellence		
Energy consumption	MWh/y	858
Total energy intensity	MJ/m2.a	109
Total energy intensity	kWh/m2.a	30.3
Percentage reduction over base case	%	61.0%
Construction cost increase (est.)	%	4.7%
Implied construction cost	$/sqm	$3,350
Incremental cost	$/sqm	$150
Electricity share of enduse:	%	90%
Global excellence		
Energy consumption	MWh/y	462
Total energy intensity	MJ/m2.a	58
Total energy intensity	kWh/m2.a	16.1
Percentage reduction over base case	%	79%
Construction cost increase (est.)	%	6.7%
Implied construction cost	$/sqm	$3,433

Parameter	Units	Value
Incremental cost	$/sqm	$214
Electricity share of enduse:	%	95%
Net zero		
(Purchased or external) energy consumption	MWh/y	0
Total energy intensity[131]	MJ/m2.a	0
Total energy intensity	kWh/m2.a	0
Percentage reduction over base case	%	100%
Construction cost increase (est.)	%	7.8%
Implied construction cost	$/sqm	$3,468
Incremental cost	$/sqm	$249
Electricity share of enduse:	%	100%

Table 16: Melbourne Building: Key Modelling Parameters

Parameter	Units	Value
Base case (NB: Section J -10%)		
Energy consumption	MWh/y	4200
GFA	sqm	47,968
Total energy intensity	MJ/m2.a	315
Total energy intensity	kWh/m2.a	87.5
Construction cost	$/sqm	$3,523
Electricity share of enduse:	%	80%
Stated building value	$m	$335
Australian excellence		
Energy consumption	MWh/y	1750
Total energy intensity	MJ/m2.a	131
Total energy intensity	kWh/m2.a	36.4
Percentage reduction over base case	%	58.3%
Construction cost increase (est.)	%	4.7%
Implied construction cost	$/sqm	$3,689
Incremental cost	$/sqm	$166
Electricity share of enduse:	%	90%
Global excellence		
Energy consumption	MWh/y	1100
Total energy intensity	MJ/m2.a	83
Total energy intensity	kWh/m2.a	23
Percentage reduction over base case	%	74%
Construction cost increase (est.)	%	6.7%
Implied construction cost	$/sqm	$3,779

[131] On a purchased energy basis. Actual energy consumption energy intensity is identical to the global excellence case.

Parameter	Units	Value
Incremental cost	$/sqm	$235
Electricity share of enduse:	%	95%
Net zero		
(Purchased or external) energy consumption	MWh/y	0
Total energy intensity[132]	MJ/m2.a	0
Total energy intensity	kWh/m2.a	0
Percentage reduction over base case	%	100%
Construction cost increase (est.)	%	8.2%
Implied construction cost	$/sqm	$3,832
Incremental cost	$/sqm	$288
Electricity share of enduse:	%	100%

Our benefit cost analysis methodology models operational energy consumption by fuel, the cost of energy consumption, and greenhouse gas emissions, annually. Embodied emissions are not calculated. For each successive performance specification above base case, incremental construction costs are modelled and compared to the resulting energy cost savings, based on ark resources simulation modelling results above. This generates a suite of results relating to the 'direct' costs and benefits, which is limited to the extra construction cost/reduced operational cost trade-off. The results are expressed as:

1. The present value of the stream of energy cost savings, discounted at 7% real annually;
2. The present value of incremental construction costs (modelled as incurred in the first year, and therefore not discounted);
3. The present value of net (direct) benefits (= #1 – #2);
4. The benefit cost ratio (= #1/#2);
5. The internal rate of return (IRR) on the additional construction cost investment (which effectively represents the real interest rate earned over time in return on that investment – in this case, limited to the direct value of energy savings only).

Energy Prices

Electricity and gas prices are taken from current **pitt&sherry** modelling work being undertaken for the Australian Energy Markets Operator (AEMO) in the context of its forthcoming electricity and gas forecasts. The projections are attributable to **pitt&sherry** and not to AEMO. We assume, for the Melbourne building, a real (that is, inflation-adjusted) electricity price of $0.212c/kWh in 2017, rising to $0.236c/kWh over the longer term. Note that this includes an estimate of both the fixed and variable components of the retail price. We note that owners corporations are likely to be able to achieve lower prices for the energy component of prices for common area consumption than residents will for their apartment electricity use. We also use an average rate that may not capture the value of cost implications of time of use tariffs and standing charges like peak capacity charges. They also assume no carbon price in future. These assumptions could be relaxed – if good data could be obtained regarding the actual pricing paid by the two reference buildings – but this would not be expected to have a significant impact on the benefit cost analysis results.

[132] On a purchased energy basis. Actual energy consumption intensity is identical to the global excellence case.

The Melbourne gas price is assumed to average $16.67/GJ in 2017 and remaining broadly at that level through time, again in real terms. This is also a conservative assumption. Energy prices in Sydney are quite distinct from those in Melbourne and generally higher, a factor which does impact on the benefit cost analysis results below. For the Sydney building we assume an electricity price in 2017 of $0.241c/kWh, rising to $0.248c/kWh over the longer term, while gas prices are assumed to be $29.97/GJ in 2017 and falling modestly to $27.37/GJ over the longer term.

Greenhouse Intensity Factors

Greenhouse intensity factors are again taken from our recent work with AEMO. The underlying and historical source is the Australian Government's National Greenhouse Accounts (NGA) Factors Workbook. To the historical (2015) actual values for 'as generated' emissions intensity of electricity by state, we add a 7% loss factor to represent 'delivered' emissions intensity. 2016 values are set at 0.9 t CO_2-e/MWh in Sydney and 1.23 t CO_2-e/MWh in Melbourne. We then represent an expectation of falling emission intensity of grid-supplied electricity in a simple, linear manner, assuming that these values fall by 0.01 t CO_2-e/MWh annually every year to 2050, reflecting a general expectation of rising renewable energy shares in electricity production.[133] The emissions intensity of gas consumption is set using the NGA Factors Workbook reference value of 51.33 t CO_2-e/GJ.

Cost Estimation

The estimation of additional or incremental costs associated with the above-baseline performance specification building forms was carried out based on a highly detailed actual cost break-down of EQ Tower. This enabled all cost classes not affected by energy performance – like demolition, groundworks, piling and site retention and indeed many other cost classes – to be set aside. For the relevant cost classes – glazing, facade, whitegoods/appliances, electrical services, mechanical services and vertical transportation services – we applied cost uplift factors based on the analysis in Section 4.6 above and Chapter 3, and summarised in Table 14 below. We assumed similar percentage cost uplifts for the Sydney building, although BiPV costs are lower due to the lower facade area covered.

We note that careful, quantity surveyor cost estimates could be commissioned, and would indeed be useful to validate the above estimates. However, such as exercise is beyond the scope of the current project. Knowing that, we focused on incremental cost assumptions in our stakeholder consultations, and the majority of industry stakeholders felt that our assumptions are conservative, and that total incremental costs could be lower than estimated, even today. Some, however, expressed caution about these estimates and called for further research in this important area. We do note that the results align well with recent benefit cost analysis of 6 star offices, where changes in energy performance and incremental cost fall in-between the Australian and Global Excellence levels modelled here. That is, Global Excellence is here modelled to be somewhat higher than 6 star, while Australian Excellence is somewhat less, in terms of improvement in performance over minimal compliance.

[133] The value represent an assumption, not a forecast.

