“Australia’s commercial and residential buildings are responsible for 23 per cent of our greenhouse gas emissions. At the same time, we know the built environment can deliver rapid and cost-effective reductions to emissions and energy consumption using technologies and approaches that are widely available today. Research from the Green Building Council of Australia has found that energy-efficient, Green Star-rated buildings produce 62 per cent fewer greenhouse gas emissions and use 66 per cent less electricity than the average Australian building. We must work together to capture the benefits that green buildings deliver to the environment, the economy and the community.”

-- ROBIN MELLON

CHIEF OPERATING OFFICER, GREEN BUILDING COUNCIL AUSTRALIA

“Wow! What a wealth of practical information. This publication is so much more than a plan to revolutionise Australia’s building stock: it should be compulsory reading for anyone who aspires to design, construct or operate buildings in Australia. BZE’s recommendations deserve to be taken very seriously.”

-- CRAIG ROUSSAC

CEO, BUILDINGS ALIVE

“There is no longer any doubt that we must transition from fossil fuel energy to clean renewable sources very quickly if we are to avoid an average global warming of greater than 2 degrees C. To allow the planet to warm even to 2 degrees will have very significant and adverse effects on human health, species extinction, extreme weather, and sea level rise. BZE has demonstrated that we can source our energy entirely from renewable sources over the next ten years if we can muster the will to do so. But it will need a coordinated approach by all energy using sectors. If fully implemented, this Buildings Plan will substantially lower end use energy demand from the property sector, and facilitate early achievement of the Stationary Energy Plan. The Buildings Plan debunks a number of long held myths that have skewed end use demand in favour of alternate fossil fuels over electricity per se, neglecting the amazing energy efficiency that can be achieved with smart building design, new technologies, and rethinking energy end use in favour of electricity generated from renewable sources.”

-- DAVID A HOOD AM FIEAUST CPENG FIPENZ FISEAM MASCE

NATIONAL PRESIDENT (2012), ENGINEERS AUSTRALIA

ADJUNCT PROF, FACULTY OF SCIENCE & ENGINEERING, QUT

“This is an important piece of work. It is exciting to see something that comprehensively looks at how buildings could move towards being zero carbon. The case studies and depth of research provide a clear road map for Australia’s built environment.”

-- DR. DOMINIQUE HES

SENIOR LECTURER, UNIVERSITY OF MELBOURNE

FOUNDING DIRECTOR, LIVING FUTURE INSTITUTE - AUSTRALIA
“The Living Futures Institute Australia strongly supports the move to a zero carbon future for Australia, with all energy required for an energy efficient built environment coming from renewable, non-combustible sources. This plan, as part of a suite of six inter-related plans, shows a good understanding the need for the wide ranging and coordinated measures required to achieve this. We would strongly advocate for the use of the Living Building Challenge as a framework for assisting people developing built environment projects to achieve this ambitious goal. Other aligned frameworks, such as One Planet Living, Passiv Haus, Biomimicry and Greenstar can also be integrated to support these moves.

The International Living Futures Institute (ILFI) is also supportive. Amanda Surgeon, Vice President Living Building Challenge, said ‘It looks like a fabulous project with solid and ambitious goals.’”

-- CAROLINE PIDCOCK
LIVING FUTURES INSTITUTE - AUSTRALIA

“This zero carbon plan carefully sets out the essential first step on the road to sustainability, in a way that everyone can understand. The design and retrofitting of the built environment is one area where we can ‘decouple’ economic growth from negative environmental impacts. Through eco-positive design, we can create cohesive communities, a healthy economy and, ultimately, increase the ecological life support system. In fact, it is now possible to create net positive developments that give back more to nature than they take over their life cycle. This plan should have been rolled out by government decades ago, but it is not too late to reverse the trajectory caused by past system design errors. It should also be mandatory reading in all architecture, planning and engineering schools.”

-- DR. JANIS BIRKELAND
PROFESSOR OF SUSTAINABLE DESIGN, UNIVERSITY OF AUCKLAND,
AND DESIGNER OF THE ‘POSITIVE DEVELOPMENT’ PARADIGM.

“BZE have produced an ambitious and detailed plan to transform the built environment. Their case is ably supported by computer models provided by respected industry experts. The outcome is a series of strategies to upgrade the existing Australian building stock for energy efficiency. BZE have thrown down the gauntlet to Australian building designers and operators. I hope they are up to the challenge.”

-- STEVE MOLLER
SENIOR ASSOCIATE, SUSTAINABLE BUILT ENVIRONMENTS
“This report comprehensively proves how we can reduce our buildings emissions, and demonstrates how individuals can contribute. The leadership shown by Beyond Zero Emissions is what the world needs, effective communication of practical applications to solve our current climate crisis.’

-- JIGAR SHAH
BOARD MEMBER OF THE CARBON WAR ROOM, SOLARNEXUS, KMR INFRASTRUCTURE, PROMETHEUS INSTITUTE AND GREENPEACE USA.

“We NOW have a vital role and a unique opportunity to lead our current and coming generations to an exciting new future. Renewable energy sources provide the technology, the Buildings Plan provides the knowledge, NOW we must implement.

Our design solutions will be developed with greater confidence following the extensive research and practical knowledge contained in the Buildings Plan. The launch timing of the Buildings Plan, following the Climate Commissions’ “The Critical Decade-2013-Climate Change Science, Risks and Responses, is ideal to guide Australia confidently to a low carbon future. I encourage all designers to embrace this plan, implement the information within and build positive development solutions for Australia.”

-- MARK THOMSON
ARCHITECT, PRESIDENT OF AUSTRALIAN GREEN DEVELOPMENT FORUM, CORPORATE SUSTAINABILITY PRINCIPAL AT SCHIAVELLO

“The Zero Carbon Australia Buildings Plan provides a compelling case for approaching the issue of energy efficiency in the building sector nationwide. The report shows how a technological approach can halve energy consumption and reduce the significant ecological impact of the built environment in this country. This research challenges all designers to go even further on individual projects: to retrofit buildings and neighbourhoods beyond carbon neutrality, and to produce more energy than they consume.

DesignInc promotes a restorative and ultimately regenerative, precinct based approach to infrastructure and city form. We believe that individual carbon neutral buildings must be replaced by oxygen positive cities. We are proud to be part of an industry that continues to push the boundaries in environmental and sustainably designed buildings, both here in Australia and overseas.”

-- JOHN MACDONALD
DIRECTOR, DESIGNINC MELBOURNE
Zero Carbon Australia
Buildings Plan

Beyond Zero Emissions
Melbourne Energy Institute, The University of Melbourne
Researching Zero Carbon solutions for Australia is a hard job. The fact is that Beyond Zero Emissions relies on donations from hundreds of donors, both small and large. People like you. We don't get Government backing. We are very careful to ensure that our research is independent. To do the research that needs to be done, to get the word out there, to empower Australians by providing them with scientifically sound facts, all costs money. Your help will allow us to continue researching our Zero Carbon Australia solutions. And every cent helps.

Who are Beyond Zero Emissions?
Beyond Zero Emissions is a not-for-profit research & education organisation. This is the second of six ZCA plans to be delivered. We are working to deliver a zero carbon Australia, relying on the support of people like you.

What is the Zero Carbon Australia project?
The Zero Carbon Australia (ZCA) project is an exciting initiative of Beyond Zero Emissions and the University of Melbourne's Energy Research Institute. The project is a road map for the transition to a decarbonised Australian economy. The latest and most credible science tell us such a transition is necessary in order to reverse climate disruption. The project draws on the enormous wealth of knowledge, experience and expertise within Beyond Zero Emissions and the community to develop a blueprint for a zero carbon future for Australia. There's more about the ZCA project on the back of this page.

How can you help?
Please tear out the donations form to the right, fill it in, seal the edges and send it to Beyond Zero Emissions, Suite 10, 288 Brunswick Street, Fitzroy, Vic 3065

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The Zero Carbon Australia project

Six ZCA plans will provide a detailed, costed and fully researched road map to a zero-carbon economy for Australia. Following seven guiding principles, each plan will use existing technology to find a solution for different sectors of the Australian economy.

Stationary Energy plan

The plan details how a program of renewable energy construction and energy efficiency can meet the future energy needs of the Australian economy.

Transport plan

The plan will show how Australia could run a zero fossil fuel passenger and freight transport system. The main focus is on the large-scale roll-out of electric rail and road vehicles, with the application of sustainable bio-fuels where appropriate and necessary.

Buildings plan

This is the plan you're holding.

Industrial Processes plan

The plan will show how our industrial energy requirements can be supplied primarily from 100% renewable grid and investigate replacing fossil fuels with chemical equivalents.

Land Use, Forestry & Agriculture plan

With a significant proportion of Australia’s emissions from land-use change, forestry and agriculture, the plan will also address broader issues like land-use efficiency and competition for different uses of land for different purposes and products.

Renewable Energy Superpower plan

There are huge opportunities for Australia to leverage its natural advantages in solar and wind resources. Photosynthesis and direct solar heat processing could allow Australia to become a leading supplier of the next generations of bio-fuels.

ZCA Guiding Principles

1. Australia’s energy is provided entirely from renewable sources at the end of the transition period.

2. All technology solutions used are from proven and scaleable technology which is commercially available.

3. The security & reliability of Australia’s energy is maintained or enhanced by the transition.

4. Food and water security are maintained or enhanced by the transition.

5. The high living standard currently enjoyed by Australians in maintained or enhanced by the transition.

6. Other environmental indices are maintained or enhanced by the transition.
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Strange things are afoot in Australia’s energy system. For one thing, demand for electricity has been falling at about 2% each year for the last four years. And more importantly, the CO₂-emissions intensity of our domestic electricity supply is now falling fast. Having peaked in financial year 2008-09, total CO₂ emissions from our electricity sector have fallen 13% from 188 million tonnes to 163 million tonnes, at an average rate of 3.3% per year. In the financial year to end June 2013, CO₂ emissions from our electricity sector fell a staggering 7%, at twice the rate of demand reduction.

For those of us concerned with the need to urgently decarbonise our energy systems to avert potentially devastating consequences for future generations, this reduction in emissions intensity is welcome news. That Australia has the highest emission intensity, and hence greatest carbon exposure, of any developed economy makes it particularly timely. The story of this demand reduction for ‘poles & wires’ electricity is nuanced and has significant implications for the future of our electricity supply. And buildings are playing a key part in this quiet revolution.

The reduction in demand for ‘poles & wires’ electricity splits in about equal measures to shifts in our economy away from energy-intensive industry, and shifts in our domestic sector directly related to our buildings and the ‘punters’ who occupy them. Our buildings are rapidly becoming significant electricity producers. With more than one million domestic rooftop systems now installed, solar PV is reshaping demand profiles for ‘poles & wires’ electricity. In South Australia, midday demand is down around 10%, compared to where it was just three years ago, just because of solar PV.

Our buildings are becoming more energy efficient. The great positive in the political debacle of the ‘pink batts’ scheme is that it has been manifest in reducing energy demand, as was the intention. And, perhaps most importantly of all, our building occupants are becoming more energy-wise, with price sensitivity now impacting electricity demand in what historically has been a notoriously inelastic market. While all of the factors contribute to a decline in demand for electricity served over the ‘poles & wires’, there is growing awareness that we have only just begun to realise the full potential to drive energy savings through our buildings. For example, a doubling of solar PV units in SA will see midday demand fall to levels comparable to the early morning off-peak minimum. And the energy efficiency of our building stock still leaves huge room for improvement.

While the reduction in electricity demand is welcome in helping to reduce the emissions intensity, it is producing challenging issues in the way we provide electrical power services. And buildings are essential to meeting these challenges. As our demand for electricity reduces, we are necessarily seeing a dramatic reduction in the way we utilise the ‘poles & wires’ distribution system. By some estimates the utilisation rate of our distribution network is now declining at about 2% each year. This is necessarily putting upward pressure on the cost of delivering ‘poles & wires’ electricity, and is presenting huge challenges in managing the business of electricity, as well as meeting the challenge of improving national productivity.

A particular challenge is that our expectation of peak demand for electricity is continuing to grow, while our average demand is falling. Unless we can curtail peak demand growth, the price pressures on our delivery of electrical power services will continue to surge raising some analysts to raise the spectre of an impending “death spiral” for the industry. Managing peak demand is all about what is going on in our buildings.

To alleviate peak demand growth and allow for cost effective electrical services into the future we urgently need to rethink how our buildings can contribute to more effective demand management, both as electricity producers and consumers.

This report provides a welcome insight into the opportunities and challenges for Australia in how our buildings can help in the challenge of the radical decarbonisation of Australia’s energy system. I recommend it to you.

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Executive Summary
Executive Summary

This is a practical plan to fix Australia’s buildings in a decade. We can act now to halve the energy use of our buildings, deliver energy freedom to people and transform our homes and workplaces to provide greater comfort with lower energy bills.

The vision. The Zero Carbon Australia Buildings Plan is the first comprehensive, nationwide plan to retrofit Australia’s buildings. This plan demonstrates how all existing buildings can reach zero emissions from their operation within ten years. It sets out how Australia can transform its building stock to reduce energy bills, generate renewable energy, add health and comfort to our living spaces, and make our workplaces more productive.

The rationale. Australia’s existing buildings are not adequately designed to meet many of the challenges we face today. Australian houses and workplaces are often unnecessarily cold in winter, hot in summer, and expensive to run. We now have the technologies and know-how to make our buildings far more comfortable, while protecting us from rising electricity and gas bills.

The science is clear that, in order to reverse climate disruption, developed nations must begin transitioning their economies to zero greenhouse gas emissions, starting now. Accordingly, in June 2010, Beyond Zero Emissions (BZE) launched the ground-breaking Zero Carbon Australia (ZCA) Stationary Energy Plan that showed how Australia’s electricity could be supplied by 100% renewable energy sources within 10 years. This acclaimed Plan has since been followed by the government sponsored 100% renewable energy plans by the Australian Energy Market Operator (AEMO).

The ZCA Buildings Plan is the next step in this transition.

This plan contains detailed bottom-up research, modelling and analysis into Australia’s existing buildings and energy consumption. We have collaborated extensively with industry, ensuring our recommended suite of retrofit measures is practical and widely applicable.

FIGURE 0.1
An Australian home well on its way to being a zero carbon building
Executive Summary

Under this plan:

◉ **Residential energy use is halved.** The measures in this plan will, together, reduce the residential sector’s annual energy usage by 53%.

◉ **Homes become renewable energy power stations.** There is enough solar exposed roof space on residential buildings to install 31 GW of rooftop solar photovoltaics. This installation will allow the average Australian home to generate more electricity than it uses over a year.

◉ **Australian buildings go gas free.** The use of fossil gas (conventional fossil gas, coal seam gas, shale gas & others) is completely removed from the buildings sector. Fossil gas appliances are replaced with higher-efficiency electric alternatives, eliminating gas bills and leading to significant reductions in energy use while avoiding the climate and environmental damage caused by gas.

◉ **Households save money.** Households currently spend approximately $15 billion per year on electricity and gas bills. The ZCA Buildings Plan will eliminate gas bills while significantly reducing electricity costs. The full upgrade can save $40 billion over the next 30 years.

◉ **Non-residential energy use nearly halved.** The energy used in non-residential buildings, on average, can be reduced by 44%. 2.5 GW of rooftop solar photovoltaics can be installed on non-residential buildings and the total cost is equivalent to business as usual over 30 years.

◉ **Energy freedom is achievable.** The plan shows that with the above actions, households and businesses can achieve energy freedom by generating more energy than they use and removing gas as an energy source.

◉ **Tens of thousands of jobs will be created.** From residential retrofits alone, around fifty thousand jobs can be created in the trades sector employing people to fix Australia’s buildings.

◉ **The transition to 100% Renewable Energy is now $37 Billion cheaper and 15% more achievable.** By detailed testing of the assumptions used in the ZCA Stationary Energy Plan, we show we need 15% less (excluding rooftop solar contribution) stationary renewable energy. By rolling out energy saving measures and rooftop solar we can make the transition to 100% renewable energy for Australia easier and cheaper.

**Achieving energy savings**

Extensive research, modelling, and analysis have led to the selection of a suite of widely applicable technologies and strategies aimed at decarbonising Australia’s existing building stock. Only proven, existing, commercial off-the-shelf building and appliance technologies are employed, and these are listed below:

Fixing Australia’s buildings through:

- Full insulation retrofit
- Full draft proofing
- Efficient window glazing
- Better shading
- Cool roof paint
- Installing new chilled water cooling systems and improvements to air handling in commercial buildings

Going gas free through:

- Electric heat pump heating for space heating
  - Uses renewable ambient heat by extracting heat from the air,
  - Five times more efficient than gas, at less than half the running costs

---

**FIGURE 0.2**

Roof insulation retrofit is a key recommendation

[Simon Williams]
In combination, these measures were found to achieve a 60-80% saving in eleven different building cases (from the various residential, office, education and retail building types). These savings were achievable across the range of Australia’s climate zones.

Summary

The following chapters show how acting on energy efficiency and delivering energy freedom for Australian homes and buildings is achievable, desirable and that now is the right time to start.

This plan confirms what many leading studies worldwide have shown: that investing in efficiency, deploying onsite renewable energy, and leaving gas in the ground are all important steps that make the necessary transition to a zero carbon future easier.

Bringing this plan’s recommendations into reality will require our political leaders to step up to the plate, our industry leaders to stay true to the job at hand, and all of us; homeowners, business managers, investors, and citizens, to be active in calling for the change we know Australia and our buildings need.

**CUMULATIVE ENERGY USE SAVINGS FOR MELBOURNE RESIDENTIAL BUILDINGS CIRCA 1950**

Demonstrating a series of retrofit actions as progressive modelling stages and the effects on various components of building energy usage.

**FIGURE 0.3**

Key Retrofit recommendations and energy savings for a Residential Home in Melbourne
Part 1: Introduction and Overview

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1 Summary

Australia’s buildings were not designed to meet many of the challenges we face today.

In an era of inexpensive energy little attention was paid to insulating houses because we could heat and cool them affordably with gas and electricity. Even when much of the hot and cool air escaped outside almost immediately, it didn’t seem to matter.

Were we also less aware of the damage that burning coal and gas were doing to the atmosphere by creating greenhouse gases.

In the past, we lacked the extraordinary materials that now allow us to insulate our houses so that they require very little energy to heat or cool. We now also have more efficient technologies to provide heating and cooling, lighting and other services. These use much less energy than in the past.

An electric heat pump (air-conditioner) can now provide our living room with the same amount of heat as a gas heater, using one-fifth the energy and for less the cost. It will also keep the room cool in summer. A heat pump driven hot water systems can provide similar cost and energy savings compared to the old gas and electric systems.

And this is even before we experience the steep export-driven gas price rises expected over the next few years.

A modest investment in insulation and draft proofing can cut down energy use and bills even more.

While there is no doubt that individuals can benefit enormously from insulating their building and swapping their gas heaters for electric heat pumps, if Australia is to meet the challenges of climate change and rising energy costs within a meaningful timeframe, we need to act decisively on many levels.

If we act decisively, the benefits and savings that can be achieved by individuals can also be achieved by the nation as a whole.

The Zero Carbon Australia Buildings plan is the first national plan to transform Australia’s building stock to meet these challenges.

2 The case for change

The Tyndall Climate Centre in a call for papers for its December 2013 “Radical Emissions Reductions” Conference said,

“Today, in 2013, we face an unavoidably radical future. We either continue with rising emissions and reap the radical repercussions of severe climate change, or we acknowledge that we have a choice and pursue radical emission reductions: No longer is there a non-radical option.”

Business as usual is not a liveable future

Both the World Bank and International Energy Agency released reports in November 2012 and July 2013 respectively which evaluated current climate change policies and targets and concluded that “business as usual” was likely to result in four degrees of warming. As Joachim Schellnhuber said in 2011 at a gathering of international experts on climate change “The difference between two degrees and four degrees is human civilisation”.

The World Bank Group President Jim Yong Kim said “A four degree warmer world can, and must be, avoided”. He further stated that “Climate change is one of the single biggest challenges facing development, and we need to assume the moral responsibility to take action on behalf of future generations, especially the poorest.”

As Kevin Anderson of the Tyndall Climate Institute said, in a June 2013 interview, a four degree average surface temperature rise corresponds to much larger actual temperature increases on land. “The Hadley Centre estimates that, on the hottest days, the temperature would be 6-8 degrees higher in China, 8-10 degrees in Europe and 10-12 degrees in New York. Such unprecedented increases would give rise to a host of issues about how the ageing infrastructure of our cities could deliver even survival-level services.” This is due to the fact that most of the earth’s surface is water which heats up at a slower rate.

FIGURE 1.1
The extent of artic sea ice melt in September 2012 [NASA]
The 2013 atmospheric CO₂ levels are at about 400ppm. It is generally accepted by climate scientists that the CO₂ level was 280ppm during the Holocene Period - a ten thousand year era of stable climates, which supported the development of human civilisation. Now there is already too much carbon in the atmosphere. The current level of emissions has led to a 0.8 degree temperature increase. Already the planet is experiencing the impact of high emissions and rising temperatures. The 2012 summer arctic sea ice levels had record minimum in area and volume. Some scientists have predicted the total loss of arctic sea ice with the next decade.

Positive feedback mechanisms are being triggered as the reduction in Arctic ice reduces the reflectivity of the globe and the melting of permafrost leads to release of trapped methane. These feedback mechanisms could lead to a global temperature rise between 1.8°C and 2.3°C above pre-industrial levels regardless of any action that may be taken subsequently to reduce emissions. The current estimate for the melting of Greenland's ice sheets is 1.6°C above pre-industrial levels, well within the range of two degrees that is considered a safe guardrail. The melting of Greenland's ice sheets would lead to an eventual sea level rise of seven metres.

The scientific evidence points towards significant climate disruption under a business as usual scenario. It is an imperative that society and decision makers act now to decarbonise our economies.

3 A paradigm shift versus incremental change

The Critical Decade report by the Australian Climate Commission found that carbon emissions must peak within the next few years and then strongly decline to avoid warming greater than two degrees.

The majority of low carbon scenarios informing policy makers suggest that emissions must peak by 2016. But the current political debate is about small emissions reductions in the next five to ten years with the bulk of emissions reductions occurring near the year 2050.

The international and Australian policy debate about emissions reductions is around interim targets, small steps in the right direction, market corrections, limited support for zero emissions alternatives. These incremental changes are promoted by environmental interest groups because they seem realistically achievable and are aimed at the level of awareness and concern of politicians. The debate is set by what is deemed politically achievable not what the climate science states is necessary.

A paradigm shift is needed towards policy and actions which are in line with what the science demands. This means planned, coordinated, economic and industrial shifts within time frames not typical of those that markets operate in. Such shifts are achievable only by utilising various economic levers and setting a target for economic transformation.
The social implications of not acting are significant, but much of the debate is about the economic impacts of acting - about economic policy not social policy.

Currently, actions aimed at reducing greenhouse emissions, such as those proposed by the building and energy efficiency industries in Australia, are usually required to prove their efficacy with cost benefit ratios. Only when the benefits outweigh the costs by a required proportion is it considered viable to undertake those actions. In a Government setting, action (through investment in public services, or regulation of economic markets) may only be justified on the basis of the benefits out weighing the costs, through a Regulatory Impact Statement (RIS). This cost benefit approach has some limitations, particularly in the face of environmental and social problems, like climate change.

Cost benefit analysis is inherently efficiency oriented, and is best suited to situations where the goal of policy is economic efficiency. Policy goals, particularly in respect to social and environmental criteria, are much wider than economic efficiency alone. This is an important distinction, as the cost-benefit approach intrinsically grants priority to economic efficiency over other values. As a consequence, ‘economic efficiency’ objectives are transferred to problems for which they are inappropriate (such as health and welfare). At a fundamental level, this results in a serious ethical objection, with matters affecting the health and life of humans being weigh up against economic interests, and decisions merely taken on the basis of efficiency considerations.

It is also important to note that cost benefit analysis only makes sense when there is discretionary room to adopt or reject a particular project. Cost benefit analysis is a good method if there are, say, two or more sound options to compare. In this context ‘Business as usual’ cannot be considered a reasonable or fair option, in the face of catastrophic climate change. If decision making is rational, and efficiency was the only goal, cost benefit analysis alone would be sufficient. However this is often not the case.

The general approach of a cost benefit analysis is to value all project costs and benefits in monetary terms, based on market prices. This limits the scope of any analysis to costs and benefits that are easily quantifiable, or with some explicit market value. Whilst costs can usually be quantified, not all the benefits are easily quantified in financial terms and often involve subjective value judgements.

From the point of view of buildings, how do we value improved comfort? We could look at data such as reduced hospitalisation due to exposure to extreme temperatures, or improved productivity, but a range of non-economic benefits are not immediately quantifiable.

Related, market failure is another fundamental limitation of any economic analysis. Cost benefit analysis typically relies on the costs and benefits of current or forecast market prices. In the context of climate change, the externalized cost of carbon emissions is a significant market failure. From a strict economic perspective, this cost should be internalized, and reflect the marginal cost (damage) per unit of emissions. Current attempts to realize this through carbon pricing illustrate a clear mismatch between economic theory and political reality. ‘Real world’ considerations will always impact the political negotiation of either a carbon price or an emissions cap, and as such prices will remain at inefficient levels. Without properly accounting for the cost of carbon, use of current and forecast market prices will not reflect true project costs (and benefits).

Whilst carbon is the main market failure (from the perspective of climate policy) there are many other distortions or failures (for example, fossil fuel subsidies, health costs, or knowledge spillovers). Failure to correctly capture these will lead to an inefficient allocation of resources, and an inaccurate cost benefit analysis.