Table 17: Incremental Costs (relative to minimum compliance)

Cost Element	Australian Excellence	Global Excellence	Net Zero
Glazing	10%	20%	20%
Facade	10%	20%	20%
Whitegoods/appliances	10%	20%	20%
Electrical services (incl. lighting)	30%	40%	40%
Mechanical services (incl. HVAC)	20%	20%	20%
Vertical transport	20%	20%	20%
BiPV	-	-	+1.5% of total construction cost (1.1% in Sydney)
Total incremental cost (Sydney):	4.7%	6.7%	7.8%
Total incremental cost (Melbourne)	4.7%	6.7%	8.2%

NB: m^2 refers to gross floor area in each case, and costs are incremental or additional to base case. Base case costs are different between the two buildings.

The 7.8% - 8.2% incremental cost range estimated, to reach net zero relative to the minimum compliance base case, is equivalent to between $249/sqm - $288/sqm in absolute terms. We stress, however, that these are estimates only, and we recommended that quantity surveyor cost calculations, as well as industry expertise, are brought to bear on these estimates.

A US source, the *Net Zero and Living Building Challenge Financial Study*, cites incremental costs for net zero in that market in the 5% - 19% range. As in this Report, that study finds that the return on investment in net-zero is higher than that available for high levels of energy efficiency.[134]

As noted earlier, a City of London study found incremental costs in the 1 – 1.4% range, while a European Commission report (2013) found incremental costs for net zero apartment buildings between 0 and 27 Euros per square metre.[135] A study by the National University of Singapore and the Singapore Institute of Real Estate Studies found a more nuanced result in that country: "While we observe a statistically significant green price premium associated with the Green Mark-rated dwelling units...further investigation point out that the premium is realised largely during resale transactions, and is much smaller during the presale phase. Therefore, developers only reap part of the benefits from their energy-efficiency investments, and achieve a lower economic return."[136] We note that the strong consumer secondary demand for 'green' apartments suggests that there are increasing levels of consumer engagement with this product in that market over time. We take up the issue of 'the developers' perspective' in Chapter 6 below.

Stakeholder feedback on the draft report included a request for a detailed ranking of all technical treatments by cost and cost-effectiveness. Such information could be compiled into useful formats such as

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[134] http://newbuildings.org/wp-content/uploads/2015/11/ZNECostComparisonBuildingsDC1.pdf

[135] Bio Intelligence Service and Institute - European Environmental Policy, *Energy performance certification in buildings and their impact on transaction prices and rents in selected EU countries*, commissioned by the European Commission (DG Energy), April 2013.

[136] National University of Singapore and the Institute of Real Estate Studies, IRES Working Paper Series, *Economic Returns to Residential Green Building Development: The Developers' Perspective*, July 2013.

waterfall charts, marginal abatement cost curves or others. We agree this would be extremely valuable, but it would be a significant undertaking in its own right and was not able to be accommodated within the scope of this project. It would make a very valuable follow-on project, as it would provide useful information in a form of direct relevance to designers and developers.

At the same time, it is important to recall the limitations of such analyses. Almost every treatment or building efficiency technology will realise different savings and incur different costs, depending upon the particular building context into which they are introduced; along with the climate zone, building occupancy and use patterns and many other variables. At best, then, such curves can only ever be illustrative, with care needed to avoid making presumptions about the expected performance of any given solution in any given building.

- ***Avoided Network Expenditure***

With lower demand for energy associated with more energy efficient, and ultimately net zero, high rise residential buildings, investment in electricity network and generation infrastructure could be deferred or avoided. This amounts to an additional economic benefit attributable to the efficiency measures.

During consultations on the draft report, it was pointed out that the developer is in a position to capture this avoided cost, making this a direct benefit. In a competitive market, this avoided cost would translate into lower cost apartments, although in reality this benefit is likely to be shared between the developer and future owners. In any case, such an avoided cost amounts to a direct benefit, and we treat it this way in our benefit cost analysis.

Ausgrid also noted that network expenditure in its franchise area – but to varying degrees across Australia – is expected to be modest in the immediate future, given the high level of investment in the past, together with an expectation of modest growth in electricity and peak demand in the next few years. We accept this point but would expect this to be a temporary phenomenon, and therefore we consider it reasonable to assume some avoided network expenditure costs in our benefit cost analysis.

Some industry stakeholders noted that there are many potential values created by buildings that feature distributed energy generation and potentially also storage, associated with smart controls and smart-grid/smart city applications. Benefits such as reducing energy losses in distribution and transmission networks, contributing a range of ancillary services (such as local voltage or frequency support), reducing the need for remote generation, reducing demand peaks and associated spot market price spikes, actively participating in demand side management measures, as well as reducing expenditure on local network infrastructure such as distribution transformers, could all potentially be recognised and valued in future, although this is difficult under the present National Energy Market rules. At the same time, some features like induction hobs, and potentially electric vehicle recharging in future, can add to peak demands. A whole of building approach, taking into account anticipated and then actual load profiles (ie, features that reduce peak load as well as increase it); moves towards (genuine) cost reflective network pricing; and steps to simplify and 'even up' the consumer/developer-network negotiation process (eg, effective ombudsmen, consumer challenge panels, etc) would all assist to deliver optimal outcomes.

Indeed, during this project, developers noted that they find it exceedingly difficult to negotiate with electricity network businesses. This was attributed to the complexity of network pricing and operational requirements, but also to the fact that the network businesses, understandably, have a risk-averse approach to anything that they consider could threaten the reliability of electricity supply (this is a primary

KPI for them). It is also the case that the key business model for networks is to expand their regulated asset base, and this tends to push them towards infrastructure based solutions. Aware of this, however, governments are placing increasing requirements on network service providers to at least investigate non-network solutions (such as demand management for example), and this opens up the potential for more constructive dialogue.

Finally, we note that a similar avoided cost effect could occur for gas savings, as a reduction in gas demand, or removal of the need for a gas connection at all, frees up demand for other consumers and, at the margin, reduces prices. However, the potential for avoiding gas network costs through efficiency measures would only occur in specific circumstances, such as when the gas network was close to fully utilised. We have therefore not modelled such an effect. Gas demand from the modelled buildings, even in their base case formats, is very modest in any case.

The methodology for calculating the value of avoided electricity network costs that we use is ultimately based on quantitative research linking different types of avoided demand to amounts of avoided electricity infrastructure capacity investment. It should be noted that the underlying relationships can vary through time, and the linkage between energy demand and peak load is complex and difficult to forecast. It cannot simply be assumed that avoided demand always leads to the same quantum of reduction in required system capacity – this is also affected by the load shape in different regions, the nature of generation technologies supplying those regions, reserve and other security requirements, load shedding capabilities and other factors. Therefore the modelled estimates should be treated as indicative only, and we note again Ausgrid's caution that network expenditure in the short term is expected to be low in any case.

Modelling the connection between energy efficiency and the economic benefits of peak load reduction involves two steps: firstly, to link energy efficiency improvements to reductions in consumer demand; and secondly, to link reductions in consumer demand to reduced network costs. Recent studies in Australia (UTS 2010) and (EES 2011) have addressed these issues to develop estimates of the economic benefits of peak load reduction as a consequence of energy efficiency. Both studies drew on the concept of the Conservation Load Factor (CLF) (Koomey 1990) which is a method of estimating the likely energy savings in peak load due to the application of an energy saving measure.

The CLF concept was developed in order to provide a simple basis for estimating the peak load savings and consequential financial benefit from a reduction in peak load. The CLF is defined as the average annual load savings divided by the peak load savings, where both are based on measured data or the output of an hourly simulation model:

CLF = [Annual Energy Savings (kWh)/8760]/Peak Load Savings (kW)

The concept is analogous to a demand side capacity factor, or a measure of the peakiness of end use. For end-uses like refrigeration, with a relatively flat based load throughout the year, values of 0.7 are typical. For end-uses such as residential air conditioning, with a relatively peaky performance throughout the year, the CLF value is much lower, typically between 0.01 and 0.1. High air conditioning demand is weather related, so that air conditioning use is peak coincident with large peak demand relative to total annual energy used. Typical residential space conditioning CLF values are very low, such as 0.05, which indicates a very 'peaky' load. However, larger and high-rise residential buildings that are space conditioned 24/7 are likely to be less peaky than a Class 1 (stand alone) dwelling, including due to their greater thermal inertia.

Consistent with other recent modelling, we adopted a conservative CLF value of 0.4. A value of $0.31 million/MW.a is assumed for value of electricity infrastructure savings, following UTS (2010).

Indirect Benefits

Next we consider a range of indirect benefits attributable to this investment, including avoided greenhouse gas emissions and the expected lift in the capital value of higher performing and higher rated buildings.

- ***Avoided Greenhouse Gas Emissions***

In benefit cost analysis, strictly what should be modelled is the avoided damage costs associated with reduced greenhouse gas emissions. However, there are no authoritative estimates of the damage function associated with incremental changes in greenhouse gas emissions, owing to the global nature of that function, the vast number of damage elements involved around the world and uncertainty as to the speed and severity of impacts, particularly in specific locations. It is likely that the avoided damage costs per tonne of greenhouse gas abatement are very large indeed. However, given the uncertainty, a common proxy is to assume that carbon prices – or proxies for the carbon price – adequately represent at least what is known today about this damage function. Australia has in recent years abolished its carbon pricing system, at a time when the prevailing carbon price was around $25/t CO_2-e. For this study we assume as a proxy or shadow carbon price a value of $16/t CO_2-e, which is a typical figure paid for credible and certified offsets in Australia. The rationale is that, should a building owner or manager wish to represent a building as 'net zero', they would be required to purchase offsets to cover any emissions not abated through energy efficiency or renewable energy investments. Therefore the price of offsets represents the marginal cost of abatement. This approach is broadly consistent with the emerging NCOS framework for carbon neutral buildings discussed in Chapter 2 above.

- ***Enhanced Capital Values***

In our benefit cost analysis, we do not calculate any benefit from the expected higher value of net-zero buildings. This may appear odd, as there is evidence from a range of different building classes – at least offices and residential, although not specifically *high-rise* residential – that higher energy performing buildings, and high rated buildings, have enhanced capital values when compared with lower-performing, lower-rated buildings in similar markets.[137, 138,139] This evidence is unsurprising for at least two reasons: first, higher-performing buildings typically demand a cost premium, and rational owners/developers would not incur such costs unless they expected to at least recover them in the market; second, from the consumers' perspective, these buildings offer lower lifetime operational costs, which means that it would be rational for tenants/occupants to pay more upfront to avoid these operational costs.

While the capital value of a building is critically important to its owner, and to investors and developers of new high-rise residential buildings, we leave this out of our benefit cost analysis because an increase in building (or other asset) value is generally considered a private rather than a public benefit. In economic terms, it represents a transfer of value rather than a net increase. For example, the higher value presents a benefit to the current owner but an equal and opposite cost to a new owner. Second, there is a view – based on economic theory rather than observation – that the lift in the capital value of a more energy efficient building simply reflects the discounted present value of avoided future energy costs. On this view

[137] For a key Australian reference, see G. Newell et al, *Building Better Returns: a study of the financial performance of green office buildings in Australia*, API, September 2011.
[138] DEWHA/NSEE, *Energy Efficiency Rating and House Price in the ACT*, 2008, prepared by the Australian Bureau of Statistics.
[139] http://www.thefifthestate.com.au/innovation/case-studies/how-to-make-old-houses-energy-efficient/84366

– espoused for example by the Australian Government's Office of Best Practice Regulation best practice guidelines for benefit analysis[140] – the enhanced capital value is not an additional benefit to the energy savings and therefore should not be counted twice.

Stakeholder feedback on this issue was mixed, with some doubting that developers would be able to access such premiums in the marketplace, and others the opposite. Some noted that the modelled incremental costs are low when compared to developer's margins. Our view is that such margins vary widely, and it is not reasonable to expect developers to absorb these costs. Net-zero creates benefits for apartment buyers as well as the wider public, and so a key question is the willingness of those buyers to pay the premiums required to deliver net-zero buildings. Ideally, some applied 'willingness to pay' research would be undertaken to explore this issue further, as is recommended under *Further work* in Chapter 6. There is at least anecdotal evidence that many consumers are willing to pay for public benefits – including greenhouse gas reduction – and not only for private ones, as is assumed in classical economics. Clearly, the 'values-case', and not just the 'business-case', has to be presenting in an authentic and compelling manner.

Terminology

'Net social benefit' refers to the sum of the present values of all of the classes of direct and indirect benefit noted above, less the present value of additional construction costs, and less the expected increase in building value. 'Social benefit cost ratio' expresses the sum of the present values of direct and indirect benefits, less the expected increase in building value, over the present value of incremental construction costs. The 'social return on investment' represents the effective 'interest rate' (in terms of a flow of social benefits through time, again excluding the expected lift in building value) earned by the initial investment of additional construction costs.

5.2 Results

5.2.1 Sydney

Table 18 below provides key benefit cost analysis results for the Sydney building. Generally we observe that net zero is more cost effective that either Australian or global excellence; while global excellence is slightly less cost effective than Australian excellence.

However, *all of these performance levels, including net zero,* are shown to be *cost effective on the basis of direct costs and benefits alone* – albeit not by large margins – for the Sydney building. This reflects the fact that the Sydney base building has a lower level of modelled thermal energy performance than the Melbourne building, and therefore it is less costly, in relative terms, to improve its performance.

The absolute values – in terms of both costs and benefits – are lower for the Sydney building than for Melbourne primarily because it is a smaller and lower cost/value building. Despite this, the net zero building offers a net financial surplus, on direct costs and benefits alone, of over $1 million, while the net social value of that building performance level, compared to the base case, is just under $6 million; a social benefit cost ratio of 1.8 and a social return on investment of 14% real. These are healthy numbers by any estimation.

[140] Australian Government Department of the Prime Minister and Cabinet - Office of Best Practice Regulation, *Guidance Note: Cost Benefit Analysis*, February 2016.

In terms of avoided energy costs per apartment, we estimate annual energy savings of around $2,000 per year per apartment, reflecting larger apartment sizes and lower starting point energy efficiencies, with these two factors offset somewhat by Sydney's milder climate relative to Melbourne.

While we observe that the three performance levels offer similar social benefit cost ratios and social returns on investment, the *highest* social value is achieved when this building is built as a net zero building, and this by a comfortable margin of over $1.2 million.