Further to this, it is often argued that cost benefit analysis is not ‘transparent’. This limits the scope of any analysis to costs and benefits that are easily quantifiable, or with some explicit market value. Whilst costs can usually be quantified, not all the benefits are easily quantified in financial terms and often involve subjective value judgements.

Importantly the assumptions that underpin these analyses do not consider the impacts of increases in scale that might lead to sudden leaps in the costs of particular measures or the benefits. A good example is the thermal performance of a new building design. From a linear cost-benefit point of view the incremental benefit of each star rating is the reduced consumption from heating and cooling appliances. But at some point the building envelope becomes sufficiently insulated and air-tight to avoid needing to install heating and cooling systems entirely, giving a jump in the capital expenditure savings. This is already so in the UK where policies are driving substantial improvements in the building envelope and where the climate typically requires expensive centralised heating systems. Another example is double glazing. Currently only 2.5% of homes have double glazing in Australia, leaving this industry a niche market. Incremental improvements in building standards will only lead to incremental reductions in the cost of double glazing until a particular industry scale is met, and then large jumps are possible. In international markets, serious government programs to promote double glazing have driven substantial shifts in the industry leading to double glazing often costing less than single glazing due to the much higher production volumes.
4 The role of energy efficiency

The global energy system is based on the premise of cheap abundant fossil fuels, on large centralised power stations and a web of transmission and distribution lines that step down to the household and business level. Households and business are seen as energy consumers.

For buildings in Australia, cheap energy and centralised fossil-fuel generation has had a negative impact. We have poorly insulated and leaky buildings which rely on artificial heating and cooling to be comfortable.

Today rising energy prices are putting low income households at risk of fuel poverty - with households having to choose which appliance to prioritise running to save money on their bills.

In Europe and Northern America, conventional fossil fuel scarcity, and more extreme climate have driven a greater interest in building retrofits, energy efficiency, and solar photovoltaic programs. However Australia’s large reserves of conventional and unconventional fossil fuel reserves have maintained our dependence on them, keeping energy prices relatively low and limiting the political interest in programs to increase energy independence for households and businesses.

Energy efficiency is widely recognised as one of the easiest, cheapest and fastest ways to reduce greenhouse gas emissions. As the diagram below shows, if emissions are to peak within the next five years then this is a limited time to build new infrastructure, whereas it is possible to rapidly install low energy appliances and retrofit insulation, draught proofing, improved glazing, etc.
The International Energy Agency (IEA) has recently published a report specifically addressing this in its “Transitions to Sustainable Buildings – Strategies and Opportunities to 2050.” Its recommendations are similar to those in the Zero Carbon Australia Buildings Plan: advanced retrofits of existing building thermal envelopes, widespread deployment of best-practice lighting and appliance technologies, using heat pumps for space heating and hot water, and supplying the remaining energy demand from a decarbonised electricity system. The IEA projects this could result in a 77% reduction in global greenhouse emissions associated with the buildings sector by 2050. The ZCA Buildings Plan takes it one step further by demonstrating that Australia can and should do this in ten years.

Australian homes are typically cold in winter and hot in summer, draughty, damp, and provide poor shelter from the elements. Households have large amounts of inefficient halogen downlights, sometimes as many as one hundred lights, each consuming 50W of electricity. Consumer electronics hog powerboards drawing large amounts of power on standby. Leaky homes and poor thermal resistance of the building fabric require large amounts of artificial heating and cooling from inefficient appliances, especially gas space heating. Commercial buildings often have poor indoor environment quality, with limited natural light, inefficient artificial lighting, poor air-movement, ventilation, uneven air temperatures and humidity levels, with inefficient electrical appliances generating large amounts of internal heat loads, requiring large amounts of artificial cooling to maintain suitable comfort levels.

Energy prices have already risen by more than 70% (in real terms) since June 2007, and are continuing to rise. Although the bulk of price rises are from increased network charges, concerns about the impact of a carbon price on rising energy prices have also raised public anxiety about the rising cost of living. The major energy retailers hold a near-monopoly position in the market and own generation assets, giving them a disincentive for reducing household and business energy use. Their retail margins also comprise a significant portion of energy price rises (see Part 2 for more on electricity prices).

Australia needs a national program of works to go street by street, house by house, office by office, to fix our buildings. Building owners and occupants are currently in a position of weakness, dependent on energy retailers for their energy supply, facing increasing costs and not necessarily able (or willing) to invest in the needed energy-efficiency measures. A combination of incentives and regulation is needed to ensure the transition does occur, in a timely fashion. Reducing energy demand will permanently insure households and businesses against future price rises, and along with rooftop solar, will give them greater independence from energy retailers. It will make the transition to renewable energy easier.

### 5 The Future is Renewable Energy

A reliable, secure national electricity grid supplied by 100% renewable energy sources is technically feasible and affordable in Australia. It could be achieved within ten years, with sufficient commitment and investment.

The technical feasibility of 100% renewable electricity was demonstrated in the Zero Carbon Australia Stationary Energy Plan in 2010. Since then, researchers from the University of New South Wales (UNSW) have released studies with similar results. The Australian Energy Market Operator (AEMO) has performed its own detailed analysis showing that a number of scenarios of 100% renewables in the National Electricity Market are feasible and affordable.

In these studies, one of the primary renewable energy technologies used to ensure reliable supply was concentrating solar thermal power (CSP) with molten salt storage. By storing the sun’s energy as heat in tanks of high-temperature molten sodium nitrate and potassium nitrate, CSP can generate electricity on demand 24 hours a day, independent of whether the sun is shining or not. Deployed commercially in Spain and southwest USA, the use of CSP in tandem with other variable renewables such as wind and solar photovoltaics (PV) allows a 100% renewable grid to operate with same reliability as today’s fossil-fuel electricity grid.

The ZCA Stationary Energy Plan designed and costed a 100% renewable electricity scenario using primarily CSP and wind across Australia, with upgraded transmission allowing the efficient transfer of power across the grid depending on available renewable resources at any point in time. Detailed modelling of supply and demand on an hourly timescale was performed over several years of actual data for electricity demand, wind power and solar resources, to confirm that the mix of technologies and storage was sufficient to ensure reliability.

The UNSW study “Simulations of scenarios with 100% renewable electricity in the Australian National Electricity Market” performed a similar analysis using hourly wind, solar and electricity demand data, and tested out several different scenarios of storage and bioenergy backup to further optimise the amount of each technology based on cost and reliability. While any such study is dependent upon the input assumptions, the results indicated that a 100% renewable grid could require less storage than modelled in the ZCA Stationary Energy Plan.

AEMO, the organisation that operates the National Electricity Market and therefore is directly tasked with ensuring reliable supply for approximately 90% of Australia’s electricity consumption, undertook analysis in 2012-13 for the Department of Climate Change into the feasibility of 100% renewable energy in the NEM. The study iteratively modeled and adjusted hundreds of scenarios for providing.
100% renewables in the NEM with different combinations of technologies. It considered several different overall scenarios with different assumptions on the costs of various technologies, which was a more significant factor in determining the optimal system than the variability of operational characteristics of the different types of renewable energy. The scenarios ranged from traditional baseload power stations providing the bulk of energy supply to high penetrations of variable renewable energy technologies (e.g. wind, solar PV). In one scenario wind was modelled to make up over 40% of the energy generated.

Furthermore, as part of the study, AEMO’s technical operations team performed a high-level operations review of whether issues such as power system frequency control, grid code performance standards, fault level design and forecasting variable energy sources would impact AEMO’s ability to ensure reliability. This review found “that the operational issues identified in this study appear to be manageable and should not prevent secure and reliable operability of a 100 per cent renewable future NEM power system” and that future work would include undertaking more detailed power system studies to understand precisely what changes would need to be made to operating strategies to ensure such technical issues were dealt with.

Both the ZCA Stationary Energy Plan and AEMO studies put a cost on the 100% renewables system. These must be viewed in comparison to likely future electricity prices, which are set to increase relative to today under any conceivable scenario of future energy generation mixes. This increase is with the same range as the increase in wholesale electricity prices expected under ‘business as usual’ by 2030 (5.5-7.5 cents). The increase is also well within the range of recent electricity price increases resulting from distribution network investment, and well worth paying for the climate protection and other benefits of a 100% renewable, zero-emissions electricity grid.

For those concerned about sustainability in the building industry, a 100% renewable energy grid is a necessary and viable future which should be planned for. The building industry can either provide a shortcut to that future, by removing fossil gas usage, moving to a 100% electricity supply and reducing demand, or it can create a diversion to this future by substantially increasing dependence on fossil gas.
6 Going Fossil-Gas-Free

Mains gas is frequently described as an appropriate low-emissions fuel for use in buildings. Mains gas provides energy to 48% of Australian homes. It contributes 17% of the energy to commercial buildings and about 34% of energy to residential buildings (see Part 2 Section 5). However, the use of gas is entirely inconsistent with the goal of achieving zero carbon emissions. The Stationary Energy Plan, shows that the energy demands of Australian buildings can and should be met entirely with renewable energy. When zero-emission electricity predominates, gas will become redundant. Its use in buildings should be phased out over a ten-year period.

6.1 The problems with gas

* **Low-emission gas is an illusion.** Industry claims of the ‘green’ merits of gas are often based on the relative emission intensity of gas versus coal, at the point of combustion. However, a) emissions from gas combustion are still too high for gas to make a useful contribution to climate change mitigation, current standard emission factors (kg-CO$_2$/e/GJ) for combustion are 51.3 for gas, 88.4 for black coal, and 93.1 for brown coal, and b) combustion emissions are not the only emissions associated with gas.

* **Gas emission factors are rising.** Per unit of energy delivered, the emissions associated with gas are increasing as conventional gas reserves are depleted, and unconventional forms of gas, like coal-seam gas (CSG), tight gas and shale gas are brought into production. Emissions from ageing conventional reserves increase because a) the need to pressurise where previously the gas came out under its own pressure, and b) necessary additional processing of the gas stream as progressively lower-quality reserves are tapped and CO$_2$ is vented to the atmosphere. The full picture with CSG emissions is still emerging, but CSG emissions are comparable with coal emissions, BZE is of the view that unconventional gas emissions are potentially higher than those from coal. Recent research from Southern Cross University (SCU) and others suggest that current industry assumptions for CSG production fugitive emissions (0.12%) are understated by a very large amount. Real rates of leakage are likely to be at least 1% and these published results are consistent with leakage rates of 4%.

* **Un-burned gas is much worse than CO$_2$.** Emissions from the leakage of gas are known as fugitive emissions or migratory emissions and they occur throughout the system of production and distribution of gas. The global warming potential (GWP) value of methane is now reckoned to be 105 times that of CO$_2$ according to NASA research by Drew Shindell.

* **Gas networks leak.** In the UK, Mitchell and Sweet (1990) estimated that in traditional gas networks, a leak of 5.8% would mean that any emission benefit of conventional gas over coal is lost. They estimated that between 5.3% and 10.8% of gas is lost from transmission and distribution pipelines before the point of consumption. A 2013 study from New York City concludes leakage exceeds 5%. Data from Adelaide reports leakage rates as high as 7.8%.

* **Environmental and health risks of CSG.** CSG poses significant risks to the environment. The negative side effects of CSG production are broadly related to water, salts, erosion, clearing, fire risk, air pollution, and contamination. These side effects have significant implications to public health, biodiversity and agricultural production.

* **Gas scarcity and rising costs.** The Australian domestic gas market has been isolated from world parity because East-coast petroleum gas has not been traded on global market. This is likely to change in anticipation of the Gladstone LNG export terminal opening in 2014, exposing Australian consumers to significantly tighter and less-stable market conditions. For the consumer this means higher prices and price volatility, and reduced security of supply. A study by BNEF reports that life-cycle costs of new wind and PV generation are already cheaper than new gas for large-scale generation. Under business as usual, there is every possibility that gas supply will be highly contested in 20 years time.

* **Gas safety concerns.** Gas in and around our buildings is a hazard because of toxicity and flammability issues. According to the Gas Regulators Technical Committee “Carbon monoxide is a silent killer and is the major cause of gas related deaths and chronic illnesses throughout the world”. The combustion by-products of gas include nitrous oxides (NO$_x$), formaldehyde, carbon monoxide (CO), CO$_2$ and sulphur oxides (SO$_x$), which can have direct effects

![Darwin Inpex gas processing plant](Source: INPEX)
on respiratory and cardiovascular health. Poorly maintained gas heaters can be fatal, as was tragically seen in 2010 when two young boys died. Use of gas for urban cogeneration poses a risk to air quality.

- **Draughts.** To be safe, indoor combustion of gas, such as gas cooking and un-flued heaters, requires higher levels of ventilation, which can be at odds with the need to save energy by reducing draughts.

- **Abundant renewable gas is a false promise.** Methane can be synthesised from a wide variety of bio waste streams such as sewage, landfill waste, and agricultural residues. This is sometimes called bio-gas. In special cases it makes sense to generate and use biogas on-site, for example for power generation in piggeries and feed lots. It makes sense to tap landfill gas. However, there is insufficient capacity in Australia to substantially displace current usage of fossil gas with bio-gas. BZE envisages that most

- **Efficient alternatives.** Electrically-driven heat pumps (chillers) are substantially more efficient than the absorption chillers upon which tri-generation systems depend. A typical large absorption chiller might typically have an efficiency of 70% (ie a CoP of 0.7), whereas good vapor-compression heat pumps (chillers) might typically have an efficiency of 50% (ie a CoP value of 2).

- **Cost and space.** Tri-generation plants are large, complex and expensive capital items compared to traditional HVAC plant. They have higher maintenance costs due to lack of expertise in absorption chillers and added complexity. Tri-generation systems require much larger cooling towers than conventional HVAC plant and have correspondingly greater pump energy requirements;

- **Inflexibility.** The generation rate of coolth (by the absorption chiller) and electricity are often not well matched to respective demand, so additional traditional plant is still required. This is because the instantaneous cooling power is directly determined by the electrical generation, whereas the cooling demand and electrical demand are usually independent;

- **Inter-building complexity.** The issues of cost, space and flexibility (above) can be partially mitigated by economies of scale from larger tri-generation plant which can be shared between buildings. However this then requires new inter-building piping which can be costly and complicated, and introduces its own inefficiencies and risks;

- **Grid connection issues.** Power distributors impose specific connection requirements because of the very large fault currents associated with the on-site power generation. Meeting these connection requirements can be expensive and onerous;

- **Noise and vibration.** Tri-generation plants create high levels of noise and vibration which constrains where they can be sited;

- **Resilience.** The size, weight and sound-proofing demands for tri-generation installation tend to rule out above-ground installation. This will be increasingly problematic as climate-safe resilient design would suggest that key building plant not be installed where there is a risk of inundation from flood or storm;

- **Capacity for retrofit.** The size, weight and sound-proofing demands make retrofit of tri-generation problematic since finding a suitable location within existing buildings is likely to be difficult. In addition, the heat rejection requirements for tri-generation plants are in the order of twice that for conventional plant. This has implications for the sizing of pipes and the number/size of cooling towers.

- **Pollution.** Tri-generation systems emit pollution, including CO₂, SO₂ and NOₓ. They therefore require pollution control systems to treat emissions. Localised pollution from multiple cogeneration systems operating in urban areas could affect air-quality (especially NOₓ emissions).
The Zero Carbon Australia Buildings Plan is the first comprehensive, nationwide retrofit plan for Australia’s building sector and investigates how existing buildings can drastically reduce their energy consumption as a major step towards achieving a zero emissions economy.

For the ZCA Buildings Plan, zero-emissions buildings means that no building generates any greenhouse gas emissions during its operation. This implies the existence of a zero-emissions network energy source (e.g. concentrating solar power) for energy supply. The Buildings Plan adds to the Zero Carbon Australia Stationary Energy Plan which was a detailed fully costed plan to replace Australia’s existing fossil fuel power generation industry with renewable energy in ten years. The Buildings Plan is therefore developed to work in conjunction with a zero emissions electricity grid.

The Buildings Plan did not aim for buildings to be able to generate as much energy from on-site renewables as they consume, but the outcomes of this research found this is achievable in residences.

Buildings have significant energy and resource demands over their life time. The two main stages in the life cycle of a building are production and use (Figure 1.6). To manage all the emissions, it is important to account for energy and material demand at all stages of the building life cycle. The energy demand across all stages is called the ‘full life cycle energy demand.’ Energy in the production stage is termed ‘Embodied Energy’. Energy in the use stage is known as ‘Operating Energy.’

Each stage of the building life cycle results in energy consumption, resource consumption and environmental impacts. It is important to account for this consumption at all stages of the building life cycle to better manage the allocation of resources and to reduce impacts.

The ZCA Buildings Plan addresses only operating energy and emissions, however it is acknowledged that the embodied emissions from the remainder of the building’s life cycle may be just as significant, if not more so, than the emissions during use. For example, studies using comprehensive embodied energy and emissions assessment techniques have shown that non-operational related emissions can be equal to or higher than operational emissions. The sources of operating greenhouse gas emissions considered in this study are:

1. Gas, electricity, and wood consumption for heating and cooling loads, which are influenced by the building shell thermal performance, the performance of installed space conditioning equipment and user behaviour.
2. Gas, electricity, and wood consumption for cooking
3. Gas, electricity, and wood consumption for water heating

**FIGURE 1.6**
4. Electricity consumption for various appliances, eg refrigerators, washers, televisions, computers etc.
5. Electricity consumption for lighting
6. Refrigerant leakage.

It should be noted that this definition does not take into account any emissions generated by the occupants of the building or services performed in the building that do not directly interact with the building, eg form of transport taken, goods and services consumed (other than standard entertainment appliances and white-goods), or manufacturing processes. However, when taken as a whole, the Zero Carbon Australia Project aims to decarbonise all economic sectors and therefore a zero-emissions building will be one that produces no emissions over its full life cycle, not just during its operation. Only existing buildings were considered in the Buildings Plan, partly to limit its scope, but also because a number of reports are already available demonstrating the cost effectiveness of high performance buildings and with the only added requirement that new buildings need to be zero fossil gas. Furthermore many of the measures discussed here apply equally to new buildings.

Following from the basis of a zero emissions electricity grid, the Buildings Plan addresses the challenge of achieving zero emissions in the built environment by:

1. Removal of fossil fuel consumption – primarily fossil gas. Fossil gas appliances are to be replaced with efficient electric alternatives that perform as well as or better than original.
2. A retrofit program to improve the thermal performance of the building fabric. This will significantly reduce space conditioning energy demand.
3. Raising the bar on the performance of electrical appliances and widespread adoption of LED lighting.
4. Utilising rooftop solar photovoltaic to power every home. Available roof space in non-residential buildings also used for solar PV.

A comprehensive review of available energy efficiency technologies and strategies was undertaken to obtain a set of widely applicable measures across a range of building types and locations. Individual options were not ranked on a cost benefit approach. BZE believes these measures should all be undertaken, rather than only those measures deemed financially acceptable to individuals. Taken together these measures are considered the minimum necessary to get Australia’s building stock up to scratch and to address each major weakness with the best available solution. Such an approach would lead to a half hearted effort that misses out on the more costly measures, like double glazing and wall insulation, which are highly effective in reducing energy consumption and addressing a key weakness of the building envelope.

The plan characterises the building stock into categories that represent the largest overall percentages- residential, retail, education and office buildings. The plan creates generic representational building models and develops a semi-tailored package of upgrades or new building attributes for each category. The specific measures proposed have been developed with extensive industry and expert engagement - in some cases with direct simulation of the performance improvement.

Economic modelling is undertaken, to compare the overall costs of the Buildings Plan with a “business as usual” scenario. This allows for consideration of the economic impacts of the two pathways at a societal level, with the full understanding that business as usual is not an option we can choose. Economic analysis at the level of individual buildings is also undertaken to determine the net present costs of particular case studies.
8 Zero Carbon Australia Project Overview

The Zero Carbon Australia Project (ZCA) is an initiative of Beyond Zero Emissions and the University of Melbourne's Energy Research Institute. The Project is developing a roadmap for the transition to a decarbonised Australian economy over ten years. The latest and most credible science tells us that such a transition is necessary to maintain a safe climate.

The ZCA Project envisions six plans:

Plan 1: The ZCA Stationary Energy Plan - re-powering of Australia's stationary energy sector with zero-emissions technology (published in 2009)

Plan 2: The ZCA Buildings Plan - measures to improve energy efficiency and electrify current natural gas services

Plan 3: The ZCA Transport Plan - powering private and public transportation with renewable electricity

Plan 4: The ZCA Industrial Processes Plan - measures to reduce emissions from industry

Plan 5: The ZCA Land Use Plan changes to agriculture, forestry and other land use practices to minimise future emissions and draw down historic emissions

Plan 6: The ZCA Renewable Superpower Plan focuses on Australia's large fossil fuel exports.

The ZCA Project differs from other emissions reductions projects because it has a target of zero emissions within ten years. Most other transition schemes aim to move towards a low emissions economy over a period of indeterminate length. A rapid transition to a zero-emissions economy is preferred to proceeding slowly to a low emissions economy over fifty years or so.

These Plans draw on the enormous wealth of knowledge, experience and expertise in the community and together will represent a comprehensive blueprint for a zero carbon future in Australia.

The Project's guiding principles are:

1. Australia's energy is provided entirely from renewable sources at the end of the transition period.
2. All technological solutions employed are from proven and scaleable technology which is commercially available.
3. The security and reliability of Australia's energy supply is maintained or enhanced by the transition.
4. Food and water security are maintained or enhanced by the transition.
5. The high standard of living currently enjoyed by Australians is maintained or enhanced by the transition.
6. Social equity is maintained or enhanced by the transition.
7. Other environmental indices are maintained or enhanced by the transition.
9 Project Methodology

The ZCA Buildings Plan is one of the largest crowdsourcing research projects in Australian history. Work on this report began in September 2010, led by a small team of staff at Beyond Zero Emissions. The primary role of those staff was the coordination of volunteer based research teams and industry engagement. As a consequence over one hundred volunteers from across Australia and the globe have contributed research, modelling, and text to the final report.

These volunteers are engineers, architects, designers, energy consultants, students, PhD candidates, and enthusiasts from the building, property management and energy efficiency fields, and government.

The Buildings Plan has also benefited from a number of companies that have provided their services on a pro-bono basis.

Energy Efficient Strategies, a well-known energy policy and planning consulting company contributed approximately $50,000 worth of pro-bono time to undertake modelling of baseline residential energy consumption and the forecast savings from implementing the retrofit measures. This built on their 2008 residential energy baseline analysis for the Department of Environment Water Heritage and the Arts. Lloyd Harrington and Rob Foster of EES provided substantial advice on the existing building stock, government energy policy, and energy efficiency measures.

WSP Built Ecology and GHD provided substantial support for thermodynamic simulation of non-residential buildings using the simulation software, IES Virtual Environment. They also provided valuable advice for the establishment of building models which served as archetypes in high level energy analysis and economic modelling.

VIPAC, a multi-disciplinary technical consultancy specialising in mechanical and systems engineering, testing and instrumentation in a range of industries, assisted BZE in assessing the small wind potential on high rise buildings in the urban area. This project involved Computational Fluid Dynamics simulation of wind flows in the Melbourne CBD and validation testing in VIPACs wind tunnel.

Department of Sustainability and the Environment and Entura Consulting analysed results and data from the Urban Solar Atlas pilot projects to estimate the total rooftop potential of Solar Photovoltaic in Boroondara and Port Philip. The Urban Solar Atlas project uses aerial laser technology and GIS software to map the rooftop solar potential. BZE used these results to extrapolate an estimate of rooftop resource to the whole of Australia.

Solem Consulting, an experienced consultancy in solar thermal technology for building and process services, assisting BZE in the development of a TRNSYS simulation to optimise a domestic hot water system. Solem also provided advice on a range of solar hot water technologies for buildings.

Facilities Management Association, the national

FIGURE 1.10
LED lighting is proposed to be widely adopted to drastically increase building energy efficiency [R. Keech]
representative body for facility managers, has worked in conjunction with BZE to develop a range of minimum training standards for facility managers and the estimated energy savings for improving facility management in commercial buildings.

Mirus Consulting Services', Director Mark Waring provided commercial HVAC costings based on his own extensive knowledge and in consultation with a highly experienced estimator.

A number of other companies, and government departments have provided data at reduced cost or free of charge. These include: Geosciences Australia (NEXIS), Melbourne City Council, NSW Office of Environment and Heritage (NABERS), Investa, GPT, Charter Hall, Stocklands, Commercial Energy Services, Sustainable Built Environments.

The Buildings team also communicated with Pitt & Sherry during their concurrent study on forecasting energy consumption of commercial buildings for the Department of Climate Change and Energy Efficiency.

The Buildings Plan was built from the ground up through extensive industry consultation and engagement. This has been through individual meetings with stakeholders across Australia, such as those involved in the companies and institutions listed above.

In May 2011 BZE held in conjunction with Melbourne Energy Institute an Energy Retrofit Workshop at Melbourne University. The workshop involved 35 participants from 13 companies, government bodies and industry associations and three prominent academics, Alan Pears, Sara Wilkinson and Dominique Hes. The event was held to allow expert input into the development of non-residential building typologies and the most appropriate retrofit options, prioritising building fabric upgrades. The final list of proposed retrofits was further refined by an engineer at Aurecon and used as the basis of Buildings Plan non-residential strategies.