Table 18: Sydney Building: Key Modelling Outputs

Parameter	Units	Value
Australian excellence		
Direct benefits/costs		
Present value of direct benefits (incl. avoided network costs, as below)	$	$4,677,046
Present value of avoided network costs	$	$1,123,324
Present value of costs	$	$4,280,400
Net Present Value	$	$396,646
Benefit Cost Ratio		1.09
Internal Rate of Return		7.8%
Indirect benefits/costs		
Present value of avoided ghg emissions	$	$3,898,474
Net social benefit	$	$4,295,120
Social benefit cost ratio		2.0
Social return on investment	%	15%
Global excellence		
Direct benefits/costs		
Present value of direct benefits (incl. avoided network costs, as below)	$	$6,181,606
Present value of avoided network costs	$	$1,502,353
Present value of costs	$	$6,082,865
Net Present Value	$	$98,741
Benefit Cost Ratio		1.02
Internal Rate of Return	%	7.1%
Indirect benefits/costs		
Present value of avoided ghg emissions	$	$4,614,124
Net social benefit	$	$4,712,865
Social benefit cost ratio		1.8
Social return on investment	%	14%
Net Zero		
Direct benefits/costs		
Present value of direct benefits (incl. avoided network costs, as below)	$	$8,085,873
Present value of avoided network costs	$	$2,001,469
Present value of costs	$	$7,084,235
Net Present Value	$	$1,001,638
Benefit Cost Ratio		1.14
Internal Rate of Return	%	8.3%
Indirect benefits/costs		
Present value of avoided ghg emissions	$	$4,928,754
Net social benefit	$	$5,930,392
Social benefit cost ratio		1.8
Social return on investment	%	14%

5.2.2 Melbourne

The key results of the benefit cost analysis for the Melbourne building are summarised in Table 19 and then analysed below.

Table 19: Melbourne Building: Key Modelling Outputs

Parameter	Units	Value
Australian excellence		
Direct benefits/costs		
Present value of direct benefits (incl. avoided network costs, as below)	$	$7,832,982
Present value of avoided network costs	$	$2,029,899
Present value of costs	$	$7,946,380
Net Present Value	$	-$113,398
Benefit Cost Ratio		0.99
Internal Rate of Return	%	6.9%
Indirect benefits/costs		
Present value of avoided ghg emissions	$	$7,426,629
Net social benefit		$9,313,230
Social benefit cost ratio		1.9
Social return on investment	%	15%
Global excellence		
Direct benefits/costs		
Present value of direct benefits (incl. avoided network costs, as below)	$	$10,100,987
Present value of avoided network costs	$	$2,632,614
Present value of costs	$	$11,292,580
Net Present Value	$	-$1,191,593
Benefit Cost Ratio		0.89
Internal Rate of Return	%	6.0%
Indirect benefits/costs		
Present value of avoided ghg emissions	$	$8,814,104
Net social benefit		$7,622,511
Social benefit cost ratio		1.7
Social return on investment	%	13%
Net Zero		
Direct benefits/costs		
Present value of direct benefits (incl. avoided network costs, as below)	$	$14,437,389
Present value of avoided network costs	$	$3,820,986
Present value of costs	$	$13,858,000
Net Present Value	$	$609,809
Benefit Cost Ratio		1.04
Internal Rate of Return	%	7.4%
Indirect benefits/costs		
Present value of avoided ghg emissions	$	$9,632,643
Net social benefit	$	$10,242,452
Social benefit cost ratio	%	1.7
Social return on investment	%	13%

Australian Excellence

The Australian excellence case is shown to be virtually cost effective *on the basis of direct costs and benefits alone*, returning a benefit cost ratio of 0.99 (1 is considered cost effective) and an internal rate of return (IRR) of 6.9% real (compared to our reference discount rate of 7% real).

This result may seem remarkable, recalling that this performance level represents a 58% improvement on the base case, which is already a 6.5 star average. However, we note that it is consistent with our recent

2016 Update of the *Pathway to 2020* research where we find, inter alia, that 9 star shell performance for Class 2 buildings would be cost effective in NSW in 2019, without a carbon price, provided that incremental costs fall to zero after seven years.[141]

When the value of indirect benefits is considered, the wider social benefit associated with this lift in building performance is fully revealed. At $16/t CO_2-e, the present value of avoided greenhouse gas emissions is some $7.4 million. When this is added to the present value of direct benefits (~$7.8m), less the incremental construction costs (~$7.9m), then the net social value of this investment (in beyond baseline energy performance) is $7.3 million. This represents a social benefit cost ratio of 1.9 and a social return on investment of 15% real. As noted, these values do not include any assumptions regarding uplift in building value.

Overall, while Australian excellence performance is marginally cost effective on direct costs and benefits alone for the Melbourne building, it is highly cost effective from a social perspective.

Global Excellence

Global excellence ratchets up the energy performance to a 74% improvement over the (6.5 star average) base case, for an additional cost of some $11.3 million or 6.7%. This performance level is slightly less cost effective than Australian excellence – when only direct costs and benefits are considered – indicating that the uplift in cost has been greater, in proportionate terms, than the uplift in performance, in moving from 58% to 74% performance improvement. This result is consistent with diminishing returns as higher and higher energy performance is sought, without the use of BiPV (as in the net zero case).

Overall, however, this performance level generates a very creditable benefit cost ratio of 0.89 and an internal rate of return of 6% on the basis of direct costs and benefits alone. We conducted some sensitivity analysis and observed that if the incremental costs of this performance level were 6%, rather than the 6.7% estimated, then it would be cost effective even before considering indirect benefits.

When we consider the value of avoided greenhouse gas emissions (some $8.8 million in present value terms), the net social benefit from this performance level is nearly $7.6 million; that is, higher than the Australian excellence case. This net social value represents a social benefit cost ratio of 1.7 and a social return on investment of 13% real.

Overall, the higher energy performance associated with global excellence is slightly more cost effective than Australian excellence, from a social perspective, and slightly less so from a private or direct benefit/cost perspective. What stands out, however, is not how different the results are, but rather how similar they are – despite the fact that the global excellence performance level offers a further 16 percentage points of energy performance improvement, amounting to almost a 75% improvement over the base case – which is already above the current mandatory minimum Code level.

Net Zero

In its net zero form, the Melbourne building offers a 100% reduction in annual (purchased) energy consumption, in return for an incremental construction cost estimated at 8.2%. On the assumptions noted above, this performance level is *cost effective on the basis of direct costs and benefits alone*. That is, the combined present values of avoided energy costs (~$10.6 m) and avoided infrastructure costs (~3.8 m)

[141] http://www.nathers.gov.au/sites/prod.nathers/files/u20/Pathways%20update%20report%20-%20final.pdf

exceed the incremental construction costs (~$13.9 m), generating a net financial surplus of nearly $580k and a benefit cost ratio of 1.04.

Stakeholders asked what the avoided strata costs might be. This requires many assumptions to be made. However we can note that the average annual value of energy savings per apartment in this building would be around $1,200 in 2017, rising to around $1,320 in 2030. These values are smaller than for the Sydney building, even though the climate is more severe in Melbourne than in Sydney, due to the Melbourne building's higher starting point efficiency and smaller average apartment size.

It may be noted that net zero is more cost effective than either Australian excellence or global excellence, even before indirect benefits are considered. The explanation for this result is that the lift in energy performance (from 74% improvement in the global excellence case, to 100% in this case) is achieved more cost effectively, on average, than was the lift from 58% to 74%. This in turn implies that the BiPV solution modelled to attain net zero is more cost effective than the higher cost energy efficiency improvements that were required to attain global excellence. This is consistent with the diminishing returns to very high levels of energy efficiency improvement that we observed above.

When the value of indirect benefits is considered, the net social value created by this building exceeds $10.2 million, representing (as per the global excellence case) a social benefit cost ratio of 1.7 and a social return on investment of 13% real. However, because more energy and greenhouse gas savings are being achieved, the building in its net zero form generates a greater value of social benefit than in any other performance specification.