BZE has also been invited as a speaker at a number of industry events. Some of these were:

2. Victorian Branch of the Property Council of Australia, February 2011, Melbourne
5. Solar Cities Conference, November 2012, Brisbane

When BZE began this ambitious project there was little up-to-date, centrally collected data on Australia's building stock and energy consumption. BZE therefore undertook to build an in-house stock model for non-residential buildings drawing together a vast array of data from free or very low cost sources. In addition BZE needed to segment the building stock into different archetypes according to age, construction type and mechanical systems. These archetypes allowed for the simplification of the building stock into representative cases that allowed the compilation of retrofit measures into a single package for each building type. This work required consultation with architectural historians, other data collection agencies, experts in building renovations, and Melbourne and Sydney city councils who have undertaken similar segmentation analyses.

The selection of widely applicable retrofit measures required significant discussion with experts in the industry, modelling of the impacts of different plausible options, desk top research, and consultation with suppliers and manufacturers. This represented a substantial undertaken the outcome of which is a collection of simple but effective measures that are translatable across many different buildings and climates.

Thermodynamic modelling of packages of these retrofit measures, tailored for different building types, was necessary to estimate the percentage energy savings. This was undertaken both in-house and by external in-kind contributors, but depended on support and advice from individuals with experience in modelling.

A significant body of work was contributed to the project by Energy Efficient Strategies. Their residential energy model is highly comprehensive and includes different appliance characteristics, penetrations, replacement cycles, and 72 individual building shell models. BZE worked closely with EES to adjust aspects of their model and incorporate the proposed retrofit measures and their corresponding estimated energy savings or performance characteristics.

The Buildings Plan as a consequence presents the most up-to-date picture of Australia's energy baseline energy consumption and forecasts over the next seven to ten years. It is also built on a solid foundation such that any projected energy savings from undertaking the plan can be confidently depended on.

A full cost model had to be created with over 45 different cost inputs derived from quotes, consultation with industry experts, cost guides, online search, and direct experience from building owners having undertaken similar retrofits themselves. These costs were then applied to the building archetypes and total stock area for each category of building. Finally detailed economic analysis was undertaken.

Substantial graphic design was necessary to maximise the communication of the reports contents. BZE built it's own in house graphic design capacity utilising skilled volunteers and companies providing pro-bono time.

Finally, Associate Professor Alan Pears undertook a full peer review of the report and provided valuable assistance and advice throughout the production of the Buildings Plan.
10 Report Outline

Part 2
Part 2 of this report outlines the regulations, schemes and policy considerations that relate to energy in buildings in Australia. It describes Australia’s current building stock, and ongoing trends in energy efficiency and energy prices are described.

Part 3
Part 3 details the low-energy building technologies and strategies employed in the Buildings Plan. It shows how significantly reducing building energy demand and ending the use of gas in buildings can be achieved.

Part 4
Part 4 describes the building stock model, utilising building type and climate zone categories to make recommendations for various retrofit measures. Six case studies illustrate the retrofit recommendations.

Part 5
Part 5 explains the computer modelling and analysis undertaken to investigate the potential reduction in grid energy demand, including the use of rooftop solar.

Part 6
Part 6 shows the economics of the plan, costing the transition and comparing this to current, ‘business as usual’ economic data.

11 About Beyond Zero Emissions

Beyond Zero Emissions Inc. is a not-for-profit research and education organisation that works to design and implement a zero emissions economy for Australia. Our goal is to transform Australia from a 19th century fossil-fuel-based, emissions intensive economy to a 21st century leader in sustainable energy.

In partnership with the University of Melbourne’s Energy Institute, BZE publishes plans in the Zero Carbon Australia Project.

Through the Zero Carbon Australia research project, BZE pushes for policy that is in line with the latest climate science. By sharing this research with thousands of Australians via our public engagement program, BZE is engaging, educating, and inspiring the community with real solutions to climate change.
12 References


Part 1: Introduction and Overview


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## Part 2: Factors Influencing Energy in Buildings

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1 Overview

Part 2 of this report outlines the regulations, schemes and policy considerations that relate to energy in buildings.

Systems to regulate building energy use from various countries are contrasted with those in Australia. Australia’s building rating schemes (NatHERS, Green Star and NABERS) are outlined, as are product energy rating schemes. Definitions and debates about energy efficiency in the home are surveyed.

The profile of the current building stock in Australia is outlined, based on detailed modelling: the various commercial building categories as well as residential buildings, and the breakdown of energy use in these various building categories is included.

Finally, ongoing trends in energy efficiency and energy prices are described.

2 Energy Building Regulations, Standards and Policies

Internationally, the potential for energy efficiency and emissions reductions from the buildings sector is well recognised. For example, a survey of eighty international studies found that there is a global potential to cost-effectively reduce around 29% of the projected baseline emissions in the residential and commercial sectors by 20201.

To date, Australia has not adopted world-best practice in energy efficiency policy in the building sector. While many countries are addressing both the energy efficiency ‘floor’ and the ‘ceiling’ — improving the minimum acceptable efficiency standard and extending the maximum — Australian measures have generally focused on the floor alone. The 2010 report of the Prime Minister’s Task Group on Energy Efficiency stated that “although... difficult to measure with precision, it seems clear that the level and the rate of improvement of energy efficiency in Australia lag behind those of much of the rest of the world”2. Many countries have started adopting long-term strategies which set a pathway towards zero-energy or zero-emissions buildings.

The following is a summary of relevant international targets and policy aims which illustrate the proactive approach taken by various other countries in transforming the emissions profile of the building sector.

2.1 United Kingdom

The UK Government has committed to net zero carbon emissions for new homes by 2016, for public sector buildings by 2018 and commercial premises by 20193. These targets are to be achieved via a steady escalation of building regulations, enabling all new buildings to be zero carbon by the target dates. Since October 2010, building regulations have required a flat 25% carbon reduction in new domestic buildings (based on 2006 standards) and an aggregate 25% carbon reduction in non-domestic buildings4. Planned updates to the Building Regulations include a reduction of 60% for new homes by 2013 to meet the net zero target by 20165.

To encourage continuous sustainability improvement of new homes and to support emissions targets, the Government also introduced the Code for Sustainable Homes as a national standard in 2007. The Code sets levels of performance for all key Government sustainability targets, measuring impacts such as energy and CO₂ emissions, pollution, water, waste, materials, health and well being, management, surface water run-off and ecology. Every new home built must contain a rating against the Code. The Code increasingly underpins the Building Regulations and provides the basis for future changes to the regulations6.
2.2 Europe

In 2010, the EU adopted the Energy Performance of Buildings Directive 2010/31/EU (EPBD) which requires Member States to “establish and apply minimum energy performance requirements for new and existing buildings, ensure the certification of building energy performance and require the regular inspection of boilers and air conditioning systems in buildings”\(^7\). This built on the original 2002 EU directive and subsequent 2008 recast showing the EU’s continuing commitment to energy efficiency. Additionally under the Directive, by 2021 all new buildings in Member States are required to be ‘nearly zero-energy buildings’.

In 2013 the Commission published a study including residential and commercial buildings that shows a positive economic impact on sales and rental prices of the Energy Performance Certificate under the EPBD. The study shows that better energy efficiency is rewarded in the market\(^8\).

2.3 United States of America

The ‘2030 Challenge’ is a strategy which has been widely adopted across the United States by numerous professional and industry organisations, as well as numerous cities, counties, and states. The challenge sets emissions targets for all new buildings, developments and major renovations. It proposes that performance of new buildings be increased progressively to be carbon-neutral by 2030\(^9\).

Governments in the USA at all levels have also adopted the 2030 Challenge targets. At the federal level, the Energy Independence and Security Act 2007 (EISA) was passed which requires that all new federal buildings and major renovations reduce their fossil fuel energy use to 55% (relative to the 2003 level) by 2010 and be eliminated by 2030\(^10\). EISA 2007 also included a mandate to develop and disseminate technologies, practices, and policies to reach the goals of achieving zero net energy use for new commercial buildings after 2025 and retrofitting all pre-2025 buildings to zero net energy use by 2050.

In 2009, Sec. 201 of the American Clean Energy and Security Act of 2009 (H.R. 2454) passed by the House of Representatives called for national building code energy reduction targets which are derived from the 2030 Challenge. These targets were amended in 2010. This Bill also authorizes the Secretary to set further energy savings targets on a path to achieving zero net energy or “carbon neutral” buildings.

State Governments adopting 2030 Challenge Targets (or 2030 inspired targets) include the states of California, Washington, Illinois, Minnesota and New Mexico. In 2007, the U.S. Conference of Mayors passed resolution #50 which called for all new buildings and renovations in the cities to meet the 2030 Challenge Targets\(^9\).

2.4 Canada

In Canada, both federal and provincial standards govern the minimum efficiency of home heating, cooling, refrigeration, and other equipment that can be installed in homes.

Canada has a long-standing voluntary national programme (now called ecoENERGY) to promote residential efficiency retrofits, based on the use of national, standard audit and incentives for recommended measures\(^11\). The program offered CAD 300 million over two years and has a GHG reduction target of 1.66 Mt by 2011\(^12\). This program is built upon by provincial government and utility programmes, typically by including additional financial incentives.

Of the numerous policies implemented at multiple levels of government, an example which can provide a model for Australian cities is Vancouver City which in 2008 set a target of a citywide reduction of 33% of current GHG emissions by 2020 and an 80% reduction by 2050, with carbon neutrality for all new buildings by 2030\(^13\). To achieve these goals, the Vancouver Council commenced a major EcoDensity initiative.

2.5 Japan

Japan’s Strategic Energy Plan (latest revision June 2010) proposes targets such as doubling the energy self-sufficiency ratio (18% at present) and self-developed fossil fuel supply ratio (20% at present) resulting in an increase of its “energy independence ratio” to about 70% (38% at present). Other targets include raising the zero-emission power source ratio to about 70% (34% at present), halving CO\(_2\) emissions from the residential sector, maintaining and enhancing energy efficiency in the industrial sector at the highest level in the world and maintaining or obtaining top-class shares of global markets for energy-related products and systems\(^14\).

As part of these targets, measures are proposed for the residential and commercial building sectors including moving towards zero net energy buildings, setting energy-saving standards and replacing old equipment.

Japan’s Top Runner programme\(^15\) is an electrical appliance rating program that determines the most efficient model on the market and makes that model’s level of efficiency the new baseline. The legal framework for the Top Runner Program is covered under the Energy Conservation Law and has led to dramatic advances since the program’s inception in 1998.

Top Runner standards have required rates of energy efficiency improvement of between 16% and 80%. So far
there has been a 100% compliance rate with some products achieving a higher improvement in efficiency.

**TABLE 2.1**

Japanese energy efficiency improvement of major products with Top Runner Standards

<table>
<thead>
<tr>
<th>Product</th>
<th>Estimated improvement with Top Runner Standards</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room air conditioners</td>
<td>66.1% increase in COP (FY 1997 vs FY 2004)</td>
<td>67.8%</td>
</tr>
<tr>
<td>Refrigerators</td>
<td>30.5% decrease in kWh/annum (FY 1998 vs FY 2004)</td>
<td>55.2%</td>
</tr>
<tr>
<td>TV receivers</td>
<td>16.4% decrease in kWh/annum (FY 1997 vs FY 2003)</td>
<td>25.7%</td>
</tr>
<tr>
<td>Computers</td>
<td>83.0% decrease in kWh/annum (FY 1997 vs FY 2005)</td>
<td>99.1%</td>
</tr>
<tr>
<td>Fluorescent lights</td>
<td>16.6% increase in lumen/W (FY 1997 vs FY 2005)</td>
<td>78.0%</td>
</tr>
</tbody>
</table>


* Estimated improvement of weighted average energy efficiency of all categories within each product group

Figure 2.1 shows the effects of the program on the efficiency of air conditioners sold in Japan during the first seven years of the program. The blue dotted line shows when the Top Runner target was set (1998), with the blue circle at the top showing the target level of efficiency. Air conditioners at the top of the market improve gradually, but air conditioners at the bottom end of the market don’t improve much at all. However, during 2003 the efficiency of air conditioners at the lower end of the market improves dramatically as producers work to reach targets by the 2004 deadline.

**2.6 Australia**

In April 2009, as a first step to improve the energy efficiency of residential and commercial buildings across Australia, the Council of Australian Governments (COAG) agreed to the introduction of key measures through the National Strategy on Energy Efficiency (NSEE). In brief, COAG increased energy efficiency provisions for building by:

1. An increase to a six star energy rating, or equivalent, for new residential buildings
2. A significant increase in the energy efficiency requirements for all new commercial buildings
3. Phase in of mandatory disclosure of building energy efficiency
Part 2: Factors Influencing Energy in Buildings

3 Existing energy efficiency measures, and their impacts in Australia

3.1 Declining demand for grid electricity

In the eight years up to 2007-2008, the electrical energy flows on the National Electricity Market (NEM) grew steadily at an average rate of 2.8%. However, since 2007-2008, the electricity demand in the NEM has steadily declined at an average annual rate of 1.9%. These trends are shown in Figure 2.2.

The Australian Energy Market Operator has said the "changing economic landscape, a more energy-conscious public, the impact of rooftop solar photovoltaic installations and milder weather have all contributed to lower than forecast annual energy across Eastern and South Eastern Australia". Significantly, AEMO stated that it "is becoming apparent that electricity consumers are changing their energy use in response to rising electricity prices and are adopting energy efficiency programs and the installation of rooftop solar photovoltaic systems". This indicates that Australian Federal and State Government energy efficiency programs have made a discernable impact on building energy consumption, and that these programs create a benefit that extends beyond individual households and businesses.

Some of the factors thought to contribute to reduction in electricity consumption include:

* **Improvements in efficiency of commercial buildings.** Adoption and mandatory disclosure of NABERS, Green Star rating, along with more stringent building regulations implemented in 2006 and 2010, have driven the implementation of energy efficiency technology in commercial buildings. Higher rents fetched by energy efficient buildings with lower emissions and operating costs built a strong business case for implementation of these energy efficiency technologies.

* **Energy efficiency in the residential sector.** More stringent regulations on lighting and off-peak hot water services on newly built homes have been imposed. As an example, according to a report from Ausgrid, energy saving of up to 8% in some households has been achieved through installation of efficient hot water systems. Improvements in efficiency of household appliances such as air conditioners and TVs, together with the shift to fluorescent, and more recently LED lighting, have translated into lower electricity demand.
3.2 Incentives and Barriers

There are many good reasons to invest in energy efficient premises. Green buildings reduce energy costs, which can give a competitive advantage in the marketplace, and generate productivity benefits from more satisfied occupants\(^2\). Yet there remain barriers that can delay this shift. Australia’s relatively low energy prices reduce the financial incentive to act. There is a lack of knowledge in the community, and there can often be contradictory incentives between tenants and building owners.

The balance between incentives and barriers will ultimately decide how and when property owners invest in more sustainable buildings. To encourage this shift, the Federal Government has raised the minimum efficiency standards in Australia’s building codes. By bringing in mandatory disclosure legislation such as the Energy Efficiency Opportunities scheme, the Federal Government has also forced large corporations (those that use more than 0.5 petajoules (PJ) of energy per year) to confront the issue of energy efficiency head-on. Nonetheless greater government support is needed to achieve the substantial improvements that are economically viable.

3.2.1 Incentives

3.2.1.1 Cost savings

Increasing energy and water efficiency will result in lower energy costs. The amounts will vary from case to case, but

- **Online shopping.** The growth in volume of online shopping reduces electricity demand in the retail sector.
- **Higher population density.** The population growth rate has declined in recent years. This, coupled with the peaking of new home sizes, is expected to result in a decline of energy consumption over the longer term.
- **On-site power generation.** The installation of roof-mounted solar photovoltaic systems in the residential and commercial sectors has helped offset electricity consumption. A close match between the power generated by the PV systems and the load profiles of commercial buildings allows effective offsetting of peak electricity consumption. In addition, a growing interest in co-generation and tri-generation in the commercial sector work to offset grid electricity demand.
- **Improved street lighting.** A growing number of local councils have focused on improving efficiency of their street lighting.
- **Higher electricity prices.** Recent electricity price increases have created stronger energy efficiency and conservation incentives for businesses and households.
- **Macroeconomic effects.** The higher Australian dollar has put further pressure onto the energy-intensive manufacturing sector, and accelerated a long-term trend of relocation overseas.
- **Climatic.** Milder winters may have contributed to reduced heating demand.

![COMPARISON OF THE NEM-WIDE ENERGY PROJECTIONS](image)
Part 2: Factors Influencing Energy in Buildings

at the top of the range, companies have reported energy savings of up to 70%\textsuperscript{22}.

A study conducted by The Warren Centre for Advanced Engineering entitled “Low Energy High Rise” investigated which management strategies have the greatest positive impact on energy efficiency. The study found that building managers were more likely to invest in energy efficiency programs when the energy savings were returned to the building budget\textsuperscript{23}.

3.2.1.2 Competitive advantage

Large corporations, especially those at the top end of the market, care about the environmental performance of the buildings they occupy. Most companies have public reporting responsibilities which play an important role in maintaining their corporate image - a good corporate image requires some degree of environmental sustainability. The Commercial Building Disclosure Scheme, passed in 2011, further encourages competition by forcing owners of large commercial properties to disclose their energy efficiency rating prior to selling or leasing their building.

As corporate culture shifts, building owners are encouraged to improve the efficiency of their properties. A recent survey of Melbourne’s commercial property market found that a majority of respondents considered public sustainability certification important for tenant attraction and retention\textsuperscript{24}.

3.2.1.3 Benefits from improved worker productivity

Recent research suggests that there are measurable gains to be made by providing employees with a more environmentally friendly office environment.

In Melbourne, after the offices at 500 Collins St were retrofitted to receive Australia’s first five-star Green Star rating for an existing building, Sustainability Victoria and the BOE Business Consultancy conducted an independent productivity study on the buildings’ tenants\textsuperscript{25}. The study found that employee productivity had increased 12%, with number of reported sick days down 44%. While the sample sizes for this survey were small, the results correlate with a similar survey conducted in the United States that registered statistically significant productivity benefits in environments that offered natural lighting and improved air quality\textsuperscript{26}.

More-productive employees means lower costs and higher output for businesses, so this research should encourage corporate decision makers to improve the sustainability of their offices.

3.2.2 Barriers

In 2009, as part of an academic study into promoting energy efficiency in Australian office buildings, property market stakeholders were asked what they saw as the barriers to promoting energy efficiency in offices\textsuperscript{27}. Altogether, 70% of respondents believed there was an increasing demand for ‘green’ office space, and most expressed a desire to improve the sustainability of their own office environments through better ventilation, temperature control and natural light. Yet there is much to be done in this field.

Survey respondents listed a host of barriers that were holding back progress towards energy efficiency. These barriers to change fell broadly into three categories: 1) financial, 2) organisational and 3) the split incentives between owner and tenant.

3.2.2.1 Financial

- **Perceived Upfront Costs.** The practical costs of office refurbishments, combined with the administrative costs of green certification, were seen by some property managers as too high. A 2007 study conducted by the World Business Council for Sustainable Development found that, on average, business leaders erroneously believed the cost of green buildings to be 17% higher than their traditional counterparts\textsuperscript{28}. Such opinion is shifting as costs come down, but some still see upfront refurbishment and construction costs as outweighing future running costs.

- **Low Utility Prices.** All participants in the 2009 survey (see 3.2.2) agreed that, in comparison to rent and salaries, energy prices in Australia were a very small fraction of an office’s running costs. This reduces any financial incentive for building owners to save energy.

- **Risks.** A commonly perceived risk in investing in sustainability was that unforeseen additional costs may arise. Building operators know exactly how much their energy bills cost, but are less certain about the price of an office refurbishment.

- **Vacancy costs.** Usually, refitting an office for energy efficiency will mean vacating it for several weeks. The resulting loss of revenue for lesers and tenants can be significant.

3.2.2.2 Organisational

- **Lack of Knowledge and Experience.** There was a lack of knowledge and experience about the details of energy efficiency measures. Half of the 2009 survey respondents had not heard about the possibility of government grants for office refurbishment.

- **Lack of Knowledge about Energy Costs.** There was also a general lack of knowledge about the details of energy costs. Only 14% of respondents knew details about the energy consumption of their building. Other respondents said they would like to know but had trouble obtaining the data.
3.3 Building Rating Schemes & Tools

Star Ratings are a popular tool for rating the energy efficiency of buildings, as they are easily understood by the public and simplify comparisons between properties and products. Star Rating programs such as BREEAM (UK and Europe) or LEED (USA) have been around since the 1990s. In Australia, there are three main national rating schemes in general use, NatHERS, Green Star and the National Australian Built Environment Rating Scheme (NABERS). Generally, NatHERS (for homes) & Green Star (for other buildings) assess how a building is designed and constructed, while NABERS assesses the performance in operation.

3.3.1 NatHERS

The Nationwide House Energy Rating Scheme (NatHERS) is the federal scheme for rating the thermal performance of home designs throughout Australia. Its scope is limited to the thermal performance of the building structure and is intended to indicate the heating and cooling requirements. It specifically excludes other home energy use such as hot water, lighting and appliances.

Climate Zones. The scheme defines sixty nine climate zones. For more information on climate zones, see Appendix 2.

Scale. NatHERS assesses building designs on a scale from one-star (worst) to ten-star (best) in half-point increments. The rating is based on an adjusted energy density expressed in MJ/m² of floor area. The correspondence between energy values and star rating varies according to locality. For example, in climate zone ten (Brisbane), the scale is from 245 MJ/m² (0.5 star) to 10 MJ/m² (ten-star). In climate zone 65 (Orange, NSW) the same scale is from 1,156 MJ/m² down to 2 MJ/m². A ten-star rating indicates that a house needs zero (or near zero) mains energy for heating and cooling.

Local applicability. The application of NatHERS varies from state to state. The individual states of Australia have chosen to apply it and extend it in slightly different ways. NatHERS is not used at all in NSW. Instead the BASIX scheme applies. BASIX scores designs based on potential for both energy savings and water savings, and it does not limit energy saving potential to space conditioning.

Design vs implementation. NatHERS ratings are applied to building designs, which may or may not agree with homes as built. The scheme has no mechanism for reconciling the as-built state of a house with its design.

Behaviour. The actual energy used by a home for heating and cooling is fundamentally influenced by occupant-behavioural and other factors that are beyond the scope of NatHERS to assess. Accordingly the assessment is performed based on an assumed operational profile as shown below:
Part 2: Factors Influencing Energy in Buildings

3.3.2 Green Star

The Green Star program is a voluntary environmental rating system developed by the Green Buildings Council of Australia (GBCA). It is similar to international tools like BREEAM and LEED. Green Star rates properties on their design and construction, not their operational performance. As such, Green Star is usually used to rate new projects rather than existing buildings, and assessments must be conducted within 24 months of construction\(^7\).

Green Star utilizes a six-star rating scale, certifying buildings based on their performance in nine categories which reflect a much broader view of sustainability than NatHERS or NABERS.

- Management
- Indoor Environment Quality
- Energy
- Transport
- Water
- Materials
- Land Use and Ecology
- Emissions
- Innovation

**Scoring.** Points are given in each category, and the total performance is then weighted by category and climatic region. The Green Star rating is therefore a holistic tool, designed to promote integrated, sustainable building design. Buildings are scored out of a hundred, and the threshold for each level is shown in the table below. Certifications are only given when a building rates as four star or better. The composite nature of the scoring means performance on some criteria may be poor, even for a high overall rated building.

<table>
<thead>
<tr>
<th>Green Star Scoring Framework Score Threshold</th>
<th>Star Rating</th>
<th>Merit Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1</td>
<td>Minimum Practice</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>Average Practice</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
<td>Good Practice</td>
</tr>
<tr>
<td>45</td>
<td>4</td>
<td>Best Practice</td>
</tr>
<tr>
<td>60</td>
<td>5</td>
<td>Australian Excellence</td>
</tr>
<tr>
<td>75+</td>
<td>6</td>
<td>World Leadership</td>
</tr>
</tbody>
</table>

**Scope.** Green Star is adapted for different building types and has separate rating methodologies (otherwise known as ‘tools’) to rate offices, educational facilities, healthcare facilities, industry, multi-unit residential apartments, shopping centres and public buildings such as libraries or...
churches. The ‘office’ rating tool was the first and is currently the most widely used.

**Design vs as-built.** A rating can be applied either at the design stage or after completion, or both. Since there is always some variation between how a building is designed and how it’s built, it’s important to know if a quoted rating is a design rating or an as-built rating.

**Occupant behaviour.** A limitation of Green Star is that it cannot fully account for the great variations in how a building is used and managed. Occupant behavior can significantly influence the operational sustainability of a Green Star-certified building.

### 3.3.3 NABERS

The National Australian Built Environment Rating Scheme (NABERS)\(^{38}\) is managed by the New South Wales government’s Office of Environment and Heritage. Like the Green Star program, NABERS rates buildings on a six star scale. However, in contrast to Green Star, NABERS was designed mainly to assess the operational performance of existing buildings (although there are ways to apply NABERS to new buildings\(^{39}\)). The scale\(^{40},^{41}\) is defined in Table 2.3.

<table>
<thead>
<tr>
<th>Nabers Rating</th>
<th>Merit Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Very poor</td>
</tr>
<tr>
<td>1</td>
<td>Poor</td>
</tr>
<tr>
<td>2</td>
<td>Below average</td>
</tr>
<tr>
<td>2.5 to 3</td>
<td>Average</td>
</tr>
<tr>
<td>4</td>
<td>Good</td>
</tr>
<tr>
<td>5</td>
<td>Excellent</td>
</tr>
<tr>
<td>6</td>
<td>Market leading</td>
</tr>
</tbody>
</table>

**Scope.** In application, NABERS has separate ratings ‘tools’ (methodologies) for offices, hotels, retail and data centers. There is also a self-assessed method for homes, i.e. there is no provision for home-owners to have a certified 3rd party perform a NABERS assessment on their home. There are NABERS tools for schools and hospitals under development. In the case of the office rating (the most common), it does this by assessing performance in some or all of the following categories and a separate score is given for each category:

- energy use
- water use
- waste generation
- indoor environment
- transport.

NABERS assessments can be conducted at three levels. A **Base Building assessment** measures the conditions in the common areas of a building, such as lifts and lobbies. A **Tenancy Assessment** measures conditions in rooms leased to tenants, such as company offices. These assessments can be combined into a **Whole Building report**, which will give the most accurate measure of a building’s performance.

Accredited NABERS assessors base their ratings on the building’s performance data over a year. This is based on verified, 3rd-party, quantitative data, such as water or energy bills. The collected data is adjusted to take into account variables like building size, climate, or hours of operation, and then compared to NABERS benchmark levels.

Because of the flexibility of the NABERS system, assessments can measure criteria as narrow as the energy use in one tenant’s office, or provide a whole-of-building report covering all four categories of performance.

On average, an improvement of one NABERS Energy star equates to a decrease in greenhouse gas emissions of over 15%\(^{42}\).

Typical assessment activity conducted along with a NABERS rating would offer tools and resources aimed at enabling building owners and managers to identify and achieve efficiency gains. By focusing on issues within the control of building managers, NABERS reports empower them to make positive changes in their operations.

NABERS has seen its profile raised by the Federal Government’s Energy Efficiency in Governmental Operations (EEGO) policy\(^{43}\). This policy, introduced in 2006, has made it mandatory for Federal Government leased buildings to achieve a minimum 4.5 stars in the NABERS Energy rating. State Governments have followed suit.

**NABERS Energy.** The NABERS Energy rating is based on greenhouse gas emissions attributable to a building’s energy use, adjusted for building size, considering data from at least one year of operation. The scale applied varies between states to account for the local climate. In other words, in a demanding climate, greater energy use is allowed for a given star rating. For any given locality, the emissions corresponding to a 6 star rating are half those of a 5 Star...\(^\text{32}\)...
Part 2: Factors Influencing Energy in Buildings

3.3.4 Mandatory Disclosure

Commercial. Since November 2011 it has been mandatory for those selling or letting commercial buildings with a floor space (net-lettable area) over 2,000 m² to undertake a NABERS Energy assessment. The assessment then forms the core of a Building Energy Efficiency Certificate (BEEC) which is publically disclosed. This Commercial Building Disclosure Scheme has been introduced by the Department of Climate Change in the hope that it will create an incentive for building managers to improve the sustainability of their properties. The scheme, by itself, imposes no energy efficiency targets. The expectation is that by exposing the energy performance publicly market forces will naturally tend to favour properties with higher energy efficiency ratings.

Residential. The scheme is expected to be extended to the residential sector. Considerations are at the stage where a regulatory impact statement (RIS) has been issued by government. Residential mandatory disclosure has been operating in the ACT since 1999. The effect in 2006 was a 1.9% increase in sale price per 0.5 star increment in rated performance.

3.3.5 Green Star vs NABERS

Although the Green Star and NABERS ratings can be seen as complementing each other, the existence of two rating systems has caused confusion among property owners and tenants. In an attempt to rectify this, a new Green Star Performance system is planned for late 2013 that will merge features from both systems.

Like the standard Green Star system, Green Star Performance will take a holistic approach that provides one rating based on the nine Green Star categories. Rather than design, Green Star Performance will measure operational performance. Effectively, it is an expanded version of the NABERS process. Certification will be valid for three years, after which building managers will need to request a reassessment.

It is currently intended that existing NABERS tools will be encapsulated in the new Green Star Performance process. For example, energy usage will be calculated using the existing NABERS Energy assessment. At the moment, however, the new tool remains in the drafting phase.

FIGURE 2.7
CBD logo

NABERS ENERGY SCALE FOR A TYPICAL OFFICE
FIFTY HOURS/WEK WORK OPERATION
USING ELECTRICITY AS ONLY ENERGY SOURCE

FIGURE 2.8
NABERS (Base Building) Energy scale for a typical office operating fifty hours/week using electricity as the only energy source [www.nabers.com.au]
3.4 Product Energy Efficiency

The efficiency of devices and equipment used in a building is substantially influenced by both government regulation and industry-driven efficiency initiatives. There are broadly two sides to the regulation of equipment energy efficiency in Australia - the MEPS scheme (Minimum Energy Performance Standard)\(^51\), and energy ratings labels\(^52\). Each of these is a Federal Government program under the broader \textit{E3} (Equipment Energy Efficiency) program:

- **MEPS.** The MEPS scheme applies mandatory minimum performance levels to a broad range of electrical and gas equipment product categories. Generally the scope of the scheme is broadening to include more types of equipment. Also, the minimum performance thresholds are being adjusted upwards to reflect improvements over time. However, it is open to debate whether the scope and performance thresholds are sufficiently ambitious.

- **Energy Ratings Labels.** This scheme defines labelling of devices, often mandatory, to indicate energy performance using the familiar star rating scheme. However the scheme does not impose mandatory performance thresholds. Many types of equipment would have both a defined MEPS threshold, and an energy rating label requirement.

\textit{E3.} The current operation of MEPS and energy rating labels arises from the National Strategy on Energy Efficiency from the Council of Australian Governments in 2009\(^53\).

\textit{GEMS.} The Greenhouse and Energy Minimum Standards (GEMS) legislation was adopted in October 2012\(^54\) and replaces overlapping state laws. It now serves as the overarching legal basis for the operation of Australian equipment energy efficiency programs. It is of most interest to suppliers of equipment which is covered by the relevant schemes.

Note, some specific examples of electrical appliances’ energy use is discussed in Part 3.

3.4.1 The MEPS Scheme

The MEPS scheme has the effect of defining, for relevant devices, an energy performance level below which it is illegal to sell in Australia. By adjusting the scope and performance levels over time, this regulation has had the effect of significantly raising the bar in terms of energy performance. An example of the use of this scheme was its application to light bulbs by (the then minister for Environment) Malcolm Turnbull\(^55, 56, 57\). In this case, the minister announced, in Feb 2007, the adoption of a new regulation which made most incandescent light bulbs subject to MEPS, commencing from February 2009. MEPS is a national programme. MEPS standards apply to many classes of equipment as shown in the table below.

3.4.2 Star Ratings, and Energy Rating Labels

Mandatory energy rating labels apply to some electric equipment\(^52\). Most domestic gas equipment is also subject to energy rating labels but these are optional, ie their use is at the discretion of the manufacturer.

\textit{Star ratings.} A figure of merit of equipment energy performance (the star rating) is calculated based on formulae defined in the relevant standards\(^58\). The criteria and rating scale vary from device to device and are subject to change over time. However the rated performance level is generally expressed on a ten-star scale. Generally the results are expressed in half-star increments to six stars, and one-star increments above that. Ratings above six out of ten are generally considered to be super-efficient.

\begin{table}[h]
\centering
\caption{Energy rating labels for some different classes of equipment}
\begin{tabular}{|c|c|c|c|}
\hline
Label for a gas heater & Label for an air conditioner & Label for a window & Label for a PC \\
\hline
\includegraphics[width=0.2\textwidth]{gas_heater_label} & \includegraphics[width=0.2\textwidth]{air_conditioner_label} & \includegraphics[width=0.2\textwidth]{window_label} & \includegraphics[width=0.2\textwidth]{pc_label} \\
\hline
\end{tabular}
\end{table}
### TABLE 2.5

Applicable efficiency rating schemes for several classes of equipment and appliances

<table>
<thead>
<tr>
<th>Product Type</th>
<th>MEPS</th>
<th>MEPS Dates</th>
<th>Rating scale</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitors</td>
<td>Yes</td>
<td>2013</td>
<td>Stars + Energy Star</td>
<td>AS/NZS5815</td>
</tr>
<tr>
<td>Household Refrigeration</td>
<td>Yes</td>
<td>1999, 2005</td>
<td>Stars</td>
<td>AS/NZS4474, Proposed new MEPS 2017</td>
</tr>
<tr>
<td>Gas Space Heaters</td>
<td>Yes</td>
<td>Circa 1990S</td>
<td>Stars</td>
<td>Industry run scheme, AS4553 (non-ducted) and AS4556 (ducted)</td>
</tr>
<tr>
<td>Gas Water Heaters</td>
<td>Yes</td>
<td>Industry 1990S, Regulated 2010</td>
<td>Stars</td>
<td>AS4552, includes storage and instantaneous, previously industry run</td>
</tr>
<tr>
<td>Televisions</td>
<td>Yes</td>
<td>2009, 2013</td>
<td>Stars</td>
<td>AS/NZS62087.2.2</td>
</tr>
<tr>
<td>Commercial Refrigeration</td>
<td>Yes</td>
<td>2004</td>
<td>HE</td>
<td>AS1731, new MEPS &amp; vending machines UC</td>
</tr>
<tr>
<td>Three-Phase Electric Motors</td>
<td>Yes</td>
<td>2001, 2006</td>
<td>HE</td>
<td>AS/NZS1359, new MEPS UC, scope 0.75 kW to 150 kW</td>
</tr>
<tr>
<td>Distribution Transformers</td>
<td>Yes</td>
<td>2004</td>
<td>HE</td>
<td>AS2374.1.2 10 kVA to 2,500 kVA to 24 kV</td>
</tr>
<tr>
<td>Set Top Boxes</td>
<td>Yes</td>
<td>2008</td>
<td>Energy Star</td>
<td>AS/NZS62087.2.1, plus voluntary code with pay television providers</td>
</tr>
<tr>
<td>Computers</td>
<td>Yes</td>
<td>2013</td>
<td>Energy Star</td>
<td>AS/NZS5813</td>
</tr>
<tr>
<td>Linear Fluorescent Lamp Ballasts</td>
<td>Yes</td>
<td>2003</td>
<td>Eff Mark</td>
<td>A1 to D efficiency, AS/NZS4783</td>
</tr>
<tr>
<td>External Power Supplies</td>
<td>Yes</td>
<td>2006</td>
<td>Eff Mark</td>
<td>AS/NZS4665, efficiency mark scales from 1 (least eff) to 6 (most eff) – open ended</td>
</tr>
<tr>
<td>Linear Fluorescent Lamps</td>
<td>Yes</td>
<td>2004</td>
<td>Voluntary*</td>
<td>AS/NZS4782 * EU label permitted</td>
</tr>
<tr>
<td>Self Ballasted Lamps (Cfl)</td>
<td>Yes</td>
<td>2009</td>
<td>Voluntary*</td>
<td>AS/NZS4847 * EU label permitted</td>
</tr>
<tr>
<td>Incandescent Lamps For Gls</td>
<td>Yes</td>
<td>2009</td>
<td>Voluntary*</td>
<td>AS/NZS4934 * EU label permitted</td>
</tr>
<tr>
<td>Chillers</td>
<td>Yes</td>
<td>2009</td>
<td>None</td>
<td>AS4776, larger than 300 kW</td>
</tr>
<tr>
<td>Close Control Air Conditioners</td>
<td>Yes</td>
<td>2009</td>
<td>None</td>
<td>AS/NZS4695, computer rooms and communications facilities</td>
</tr>
<tr>
<td>Electric Storage Water Heaters</td>
<td>Yes</td>
<td>1999, 2005</td>
<td>None</td>
<td>Mains pressure, low pressure and heat exchange, AS/NZS4692, AS1361, AS1056</td>
</tr>
<tr>
<td>Elv Transformers</td>
<td>Yes</td>
<td>2010</td>
<td>None</td>
<td>AS/NZS4879</td>
</tr>
<tr>
<td>Solar &amp; Heat Pump Water Heaters</td>
<td>Voluntary</td>
<td>N/A</td>
<td>Voluntary STC Count</td>
<td>AS5102, propose to mandatory star rating label and MEPS in future</td>
</tr>
</tbody>
</table>
TABLE 2.5 (CONT.)

Energy rating labels for some different classes of equipment

<table>
<thead>
<tr>
<th>Product Type</th>
<th>MEPS</th>
<th>MEPS Dates</th>
<th>Rating scale</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clothes Dryers</td>
<td>No</td>
<td>N/A</td>
<td>Stars</td>
<td>AS/NZS2442</td>
</tr>
<tr>
<td>Dishwashers</td>
<td>No</td>
<td>N/A</td>
<td>Stars</td>
<td>AS/NZS2007</td>
</tr>
<tr>
<td>Windows</td>
<td>No</td>
<td></td>
<td>Stars</td>
<td>Voluntary scheme run by Fenestration Council of Australia (WERS)</td>
</tr>
<tr>
<td>Other Home Office</td>
<td>No</td>
<td>N/A</td>
<td>Energy Star</td>
<td>Wide range of product in ES program</td>
</tr>
<tr>
<td>Swimming Pool Pumps</td>
<td>No</td>
<td>2010</td>
<td>Voluntary</td>
<td>AS5102, propose to mandatory star rating label and MEPS in future</td>
</tr>
<tr>
<td>Electric Cooking</td>
<td>No</td>
<td></td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Water Dispensers</td>
<td>No</td>
<td></td>
<td>None</td>
<td>Considered a priority</td>
</tr>
<tr>
<td>Vending Machines</td>
<td>No</td>
<td></td>
<td>None</td>
<td>Under consideration, Sept 2008</td>
</tr>
<tr>
<td>Fans</td>
<td>No</td>
<td></td>
<td>None</td>
<td>India have regulated fan efficiency</td>
</tr>
</tbody>
</table>

Notes: Stars is standard star rating label for appliances, UC = under consideration

A number of products listed above have increased MEPS levels under consideration – these are in various stages. Other products where regulation is under consideration: industrial fans; wine storage cabinets (in new proposal for refrigerators in 2017); standby power.

MEPS IMPACT
AVERAGE NEW EFFICIENCY OF GROUP 5T REFRIGERATION PRODUCTS FOR DIFFERENT SCENARIOS

Figure 2.9
Improvement in refrigerator efficiency. Source: Energy Efficient Strategies 2010
Part 2: Factors Influencing Energy in Buildings

Window rating. The Window Energy Rating Scheme (WERS) defines a ten-star scale for the energy impact that particular windows can have on the energy consumption of a house. The methodology used is defined by the Australian Fenestration Rating Council (AFRC, see www.afrc.org.au). The Australian rating system is broadly based on that from the U.S. National Fenestration Rating Council (NFRC). See Part 3 Section 2.3 for more information on high-performance windows. A separate rating is given for heating and cooling. The WERS rating can apply not only to entire windows, but also to window-tinting films, permanently attached security screens, and to secondary glazing systems.

Energy star. The US Government’s Energy Star (or ‘E*’) scheme, as used in Australia, only applies to office equipment and consumer electronics, including computers, printers, fax machines, photocopiers, televisions and DVD players. It is a voluntary labelling program to identify energy-efficient products. In the US the scheme has a much broader scope. There is no star rating or figure of merit of energy performance that goes with an Energy Star-compliant product.

Labelling of products commenced in 1986 (refrigerators) then air conditioners (1987), dishwashers (1988), dryers (1989) and washers (1990). All star rating labels were re-graded in 2000. Refrigerators and air conditioners were re-graded again in 2010. Television sets were first labelled in 2009 and were re-graded in 2013. Computer monitors were added for the first time in 2013.

An example of the improvement in energy performance attributable to the MEPS is the case of refrigerators shown in the Figure 2.9.

3.4.2.1 Insufficiently regulated products

Some energy-consuming products are insufficiently regulated. The most prominent example is refrigerated water dispensers, which will consume an estimated 570 GWh/annum in 2020. This corresponds to 66 MW of average continuous electric power - as much as produced by the Roma gas-fired power station. Other products considered in need of stronger energy regulation are ICT equipment such as PCs, laptops and printers. The Energy Star energy performance framework and labelling applies to this ICT equipment however this is entirely voluntary.

Another product in need of stronger energy-performance regulation is vending machines. These devices are estimated to use 576 GWh/annum in 2020. An Energy Star standard exists for these in the US. The Energy Star-compliant products on the market have the potential to save about 50% of the energy currently used.

4 Side effects of energy efficiency measures

4.1 Energy efficiency and the Rebound effect

The Rebound effect. Economists recognise a phenomenon, called the Rebound effect (also known as Jevon’s Paradox and the Khazoom Brooks Postulate) in which efficiencies in delivery of a commodity lead to lower prices which then stimulates increased consumption. It is evident in the idea that as machines use less energy, those machines are used more. As applied to energy consumption, it has been used by some to argue that governments should not spend taxes on programs to improve efficiency and instead should leave it up to the market. For example, The Breakthrough Institute (BTI) argued that “there is a large expert consensus and strong evidence that below-cost energy efficiency measures drive a rebound in energy consumption that erodes much and in some cases all of the expected energy savings”. Specifically they claimed that usage may increase by 60-100%, nearly cancelling any benefit derived. If the Rebound effect applies as described by the BTI then the capacity of energy efficiency to reduce global emissions would be significantly compromised.

Demand elasticity and rebound. Central to the idea of rebound is demand elasticity, which is the extent to which demand is effected by prices. Demand for a commodity with inelastic demand will change very little as price changes. End-use demand for electricity is regarded as somewhat inelastic, however rebound can occur because of indirect and macro-economic effects.

Critiques of Rebound. In an analysis of the BTI arguments, Afsar et al have concluded that:

- the Rebound Effect is more like 10-30% of energy savings rather than the 60-100% cited;
- anecdotal cases reported by the popular press can be discounted by looking at actual energy use data (eg information from the US Energy Information Agency shows that, yes, more homes do have two refrigerators, but total energy used in refrigeration has still reduced);
- increases in energy use (as well as TV sizes and number of refrigerators) have more to do with growth in GDP and population than the Rebound Effect itself;
- the underlying model used by the Breakthrough Institute contains a number of highly questionable assumptions; not least of which is a built-in assertion that increased efficiency will result in increased usage. These points weaken the case substantially;
- a statistical analysis of data provided by the American Council for Energy Efficient Economy demonstrates...
a real correlation between the quality of a US state’s energy efficiency program and a reduction in per-capita energy use. A particularly clear trend is evident in the per capita electricity use between California and the rest of the US over the last twenty years.

Pears suggests that energy efficiency measures can give rise to further energy efficiency, ie a contra-rebound effect

“...it can be argued that EE (energy efficiency) measures can have an amplification effect whereby satisfaction with one EE product can encourage use of the savings to buy other EE products, and this drives down cost of EE products for society”.

**Price and efficiency.** Under ‘rebound’ theory, unit energy prices fall in response to efficiency-driven falls in demand. In the years ahead, retail energy tariffs are unlikely to fall with demand because of countervailing factors such as a) energy resource constraints, b) carbon pricing, and c) increased network charges (see Energy Prices Forecast). This is apparent in recent years (ie since late 2008) where Australian net grid electrical demand has fallen (see 3.1 above) while prices have risen.

**Summary.** To the extent that rebound exists at all in the case of national energy efficiency, BZE takes the view that it is not significant, and does not counter the demonstrable effects that efficiency programs have on overall energy consumption. Accordingly, the Buildings Plan has not incorporated any Rebound effect into the modelling because no structural reduction in grid energy price is expected. Furthermore the authors of the plan take the view that energy efficiency measures can lead to significant net reductions in energy consumption and are confident that the estimates from the proposed retrofits are realisable, if widely adopted in Australia.

### 4.2 Home Insulation Program

In Australia, the media response to the Home Insulation Program (HIP) has led to scepticism about the efficacy of government regulation and programs. Unfortunately, there is a misconception that the HIP was generally a failure and caused a significant number of house fires and deaths. Whilst it is true that 156 fires occurred, what has not been reported widely is the set of conclusions from the CSIRO Report. Analysis of the CSIRO Report found that the rate of fires within the twelve month period after insulation installation was 13.9 per 100,000 under the HIP, compared to the historic rate of 47.3 per 100,000. The long term rate of insulation-related fires (greater than 12 months) was found to be between 0.6 and 1.1 fires per 100,000 under the scheme, compared to the long term average of 2.6 per 100,000. So the HIP actually represented a significant reduction on the long term rates of insulation associated fires!

The Home Insulation Program led to 1.1 million homes receiving ceiling insulation, a measure that is generally considered to be the single most effective action for reducing space conditioning loads and improving comfort (this is supported by modelling in this report). A report commissioned by the Insulation Council of Australia and New Zealand (ICANZ) found that installing ceiling insulation could on average increase a building’s performance by 2.2 stars and save households $300 per annum. The 2011 Update to the Garnaut Review stated that “industry sources also suggest that the insulation program and photovoltaic installations have had some effect.”

The update also indicated that “despite recent difficulties in administration of energy efficient assistance programs, such as the Home Insulation Program (ANAO 2010), the weight of evidence suggests that it is possible for such programs to be safely and effectively delivered”.

What has not been quantified, is the number of lives that have already been saved (and will be saved in the future) by improving the thermal comfort of dwellings and reducing exposure of occupants to extreme temperatures.
5 Building energy use in context

While this plan focusses on Australian building energy (usage and sources), it needs to be viewed in context. Broadly, the energy used by buildings represents about 20% of total energy consumption in Australia. In Figure 2.10 building energy use is mainly in the last two categories. According to CSIRO the energy used in buildings contributes about 26% of Australia’s (anthropogenic) greenhouse emissions.

This provides some interesting insights into industry energy consumption, showing that the majority of energy consumption (72%) in the “commercial services” sector is electricity, with natural gas representing the second largest (16%), followed by refined products (10%). In the residential sector, electricity energy consumption represents 50%, natural gas 33.5% and other (mainly wood for space heating) 16%. This indicates that a conversion to zero emissions for commercial services is relatively straightforward after demand-side reduction measures are utilised, given a 100% renewable energy electricity supply as proposed in the Stationary Energy Plan. For residential buildings, where natural gas is used predominantly in space heating and hot water, there is a need to develop strategies to convert these services to efficient electric alternatives.

6 Business-as-Usual Projections

This section considers how much energy is used today in buildings, both residential and non-residential. It then considers what energy use is likely under a business-as-usual scenario. As such it provides a basis for comparing the effects of measures in this plan.

6.1 Non Residential

In 2012 the Department of Climate Change and Energy Efficiency released a study, prepared by Pitt & Sherry, Exergy, and Bis Shrapnel, that estimated the historic and projected energy consumption of each commercial sector. Viewed by building type, non-residential energy use is shown in Figure 2.12.

This plan’s analysis of non-residential energy saving potential uses a model of the building stock developed independently of Pitt & Sherry, and described in Part 5, Section 3.1.

6.1.1 Offices

Within the Australian non-residential building sector, the office-building category represents a large proportion of the total floor area and, as shown in Figure 2.11, energy...
Figure 2.11
Total Floor Area of Office Buildings by State

Figure 2.12
Energy Consumption for Non-Residential Buildings

Energy consumption projection for non-residential buildings 76
use. The data collected for the Buildings Plan stock model included floor area totals for office buildings by state. The results in Figure 2.11 show that the majority of office space in Australia is located within New South Wales and Victoria. Further analysis indicated that a large proportion of this floor area was in the major cities of Sydney and Melbourne.

Average office sizes in each state were similar. The national average office size was 485.3 m².

Figure 2.13 shows the percentage breakdown of office building age at a national level. It shows that the majority of office buildings in Australia were built after 1980.

The breakdown by construction period was important for the thermal performance modelling (see Part 5) because construction materials and construction method are strongly correlated to building thermal energy performance. The Buildings Plan stock model also collected office energy use data by state. The average energy intensity values are displayed in Figure 2.14. Results were very similar across most states with only Victoria’s average energy intensity being noticeably lower than the other states. The national average for energy intensity in office buildings was found to be 974.5 MJ/m²/annum.
6.1.2 Retail

The retail sector in Australia has the largest total floor area of all building categories in the Buildings Plan stock model. Total retail floor area by state is shown in Figure 2.15. As was the case for office floor area, the majority of retail space in Australia was located within New South Wales, Victoria and Queensland.

To accurately describe the energy characteristics of the retail sector, retail was further separated into several sub-categories: shopping centres, high street retail, neighbourhood centres and big box retail. The total floor area values for each retail subcategory are shown in Figure 2.16. High street retail accounted for approximately 62% of the total retail floor area in Australia while shopping centres accounted for approximately 23%.

The breakdown of energy consumption for the retail sub-categories is provided in Figure 2.17. The average energy intensities of each sub-category can be found in Figure 2.18. Shopping centres account for 53% of the total retail energy use in Australia - significantly higher than the percentage of the floor area total that they represent.

As shown by the average energy intensity values in Figure 2.18, shopping centres are significantly higher users of energy when compared to high street retail buildings. This is due to a number of different factors such as their size, cooling loads and the presence of high energy users such as supermarkets. Similarly, neighbourhood centres have high energy intensities. A neighbourhood centre is classified as a shopping centre with a supermarket and up to 35 specialty shops.

6.1.3 Education

Primary and secondary school buildings are classified in the Buildings Plan under the education category. Universities were modelled separately from schools because they generally have higher energy intensities due to the requirement for larger and more complex building energy services. The state-wide floor area totals for education buildings are shown in Figure 2.19. The largest total education floor areas were in New South Wales, Victoria and Queensland.

Education buildings were also broken down into sub-categories based on their construction year. The breakdown of floor area by construction year is presented in Figure 2.20 which shows that the majority of education buildings were built within the last 70 years. Additionally, an estimate of the average education building floor area size by state is shown in Figure 2.21. Some significant variations in building sizes were found across Australia particularly in the Northern Territory.