5.2.3 Conclusions

We stress that none of these results is cast in stone. For example, as energy efficient technologies and solutions improve their performance and reduce their cost, the opportunity to attain higher levels of energy performance cost effectively, via energy efficiency alone, will increase. At the same time, however, it is very likely that the performance and cost of BiPV will also improve, and potentially at an even faster rate than for energy efficiency, reflecting the very considerable global research effort being made in the PV area. Therefore it is also possible that the cost effectiveness of the net zero building will continue to improve at a *faster* rate than the Australian or global excellence levels of efficiency. There is no contradiction here: PV and energy efficiency technologies emerge from different markets and there is no reason why we should expect their performance and cost effectiveness to improve at the same rate through time.

Nevertheless, this detailed benefit cost analysis – conducted only on two buildings only, albeit two actual buildings – shows that net-zero high-rise residential buildings can be highly cost effective from a social perspective in Australia in today. However, a significant part of the social benefit created is avoided greenhouse gas emissions which, since the abolition of Australia's emissions trading scheme, are unpriced. This means that the investor or developer would not be paid for the social benefit that they would create by building a net-zero high-rise. As a result, they are much less likely to create it in the first place.

Net-zero high-rise residential buildings also appear to be either marginally cost effective, or else very nearly so, from a private perspective; that is, even ignoring the wider social benefits created. Very small changes to some key assumptions – and particularly to the incremental costs of achieving this performance level –

make a big difference. For example, if a thorough and careful quantity surveyor based cost estimation was undertaken, it may be that net-zero would appear even more cost-effective than portrayed here.

Stakeholders expressed the desire to have more information about the relative costs and cost effectiveness of the various strategies available to improve building performance towards net zero, and we recommend that work be done as a follow-up study. Others called for additional locations/climate zones/building designs to be examined, while some called for specific strategies – such as reduced window-to-wall ratios to be market-tested. We take this as evidence that there is considerable interest within the buildings community in the concept of net-zero high-rise, and at least a potential appetite to take it forward.

Chapter 6 sets out how this could be done.

6. Pathways to Net-Zero High-Rise in Australia

6.1 Introduction

Thus far, this project has established that it is technically feasible, even today, to achieve net-zero performance for high-rise residential buildings in Australia. We stress that that may not *always* be the case – at least using the stricter, US definition of net-zero – because the technical solution relies on building-integrated PV, and this strategy will not always be available, for example at a site that is significantly over-shaded. That said, precinct-scale or remote renewables may be acceptable substitutes for BiPV, and this is likely to be more cost effective, at least for the time being.

Second, we have shown that net-zero high-rise residential buildings are easily cost effective in Australia today from a social perspective, but – subject to further research on costs – only marginally so from a purely private perspective.

The question, then, is whether there are sufficient incentives for the development of net-zero high-rise residential buildings in Australia in the short term, or whether additional incentives are required.

When we consider the total pie of social benefits created by such buildings, they are split three ways:

1. The greenhouse benefit would be freely transferred to the wider public without any payment in return. Some apartment buyers may nevertheless be willing to pay a (justified) premium to secure a genuine greenhouse benefit for the planet – that is a motivator for some potential residents.
2. The avoided energy costs would be captured by residents, but these are not currently large enough on their own to justify the (expected) additional costs, at least in the short term until costs come down. In any case, the costs accrue to the investor. Potential residents cannot express their willingness to pay for such energy performance – and the other values created such as reduced emissions – unless investors/developers first accept the risks and costs of building them. Also, the paucity of suitable ratings tools – covering the whole building performance – for high-rise residential buildings, together with the absence of mandatory disclosure of whole building performance, makes it harder for potential residents to assess and have confidence in the value proposition on offer.
3. Any avoided electricity network costs effectively accrue to the developer and investor, and would have the effect of reducing the cost of construction.

The remedy for the first issue is unambiguous: put a price on carbon pollution, so that there is a fair return to those who choose to invest in pollution reduction. Some programs, such the Emissions Reduction Fund federally, or the Energy Savings Scheme in NSW, can create some financial benefits for abatement, but no programs is an effective substitute for a carbon price. Eligibility criteria often create barriers to the uptake of program funds; there are administration and compliance costs to be managed; and the funds themselves are budget-limited and unpredictable in duration. Finally, the scale of the financial incentive on offer is often too small to be effective in inducing significant investments, leading to program funds being spent at least in part on business as usual activities, such as upgrading the efficiency of equipment at end of the old equipment's economic life.

For the second issue – incremental costs and willingness to pay – there are three underlying concerns: first, there is uncertainty about what the actual costs will be; second, there is uncertainty about the extent to which apartment buyers would be willing to pay these costs, whatever they are; and third, the costs need to be reduced as far as possible to accelerate uptake.

Uncertainty can be reduced, at least in part, through market and cost research, as proposed in Chapter 5. If, for example, there is evidence that buyers have been willing to pay for higher energy performance, specifically in high-rise buildings, or that there is a faster rate of sales of apartments in such buildings, this would improve the business case for investors. At the same time, the absence of such evidence does not mean that these value streams are unavailable. Rather, it may mean that the research has not been done. Also, we need to be aware that residents can only express their willingness to pay to the extent that the market offers them choices. There is no direct or historical evidence about consumers' willingness to pay for net-zero, as that choice is not yet available to them. This means that we must proceed by analogy and work with imperfect data.

Beyond market and cost research, however, there is also an extent to which *actual* costs need to be discovered during the design and construction process. There is no real substitute for experience and the learning that it creates. This means, however, that there is considerable 'first of a kind' risk for investors and/or developers, at least until such time as the market develops and matures. These risks are exacerbated by the relatively immature state of Australia's high-energy-performance building market, when compared to other countries, reflecting our relatively low energy performance standards and hence limited demand for extensive expertise in this area amongst building professionals.

If governments wish to promote the accelerated roll-out of net-zero high rise residential buildings, they could effectively 'buy down' this risk. Further, there is a whole array of proven strategies for market transformation to reduce the cost of high performance buildings and building components, that were touched in Chapter 1 and which are expanded upon below.

What is clear is that policy gaps – such as the absence of carbon pricing, mandatory disclosure, market transformation strategies, limited ratings tools and others (discussed further below) – together with the market risks, will constrain the rate of development of net-zero high-rise residential buildings in Australia.

However, such a slow rate of uptake of high and net-zero performance buildings in Australia is not inevitable – rather it would represent a deliberate public policy choice to forego the net social benefits, including economic and environmental benefits, available. A decision *not* to make a policy is also a policy decision. Other countries around the world have consciously used well-designed, executed and co-ordinated policy mechanisms to help create a pathway to market for high-performance, or in this case net-zero performance, buildings: to make it a new business-as-usual.

6.2 A Strategic and Integrated Approach

Given the challenges but also the opportunities described in this report, we have identified four key elements that together comprise a strategic and integrated approach to achieving the goal of accelerating the uptake of net-zero high-rise residential buildings in Australia. The four elements are summarised in Figure 79 below. Few of these initiatives are able to be implemented by local government, and many will require action by the Australian and State Governments in co-operation with industry.