The average energy intensity found for education buildings nationally was 218 MJ/m²/annum. This is relatively low compared to some of the other categories modelled. The highest state-wide education energy use is in New South Wales, Victoria and Queensland because the total education floor area is highest in these states.

6.1.4 National values for all building categories

Table 2.6 shows the national values for total floor area and energy use for the building categories in the stock model. State values have a similar pattern to these national values.
For each building category, New South Wales, Victoria and Queensland have the highest proportion of total floor area and energy use. In terms of the total floor areas, retail, offices, warehouses and education were the largest proportion of the building stock.

Energy intensities vary significantly across building categories. The categories of Hospitals, Museums and Galleries, Aged Care and Accommodation are all very high intensity energy users. Warehouses, Cinemas and Education had relatively low energy intensities. The Retail building category group had the highest energy consumption and national floor area, with the Office category a close second in both energy use and floor area. Education, the third of the three main categories in terms of floor area, had the lowest energy intensity.

6.2 Residential

6.2.1 Energy Efficient Strategies' analysis

An analysis of business-as-usual energy use in the residential sector has been provided by Energy Efficient
Strategies (EES). This data builds on EES’s “Energy Use in the Australian Residential Sector”. This work involved aggregating ABS and BIS Shrapnel data (in addition to a wide range of other data sources) to categorise the building stock, simulating thermal performance across ten climate zones and analysing trends in appliance energy penetration and user interaction. This generated a picture of the baseline energy consumption in residential buildings out to 2020. EES refreshed their baseline model for BZE in 2012 to add new data, particularly for building stock and appliances and new regulatory requirements (BCA, MEPS etc). A more detailed explanation of the EES work is outlined in Appendix 1.

Key points from the analysis of baseline and BAU energy use are:

- **Improved efficiency.** Energy use per household is declining slowly from a high base, showing the effect of efficiency measures. Under BAU, energy use per household is estimated to fall 15% between 2011 and 2020.
- **Flat overall demand.** Australia-wide residential energy use is flat because growth in the number of houses and the improvements in efficiency cancel each other.
- **Cool states dominate.** The energy requirements per household in Victoria, Tasmania and ACT are about 65 GJ/annum (~18 MWh/annum), whereas houses in all other states have lower energy requirements of between about 25 GJ/annum (~7 MWh/annum) to 30 GJ/annum (~8 MWh/annum).
### TABLE 2.6
National non-residential building characteristics

<table>
<thead>
<tr>
<th>Building category</th>
<th>National Energy Use</th>
<th>National Floor Area</th>
<th>National Average Energy Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail</td>
<td>49.3 PJ per annum</td>
<td>67,134,855 m²</td>
<td>734.6 MJ per m² per annum</td>
</tr>
<tr>
<td>Offices</td>
<td>46.0</td>
<td>47,232,731 m²</td>
<td>974.5</td>
</tr>
<tr>
<td>Education</td>
<td>6.6</td>
<td>30,194,885 m²</td>
<td>218.5</td>
</tr>
<tr>
<td>Cafes &amp; Restaurants</td>
<td>1.6</td>
<td>3,051,177 m²</td>
<td>509.3</td>
</tr>
<tr>
<td>Warehouses</td>
<td>15.3</td>
<td>39,236,929 m²</td>
<td>388.9</td>
</tr>
<tr>
<td>Accommodation</td>
<td>16.6</td>
<td>17,234,214 m²</td>
<td>963.7</td>
</tr>
<tr>
<td>Prisons</td>
<td>0.7</td>
<td>885,061 m²</td>
<td>742.5</td>
</tr>
<tr>
<td>Hospitals</td>
<td>16.1</td>
<td>12,400,571 m²</td>
<td>1297.3</td>
</tr>
<tr>
<td>Museums &amp; Galleries</td>
<td>2.2</td>
<td>1,123,200 m²</td>
<td>1927.4</td>
</tr>
<tr>
<td>Libraries</td>
<td>0.6</td>
<td>1,171,316 m²</td>
<td>546.6</td>
</tr>
<tr>
<td>Cinemas</td>
<td>0.4</td>
<td>930,813 m²</td>
<td>392.2</td>
</tr>
<tr>
<td>Clubs &amp; Pubs</td>
<td>2.6</td>
<td>5,119,455 m²</td>
<td>509.3</td>
</tr>
<tr>
<td>Universities</td>
<td>8.5</td>
<td>11,373,149 m²</td>
<td>747.2</td>
</tr>
<tr>
<td>Aged Care</td>
<td>8.3</td>
<td>8,228,250 m²</td>
<td>1011.9</td>
</tr>
</tbody>
</table>
Figure 2.25 gives the trends in energy consumption for each end use fuel type over the period 1990 to 2020.

**Space heating.** The high contribution from space heating illustrates two main problems in the current residential sector building stock:

1. Poor thermal performance of the building envelope due to lack of design considerations (e.g. solar access) and poor choice of building materials and techniques (e.g. use of brick veneer, lack of weather stripping, lack of insulation)
2. Use of inefficient gas heaters instead of more efficient space heating technologies, such as reverse cycle air-conditioners (heat pumps)

Figure 2.26 gives the share of space heating energy use by state. As discussed in the Stationary Energy Plan, Victoria is responsible for over 60% of Australia's total space heating demand, with most of that supplied by mains gas (60.4 PJ/annum out of 79.2 PJ/annum for the whole of Victoria). Indeed, the winter peak in gas usage across Australia comes almost entirely from Victorian residential demand.

Whilst much concern is raised in debate about the high energy consumption from reverse cycle air-conditioners, the reality is that it represents only a small proportion of the national space conditioning load. Whilst space cooling from air-conditioners is forecast to grow by almost five fold over the next two decades, it is only forecast to represent 14 PJ/annum by 2020 or just under 10% of space heating energy use. Table 2.7 compares the relative heating and cooling demand for each state.

**Hot water.** High hot water energy consumption has largely been due to high usage from poorly performing water devices, such as shower heads, and the (now changing) requirement for hot water supply to dish washing and clothes washing appliances. The second cause has been inefficient hot water units, particularly tank storage units (electric resistive and gas heated) which regularly re-heated the stored water throughout the day while the hot water was not required. The growing trend for dish washers and clothes washers to generate their own hot water will see hot water energy consumption decline over the next ten years. However there is still clearly high potential for energy reduction through a serious program to replace existing inefficient heaters with heat pump and solar thermal systems.

In addition to these key items of concern, the single largest contributor to growth in residential energy consumption continues to be from electrical appliances. Figure 2.27 shows the historic and predicted trends in appliance energy consumption over the period from 1986 to 2020.

From this figure we can see that the bulk of the energy consumption in appliances comes from four main areas: Lighting, Refrigeration, Other Standby and Entertainment. In fact these four categories account for over 68% of the entire appliance energy consumption. Standby power is of particular concern, as it is responsible for the largest growth in appliance energy consumption. This is true even with the 1 W maximum standby rating modelled. The reason why the consumption for this group is forecast to grow is the rapidly increasing uptake of electronic goods, which are more or less permanently connected to a power socket. A more detailed explanation of what has been modelled by EES can be found in Part 2 Section 2 and Appendix 1.

---

**RESIDENTIAL ENERGY USE BY STATE**

![Graph showing residential energy use by state from 1990 to 2020.](image-url)
**Part 2: Factors Influencing Energy in Buildings**

**RESIDENTIAL ENERGY CONSUMPTION PER HOUSEHOLD**

**BY STATE**

![Bar chart showing energy consumption per household by state over time](chart.png)

**Figure 2.23**

**AUSTRALIAN RESIDENTIAL ENERGY END-USE BREAKDOWN**

2011 AUSTRALIA

![Pie chart showing energy end-uses](chart2.png)

**Figure 2.24**
Figure 2.25
Trends in energy, by fuel

Figure 2.26
Share of space heating
7 Energy Prices Forecast

One of the main benefits of reduced energy consumption in buildings is reduced ongoing energy charges.

Household energy expenditures are a small part of overall expenditure on average: 1.9% according to ABS figures for 2009-10. However, averages can conceal a lot. For households that are having financial difficulty, any rise in costs can be difficult. Electricity prices have risen sharply in recent years, largely due to the costs of network upgrades. Many households, especially those on low incomes, have found the extra cost difficult to manage.

Unfortunately gas has been promoted as a cheap energy source. While this Plan considers gas undesirable for ecological reasons and its inefficiency, it is also going to be increasingly expensive in coming years. Wholesale prices could double or triple as Australia’s market is linked to international prices via LNG export facilities.

Reducing energy use by the measures outlined in this plan can reduce household costs directly, by lowering energy bills. Gas-free houses will also avoid the fixed network charges of a second, redundant energy network.

Reducing energy use overall - especially peak energy use - can also reduce the cost of electricity indirectly. Lower generation and grid costs can be had by reducing the need for power plants, and the high cost of generators and network upgrades to accommodate high peak loads.

Electricity prices are expected to increase further, whether under business-as-usual or if the Zero Carbon Australia plan were adopted. This section outlines the likely future

| TABLE 2.7 |
| Space heating vs Cooling by State for 2011 (PJ/annum) |

<table>
<thead>
<tr>
<th></th>
<th>NSW</th>
<th>VIC</th>
<th>QLD</th>
<th>SA</th>
<th>WA</th>
<th>TAS</th>
<th>NT</th>
<th>ACT</th>
<th>Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>22.5</td>
<td>81.0</td>
<td>2.5</td>
<td>8.4</td>
<td>5.9</td>
<td>8.0</td>
<td>0</td>
<td>4.8</td>
<td>133.1</td>
</tr>
<tr>
<td>Cooling</td>
<td>3.6</td>
<td>1.1</td>
<td>5.0</td>
<td>1.4</td>
<td>1.5</td>
<td>0.1</td>
<td>0.7</td>
<td>0.1</td>
<td>13.5</td>
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<tr>
<td>Ratio H:C</td>
<td>6</td>
<td>74</td>
<td>1</td>
<td>6</td>
<td>4</td>
<td>80</td>
<td>0</td>
<td>48</td>
<td>10</td>
</tr>
</tbody>
</table>

AUSTRALIAN RESIDENTIAL ELECTRICAL APPLIANCE ENERGY USE TRENDS BY CATEGORY

FIGURE 2.27
Trends in appliance energy consumption
Electricity and gas tariffs.

7.1 Electricity prices

Electricity price projections were evaluated for both a) a business-as-usual scenario and b) a Zero Carbon Australia (ZCA) Project scenario. The 2020 business-as-usual retail price of electricity is projected to be above 30 c/kWh and includes the impacts of a low carbon price and continued expenditure on network infrastructure. The ZCA Project price is projected to be around 38 c/kWh, and includes the additional network costs, and the cost of implementing the renewable energy deployment through large-scale feed-in tariffs. Although ZCA prices are the higher of the two, this is likely to be offset for consumers by not having the extra costs of gas connection, and by using less energy.

7.1.1 Business-as-usual

Business-As-Usual Prices. Many factors will increase electricity prices over the next ten years. Carbon pricing and network charges in particular, are expected to have substantial impacts on the electricity tariff paid by consumers. Large commercial sector users sign individual power purchasing agreements and are often able to negotiate significantly smaller tariffs due to the size of their high energy consumption. Historically, these contracts have operated over long time frames (five to ten years). However in discussion with various experts, the authors of the Buildings Plan understand that shorter contracts with prices more closely approximating the retail tariff are more typical today.

Commercial Electricity Prices. Beyond Zero Emissions (BZE) commissioned a study of commercial electricity prices from Energy Action. The energy cost data was extracted from the Energy Action Price Index, which indicates the typical median cost of procuring the contestable energy component of a retail contract (see Appendix 12). The index values are considered to be carbon inclusive, hence have been negotiated to include a carbon cost component and will not be subject to a carbon adjustment. Network data was derived from a survey of Energy Action clients based on the latest network tariffs effective as of 1 July 2012 in New South Wales, Queensland and South Australia, and 1 January in Victoria. Where applicable, the survey focused on the metro-CBD network areas operated by Ausgrid in New South Wales, Citipower in Melbourne and Energex in Queensland. Federal Environmental Costs were based on scheme targets from the Clean Energy Regulator’s website and current market rates. State based Environmental targets were sourced from the applicable state regulators – Independent Pricing and Regulatory Tribunal in New South Wales, Essential Services Commission in Victoria and the Queensland Government – and costs were based on current market rates. Metering costs are typically fixed annual costs that do not vary with onsite consumption levels. Metering costs were extrapolated into a c/kWh rate using typical metering charges against a 500 MWh site.

Wholesale Electricity. The underlying wholesale electricity price only contributes a small proportion of the total retail price for buildings. The newly introduced carbon price ($23/tonne) will have an impact upon the supply and production of emissions-intensive electricity and hence on the wholesale electricity price. Both wholesale price projections include the carbon tax. These wholesale projections were still used, as the timing of the initiation of carbon pricing has little impact on the cost projection out to 2020.

Network Charges. Network costs are the single largest contributor to retail electricity prices, and typically represent 40-50% of the total retail cost of electricity. Recent electricity price increases are largely attributable to rapidly increasing network costs, and these are likely to continue to increase over time. In some cases (eg large shopping centres, hospitals, universities) users connect into high voltage power and therefore their retail tariff would include a smaller network component. The projected Network charges for each NEM region were determined by the AER (Australian Energy Regulator) decisions for the current planning periods.

<table>
<thead>
<tr>
<th>State</th>
<th>Energy Costs</th>
<th>Network Costs</th>
<th>Environmental Costs</th>
<th>Metering Costs</th>
<th>Market Costs</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>NSW</td>
<td>6.40</td>
<td>6.75</td>
<td>10.20</td>
<td>13.90</td>
<td>1.40</td>
<td>1.56</td>
</tr>
<tr>
<td>VIC</td>
<td>5.65</td>
<td>6.10</td>
<td>5.00</td>
<td>6.10</td>
<td>1.67</td>
<td>1.85</td>
</tr>
<tr>
<td>QLD</td>
<td>5.90</td>
<td>6.35</td>
<td>7.20</td>
<td>10.60</td>
<td>1.32</td>
<td>1.47</td>
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<tr>
<td>SA</td>
<td>6.60</td>
<td>7.05</td>
<td>9.60</td>
<td>14.30</td>
<td>1.24</td>
<td>1.38</td>
</tr>
</tbody>
</table>
Part 2: Factors Influencing Energy in Buildings

FIGURE 2.28

FIGURE 2.29

Charges ($ per kWh)

Year

'BUSINESS AS USUAL' ELECTRICITY PRICE STACK

ZEROCARBON AUSTRALIA ELECTRICITY PRICE STACK

Retail
FIT
SRES
LRET
Network
Wholesale
Retailer Margins. These contribute a substantial proportion to the retail cost, and include hedging against wholesale price risks, as well as other general retail costs. (It should be noted that this margin associated with hedging purchases of wholesale electricity is often counted towards the wholesale component directly, rather than being listed explicitly as a retailer margin). The retailer margins are not expected to increase (or decrease) over time. This may prove to be conservative. The AEMC paper to COAG showed that 60% of Victoria's projected price increase will be due to increasing retailer margins, apparently to cover their increasing 'customer acquisition costs' due to the high rate of turnover. As other states follow Victoria in opening up their retail markets to competition, this price increase could happen across Australia.

Other. The remaining charges include costs of the various renewable energy schemes which typically range between 4% and 7% (depending on the state). These costs can be further broken down into the federal government’s Large-scale Renewable Energy Target (LRET) scheme (whose costs are evenly spread across all energy consumers) and the Feed-in Tariff (FiT) schemes (which are state based). These are likely to be less than 10% of retail electricity charges by 2020, even under aggressive renewable roll out scenarios. In any case, a recent paper suggests that renewables may depress electricity prices by reducing demand at peak-intermediate times.

Projection. Figure 2.28 represents an average retail electricity price projection (and price breakdown) over the next ten years under a ‘Business As Usual’ (low carbon price) scenario. This projection represents a weighted average of the entire NEM (as each state or NEM region will have a slightly different price projection). The average NEM retail price is expected to be above 30 cents by 2020.

7.1.2 Zero Carbon Australia Prices

The electricity price stack for the Zero Carbon Australia electricity generation network was also modeled. In the Zero Carbon Australia plan, a larger electricity demand is required (325 TWh/annum), and the transmission network is extended and upgraded to form one large National Electricity Market (ie the current NEM connected to South West Interconnected System (SWIS) and North West Interconnected System (NWIS), and substantial upgrade of the inter-connectors between the current NEM regions). This increased demand and transmission infrastructure were considered in this analysis.

Wholesale Electricity. The modelling assumes that the Zero Carbon Australia generating assets are constructed and financed through a National large-scale feed-in tariff. The tariff rate is assumed to be equivalent to the Long Run Marginal Cost (LRMC) for the new renewable generation. The tariff for new entrant plants is assumed to decline over time in line with International Energy Agency cost projections for CST and conservative Global Wind Energy Council (baseline) projections for Wind costs. The tariff rate was assumed to apply for twenty five years, and the construction profile was assumed. The price impact of the feed-in tariff was modelled in a low carbon-price environment.

Network Charges. The Zero Carbon Australia plan includes significant transmission upgrades to facilitate the large-scale deployment of renewable energy. The entire plan requires $92b to be invested in transmission over the ten-year period. As previously mentioned, the current NEM is expected to be upgraded and extended. Network charges are assumed to be spread across this enlarged NEM. For the purposes of the modelling, the transmission costs were assumed to be completely additional to the ‘Business As Usual’ network costs. This represents a conservative estimate, as it is likely that under a Zero Carbon Australia rollout, some of the prescribed ‘Business As Usual’ transmission upgrades would be unnecessary. The distribution network component of the network upgrade is assumed to be the same as the ‘Business As Usual’ requirement.

The additional transmission charges calculation was based on the AER’s Post Tax Revenue Model (PTRM). The transmission investment was assumed to be spread evenly over the ten-year period, and a nominal post tax WACC (Weighted Average Cost of Capital) of 8.82% was used, in line with the AER WACC decision.

Retail. As in the business-as-usual case, the retail margin was assumed to remain the same over the ten-year period. The retail margin also includes provisions for the risk related to purchase of wholesale electricity.

Other. The large-scale renewable energy feed-in tariff is assumed to drive the required deployment in renewable energy. As such, the current LRET scheme is considered unnecessary. Current LRET costs due to existing projects are expected to continue, however the magnitude per unit of energy will decrease due to the larger demand and production of electricity. New LRET costs will not however contribute to the 2020 retail price. The Small-scale Renewable Energy Scheme (SRES) and small-scale feed-in tariffs (for renewable energy) are expected to continue, in line with high PV growth.

Projection. The total electricity price under a Zero Carbon Australia roll out is anticipated to reach around 38 c/kWh by 2020. See Figure 2.29.
7.2 Gas prices

The developing Liquid Natural Gas (LNG) export industry in Eastern States is a key factor that will push prices up. Developing export capacity is linking the Australian domestic market to international markets and prices, particularly the Asian market, where prices are linked to the oil price. A similar scenario developed in Western Australia from the late 1980s, with the growth of WA’s LNG export capacity.

Figure 2.30 illustrates the recent developments in the gas price internationally. By contrast, Australian domestic prices are around $3/GJ-$4/GJ.

For our analysis, Queensland gas costs were determined by applying the expected increases to the current annual gas bill of $1,800 (based on 60 GJ usage). The network components (representing 54% of total) were increased in line with the AER average rate of 1.8% (real), and the wholesale component was increased in line with the Queensland wholesale gas price projections. The standard retail margin was maintained at the current level (which is higher than the other states), and a consumption based carbon charge was also included. Figure 2.30 illustrates the gas price projection for QLD, with the typical gas bill rising from $1,800 in 2011, to over approximately $2,300 in 2020 (and over $2,600 in 2030).

The cost of gas in the South Eastern states was determined using a similar approach. However, the cost were based on the Victorian gas bill with an average annual bill at $1,058 (2011, pre-carbon tax, for the average usage of 60 GJ per annum). This is the lowest of NSW, SA and Vic and therefore the price projections represent a conservative estimation. The factors creating price pressures (see Appendix 11) aggregated to determine the following gas cost projection, in Figure 2.31 (2011 AUD) using the same approach used for Queensland. The typical gas bill rises over 50% out to 2020 (from $1,058 to over $1,600, in real dollars), and almost 100% out to 2030 (to over $2,000, in real dollars). Refer to Figure 2.32.

The full analysis of gas price rises is available at Appendix 11.
TYPICAL ANNUAL RETAIL GAS BILL FOR SOUTH EASTERN AGGREGATE STATES
(2011 AUD)

FIGURE 2.32
Typical Annual retail gas bill for South Eastern aggregate states (2011 AUD)

TYPICAL ANNUAL RETAIL GAS BILL FOR QUEENSLAND
(2011 AUD)

FIGURE 2.31
Typical Annual retail gas bill for Queensland (2011 AUD)
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Part 3: Low-Energy Building Technologies and Strategies

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1 Overview

Part 3 describes the low-energy building technologies and strategies employed in the Buildings Plan.

As outlined in Part 1 and 2, de-carbonising the Australian buildings sector can be accomplished by:

- Significantly reducing building energy demand, and
- Ending use of fossil fuels as an energy source.

The first strategy is achieved by:

- Improving the thermal performance of the building envelope—the walls, roofs, floors, doors, and windows in external walls;
- Replacing inefficient electrical appliances and services with high-efficiency alternatives; and
- Improving building management and occupant interaction.

The second strategy is achieved by:

- Reducing mains electricity demand via distributed energy generation at individual building sites;
- Sourcing mains electricity from renewables such as wind and solar, as in the Stationary Energy Plan; and
- Replacing existing gas appliances with high-efficiency electric alternatives.

The buildings team undertook an extensive review of the strategies and technologies available to fulfil these requirements, with input from experts in each field. This part of the report, Part 3 is the outcome of that review. Costs are described in Part 6.

2 Improving the Thermal Performance of the Building Envelope

This section describes the current performance of Australian building envelopes and then describes technologies and strategies employed by the Buildings Plan to improve their performance.

2.1 Current Australian Building-Envelope Performance

As shown in Part 2, Section 6.3 the energy used for building space conditioning is often the largest component of overall building energy consumption. Building envelopes in Australia tend to have poor thermal resistance compared to world’s best practice and international benchmarks. This is due to: poor building codes, limited post-build assessments, limited retrofit programs, and insufficient incentives for building owners and occupants to invest in energy saving measures.

Construction types. The Australian Bureau of Statistics (ABS) provides some evidence of the poor thermal performance of residential dwellings. The most common construction format for residential dwellings is brick veneer, accounting for 41% of the Australian building stock (55% in Victoria and 67% in the ACT). Brick veneer has the poorest thermal performance of all construction types in most climates, especially in heating-dominated climates (e.g. Canberra, Melbourne). This is due to the fact that the main thermal mass (brick) is on the outside with the plasterboard on the inside. The thermal mass is uninsulated and therefore readily absorbs heat during warm weather and loses heat in cool weather.

Insulation extent. The ABS dataset also shows that while 69% of Australian dwellings have some form of insulation, wall insulation exists in only 18% of dwellings. Uninsulated brick veneer and timber weatherboard homes provide minimal thermal resistance. The lack of insulation for these building types in all climate zones leads to uncomfortable internal environments. In addition, ceiling insulation is inadequate. Energy Efficient Strategies (EES) estimates that the housing stock average R value for added ceiling insulation is only R2.5, which means there is substantial room for improvement even in homes with existing ceiling insulation.

Glazing and window coverings. The ABS also found that only 47% had “window coverings designed to stop heat or cold”, only 32% had outside awnings or shutters, and only 2.6% had double glazing. From an energy-efficiency standpoint, Australian windows have been described as the worst in the developed world.
Draughts. Air infiltration/leakage is an often overlooked aspect of building performance. Uncontrolled air leakage can account for 15% to 25% of winter heat loss in Australian homes. Australian homes are reported as being two to four times as draughty as those in North America or Europe.

In a study by the Moreland Energy Foundation in 2010 the performance of 15 typical Victorian homes was evaluated. Fan pressurisation tests were conducted to measure the number of air changes per hour (ACH, a measure of air infiltration). This study measured an average of 29 ACH at 50 Pa (ACH50, the number of times the total volume of air in the house changes in one hour at 50 Pa pressure differential between inside and outside the house). Comparing these findings to the Passivhaus standard of 0.6 ACH50, and Australian best practice (7-10 ACH50), indicates that there is a major problem with draught-proofing in cool-climate homes.

Non-residential. There is less information available about the thermal performance of the non-residential building stock. What is known is that the majority of inner city office building stock constructed after 1950 has curtain wall facades. Curtain wall refers to glazed cladding that hangs on the outside of a building, with each storey having floor to ceiling glass. Such walls do not support the building. Instead, most buildings with curtain wall facades have a central lift core that holds the weight of the structure. Unfortunately, curtain wall facades incorporate single glazing, which has poor thermal properties and low solar reflectance, and aluminium, which is one of the best conductors of heat. Since the introduction of Section J (energy efficiency) in the National Construction Code in 2006 attention has turned to improving the thermal performance of glazing, with a focus on reducing the overall glazed area, reducing heat conductance (U value), and introducing external shading. These provisions, however, only apply to new buildings and therefore the existing building stock with poor performing curtain wall facades needs to also be addressed. Various building industry experts who have provided advice for this report have indicated that most non-residential buildings are poorly insulated.

2.2 Insulation Technologies and Strategies

Insulation types. Adding insulation is the simplest and most well known means of improving the thermal performance of a building. Figure 3.1 shows that, in cooler temperate climates such as Victoria, a significant amount of heat flow is through the ceiling, walls, and floor, with air leakage being a major contributor. By contrast, Figure 3.2 shows the heat flow in a well-insulated building, with injection foam insulation reducing the heat loss through the walls and ceiling, and improving the overall thermal performance of the building.

FIGURE 3.1
Heat flow in an uninsulated cool-climate house.

FIGURE 3.2
Injection Foam Insulation. [R. Keech]
transfer occurs during hot and cold weather through the ceiling, walls and floor of a house without insulation, and with typical levels of air leakage. The main types of insulation are bulk, reflective, and foam. When choosing insulation for a building it is important to be mindful of local climate conditions and the construction method of the building, eg. wall type, ceiling type, etc.

**Bulk insulation.** Bulk insulation contains still air pockets trapped within the insulating material structure. Bulk insulation includes materials such as polystyrene, polyester, natural wool, glass wool, rock wool (ie. mineral fibre), and cellulose fibre. It is available as batts, blankets and boards, or as loose fill which is pumped, blown or placed by hand into an area of your home. It is important not to compress bulk insulation because the trapped air pockets inside the insulation provide the material's insulating effect.

**Reflective insulation.** Reflective insulation when installed correctly resists transferring a large majority of radiant heat across an enclosed space due to its characteristics of being highly reflective and having low-emissivity. Emissivity refers to the capacity of a material to re-radiate heat. Reflective insulation is usually made from thin sheets of highly reflective aluminium foil laminate. It is available in sheets, concertina-type sections, and in rolls. Reflective foil’s thermal resistance is influenced by the characteristics of adjacent air spaces, such as their orientation, thickness and temperature differences. For maximum effectiveness, reflective insulation requires an air layer of a minimum of 25mm next to the shiny surface.

**Foam insulation.** There are two main forms of foam used for insulation; spray foam, usually polyurethane, and injection foam made from phenolic or melamine formaldehyde resins. Spray foam insulation comes in either an open-cell or closed-cell form and involves a two component chemical reaction between Side A – a reactive chemical known as isocyanate that acts as a hardener and Side B – a polyl resin, often polyurethane, plus blowing agents and other chemicals including flame retardants. The two chemicals are sprayed onto a surface using a blowing agent, where they mix and undergo a chemical reaction to form a foam that hardens. The components of injection foam are a resin solution, catalyst, and a blowing agent that are mixed at the nozzle. Unlike spray foam, injection foam is fully expanded as it leaves the hose making it suitable for filling existing cavities such uninsulated external walls. All current forms of injection foam insulation are open-cell.

Open-cell foams contain cells with air pockets that have small holes in them. These initially contain CO₂ which is replaced with air over time. These foams must be used internally as they can deteriorate in contact with water. Closed-cell foams have a closed cellular structure, which is impermeable to moisture and sets as a harder more-rigid surface that is better suited to external applications (eg. under-floor). Most open-cell foams contain some organic
Part 3: Low Energy Technologies and Strategies

Component, either soy or castor oil and are blown with water, reducing its environmental impacts. Most closed-cell foams are blown with a hydrofluorocarbon (ozone-depleting and high-global warming potential). However products are available that use water and HFC 245 – a low-GWP option manufactured by Honeywell. Foam insulation has the added benefit of being able to stop air infiltration by weather sealing, making it an ideal option for use under timber floors and cavity walls.

Bonded-bead insulation. Bonded-bead insulation combines the well-known properties of Styrofoam bulk insulation with the cavity-filling advantage of injection foam. Bonded-bead insulation is not only certified for the purpose of retrofit wall insulation in the UK and Ireland, it is one of the preferred materials for this application under the UK Green Deal energy grant scheme. The material is formed by pumping expandable polystyrene (EPS) beads into a cavity wall. A PVA based adhesive is used to hold the beads in place. The raw material of bonded bead insulation is called Expandable Polystyrene. EPS is formed from naphtha which is a by-product of crude oil. The benzene, the ethylene and the pentane are extracted from the naphtha. Styrene is produced from the chemical reaction between benzene and ethylene. With added pentane (as an expanding gas) and water, it is polymerized and gives the Expandable Polystyrene. The grey beads shown in Figure 3.4 are white EPS bead with a graphite coating (Neopor) or they are coated using granite particles (thermabead diamond).

2.2.1 Benefits of insulation

The benefits of insulating the building fabric are significant. These include:

- Significant reduction of the amount of artificial heating and cooling required
- Opportunity to reduce the expense of heating and cooling in the home by about 50% (17 pp101)
- Improvement of the comfort of building occupants
- Long life and low maintainence
- Near-elimination of condensation on the interior of walls and ceilings
- Reduction or elimination of air infiltration
- Quieter home environment due to good sound absorption.

---

**Figure 3.5**

Thermal performance of insulation can be expressed as either thermal conduction [U] or thermal resistance [R].

---

13. Honeywell
14. 15. UK Green Deal energy grant scheme
16. Expandable Polystyrene
17. Thermabead diamond
2.2.2 Demand-Reduction Potential

Heat flow. The flow of heat into or out of a building (Q) is measured in Watts. When this is expressed per square meter of building surface, it is called heat flux [W/m²]. The basic science tells us that the conduction of heat is directly proportional to the difference in temperature between inside and outside surfaces (the 'delta T', or ΔT). This is known as Fourier's law. Doubling the temperature difference will lead to a doubling of heat flow.

Measuring insulation performance. The thermal performance of insulation is expressed as thermal conduction (U value, W/m²K) or more commonly, its arithmetic inverse, thermal resistance (R-value), ie $U = 1/R$. The relationship between thermal conduction (U) and Thermal resistance (R) is illustrated in Figure 3.5. The performance of the insulating material, per meter of thickness is Lambda (λ) [W/mK], ie $U = \lambda / d$, or $R = d / \lambda$, where d is the thickness. As the R-value increases, the insulating performance improves. Conversely, the lower the U-value, the better the insulating performance. Commonly we use R-values for ceilings, walls and floors but use U-values for windows and glazed doors, although either can be used for any building element. The λ value can be thought of as the thickness giving an R value of 1, or as the U value of one meter of thickness.

Heat flow and insulation. Combining heat flow and insulation performance, we can calculate the conductive heat loss or gain as $Q=U.A.ΔT$, or $Q=A.ΔT/R$, where A is the area. For example with a wall, where temperature difference is 10°C, and thermal resistance is 0.5, and area is 20m², then heat flow through the wall will be $Q = 10 \times 20 / 0.5 = 400$W.

The total R-value of a building element takes into account not only any insulation materials but also the construction materials (linings, cladding, timber, masonry), any internal air spaces, thermal bridging, and air films adjacent to all surfaces. So, uninsulated building elements have modest R-values: uninsulated walls typically in the range R0.5 (weatherboard, brick veneer, cavity brick) to R0.3 (concrete, 100mm thick); uninsulated timber floors around R0.4. Adding R2.5 batts into a weatherboard wall results in a total R-value for the wall of about R3.0.

Thermal bridging. Structures should avoid having any points where conductive heat can flow through very easily. Such points, which act as thermal bridges, can seriously compromise the overall thermal performance as shown in Figure 3.6, below. Ceiling joists and wall frames are examples of thermal bridges. The decreased R-value of a ceiling due to thermal bridging can be demonstrated by beginning with a bulk insulation material R-value of 2.5. When this is placed between timber joists it the resultant R-value for the whole ceiling is only R2.2. This can be further reduced if a material with a lower thermal resistance such as metal framing is used. This means that higher levels of insulation are required to compensate for this reduction in R-value.

Direction of heat flow. A particular ceiling, roof or floor has different R-values depending on whether the heat flow is up or down, relating to different performance in summer and winter. This effect is more marked where reflective insulation is used.

2.2.2.1 Combining multiple elements

R values add in series. A benefit of expressing insulation performance as an R value is that the cumulative effect of combining layers of different type is that the resultant R value is the simple sum of the thermal resistance of the layers.

Conduction adds in parallel. Calculating the net R value of side-by-side surfaces is not simply the arithmetic average of the R values. For example, one square meter of window $R_w=0.2$ alongside one square meter of wall $R_w=2$ is not as simple as the layered case because U values add in parallel. So in this example, $A_1=1$, $U_1=5$ and $A_2=1 U_2=0.5$, therefore the $U.A_{total}=5.5$, i.e. $U_{average}=2.75$, so $R_{average}=0.36$.

Net insulation performance. The fact that U.A values add in parallel means that the net insulative performance of an entire house can be calculated as the sum of the U.A values of all the external faces. This becomes convenient for calculation since units of U.A become [W/K]. So the net thermal conduction in Watts is the net U.A value multiplied by the ΔT. Note U.A is the same as A/R. This method is applied in the example below.

2.2.2.2 The effect of gaps in insulation

In some situations ceiling insulation has gaps in it, such as where downlights are installed, or where fitting has been done incorrectly. The effect of this can be disproportionate to the area uninsulated because of the arithmetic consequences of conduction adding in parallel. The more insulation is installed, the greater the effect of gaps, as the graph below shows. For example, the insulation effectiveness of R6 insulation degrades by 50% if a mere 4% of the area is left uninsulated.

Figure 3.7 gives the typical thickness of various products to achieve an R value of 1. Rigid foam products require less thickness than the fibre products; for this reason they are favoured where space is limited, such as in cavity walls.

2.2.3 Implementation Recommendations

The insulation that can be installed in a particular building depends on the type of construction. For instance the type of insulation recommended for a home built on a concrete slab would differ from a home that has a suspended timber floor. The proposed treatments generally can be implemented without any permanent alteration of the building fabric (refer to Table 3.3).
FIGURE 3.6
Insulation effectiveness degrades quickly with the size of gaps, especially for high R values.

FIGURE 3.7
Insulation Performance values for a number of insulating materials.
2.2.2.3 Example Of Thermal Improvement

So what difference does insulation actually make in a house?

As a simple illustrative example, consider a modest-sized, rectangular weatherboard or brick veneer house 8m by 12m with 2.7m high walls and suspended timber floors. It is winter and the outdoor temperature is 10°C while inside it is 23°C.

The following calculations apply the methodology described above (net insulation performance) and ignore influences such as thermal mass, air leakage, and radiation gain/loss, mainly through windows.

Wall + glazed area = perimeter x wall height
\[= 2(8 + 12) \times 2.7 = 108\text{m}^2\]

The heat, measured in watts, lost through the ceilings, walls and floors is given by the formula:
\[Q = \Delta T \cdot A / R\]
which is the same as:
\[Q = \Delta T \cdot A \cdot U\]
where A is area in m² and ΔT is temperature difference in °C.

This means that to maintain the inside temperature at 23°C we would need to continuously run a heater at 8.9 kW in the uninsulated house but at only 1.9 kW in the insulated house, representing a reduction of 7.0 kW or 79%.

Roofs. The best approach for conventional residential roofs is to install R2.5 batts between ceiling joists then lay R3.5 at right angles to reduce the thermal bridging effect of the joists. For ceilings which already have some insulation, batts should be added at right angles to ceiling joists to bring the total R-value to R6.0. Obviously if the existing insulation has been poorly laid then this should be rectified before the top layer is added. If in-roof access is unavailable, then in regions where cooling load dominates, an alternative to bulk insulation is to use a cool-roof coating (see Cool Roofs).

Walls. Adding insulation to walls is currently much less common than adding it to roofs. However in structures with timber stud frames, and with cavity brick, it will often be possible to add bonded-bead or foam insulation through holes drilled in the surface. As per the table above, the recommended method is to use bonded-bead injection. This is not yet widely available in Australia. A suitable alternative is injected foam which is currently more widely available.

Under-floor. Where under-floor access is available, floors should be insulated. If the recommended spray foam method is not possible, then a suitable alternative would be to use insulation batts in conjunction with sheets of Aircell which are non-conductively fastened between floor joists (Aircell is an insulating sheet material which looks like heavy-duty bubble wrap which is metalised on both sides. Electrical precautions apply).

2.2.4 Costs

Refer to Table 3.4.

2.2.5 Product Issues and Development

Foil insulation. Reflective foil insulation is generally electrically conductive. The fixing of this insulation using metal staples has been associated with electrical risk. This
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Type of insulation has limited application and is not generally recommended in the Buildings Plan. Where foil insulation is employed, it should be installed with due care and fixed in place using non-conductive means.

Insulation and electrical wiring. Installation of bulk insulation needs to take into account the requirements of electrical wiring standard AS/NZS 3008.1. In general this means a) insulation needs to be kept clear of light fittings (see Section 4.1.1), and b) the maximum-current rating of any wiring needs to be considered if it is covered by insulation.

Embodied chemicals. Historically there have been various issues with the manufacture of insulation. Some of these manufacturing issues have been of risk to the environment, or human health. The most significant environmental issue associated with insulation manufacture has been the use of chlorofluorocarbons (CFCs). CFCs were once used extensively as blowing agents. Almost all CFCs were phased out from insulation manufacturing by 1993. They were replaced in most products by Hydrochlorofluorocarbons (HCFCs). Whilst HCFCs contribute to global warming and some ozone depletion they have significantly less impact than CFCs. HCFC foam insulation materials are scheduled to be almost entirely eliminated by the year 2020 according to the Montreal Protocol on Substances That Deplete the

<table>
<thead>
<tr>
<th>Building element</th>
<th>Construction type</th>
<th>Residential Strategy</th>
<th>Non-Residential Strategy</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling</td>
<td>Accessible ceiling cavity, eg flat ceiling with pitched roof</td>
<td>Added insulation to R6</td>
<td>Added insulation to R4</td>
<td>For dwellings with existing insulation add directly on-top of old.</td>
</tr>
<tr>
<td>Wall</td>
<td>Timber framed eg brick veneer, weatherboard</td>
<td>Inject bonded bead insulation of added R value ~ 2.7 (for 90mm cavity)</td>
<td>Inject bonded bead insulation of added R value ~ 2.7 (for 90mm cavity)</td>
<td>Access to wall cavity via 22mm holes drilled in internal or external walls</td>
</tr>
<tr>
<td>Masonry, cavity</td>
<td>Inject bonded bead insulation of added R value ~ 1.5 (for 50mm cavity)</td>
<td>Inject bonded bead insulation of added R value ~ 1.5 (for 50mm cavity)</td>
<td></td>
<td>Bulk insulation can’t be installed in double brick walls and loose fill creates problems at demolition stage</td>
</tr>
<tr>
<td>Masonry, solid</td>
<td>None proposed</td>
<td>None proposed</td>
<td></td>
<td>Option to add expanded polystyrene cladding externally</td>
</tr>
<tr>
<td>Floor</td>
<td>Spray closed-cell spray foam to underside of floor to added R value of R2.5+</td>
<td>Spray closed-cell spray foam to underside of floor to added R value of R2.0 for education buildings, R3.0 for office and retail buildings</td>
<td></td>
<td>Alternative: bulk + reflective to R2.5+</td>
</tr>
<tr>
<td>Concrete slab on ground</td>
<td>None proposed</td>
<td>None proposed</td>
<td></td>
<td>Option for cold climate: insulate external perimeter face of slab with expanded polystyrene</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Insulation Type and R Value</th>
<th>Material cost ($/m²)</th>
<th>Cost ($/household, including installation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling</td>
<td>High-performance ceiling batts to R6.0</td>
<td>5 (for top-up from R2.5 to R6)</td>
<td>960 (for top-up from R2.5 to R6), 1,200 (for new R6)</td>
</tr>
<tr>
<td>Wall</td>
<td>Bonded-bead insulation to R2.5 (90mm cavity) or R1.5 (50mm cavity)</td>
<td>8</td>
<td>1,700</td>
</tr>
<tr>
<td>Floor</td>
<td>Closed-cell spray foam R2</td>
<td>20</td>
<td>3,900</td>
</tr>
</tbody>
</table>
Ozone Layer. Whilst HCFCs are less damaging to the environment than CFCs they should be avoided where possible and spray foams that rely on water based blowing agents are recommended.

Another issue with spray foams is the potential health hazards from exposure to the chemicals used during installation. The US EPA proposes that installers use protective equipment including respirators, eye protection, and chemical resistant clothing. This is due to concern about exposure to isocyanates, for which the US EPA says “if sensitized to isocyanates, even low concentrations of isocyanates can trigger a severe asthma attack or other lung effects, or a potentially fatal reaction”.

For the same reason it is recommended that re-entry to the building not occur before 24-72 hours have passed. While spray foams have initial risk they generally have low VOCs once fully set.

A great deal of controversy surrounds potential human health concerns regarding contact with synthetic mineral fibers, including fiberglass and mineral wool. Extensive monitoring and research by the Insulation Council of Australia and New Zealand (ICANZ) has identified that ‘no serious health effects have ever occurred in those manufacturing, using or otherwise exposed to glass wool or rockwool insulation’. The handling of glasswool and rockwool may result in skin irritation and sensible work practices, and appropriate clothing are recommended.

In the past, concerns have been raised at the presence of formaldehyde as a binding agent in mineral wool. Formaldehyde is known to off-gas as a volatile compound that can affect health, particularly for asthma sufferers. Urea-formaldehyde is no longer used as a binding agent, and other formaldehyde-free products are now on the market. In addition a number of studies have shown that once properly installed the mineral wool batts are very stable and minimal off-gassing occurs.

2.2.6 Other Service Upgrade Options

Brick and concrete walls can be insulated with external expanded polystyrene sheets. This is appropriate for temperate/heating-dominated climates as it would allow for the insulation of thermal mass, which could be utilised in conjunction with a passive solar heating strategy. Nonetheless this option is not proposed in the Buildings Plan due to diminishing returns if undertaken in conjunction with insulated cavities. Also, the proportion of the building stock that is single brick/concrete (i.e. without cavity) in temperate climates is relatively small (between 1% and 4% outside QLD & NT).

2.3 High-Performance Glazing

Uncoated single-glazed windows are considered to be the weakest thermal component in the building envelope, transmitting large amounts of heat into and out of a building. Most windows in Australia are of this type, with double/triple glazing comprising only a niche market. Types of glazing that can be applied to help insulate windows include double or triple glazing also known as “insulated glazing units” or IGUs, and low-emissivity (low-e) glazing. Frames that have good thermal properties aid the insulating properties of the glazing unit. As the Buildings Plan’s focus is on retrofitting, it considers those options which are easily retrofitted – this is particularly an issue for non-residential buildings where full replacement may be costly and disruptive. It should be noted that in hot sunny weather, these options still benefit from additional external shading.

Tinted, reflective and toned glass treatments. These can control either or both (as required) of the visible light and infrared solar gain entering a building, and are usually blue, green, grey or bronze. Selective coatings and films, which allow visible but restrict infrared radiation, provide a very discrete and low-cost way of controlling unwanted solar gain.

Low-emissivity coatings. Emissivity is the degree to which a surface radiates energy based on its temperature. For an opaque surface the sum of reflected radiation and emitted radiation should equal the incident radiation. Solar radiation is comprised primarily of visible and near-infrared (short-wave) light. When solar radiation is absorbed by glass it is either convected away by moving air or re-radiated by the glass. This emitted energy is in the form of far-infrared (long-wave) radiation. Low-e coatings and films work by selectively reducing the emissivity of different parts of the light spectrum. This corresponds to the different profiles in Figure 3.8 below. Window coatings have the added benefit of stopping most ultraviolet radiation.

For heating-dominant climates/applications a low-e outer surface will lessen the amount of long-wave infrared radiation (from internal heat loads) being re-radiated by the window, without necessarily effecting the ability to receive solar radiation. For cooling-dominant climates/applications a low-e inner surface will lessen re-radiation into the cooled building.

Double glazing. A double-glazed window has two panes of glass with a sealed air gap between them. The spacing of the glass panels is usually between 6-20mm; generally the window is more effective at 12-20mm gap. The panes are spaced with plastic or metal (sometimes sandwiched between thin rubber or similar layers, to prevent thermal conduction), and with a dessicant to prevent condensation between the panes. The gap may also be filled with a gas of lower thermal conductivity, usually argon, rather than air. The glazing can be plain glass, or a combination of the coatings above, which further improves its thermal performance. In comparison with single glazing, double glazing reduces heat conduction by about 50%.
glazing, which is becoming common in some European countries, further reduces heat conduction by about 30% (relative to double glazing). Contrary to common belief, the main contributor to improved thermal performance is not the trapped layer of air, but the number of air/glass boundaries.

2.3.1 Benefits

There are many benefits to choosing high-performance glazing that is appropriate to the climate and the building use. These benefits include:

- Reduction of energy consumption from artificial heating and cooling
- Provision of an additional measure of insulation to the building facade
- Provision of access to passive solar heating in heating-dominant climates/buildings, by maximising solar gain (in winter) while minimising conductive heat transfer
- Aid in minimising solar gain in cooling-dominant climates/buildings, in conjunction with proper shading
- Improved comfort in all climates, as thermal resistance acts to preserve internal temperatures
- Maximisation of natural light (when required) and consequent reduction of need for electric lighting
- Reduction of ultraviolet radiation that contributes to skin cell damage, and fading of furniture and carpet
- Worthwhile reduction in noise transmission
- Reduction of condensation that occurs when warm humid air it meets a relatively cold single pane of glass. This condensation is a common cause of deterioration of timber-framed windows.

2.3.2 Demand-Reduction Potential

The performance of windows or glazed doors is defined by the heat transfer coefficient – U value, solar heat gain coefficient – SHGC, and the visible light transmittance – VT 26.

![LOW-E SPECTRAL TRANSMITTANCE](image-url)

**FIGURE 3.8**

How light passes through various window types
U value, as discussed under the Insulation Section, is a measure of heat transfer by conductance and is given in W/m²K. As an example the U value of a timber-framed window with 3mm clear glass is around 5.9, and with an aluminium frame can be as high as 6.9. To calculate the conductive heat transfer though a window, multiply the U value by the area of the glazing unit and the temperature differential between inside and outside. For example, for a house with 70m² of aluminium framed windows with clear glass (with a U value of 6.2), if it is 15°C colder outside, the conductive heat loss through the windows would be about 6.2*15*70 = 6,510 W.

SHGC is the proportion of solar energy that passes through the window, both directly and indirectly. For example 3mm clear glass has a SHGC of 0.86. The lower the coefficient, the less solar heat it transmits. Low-emissivity glass that reduces emission of short-wave infrared radiation significantly reduces the proportion of solar heat transmitted through the glass, such that SHGC for a clear single glazed element can get to roughly 0.4 - 0.5 and down to 0.27 for double glazed windows.

VT measures how much light comes through the window, expressed between 0 and 1. The VT of clear glass is around 0.8. Tinted and reflective coatings can reduce this significantly.

Measurement and ratings. There is a large variation in performance for double and triple glazing from different manufacturers. Table 3.5 shows the results for two manufacturers’ products which are toward the higher quality end of the market. In Australia, the Window Energy Rating Scheme (WERS) – see www.wers.net – publishes performance data on manufacturers’ windows which have been tested by accredited testers. They include U value, SHGC, VT, air infiltration and condensation, and give a star rating for products.

Note that an effective U value is typically calculated to incorporate the effect of reflective or low-emissivity properties of material, even though these act on reducing heat transfer by radiation not conduction. The effect of reflectance or emissivity of a material is to reduce temperature difference across a surface, which would in turn influence the rate of heat transfer by conduction – even though the material constant is not altered! In practice this can be somewhat misleading, but is common practice. The low-e options presented above are of type 1, which reflect long wave infrared and transmit short wave, hence the high SHGC values.

Frames. The frame material contributes to the thermal properties of the window. Aluminium is a good conductor of heat, and particularly for double or triple glazing, aluminium frames can reduce the window performance, compared with wood or uPVC, which are much better insulators. Some manufacturers of double-glazed windows offer ‘thermally broken’ aluminium frames. These have a plastic spacer and/or air gap between the inner and outer aluminium frame, and their performance is intermediate between aluminium and wooden frames. Table 3.6 gives typical U values. A middle ground between standard and thermally-broken is commonly called ‘thermally improved’.

Films. Low-e films are the best option among films. Tinted films are available but there are problems associated with tints. They absorb heat which is then transferred into the building adding to the building’s cooling load which, in the case of an Australian non-residential building, is the dominant load. Also, they act to reduce the visible light that enters the building and distort the occupant’s view out the window. Low-e films come in thin rolls with a sticky back and can be installed to the inside of the window. They last for between 5 and 15 years. A 2012 study commissioned by the International Window Film Association reviewed a number of film products for residential and commercial applications. It found that low-e films gave SHGC of 0.2 - 0.35 for VT of 0.18 - 0.3. Whilst this shows impressive reductions in solar heat gain the low transmittance of light may be a problem for buildings with poor daylight access. Window Energy Solutions, an Australian company, sells a low-e film, marketed for commercial buildings, with high VT. Its SHGC is 0.42 (for 6 mm glass) with a VT of 0.5.

2.3.2.1 Case Studies

There have been a number of modelling studies in several countries which have looked at the potential energy savings of various building envelope improvements, including glazing. For domestic dwellings, modelled energy savings...
from advanced glazing, usually double glazing, range from 9% to up to 24%. For instance, the Moreland Energy Foundation study 34 of 15 typical Melbourne houses, found double glazing gave an average of 8.7% energy saving over single glazing with heavy drapes with pelmets, but because of the high cost of retrofitting, was the least cost-effective improvement of those examined. They pointed out that had they modelled the glazing without the addition of drapes the energy saving would have been higher. The cost of removing the existing windows and replacing with double glazing was around $580/m², while the average cost saving in electricity was $27/annum.