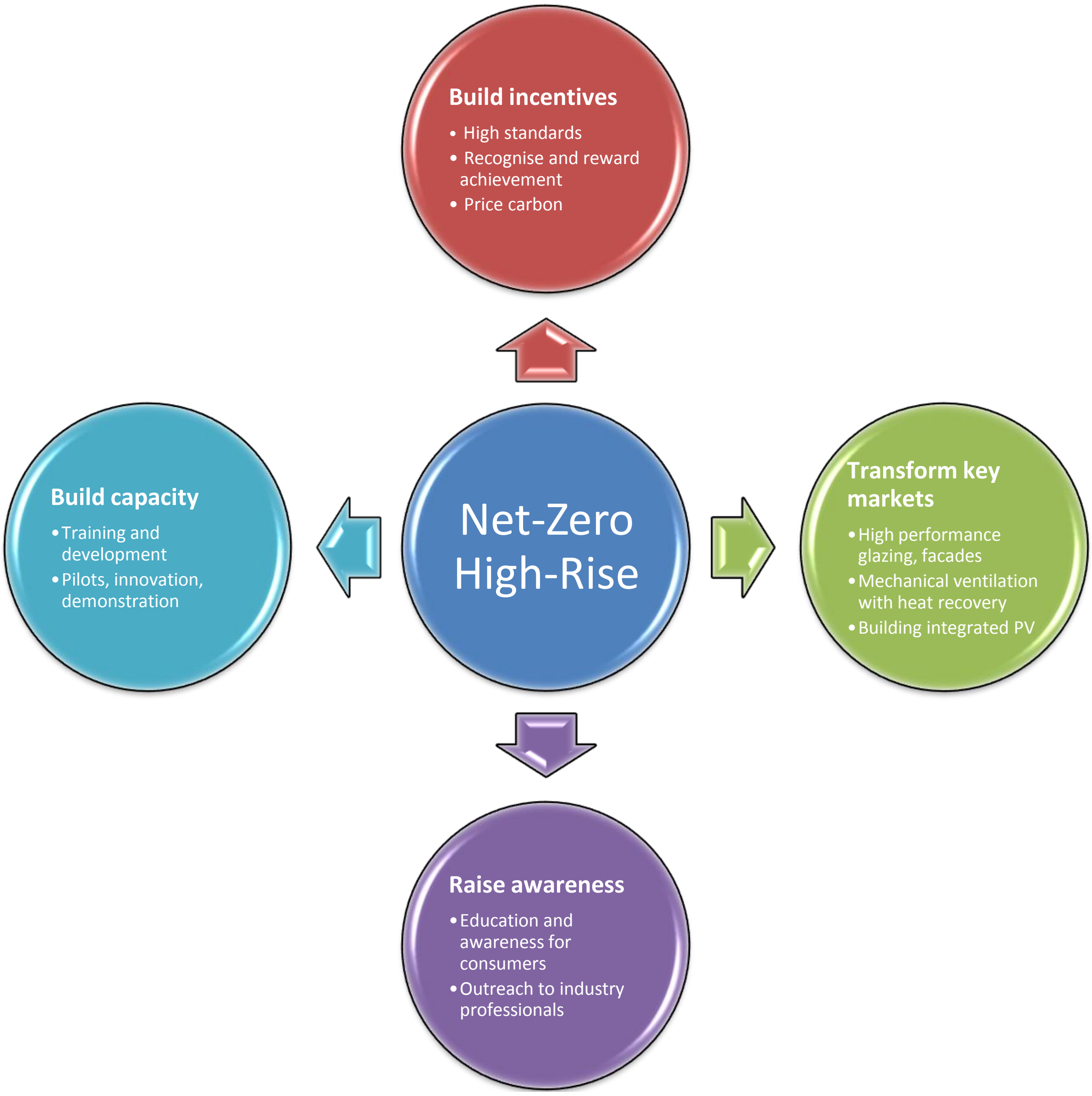

Figure 79: Achieving Net-Zero High-Rise in Australia

6.2.1 Build the incentives

Incentives drive markets and innovation, both for consumers and for industry. If incentives are strong, then innovation and progress can be rapid; if incentives are weak, technical opportunities will not be taken up, and there will be no market reward or demand for innovation.

The key strategies that can build incentives for net-zero high-rise in Australia include:

1. Set high standards
2. Recognise and reward high achievement
3. Put a price on carbon.

Set high standards

Section 1 noted that energy performance standards in the National Construction Code for Class 2 (apartment) buildings in Australia are particularly low.[142] There is also a split between the ratings for

[142] pitt&sherry, *Pathway to 2020 for Increased Stringency in New Building Energy Efficiency Standards: Benefit Cost Analysis*, 2012 (2016 update forthcoming).

apartments (under NatHERS) and the general requirements of Section J of the Code that apply to common areas. Both standards were set back in 2009 (and adopted from 2010) and are out of date – yet there is no plan to update these requirements in Australia before at least 2019. There is also a concern that energy performance standards (as distinct from other performance areas) under the BASIX scheme in NSW may be lower again.

In a 2016 update to the 2012 *Pathway to 2020 for Increased Standards in New Building Energy Efficiency Standards: Benefit Cost Analysis*, commissioned by the Australian Government, **pitt&sherry** has identified that there is considerably greater scope to cost-effectively lift energy performance standards for Class 2 buildings in Australia than there is for Class 1 (detached, semi-detached) houses.[143] This partly reflects building physics and the higher energy intensity of Class 2 buildings, but also the lower stringency of current standards. Setting higher minimum standards will help build the skills and knowhow in industry required to achieve still higher and net zero performance in the medium term.

Around the world, there is recognition that high standards lead to innovation and high performance, while low standards generally lead to poor performance.[144] A key opportunity in Australia would be to move from the current 'minimum necessary' philosophy that informs the National Construction Code to one based on a 'maximum cost-effective' approach. The next Code change window opens in 2019, but the key decisions about ambition levels will be made in the next 12 months. The need to update the Code is identified as an action within the *National Energy Productivity Plan*, however the quality of the outcome remains to be shaped.

Recognise and reward high achievement

In markets, recognition can be its own reward. This is essence of branding. At this time, 'net-zero' is an unknown brand/product in Australia. There is long term investment to be undertaken in building the public recognition of this idea. The public good nature of the outcome justifies at least some public investment in bringing it about.

While there are many ways to recognise and reward high achievement in this area, some key opportunities include:

- Ensuring that there are clear and useful ratings tools for this specific class of building, including to demonstrate the savings in running costs;
- A policy of mandatory disclosure of building energy performance for this class of building (now only applying to offices in Australia) would drive the market demand for and supply of higher performance high-rise residential buildings;
- One-off incentives, prizes and public recognition of exemplar developments.

Carbon pricing

While a 'macro' solution, the absence of a price on carbon is one factor contributing to low market demand for low- and zero-carbon solutions in all areas of the Australian economy. Emissions of carbon are associated with significant economic, social and environmental costs, and not just locally, but globally. However, there is little reason or ability for business or households to change their behaviour, in ways that would reduce those costs, when the costs are hidden to them. Pricing carbon empowers markets – both

[143] http://www.nathers.gov.au/sites/prod.nathers/files/u20/Pathways%20update%20report%20-%20final.pdf
[144] This phenomenon was widely publicised in Michael E. Porter's *The Competitive Advantage of Nations*. The Free Press, New York, 1990.

producers and consumers – to respond, in ways that work best for them, to the global challenge. Some will pay the price and continue with high-carbon lifestyles and practices. Others will change their practices, finding innovative solutions that might end up costing less than their current ones – as when more energy efficient buildings are built to replace less efficient ones for example.

Whilesoever carbon emissions remain free in Australia, those who do take action to reduce emissions – including by building net-zero high-rise residential buildings – are not rewarded for their efforts, despite the fact that they are creating social and environmental value, by reducing the costs associated with climate change. Placing a reasonable price on carbon will enable the market to participate in and drive the change process.

At the same time, just pricing carbon – while not taking the other measures recommended in this integrated pathway – would not be a least-cost path. Other measures, such as market transformation, and efficiency standards, work in different ways to carbon pricing, liberating other drivers that might not be activated, except at very high carbon prices. What carbon price, for example, would have been necessary to persuade consumers to stop using incandescent lamps? With lighting representing a trivial component of household budgets – well below a threshold where time and effort might be spent actively seeking optimal solutions – then even a very high carbon price may have been insufficient. Yet a simple regulatory change achieved the same outcome at a fraction of the cost and in a very short time. Carbon pricing would reinforce and support the other measures by increasing the reward for carbon saving effort.

6.2.2 Transform key markets

The market transformation approach has a proven track record overseas in 'tunnelling through the cost barrier' in many different markets.[145] Even in Australia, this approach was evident in the mandatory phase-out of incandescent lighting – an area where Australia led the world. This led to the rapid deployment of more efficient lighting technologies, particularly compact fluorescent lamps, and drove down the costs of that (then) new, high-efficiency technology.

Cost and scale barriers constrain the update of high-performance building products in Australia, consigning them to high-cost and small-scale market niches. That this is not the case in other countries is not widely understood in Australia. The successful policy models that have led to these outcomes overseas can be replicated in Australia. While there would be numerous candidates for the application of market transformation strategies in Australia, the following opportunities offer the prospect of 'systemic' change:

- High-performance glazing
- High-performance envelopes, more generally
- Mechanical ventilation with heat recovery (MVHR).

Glazing is a critical element of almost every building in Australia and, as noted in Chapter 3, it is particularly important for high-rise residential towers, as occupants invariably seek to take advantage of views. This drives a strong market preference of high window-wall ratios but, as noted in that chapter, this preference, combined with the poor availability and high cost in Australia of high-performance glazing, can lead to poor thermal efficiency and excessive energy consumption. Rather than trammel consumer preference, an alternative approach would be to fully commercialise, increase the supply and drive down the costs of high-performance glazing in Australia. A combination of higher mandatory standards, specifically for glazing; time-bound incentives for windows producers to invest in new production processes; and increased

[145] Attributed to Amory Lovins, Rocky Mountains Institute.

support for consumer awareness strategies such as the Windows Energy Rating Scheme, would be key elements of such an approach.

High-performance glazing, of course, forms a key element of a high-performance skin or facade, which is particularly crucial for high-rise buildings due to the high wind loading on their facades and the risk of poor air-tightness. Introducing and enforcing high standards for air-tightness, supported by appropriate compliance testing solutions (eg, pressurisation and thermal imaging, heat decay testing); insulation (uninsulated facade panels are common-place in Class 2 buildings in Australia) and other elements such as avoidance of thermal bridging, and use of appropriate shade structures, at least on Northern and Western facades, could rapidly transform the performance of this most critical building element.

Finally, air-tight and high-performance facades require mechanical ventilation ("build tight, ventilate right"). A shortcoming in the energy efficiency of many Australian residential buildings, high- and low-rise, is the lack of heat recovery on ventilation air – in some cases, a lack of adequate ventilation at all. As noted, mechanical ventilation with heat recovery (MVHR, also known as trickle ventilation) is a key strategy that underpins the passivhaus solution. This is equally applicable in Australia due to similar 'delta T's' (temperature differences), albeit shifted into a higher temperature band in Australia as compared to parts of Europe and North America. This technology is available in Australia but, just like for high-performance glazing, awareness and availability is low and unit costs relatively high, as is the common fate of niche products. Market transformation is the strategy for busting high-performance products out of niche markets and into the commercial mainstream.

Changing the Development Process

Industry feedback on the draft report confirmed that a key real-world constraint for developers is the reality of highly competitive markets, where cost cutting and profit maximisation are the main drivers. It was noted also that the nature of key project development processes – like tendering for the supply of equipment – typically offer little or no opportunity or incentive for more energy efficient or sustainable solutions to be selected. Also, it was noted that engineers are often only brought into the design/specification process late in the piece, after key decisions have already been made, with little opportunity therefore for their skills to be employed to achieve optimal energy outcomes. Finally, some stakeholders reported examples of poor construction quality where, for example, very high performance (and expensive) glazing units have been poorly fitted, allowing for significant air infiltration and heat loss.

Some of these issues reflect the fact that there has been little demand for very high performance buildings in Australia to date, and therefore some of the skills and know-how required to operate in such an environment are not yet widely spread. When market demand is higher, it might be expected that skills will be upgraded to match. However, a superior approach would be for industry associations, training institutions and governments to work together, in a co-ordinated manner, to ensure that skills are available on a just-in-time basis as required by market and regulatory developments.

We note that there may well be opportunities for industry to lead reform in the procurement process area, for example by developing and popularising model procurement processes. Ratings tools such as Green Star and NABERS could potentially contribute in this area as well, as they are already key partners with developers seeking high performance outcomes.

Further, some stakeholders noted with concern that erroneous or even fraudulent claims could be made about 'net zero' buildings, in order to attract building premiums, if there is not a good system of compliance or assurance in place. We noted earlier that similar concerns exist with performance claims made about new buildings today, regardless of their targeted energy performance, unless 'after the fact' ratings tools, like NABERS or Green Star Operational, are used.

Beyond that, policy initiatives such as mandatory disclosure have the potential to 'change the game' when it comes to procurement, by enabling developers to realise premiums for high-rated and net-zero buildings. This requires that ratings tools are appropriately designed to recognise progress, right from minimal compliance through to net-zero, which is not generally the case today. Industry (and other stakeholders, including the City of Sydney) could facilitate action in this area by calling on tool owners/managers (often State/Federal governments) to adapt those tools to meet emerging industry needs.

6.2.3 Raise awareness

Education and awareness-raising for consumers is critical to raising consumer demand for high-performance high-rise buildings. pitt&sherry's *National Energy Efficient Buildings Project* highlighted that consumer awareness of building energy efficiency issues is generally very poor. A concerted and sustained effort, including consumer education campaigns, education materials, innovative delivery platforms (online, game-format, phone apps, etc), is necessary to build the ability to discriminate high from low performance, and therefore the willingness to pay for high performance.

6.2.4 Build capacity

Finally, as stated in the City of Sydney Energy Efficiency Master Plan: "*People are effectively the most important element for the energy efficiency of buildings – deciding how efficiently to design a building, which equipment to install, how to operate and maintain services, when to refurbish, upgrade, lease and so forth. The motivations of people are at least as important as technological and design solutions for energy efficiency*." [146]

There is danger in raising the demand for a product that might not be able to be supplied with the quality, consistency and performance that consumers expect. The prevalence of the required skills and know-how in the Australian building industry is likely to be low, given the low market demand for these skills. As demand is actively built, via the market transformation approach, it is essential that skills and capacities are built in-line, or indeed somewhat in advance, of these developments.

The particular opportunities for capacity building would include limited and time-bound public support for:

- Awareness, training and professional development initiatives for industry professionals;
- Pilots, innovation, demonstration, and the dissemination of 'industry learning' in this field; and
- Case studies of actual net-zero buildings, for example via a 'Net Zero Challenge' approach.

6.3 Moving Forward

No one element of the four-part strategy can drive the change that is required on its own. Each element needs to be progressed in a co-ordinated and balanced manner for maximum impact. An integrated and co-ordinated approach, with national leadership provided both by industry and by government, is the approach most likely to deliver results.

[146] City of Sydney, 2015, *Energy Efficiency Master Plan, Improving Energy Productivity 2015-2030*, August 2015

This project has demonstrated that the case for net-zero high-rise residential buildings in Australia is compelling, even today. They offer the potential to reduce energy consumption, greenhouse gas emissions and infrastructure costs, while creating financial value for building owners and occupants. With ongoing technological and market innovation but in the absence of policy reform, we can expect to see a slow uptake of such high-performance buildings, at least for many years to come.