Two studies in warm climates (Cyprus and Greece) 35, 36 gave higher figures. The Cyprus paper modelled up to 24% saving in annual cooling load with low-e double glazing, with a payback time of 3.8 years, while the Greek paper estimated 14-20% savings with double glazing. Poel et al 37 included modelling from Austria, Denmark and the Netherlands for high performance glazing which showed energy savings of 75 to 80 kWh/m²/annum and payback times ranging from 8 to 12 years.

A paper 38 on very well insulated terrace houses in Sweden modelled the effect of different triple glazing options on the peak load and space heating demands compared to double glazing and to no windows (opaque). It showed a halving of the space heating requirements when upgrading from clear double glazing to triple glazing with one low-e film.

### 2.3.3 Implementation Recommendations

The proposed ranges for U value and solar heat gain coefficients of glazing in various climate zones are presented in Table 3.6. Visual transmission should generally be greater than 0.6 unless glare is a problem (although this can be moderated with internal blinds).

**Replacement windows.** The window performance can be achieved using new IGUs or secondary glazing as appropriate depending on the type and condition of frame. In order to achieve these performance levels the frames would need to have a low conductivity, such as uPVC, thermally broken aluminium, or timber. uPVC or thermally

---

**TABLE 3.5**

Typical U values for framed windows

<table>
<thead>
<tr>
<th>Frame type</th>
<th>Timber (U value)</th>
<th>Aluminium (U value)</th>
<th>Thermally Broken Aluminium (U value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double glazing - plain glass</td>
<td>3.0 - 3.3</td>
<td>4.9 - 5.4</td>
<td>3.1 - 3.6</td>
</tr>
<tr>
<td>Double glazing - low-E glass</td>
<td>1.7 - 2.0</td>
<td>2.5 - 5.0</td>
<td>2.1 - 2.6</td>
</tr>
<tr>
<td>Double glazing - low-E glass, argon</td>
<td>1.4 - 1.8</td>
<td>2.2 - 2.7</td>
<td>1.8 - 2.6</td>
</tr>
<tr>
<td>Triple glazing - two low-E panes, argon</td>
<td>1.2 - 1.7</td>
<td></td>
<td>2.2</td>
</tr>
</tbody>
</table>

**TABLE 3.6**

Recommended glazing

<table>
<thead>
<tr>
<th>Climate Zone Description</th>
<th>U Value</th>
<th>SHGC</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling-dominant/low-demand (Darwin, Townsville, Brisbane)</td>
<td>medium (5)</td>
<td>lowest (-0.3)</td>
<td>If existing frames in good-condition, then fit solar film. Otherwise, a) (if replacement is practical) replace windows with new low-e single glazing, or b) (if replacement is not practical), fit solar film.</td>
</tr>
<tr>
<td>Balanced moderate-demand (Sydney, Perth)</td>
<td>low (-3)</td>
<td>midrange (-0.5)</td>
<td>If existing frames good-condition and low-conductive, then fit secondary glazing. Otherwise, a) if replacement is practical then replace windows with new double glazing or b) (if replacement not practical) use low-e film.</td>
</tr>
<tr>
<td>Heating-dominant (Canberra, Hobart, Melbourne)</td>
<td>highest (-0.7)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Climate Zone descriptions are at Appendix 2. This Table necessarily reflects a simplified view and other factors may influence the final appropriate glazing for any given building.
broken aluminium is recommended here as they require less maintenance and are readily recyclable. If the existing frame is highly conductive, or in poor condition, then secondary glazing should not be considered.

*Films.* In cases where it is considered impractical to remove existing glazing, particularly retail and offices, an applied film is proposed. Specifically, low-emissivity films with high visible transmittance and low solar heat gain coefficients are recommended for use in curtain wall offices, and retail buildings with highly glazed external surfaces.

### 2.3.4 Costs

Within the current housing stock in Australia the number of dwellings which have double glazing account for less than 5% \(^{39}\). This low market share for PVC-U and aluminium framed double glazed units limits the ability of manufactures to be able to provide prices that are attractive to customers. At present the majority of pre-fabricated double glazed units are entering Australia from Europe or China. The poor economies of scale result in higher prices. There are only a limited number of PVC-U window fabricators in Australia and no profile fabricators as the demand does not warrant change within the sector at present.

European double glazing accounts for market shares above 70% (UK, France, Switzerland, Germany). In these countries the market has grown significantly in sync with new thermal regulation building codes \(^{40}\). These rises in market share combined with policy have allowed for the reduction in cost of double-glazed units as economies of scale have improved.

Within the double glazing market here in Australia, there is potential for manufacturers to meet increased demand, although the market is considered niche. In a report carried out on behalf of the ABCB by the AWA they found that 76% of manufacturers would be in position to produce mainly double glazed windows and doors within one year \(^{41}\). The authors of the current report believe that with substantial growth in the Australian market the cost of double glazing in Australia will meet parity with that of Europe. At present the cost of PVC-U residential double glazed windows in Australia is $800-$900 per square metre. Costs in the UK for double glazing per m\(^2\) range between 220-320GBP equating to AUD 337-AUD 490 (2012 dollars). In the UK the cost of double glazing is equivalent to and possibly cheaper than single glazing \(^{42}\). In Australia the cost of single glazed windows is around $500 per m\(^2\).

### 2.3.5 Other service upgrades

*Secondary glazing.* Secondary glazing systems involve affixing a second, removable glazing element (typically perspex) on top of the existing internal window frame. They give a substantial improvement over single glazing, and the performance approaches that of factory-built double glazing. Secondary glazing can be combined, if needed, with add-on window treatments to provide low-e or reduction in SHGC. Products such as EcoGlaze and Magnetite are effective solutions and would provide U values in the range of 3, sufficient for heating-dominant and balanced moderate climates. They are also significantly cheaper than full replacement of entire existing window and frame.

### 2.4 Blinds, Curtains and Shutters

Most households use blinds and curtains for decoration and privacy but they often do not provide any significant thermal resistance. However in temperate climates with cool winters the addition of suitable internal window coverings provides the means to better insulate our windows. This creates an insulating air layer between room and the window, which, along with improved glazing, provides effective management of heat.

#### 2.4.1 Benefits

The energy benefit of window coverings and pelmets is to provide an additional insulation barrier to heat loss through windows. They also provide:
Part 3: Low Energy Technologies and Strategies

1. reduced energy consumption from artificial heating and cooling by trapping thermal energy
2. assistance to passive heating in winter – if left open during the day and then closed in the evening, a room can absorb solar heat and contain it during the night
3. reduced glare
4. a limited reduction in noise.

2.4.2 Types and techniques

Pelmets. A pelmet is a box-like covering that sits over the curtain at the top of windows. Curtains and pelmets were common in the past and recognised for their thermal performance, however recently they have been considered unfashionable. Pelmets need not be large imposing boxes, with a range of invisible and minimalist options available. Pelmets are an essential addition to heavy drapes, because they stop circulation of warm air behind the drapes that creates cold draughts. If the drapes or curtains are not properly sealed to the floor or top of the window then the warm air created by a heater will rise to the top of the window and be drawn down into the space between the window and curtains, driving a current of air that moves cold air into the room. By sitting atop the curtain and being adjacent to the wall, the pelmet blocks the air from circulating around the back of the curtains. If pelmets are not used then thick blinds that are recessed into the window (on all sides) are necessary to stop the circulation of air. The appropriate types of blinds in this case are Holland, Roman and Austrian Blinds.

High-performance blinds and curtains. Good insulating qualities can arise from either backing the curtain fabric with a heavy insulating material, or from having the curtain structure with an integral air gap. An example of an air gap blind is shown in Figure 3.10, using a collapsible hexagonal cellular structure. This particular blind type, when used with (and compared to) a single-glazed window, would reduce the U value from 5.4 down to 2.4, a 56% reduction in heat flow.

Shutters. Adjustable internal shutters are becoming an increasingly common window covering in Australia. As a means of controlling heat flow they compare very well with heavy curtains so long as the shutters are able to close fully and there is minimal leakage around the sides of the shutter. They have the benefit of being adjustable, and therefore useful in daytime to control radiant heat, whereas a curtain would normally not be partially closed.

**Figure 3.11**

U value of a window with different coverings

---

10/5 Alastair Don’t forget to put objects on correct layers please!
20/6 AL Centred the Blue box for Secondary glazing and Distributed spacing @2.4mm b/w each item in Key. Reset all K values without changing font sizes.
2.4.3 Potential for Demand Reduction

A University study examined the insulative benefits of different window coverings used in conjunction with a single-glazed window. This is shown in Figure 3.11. On a single-glazed window, this shows that good window coverings provide a thermal benefit comparable to fitting double glazing. However the retractable window covering is obviously only beneficial when it is closed, which is usually at night.

2.4.4 Implementation Recommendations

The Buildings Plan proposes installing heavy drapes and pelmets (or recessed thick blinds) in residential buildings in climates with cool winters, climate zones 4, 5, 6, 7, 8 (see Appendix 2 for climate zones).

To provide good insulation drapes should be made from thick blackout material and preferably be backed with a thermal barrier. In order to avoid convection heat losses curtains need to be installed close to windows, with sufficient width to span the entire window and wrap onto the wall, and should ideally reach the ground. It is important there is no gap between the top of the curtains and the underside of the pelmet and the pelmets should be joined to the wall. This creates a vertically sealed system.

2.5 Shading

External shading devices, such as eaves, awnings, and verandahs, play a critical role in reducing unwanted solar heat gain, especially in cooling-dominant climates and during summer in temperate climates. Shading devices work firstly by restricting unwanted direct solar radiation through windows. Secondly they assist by reducing the direct heating of walls. External shading devices are the most effective way to control solar heat gain.

As discussed under the High-Performance Glazing Section, passive heating in heating-dominant (temperate and alpine) climate zones relies on maximising solar heat gain from north-facing windows in winter. However sufficient shading must exist on the north, east, and west facades to block out unwanted heat in summer.

For north-facing facades in locations south of Brisbane (latitude 27.5°) this shading can be successfully achieved with eaves or fixed horizontal overhangs at the top of the wall or window as illustrated in Figure 3.12. The short eaves block out the sunlight in summer due to its more vertical angle of incidence, but allow entry of sunlight in winter due to its more horizontal angle of incidence.

The eastern and western facades of a building receive large amounts of sunlight in the early morning and late afternoon, respectively, and are therefore more suited to adjustable shading devices such as awnings, roller shutters and louvres.

In heating-dominant climates adjustable shading also allows for full solar gain on eastern and western windows during winter, and variable levels in spring and autumn.

In cooling-dominant climates at low latitudes (tropical and hot and dry) full shading, where practical, on all sides of the building facade is necessary to minimise heat gain all year round. This can be achieved with fixed awnings, verandahs or deep overhangs.

2.5.1 Benefits

External shading devices provide the following benefits:

1. Reduced peak cooling requirements, with reductions in annual cooling energy demand of up to 15%.
2. Reduced glare and improve visual comfort, leading to increased satisfaction and productivity;

2.5.2 Implementation Recommendations

Residential

As required in each individual case, adjustable awnings are proposed for all exposed east-, west-, north-east-, and north-west-facing windows in all climates, except cooling-dominated climates (Zone 1 and 3) where fixed awnings on all exposed walls are proposed.

Education

For education buildings without appropriate shading it is proposed to add fixed awnings to north-facing windows of length 600 mm or with the shading ratio as illustrated.
The installation of shading on commercial buildings varies widely between individual buildings depending on location, surroundings, design, climate, etc. It is recommended that shading be incorporated in new buildings and where possible implemented into existing buildings, taking into consideration the following:

- The specific location and design of the building
- Wind loads due to wind tunnels, building height and other effects
- Potential wind noise problems with certain types of shading such as canvas awnings
- Prevention of reflected heat or glare into surrounding buildings
- Ongoing maintenance – one of the main reasons external shading is currently not used in many buildings
- Day lighting and winter heating needs to be balanced with shading.

2.5.5 Other Service Upgrade Options

Trees can be used to provide effective shading. However, they have not been considered as part of a national retrofit package in this plan.

2.6 Draught-Proofing

2.6.1 Air-infiltration problems

Air leakage is an often overlooked aspect of building performance. There is a need to maintain a small flow of fresh air for the sake of indoor air quality, but leaking air carries valuable heat (or coolness) with it. Uncontrolled air leakage can account for 15% to 25% of winter heat loss in Australian homes. Australian homes are reported to be two to four times as draughty as North American or European Buildings. Reports suggest that the air-tightness of Australian homes is very often well below the expected standard, compromising performance by an amount equal to as much as two stars on the star rating scale.

Non-residential. Reports on office building performance and show a very broad range of air infiltration in office buildings, highlights of which are shown in the table below. The impact of draughts on other types of non-residential buildings is not cited. In buildings with high internal thermal loads, and poorly designed HVAC (Heating Ventilation and Air Conditioning) systems, it is possible for draught reduction to actually increase cooling energy requirements slightly because of the incidental cooling effect that can arise from the draughts.

Measurement and benchmarks. The tendency of a structure

in Figure 3.12, and 300 mm fins to east- and west-facing windows.

Retail

High-street retail buildings (also known as strip shopping centre buildings) normally have awnings or walkways in place on their street frontage, however where these do not exist, fixed or adjustable awnings should be added.

Shaded walkways should also be added to neighbourhood centres and big box retail buildings where they do not already exist above glazed areas.

Office

Older or low-rise offices with masonry cladding can benefit from fixed external awnings to reduce solar heat gain. However, it is difficult to retrofit shading elements to the outside of existing curtain wall buildings without costly and inconvenient structural changes to the facade. Internally applied selective low-e films are proposed for these building types.

Other non-residential

A range of other building types, including food retail, accommodation, and warehouses could all benefit from the addition of shading devices. However, there is limited data on the extent to which they are already shaded, so no shading retrofit strategy has been proposed for these building types. Awnings need to be installed with sufficient space between the window and the awning to ensure heat does not build up in the cavity.

2.5.3 Costs

Shading and blind installation must be adapted to the window measurements of each building type. Companies offer free measurement and quote for purchase and installation and therefore calculation of costs must be undertaken on a case-by-case basis. Table 3.7 provides costing to provide insight into potential costs.

2.5.4 Product issues and development

<table>
<thead>
<tr>
<th>Shading material costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Window covering</strong></td>
</tr>
<tr>
<td>Blockout curtains</td>
</tr>
<tr>
<td>Pelmet</td>
</tr>
<tr>
<td>Awnings</td>
</tr>
</tbody>
</table>
to leak air is measured by air pressure testing and expressed as the number of air changes per hour at a specified pressure difference (usually 50 Pa pressure, which is 0.002 atmospheres)\textsuperscript{51}. The relevant standard is ISO 9972:2006. For example, expressing the leakiness of a building as 10 ACH\textsubscript{50} means that it is measured as experiencing ten air changes per hour when there is 50 Pa pressure difference between inside and out. Some benchmarks for air leakage are shown in the table below. Unforced, i.e. real-world, air changes per hour (ACH) are taken to be ACH\textsubscript{50} divided by 20\textsuperscript{52}.

**Targets for houses.** According to Air Barrier Technology,\textsuperscript{55} a benchmark target ACH\textsubscript{50} for a house is 7.0 which corresponds to 0.35 air changes per hour at natural pressure. Their report gives examples of how a house designed as 7-Star was performing at about 2.5 to 3 star because of poor draught-proofing. According to MEFL (\textsuperscript{56} Appendix D), a suitable target is 10 ACH\textsubscript{50}, or 0.5 air changes per hour at natural pressure.

**Targets for non-residential buildings.** There is no requirement under the National Construction Code (NCC) to validate air tightness of a building. However in the UK, air tightness requirements (Part L of their Building Standards) apply to buildings larger than 1,000m\textsuperscript{2} floor area, see the table below.

### TABLE 3.8

<table>
<thead>
<tr>
<th>Standard/Jurisdiction</th>
<th>Air changes per hour @ 50Pa</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive Haus</td>
<td>0.6</td>
<td>[51]</td>
</tr>
<tr>
<td>Sample of Victorian Non-star rated homes</td>
<td>13 - 73, average of 34</td>
<td>[49]</td>
</tr>
<tr>
<td>Sample of Victorian Star rated homes</td>
<td>8 - 28, average of 15</td>
<td>[49]</td>
</tr>
<tr>
<td>Average of 6 Canberra offices</td>
<td>9.2</td>
<td>[47]</td>
</tr>
<tr>
<td>Average of 68 Canberra homes</td>
<td>18</td>
<td>[47]</td>
</tr>
<tr>
<td>Swedish Houses/Appartments</td>
<td>6.0/2.3</td>
<td>[52]</td>
</tr>
</tbody>
</table>

### TABLE 3.9

<table>
<thead>
<tr>
<th>Level</th>
<th>m\textsuperscript{3}/h/m\textsuperscript{2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum standard</td>
<td>10</td>
</tr>
<tr>
<td>Normal practice</td>
<td>5</td>
</tr>
<tr>
<td>Best practice</td>
<td>2</td>
</tr>
</tbody>
</table>

Note: based on testing at 50 Pa pressure difference

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**CUMULATIVE STAR RATING IMPROVEMENT**

**ENERGY PARTNERS STUDY 2006**

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**FIGURE 3.13**

Star rating improvement with various measures.
Air curtain systems. An air curtain system is a motor-driven fan unit fixed above an open doorway which blows a jet of air downwards over the doorway providing resistance to the transfer of heat and moisture between a conditioned area and its surrounds while allowing people to pass unimpeded. Such systems are claimed to reduce the loss of conditioned air by up to 80%.

Disadvantages of air curtains are noise levels and draughts from the system itself.

Strip curtain doors. Strip curtain doors use hanging strips, usually made from transparent PVC to provide a sufficient barrier to the flow of conditioned air, while allowing relatively unimpeded flow of people or machinery. They provide most of the same advantages as an air curtain system but are cheaper. As passive systems, unlike air curtains, they require no energy to run and are silent in operation. They can be susceptible to fungal growth, condensation and frosting in refrigerated environments. In some high-use situations the strips can be prone to catch and tear on passing machinery such as forklifts. They are claimed to block at least 65% of air infiltration through the door.

Swing doors. Spring-loaded swing doors with in-built windows have long been used for rapid-operating, draught-controlled openings. Contemporary versions commonly use a single sheet of transparent PVC for each door in a pair, and the doors overlap by a small amount to provide a better restriction of air flow. Such systems can be combined with

**RELATIVE EFFECTS OF DIFFERENT DRAUGHT-PROOFING MEASURES**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Combined Benefit Average</th>
<th>Stars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealing External Vents</td>
<td>0.35</td>
<td>★★</td>
</tr>
<tr>
<td>Fixing Downlights</td>
<td>0.25</td>
<td>★★</td>
</tr>
<tr>
<td>Weather Stripping</td>
<td>0.09</td>
<td>★★</td>
</tr>
</tbody>
</table>

Note: Date Person 10/5 Alastair Don’t forget to put objects on correct layers please!
an air curtain if required. Swing doors are more expensive than strip curtains, but are more durable and effective in controlling air flow. A similar technology to swing doors is high-speed automatic roller doors also common in industrial applications.

Summary. Research has been done comparing the various door options including strip curtains, hinged vinyl doors and air curtains. The results have shown that the air curtain is superior from an energy-saving perspective. The strip curtain is a cheaper option but is more intrusive and less effective. However, the air curtain must be correctly sized so that the air jet is powerful enough to reach the floor but, not so strong that it creates draughts in the adjoining spaces.

2.6.3 Measuring the benefits

A 2006 study by Energy Partners aimed to quantify the effects of insulation and draught-proofing in Australian homes with the aid of computer modelling. The study looked at the effect of successive measures applied to models of ten existing dwellings. The modelling for all ten dwellings was performed for Darwin, Sydney, Hobart, Canberra and Melbourne. The measures applied and their effects are summarised in Figure 3.14. This shows that, taken together, the three draught-proofing measures contributed to approximately 2/3 of a rating star increase in most climate zones. Air Barrier Technologies give a real-world example where draught-proofing issues contributed to a four-star difference between a home’s actual and expected thermal performance.

Of the three measures taken, the largest benefit arises from replacing the downlights, though the effect of this measure arises both from the improved insulation and the reduced air infiltration.

According to a study by MEFL, draught-proofing measures have the shortest payback time (5.0 years) of a range of measures considered.

Case Studies. Case studies from EcoMaster show specific examples of sustainability retrofits of dwellings, where draught-proofing and other measures have significantly improved the building performance. While the studies are not able to quantify the benefits of draught-proofing in isolation to the other measures, their approach and results are consistent with the idea that dealing with uncontrolled air infiltration is a high-priority issue when improving building performance.

2.6.4 Making a Building air tight — Implementation

There are numerous possible measures to reduce uncontrolled air infiltration in a building, as follows:

Design and build issues. Attention to detail by designers and builders can help provide air-tight construction at wall/floor boundaries. Also proper selection of exhaust fans, lights and windows is important.

General draught-proofing. Sealing gaps around architraves and skirting boards can be easily done by a carpenter or handy man with ‘quad’ sectioned timber dowel. In older houses it may be necessary to find and seal up any wall vents. Such vents were originally installed to provide adequate ventilation for gas lamps and open fires, and as such are redundant. Around existing doors and windows use commercially available seals and weather seals.

Fans, vents, flues and chimneys. Exhaust fans in bathrooms and kitchens are typically poorly sealed. This is best dealt with by replacement using a fan which seals shut when turned off, for example by having fan blades that hinge shut (Figure 3.17).

Case study: Albert Heijn Supermarket

Located in Heerhugowaard in the Netherlands, the Albert Heijn Supermarket was able to reduce the energy loss through the entrance by 55%, by installing a revolving door. This energy saving corresponds to a draught penetration reduced from 7m to 60cm. This is a small supermarket with a relatively low through-traffic. Larger, busier buildings could expect more dramatic energy savings.

Revolving doors significantly reduce loss of conditioned air when occupants arrive and leave a building. This is particularly the case when the buildings have a front and rear entrance which could have an uncomfortable wind tunnel effect in moderate to high wind conditions.

FIGURE 3.15
Revolving door at a supermarket. [Boon Edam]
Chimneys should be sealed except when in use. Solutions range from simply inserting a removable item directly into the chimney when not in use, to fitting a chain-operated hinged damper flap. These solutions are applicable to both residential and commercial buildings. Vents, which provide useful ventilation in one day or season, can be a source of unwanted and uncontrolled air flow at another time. These might be roof vents provided to remove hot air in summer. Similarly the ducts and balance vents required for good operation of an evaporative air conditioner might cause significant loss of heat in winter.

**Insulation.** Building fabric insulation can have the incidental benefit of reducing draughts, particularly through suspended timber floors. It is common for older houses with floorboards to suffer high levels of infiltration through gaps between the floorboards. The fitting of under-floor insulation can significantly reduce airflow through the floor structure.

**Downlights.** Quartz-halogen downlights (aka “recessed luminaires” in AS/NZS 60598) have been widely deployed in Australia in the recent past. Aside from compromising the ceiling insulation, these light fittings also allow uncontrolled air flow because of their need for ventilation to remain cool. This problem can be addressed by replacing the quartz-halogen fittings with LED equivalents and fitting a suitable cover such as a LED Mitt. Since these operate at much lower temperatures, they do not require ventilation and also reduce the risk of fire. Downlights which are certified (in accordance with AS/NZS 3000:2007) as being able to be fully covered are denoted by the symbol shown in the symbol below.

2.6.5 Costs
Example costs for draught proofing measures taken from the Buildings Plan analysis listed in Table 3.10.

2.7 Cool roofs
Normal roof surfaces, even if they are light coloured, are highly absorbent of solar infrared energy. The term “cool

<table>
<thead>
<tr>
<th>Draught-proofing measure</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draught Proofing - external doors</td>
<td>$35</td>
</tr>
<tr>
<td>Sealable exhaust Fan</td>
<td>$35</td>
</tr>
<tr>
<td>Chimney Stopper</td>
<td>$125</td>
</tr>
<tr>
<td>Downlight Cap</td>
<td>$7</td>
</tr>
<tr>
<td>Air Curtains</td>
<td>$1000</td>
</tr>
</tbody>
</table>

**Table 3.10**

Draught-proofing product costs

**FIGURE 3.16**

Door seals, before and after.

**FIGURE 3.17**

A draught-reducing exhaust fan.
A cool roof does not have to be white. This is because the roof reflects well in the near infrared spectrum of solar radiation which is not visible to the human eye. There are a wide range of colours that are available commercially including many dark colours. However, lighter colours are still best from a thermal point of view.

2.7.1 Cool roofs and the Urban Heat Island effect

Beyond the cooling savings for a particular building is the effect that widespread adoption of cool roof technology would have on urban areas. This would raise the albedo of an urban area which could offset an effect called the urban heat island. This effect refers to increased temperatures in an urban area relative to the temperature in their surrounding area.
3 Building Space Conditioning

Across the range of building types, improving heating and cooling systems has great potential to lower building energy use. This section discusses residential and non-residential space conditioning.

Thermal comfort considerations. While the proposed building upgrades have been assessed primarily for energy efficiency, improved thermal comfort levels are anticipated with all improvements to the building envelope. HVAC upgrades can also be expected to improve overall thermal comfort by improving system control, tuning and reliability, and more complete air mixing. Flexible dress codes aid thermal comfort and reduce the incidences of building occupants introducing their own local temperature control devices, such as plug-in heaters and desk-top fans. Such items can have a detrimental effect on energy efficiency when they are positioned close to HVAC control sensors, causing the cooling system for that zone to seek an incorrect temperature. While adaptive thermal comfort measures, such as the widening of temperature bands, have not been incorporated in this Plan’s retrofit strategy, many buildings will be able to implement this strategy to further reduce energy consumption.