We therefore highlight the opportunity for national, state and territory and key local governments, such as the cities of Sydney and Melbourne, in Australia to catalyse the leadership and innovation potential of Australia's building industry, and so accelerate the transition to net-zero high-rise residential buildings in Australia.

There are opportunities at all levels of government.

- Local government's control of planning processes means that measures to accelerate or reduce the cost of achieving development approval can be highly effective, while many councils – like the City of Melbourne in this case – apply effectively higher energy performance standards than are required by state legislation and the National Construction Code. Local government can also work collaboratively with stakeholders to identify and potentially remove particular barriers facing particular developments. Precinct-scale master planning can be another opportunity for local governments to influence the quality of building development, as can incentives such as design competitions, awards, etc. Finally, larger councils and cities have considerable influence with their state governments in particular, but also potentially with the national government. An advocacy strategy focused on both tiers could be highly influential.
- State governments have significant influence through the decisions they make about wider planning laws and schemes, environmental laws, building code variations and state-specific schemes. They have access to much greater funding resources than do local governments and can and do run important resource efficiency schemes and climate abatement policies and programs. State governments also play a key role in the development of national policy, notably minimum energy performance standards for equipment, appliances and buildings. Many such areas require state-based collaboration with the national government, and the nature of interventions made by state officials and ministers can have a material impact on the quality of the decisions made and then implemented nationally. The presence or absence of state leadership on many policy issues – but particularly on building energy performance standards – can critically influence outcomes, as states implement the agreed National Construction Code through state-based legislation, and can and often do make state variations. Wherever such variations are made, there is an obligation on the state to ensure that the effect of their variation is not to undermine the agreed intent of the Code – although in practice, this is often the case.
- The Australian government has a key role to play in climate and resource efficiency policy development. Questions such as the presence or absence of carbon pricing will be determined, ultimately, by the Australian government. Also the national government's appetite for regulation in the public interest will have a major impact on the development of new building standards and appliance and equipment standards *inter alia*. Unfortunately we have seen stagnation in these areas for an extended period of time. The Australian government also has access to even greater financial resources than do state governments, and this combined with the fact that most building and building product markets are at least national, if not international, means that the national government has the greatest opportunity to roll out market transformation programs, should it choose (or be effectively lobbied) to do so.

There are also numerous existing measures and strategies that could be used to advance a net-zero high-rise market transformation strategy.

- The *National Energy Productivity Plan* includes numerous relevant elements, including #5 'Improve residential building energy ratings and disclosure'; #7 'Recognise business leadership and support voluntary action in business'; #13 'Support innovation and commercialisation'; #16 'More liveable, accessible and productive cities' and others.
- A key NEPP initiative is #31 'Advancing the National Construction Code'. This is the vehicle that is being used to advance planning for higher energy performance standards for potentially all building classes from 2019. However at this stage there is no commitment or agreement to lift standards – which will have been stagnant for 10 years by then – but only an agreement to review them. It is far from clear at this point in time that the large cost effective potential for higher standards will translate into higher standards from 2019 – many parties including local and state government, but also industry, need to get involved in a constructive manner to avoid a lowest-common-denominator outcome.
- Similar points as above could be made about NEPP #30 'Deliver a new Equipment Energy Efficiency prioritisation plan'. There is a very large and cost effective opportunity to improve energy efficiency in equipment and appliances, but this outcome is not guaranteed by the NEPP measure. Unless there is strong leadership from states in particular, if not the Australian Government, then this joint Commonwealth/State policy area will continue to perform well below its economic potential.
- At the state level, NABERS and BASIX – and at the national level, NatHERS – could all support the support the delivery of a net-zero high-rise market transformation strategy by collaborating on the development of a single, national, whole-of-building ratings tool for apartment/Class 2 buildings. At the moment, NatHERS rates only the thermal shell performance of apartments but not common areas. NABERS is considering a 'common area' rating tool, to fill the void. BASIX has a whole building approach but, like NatHERS, is based on modelled rather than actual performance. Having an effective, agreed national tool could potentially underpin demonstration of minimal compliance, voluntary commitments above minimum and mandatory disclosure of actual assessed performance.
- State-based energy efficiency targets and white certificates schemes, such as the Energy Savings Scheme in New South Wales and the Victorian Energy Efficiency Target *inter alia*, could support the strategy by ensuring that high-performance building elements – such as glazing in particular, but also mechanical ventilation heat recovery units – are eligible for support. That said, we noted above that national market transformation initiatives are likely to be more effective, as building product markets are national.

Despite the important role for government leadership – appropriate to deliver the public good values associated with net-zero high-rise – there is a critical role for the building industry as well. Governments in Australia share a great reluctance to regulate or make interventions in markets, almost regardless of the public value that is at stake. Probably the most effective foil to this approach is industry leadership. Industry stakeholders are often treated as more credible by government than other stakeholders, and governments find it hard to argue against a coherent strategy when industry is calling for its implementation. In this way, a packaged approach – with elements of regulation, incentive and facilitation – is more likely to succeed. Bodies such as ASBEC, the Better Buildings Partnership, the Green Building Council of Australia, the Property Council of Australia, and other similar bodies, may well be the ones best positioned to lead such a strategy.

6.4 Further Work

Our recommendations for further work are as follows:

1. Further investigate the incremental costs associated with attaining net-zero performance, and also to establish cost-optimised pathways (showing incremental energy savings and costs for different treatments). We note that there is no single or unique pathway and that the relative costs and savings of particular design, construction and fit-out treatments are context and path-dependent. Realistically, a case study approach on a wider range of building forms and climate zones may be required. This study could also consider the question of how quickly incremental costs are expected to fall through time and which building elements would be expected to offer the greatest return on investment in market transformation initiatives. The study should include cost assessment by qualified quantity surveyors, but should also seek input from developers, product suppliers and a range of building industry professionals.
2. Undertake market and consumer research to quantify the willingness of consumers (including important targeted consumer segments in relevant markets) to pay premiums for net-zero performance. We note that such research may need to include an element of consumer education, as 'net-zero' may not convey meaning to all consumers. This study could be linked to the first study above, by exploring consumer responses to the prospect of declining cost premiums through time. This study should explore the question of whether and how consumer willingness to pay is correlated with on- or off-site renewables, including precinct- or utility-scale/remote renewables, and potentially with other competing solutions such as Green Power and carbon offsets.

Appendix A: National Construction Code Building Classifications

The National Construction Code, Part A.3.2, classifies buildings as set out in Table 20 below. Note that there are further details specified in Part A.2.3 than reproduced below.

Table 20: National Construction Code: Building Classification Framework

Class	Description
1a)i)	A detached house
1a)ii)	A semi-detached house, or terrace house
1b)	A boarding house, guest house, hostel or the like – less than 300m2 or 12 occupants
2	An apartment building ('a building containing two or more sole-occupancy units, each being a separate dwelling')
3	Residential areas only of a hotel, boarding house, guest house, lodging house, backpackers, school, aged care, health care, detention centre.
4	A sole residential dwelling in a Class 5 – 9 building (such as a janitor's residence)
5	Office
6	Retail - including eating room, cafe, restaurant, etc
7a)	Carpark
7b)	Warehouse, wholesaling
8	Laboratory, workshop
9a)	Health care (non-residential areas)
9b)	A workshop or laboratory in a primary or secondary school
9c)	An aged care building (non-residential areas)
10)	Non-habitable buildings or structures (garages, carports, etc)

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