3.1 Space Conditioning in Residential Buildings

3.1.1 Space conditioning: Current situation

Current energy usage. In Australia, space conditioning (i.e. active heating and cooling) is the single largest category of residential energy consumption, accounting for 38% of consumption in 2011 according to EES

It is estimated that cool roofs could reduce the urban heat island effect in an area by 33% and that if everyone adopted it, there would be a reduction in city temperatures by an average of 0.4°C.

2.7.2 Technology Benefits

The benefits of cool roofs are far-reaching:
- Reduction in mains energy requirements
- Reduction in air conditioner maintenance and increased appliance life due to a reduced load on the appliance
- Reduction in air conditioner size
- Increase in thermal comfort in the building
- Reduction of heat stress on the roof materials, leading to an increased lifetime
- Abatement of the Urban Heat Island effect in the local area
- Reduction in power utility loads at the peak time of the afternoon in the summer
- Increase in effectiveness of rooftop-mounted air conditioners.

2.7.3 Implementation Recommendations

Cool roofs are effective at reducing the thermal load of buildings. However, they are year-round less cost-effective than conventional roof insulation. Accordingly, cool roofs are recommended only:
- after conventional roof insulation is installed and when additional measures are required; or
- if sufficient conventional roof insulation cannot be installed cost effectively.

Beyond these basic recommendations, green roof retrofits may also be an appropriate retrofit measure when their other benefits come into play, e.g. to provide aesthetic, storm-water, and biodiversity benefits.

Costs

Since cool roofing is a secondary measure (i.e. secondary to conventional insulation and only used selectively), it is not specifically costed here.
ratio. With climate change it is likely that the heating-to-cooling ratio will lessen further.

Energy sources. The widespread use of fossil methane as a heating fuel is a significant problem. As explained in Part 1, the position of the Zero Carbon Plan is to completely and rapidly phase out the use of fossil methane. Electricity then is the predominant mains energy source for space conditioning in this plan. As discussed in the Stationary Energy Plan, Victoria is responsible for over 60% of Australia's total space-heating demand, with most of that supplied by mains gas (60.4 PJ out of 79.2 PJ for the whole of Victoria residential space heating demand). Indeed the winter peak in gas usage across Australia comes almost entirely from Victorian residential demand. PV as an energy source is increasing, but its availability is predominantly in summer.

Wood. Wood fuel accounted for about 43 PJ/annum in Australian homes in 2011. Because of the low efficiency of wood heating, the amount of heating is lower than this energy number would suggest.

Power vs energy. Although the impact of seasonal heating demand is significant, the summer-time peak power demand most often defines the debate on electricity supply. However, summer-time peak power is fleeting. According to AEMO, it is likely that the seasonal peak demand will shift from summer to winter as summer demand is reduced by rooftop PV. This mitigates the effect on the grid of summertime air conditioner usage in afternoon but not evening.

Problems with ducted systems. The use of in-roof ducted space conditioning, although widespread in some states, is highly problematic for a number of reasons:

Ducting losses. A typical ducting arrangement in a home's ceiling space has a surface area in the area of many tens of square meters. In summertime the unconditioned space through which these ducts pass would often have temperatures exceeding 50°C. The conductive loss of heating or cooling energy through these ducts is significant. It would not be unusual for 20% to 40% of the cooling energy to be lost in the ducts alone.

Poor air mixing in winter. Warm air entering a room from a ceiling vent is generally too buoyant to mix properly because of the tendency of hot air to rise. If air velocity is increased to give better mixing, then draughts and noise levels can become annoying. As a result the level of comfort can be significantly reduced. This can be especially problematic where a conditioned space adjoins a stairwell.

Poor fan-only operation. In summer there are many hours when a good fan alone gives sufficient comfort. Unlike split systems, ducted systems generally cannot provide well-controlled air movement to create useful fan-type cooling. One key reason is that horizontal air movement from a split system will generally give better cooling comfort than any air movement from ceiling-mounted or floor-mounted vents of a ducted system.

Whole-of-house circulation. Air in a ducted system typically travels around a partly closed circuit with a single return-air vent. This requires an unobstructed air path from every conditioned space back to the return-air point. This can be associated with undesirable draughts in winter since individual rooms cannot be closed off. The other downside is that much more fan energy is required simply to move the air. Split systems, on the other hand, recirculate air within individual rooms, requiring less fan energy and allowing for fewer draughts. Thirdly, this means that circulation areas, such as hallways, end up being conditioned spaces. Thus a side effect is to condition a greater a volume than is really required.

Zoning. Typical installation of ducted systems divides homes into zones comprising more than one room each, whereas split systems are typically handled on a per-room basis. Heating a single bedroom may lead to a second bedroom being heated unnecessarily.

Leaks go un-noticed. Ducting is typically held together with adhesive tape which tends to weaken over time thereby creating leaks. To the home owner, it is generally not obvious if there are small to moderate leaks, accordingly a great deal of energy can be lost through leaks over long periods of time.

Air infiltration. A side effect of duct air leakage is that there can be a significant infiltration of outside air due to pressure imbalances.

Lack of advanced control. Ducted systems typically lack the advanced in-room control features now common on split systems. Advanced control includes, for example, the ability to use occupancy sensors to avoid heating/cooling unoccupied rooms.

Choosing a better way. Any preferred approach for residential space conditioning must:

- not use fossil gas
- (in Southern Australia) prioritise winter-time energy reduction
- be suitable for retrofit
- avoid ducted systems
- be more efficient
- be mindful of summer-time peak power issues

Much of the demand reduction will arise from passive efficiency measures. For the remaining active space conditioning, the technology best able to achieve these goals is the heat pump which is explained below.

3.1.2 Heat Pumps

The underlying technology used in refrigerators, refrigerative
Configurations. Various configurations of heat pumps are in common use for space conditioning.

Window/Wall Units. These systems have all their components in a single unit mounted permanently in a hole in the wall or window. They are suitable for room sizes up to about 70m².

Single-Split Systems. These consist of one unit located indoors and another outdoors connected by pipes. The external units can be mounted in an external wall (1.5m - 2.0m above the ground), floor or roof of the building, which makes the system quieter than window/wall units. These are suitable for rooms up to about 100m².

Multi-Split Systems. These consist of one unit outside but two or more (up to seven) indoor units, sometimes with independent control. They are suitable for areas up to about 200m².

Ducted Systems. Designed for central heating, these consist of the heat pump unit on the outside, above ceiling ducts and vents and a return air vent. They are suitable for open-plan buildings and for heating/cooling of most rooms simultaneously up to 200m².

Portable split systems. These use a flexible refrigerant line between the indoor and outdoor units. Their advantage comes from the flexibility of moving to different spaces during the day, and also when permanent installation is not possible. However, they are generally less efficient, and can be more expensive than permanent installations and are suitable for spaces of approximately 35m² compared to 70m² for window/wall units.

Portable non-split systems. A refrigerative portable room cooler can be a single upright unit which vents hot air to outside through a flexible duct.

Basic operation. Heat pumps use a low-boiling-point fluid and pump it continually around a closed circuit of pipes, heat exchangers and valves. On one side of the circuit (the ‘condenser’) heat is given off, and on the other side (the ‘evaporator’) heat is absorbed (see Figure 3.19). In a reverse-cycle heat pump, the direction can be reversed and the condenser becomes the evaporator and vice versa, allowing a heater to become a cooler.

Efficiency and emissions. Typical systems operate with a mains-energy efficiency of about 4:1. That is, four units of heat energy are moved for every one unit of electrical energy consumed. This ratio, of thermal energy moved over mains energy in, is called the coefficient of performance (COP) for a heater, or energy efficiency ratio (EER) for a cooler. The COP varies with ambient temperature. For a heat pump acting as a heater the lower the ambient temperature is, the more work the heat pump needs to do to extract heat energy from the environment leading to a lower COP. When the electricity to drive the heat pump comes from a renewable source, and there are no refrigerant leaks, then the space conditioning is effectively free of operational greenhouse emissions.

Other considerations. There are other issues about heat pumps: cold-weather operation, refrigerants, noise and ventilation requirements. These issues are generally the same as for heat-pump hot water systems as described here.
Portable systems are typically less efficient, as they are constrained in the size of the heat exchangers used.

Why not evaporative aircon?: Evaporative air conditioning is widely available and well understood. It can be suitable and more efficient than heat pumps in some situations. However, the general preference for heat pump systems over evaporative arises from:

Cooling-only. Unlike heat pumps, evaporative systems cannot be used for heating. In climates needing active heating and cooling it is desirable to combine both into a single system.

Limited applicability. The effectiveness of evaporated systems diminishes with rising humidity. As a result they are unsuited to many localities.

Limited cooling. Evaporative systems can only drop the temperature by about 80% of difference between the web-bulb temperature and the dry-bulb temperature. In extremely hot weather, the amount of cooling from evaporative systems will probably not be enough to keep a home comfortable because they cool down the very hot outside air. Heat pump systems, on the other hand, generally operate mostly with re-circulated air.

Water use. Evaporative systems depend upon a continuous supply of water, amounting to about 1L/hr for every 500W of cooling.

Ground-source vs air-source. The most familiar type of heat pumps get their heat energy from the air – they are referred to as ‘air-source heat pumps’. Another type of heat pumps exchange their energy with the ground via long underground pipes. These are called ‘ground-source heat pumps’, and can be more efficient than air-source units when weather is extreme because of the relative stability of the ground temperature. Ground-source heat pumps also have the benefit of being very quiet because they do not have a fan-forced heat exchanger on the outdoor unit. Generally there is a trade-off between efficiency and cost. Ground-source units have a much higher capital cost than air-source units because of the earthworks involved and the more specialised nature of the equipment.

3.1.2.1 Performance ratings

Refer to here in Part 2 for a broader picture of equipment energy efficiency. The application of the MEPS and energy rating labels to air conditioners is as follows 81:

Star rating. Air conditioners have been subject to star rating rules since 2000. Air conditioner energy consumption is covered by AS/NZS 3823.2-2011. This applies only to systems with capacities less than 65 kW. Evaporative systems are excluded. Ratings are on a star scale of 1 to 10, where the range 7 to 10 stars is considered super-efficient. Devices that both heat and cool have a separate star rating for each mode. The star rating is calculated using a formula (82) based on tested annual-average COP (for heating) and EER (for cooling). A 1-Star system is defined as having a minimum annual COP (or EER) of 2.75 83. For each increase in COP (or EER) of 0.25, another 0.5 stars is awarded.

MEPS. Air conditioners have been subject to MEPS since 2001 84 (updated in 2010). The threshold performance level that applies for air conditioners 85 varies according to configuration. As an example, since October 2011, split system heat pump systems (<4 kW) have a minimum annual-average COP of 3.66, which corresponds to a rating of 2.8 stars (rounded down to 2.5). Larger systems (up to 10 kW) have a threshold COP of 3.22 (1.5 stars).

3.1.2.2 Electricity Demand-Reduction Potential

High-efficiency heat pumps can, when properly chosen and installed, provide heating comfort in homes using much less energy than commonly used alternative technologies. For example, a high-efficiency split system might conceivably replace a ducted gas heater and require about ten times less mains energy to achieve the same level of heating comfort. This is illustrated in Figure 3.20 (based on Perez-Lombard et al 2011 86). A more complete explanation of the method and assumptions involved in the generation of this diagram can be found at Appendix 9.

Heat Pumps and Solar Energy

Do heat pumps provide solar energy?

The marketing of some heat pump devices describes them as providing solar energy around the clock. At one level this is clearly incorrect since the devices do not have a solar collector and are not directly dependent upon solar radiation for their operation. However, at a deeper level, claims like this are valid, since:

- the energy extracted comes from the ambient environment, and the mains energy is principally to pump the ambient energy
- the ambient heat is renewable in a very real sense
- that heat ultimately originates from solar energy

The testing and rating regime for heat pump hot water systems, for example, explicitly treats such systems as providing renewable energy and they earn STCs (a type of renewable energy credit) in a way comparable to solar hot water systems.
3.1.2.3 Costs

Split-system reverse-cycle air conditioners vary greatly in price based on size and performance. The purchase and installation of an individual high-performance system was found to typically cost in the range of $1,200 to $2,400 per room based on a survey of a range of products. For example a high-performance multi-head split system with four indoor units costs could be expected to cost around $7,000 - $8,000 fully installed.

3.1.3 Ceiling Fans

Ceiling fans are a useful complementary technology to reduce cooling requirements of a room in summer and used in reverse rotation to circulate the air in a room and distribute warm air in winter. Fans do not lower air temperature, but the effect of moving air on skin gives a cooling effect of about 3°C. This can allow the aircon thermostat to be set higher, cutting cooling costs. Where split system air conditioning is installed (see above), separate ceiling fans are unlikely to be necessary because the fan-only mode of split systems gives equivalent (or better) behaviour. In Australia, unlike India, there is no MEPS or star rating for fans. The efficiency, and energy requirements, of different fans can vary greatly.

Operation. In summer, the fan is rotated at a high speed to generate a wind chill effect by creating a strong down draught. The down draught rushes past the skin and causes the human sweat to evaporate causing a perception of a temperature several degrees below the actual reading in a room. This does not lower the temperature in the room as air conditioning does and the effect will be negated if the fan is switched off. It should be noted that “Cooling building occupants by airflow uses less than 10% of the energy needed for air conditioning”.

In winter, the fan is made to rotate slowly in the reverse direction which has the effect of drawing the cold air near the floor upwards and making the warm air near the ceiling circulate downwards. This creates a better heat distribution within the room. The fan is rotated at a slower speed to lessen discomfort from draughts.

The prices of ceiling fans vary widely but are generally between $100 and $400 each. They can be installed for approximately $110 per fan.

3.1.4 Residential Space Conditioning Implementation Recommendations

Technology. Where active systems are required, the recommended method of achieving high-efficiency heating and cooling in Australian homes is with split-system style

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**Figure 3.20**

Useful heat delivered from a split system heat pump is produced 6.4 times more efficiently than a ducted gas burner system.
heat pumps. Systems with low-GWP refrigerants are strongly preferred.

**Appropriate shading comes first.** Windows exposed to direct sun in summer should be shaded, if possible, before air conditioning is installed.

**Active gas replacement.** The Buildings Plan recommends the active replacement of existing gas heating systems with heat pump systems.

**Minimum performance.** Split systems with a minimum performance rating (heating and cooling) of 4.5 stars are recommended.

**Configuration.** Multi-split-style heat pumps configurations are recommended for houses that need to service more than about four separate areas.

**Installation considerations.** Systems should be installed with pipe insulation of a high standard, and with good attention to detail to reduce the risk of thermal bridging.

**Operating considerations.** In using the split system for heating and cooling, the following good-practices apply:

- **Fan.** The use of the fan-only mode is encouraged for temperatures up to about 28°C to reduce the number of hours of active cooling.

- **Doors and windows closed.** Close doors and windows in rooms which are conditioned to reduce draughts and to constrain the conditioned space. Windows exposed to direct sun should be shaded.

- **Cool-climate performance.** Be mindful that the heating performance in cold weather can vary greatly between models. Choose carefully.

**Sizing.** Typical ranges of sizes would be ~2 kW(t) for each bedroom and 4-5 kW(t) for living rooms. Smaller heat pumps tend to be more efficient than larger capacity units within the range of sizes suitable for building air conditioning. For post-retrofitted thermally efficient building envelopes, the actual heating and cooling demand will be lower than for typical current building practice. In cold regions, heat pumps that perform well at lower temperatures should be selected.

**Minimum performance.** Split systems with a minimum performance rating (heating and cooling) of 4.5 stars are recommended.

3.2 **Space Conditioning in Commercial Buildings**

3.2.1 **Overview**

As in residential buildings the purpose of mechanical conditioning and ventilation is to maintain air quality and thermal comfort in buildings, with the defining difference generally being the number of people and equipment within the building. The conditions inside buildings are typically defined by the concentration of pollutants such as carbon dioxide, carbon monoxide, ozone and volatile organics, air temperature and humidity, which are all influenced by the level of activity, and the number of people and equipment. The higher density of pollutant sources, higher heat loads along with deeper floor plates and larger buildings often mean that appropriate conditions can be difficult to maintain without mechanical ventilation and conditioning. Conversely the internal density of heat gains from humans and equipment means that if a commercial building is well insulated and well sealed then the requirement for additional heating can be very low.

The fabric of the building has a huge affect on the requirement for mechanical heating, cooling and ventilation, with many commercial buildings built with little regard for the performance of the building envelope. Buildings with a curtain wall façade will have low insulation levels, high solar heat gains, and typically high infiltration rates. These buildings depend on high-energy heating and cooling and ventilation systems to maintain acceptable conditions.

Commercial HVAC systems do three things: generate and deliver heat into the building, extract heat from the building (cooling) and provide fresh air. A commercial HVAC system typically comprises a heat or cooling source (depending on the climate), pumping system to move hot or cold fluids, and air handling and distribution systems for ventilation and to deliver hot or cold air into the space. To minimise the energy requirements for a HVAC system the goal is to:

- minimise the requirement for heating and cooling, through passive building elements
- generate the heating and cooling efficiently
- distribute the heating or cooling efficiently
- minimise the volume of air that needs be moved to maintain ideal indoor air quality
- move the required fresh air efficiently

Small to medium sized buildings typically utilise package-conditioning units for cooling and or heating, or else package-conditioning units for cooling and a gas fired heating system, normally with simple direct user control. For small buildings the technologies used are similar to those used in domestic buildings as discussed earlier, with equivalent upgrade and saving opportunities.

For medium to large buildings, more complicated heating ventilation and cooling systems are used, typically comprising a central chiller (providing chilled water), either air or water cooled (via a cooling tower), hot water boilers, air handling units comprising of fans, motors, air dampers and hot and cold radiators, air distribution systems (duct network), and a range of auxiliary equipment including, pumps, fans, pipe work, valves, sensors, actuators and dampers. HVAC systems are normally supported by a building automation system that coordinates the various components. For many systems the components are operating significantly below current best
practice and often contain substances that are now restricted, such as asbestos insulation or refrigerants with high toxicity, ozone depleting potential and global warming potential (see appendix 8). Further to this, poor system integration, losses in auxiliary equipment, lack of maintenance, sub-optimal control strategy and oversized plant with poor part load efficiency typically result in low overall efficiency and too often poor air quality and thermal comfort with in commercial buildings.

3.2.2 Retrofit options and improvement strategies

For new buildings, passive design and high-performance glazing, minimising unwanted solar heat gain in summer and maximising heat gain in winter when heating is required, along with comprehensive insulation and a tightly sealed building envelope can practically eliminate the requirement for dedicated heating plant and drastically reduce the cooling requirement relative to a typical commercial building. Further to this, holistic integrated design with attention to detail at every step including the construction and commissioning of the system can deliver dramatically improved performance in HVAC systems and often achieve a significant reduction in equipment sizing. For existing buildings the opportunities to enhance the building envelope through improved building scaling, increasing insulation and improved glazing can significantly reduce the heating and cooling requirements, are equivalent to those described earlier[89]. Upgrade of the equipment that generates heating and cooling ie boilers and chillers, is typically relatively straightforward and is achievable with minimal disruption to the building and occupants, with 2-4 fold efficiency improvements possible. Modification to the air and fluid distribution systems can be challenging or cost prohibitive due to the integration of these components into the building fabric and fit out: for example, duct work is typically integrated into the building structure and hidden behind ceilings and floors, meaning major modifications can require re-fit out of the space. Finally tuning, enhancement or upgrade of the systems that controls and integrate the various components within the HVAC system is readily achievable within an occupied building.

Unlike domestic buildings, commercial buildings typically have a bespoke HVAC systems particular to the individual building, meaning that improvements in energy efficiency need to be carried out on a case by case basis depending on the age, design quality and level of maintenance within the building. Due to the invisible service that HVAC systems provide, their complex and specialised system architecture and their tendency to be hidden from view, many systems are performing well below their potential with significant opportunities for improvements in energy efficiency and quality of service delivery.

Although the system design and the current state of the system is unique to each building, these general points are applicable: All buildings using gas heating should be upgraded to an electric heat pump, this will result in an 80% reduction in the energy required to generate heat. In Victoria, typically as much as half of a building’s total energy demand is for heating and domestic hot water requirements, as such replacing the gas boiler with a high-efficiency electric heat pump system could reduce total building energy by around 30%. In cooling only climates where cooling accounts for around 60% of total building energy consumptions, similar savings of around 30% of total building energy could be achieved through doubling the efficiency of the cooling plant.

5-20% total building energy savings can be achieved in buildings up to 5 years old with modern plant and equipment and control systems, through effective and tuning and commissioning. Often this crucial step is either ignored or under-funded in construction projects, as the builder is not responsible for the operation costs of the building.

10-30% total building energy savings can be achieved in buildings 5-10 years old through comprehensive re-commissioning, ie ensuring that all of the system components are operating as designed, updating of control strategies to best practice and updating of the building operating schedule to reflect current use along with minor upgrades such as the addition of variable-speed drives (VSDs) to fans, pumps and cooling towers. Many small changes to the controls strategy and time schedules along with component and temperature set point drift and failure over time can result in large increases in energy consumption. Recommissioning of buildings is recommended every two years and typically has a return on investment of less than one year, see case study below.

10-35% savings in building 10-15 years old can typically be achieved through implementing the above strategies, supplementing the building automation network, minor modifications to air handling systems to facilitate economy cycles and night purge and where required integrating plant and equipment that has been added over the life of the project, for example, coordinating the control of package air conditioning units that may have been added, with the central conditions systems.

15-50% total energy savings are possible for building that are 15+ years old that have not undergone any significant upgrade and have not been maintained to a high standard. Large savings can be realised through a coordinated upgrade of out dated plants along with updating of out dated control systems and commissioning to current best practice.

Reduce internal heat loads by using efficient lighting and powered equipment.

One thing common to all buildings is the importance of good system control and integration, with an out dated but well maintained system able to out perform a modern system that has been poorly commissioned and maintained.
3.2.3 HVAC System components

3.2.3.1 Cooling Plant

At the core of any cooling plant is a heat pump, which is described above. A typical chiller service life is 15-25 years of operation. Therefore, chiller upgrades will be a logical refurbishment option for buildings built in the 1980 and 90s where the chillers are due for an upgrade anyway. Further to this many chillers are operated using refrigerants that are now restricted under the Montreal protocol and are becoming less available for servicing purposes. Modern electric chillers typically have high COPs, meaning that less energy is required to produce the same amount of cooling. Further to this, older chillers typically managed variable loads by staging multiple chillers or by stop-starting a single chiller, where as modern chillers typically have variable-speed compressors that facilitate superior turn down capabilities allowing variable and part loads to be effectively and efficiently met. For larger chillers, peak COPs are often achieved at part load, where most chillers spend the majority of their operational hours. In some cases VSDs can be retrofitted to an existing fixed speed chiller to provided greater flexibility and improve part load efficiency without the need for a complete upgrade.

Some features of modern chillers that have facilitated the increase in COP include low-friction magnetic bearings leading to increased efficiency and longer service life, multiple high-efficiency brush-less DC motors with two-stage centrifugal compressors and integrated VSDs allowing for staging in electric motor start up and running. This has seen a two- to three-fold increase in chiller COPs, with older models operating at a COP of around 1-3, to modern chillers achieving COPs of greater than 7 at peak load and greater than 10 at partial load. As noted above, further improvements in performance can be achieved for water-cooled chillers by optimising condenser water temperatures at partial loads, with COPs of 13 being achievable. This represents at least a doubling in efficiency, meaning that less than half the energy is required to deliver the same amount of chilled water. Modern chillers also utilise refrigerants with low ozone-depleting potential (ODP)and lower global-warming potential (GWP) refrigerants, with moves towards using carbon dioxide as a refrigerant which has an ODP of zero and a GWP thousands of times less than many refrigerants currently in use. Carbon dioxide is particularly suited to hot water heat pump systems.

3.2.3.2 Direct-expansion chillers

Smaller chillers such as direct-expansion (DX) units, use the cooled refrigerant directly via a heat exchanger cool the internal air, which is then distributed around the building. The term DX distinguishes a system from those chiller-based systems which first cool water, and then use a secondary heat exchanger to cool the air. For a DX unit, the condenser must be located close to the evaporator to cool the building. Direct expansion units typically have limited load flexibility and the size of the unit needs to be well matched for the demand. Care must be taken to ensure sufficient air flow is maintained over the evaporator coils, which can limit the use of variable-fan-speed strategies and economy cycles. Where the demand and load are consistent the DX approach is simpler and reduces cooling losses relative to chilled water systems as there is one less heat exchange step.

3.2.3.3 Variable Refrigerant Volume

Variable refrigerant volume (VRV), also known as variable refrigerant flow (VRF), systems also use the refrigerant directly to cool the air. However, by varying the volume of refrigerant moving between the condenser and evaporator based on demand, greater flexibility can be achieved and larger areas, such as the floor of a larger building or multiple floors of a small building, can be cooled. The advantage of these two systems is that they can be readily deployed off the shelf and can accommodate mixed cooling requirements within a building such as where a single server room requires continuous cooling. A dedicated system or part of the VRV can service this load while the rest of the system is off. Further to this, many VRV systems are able to provide heating and cooling, as such the existing chiller and boiler could be replaced by a single high-efficiency system in appropriate buildings. This option may be cost-prohibitive in buildings that currently use a chilled-water distribution system.

3.2.3.4 Chilled-water systems

Larger buildings often use chilled-water systems where the cooled refrigerant is used to cool water. The water is then distributed around the building to heat exchangers. This extra conversion step reduces the efficiency of the system, however, it allows greater flexibility for variable demand and allows centralisation of cooling plant with the chillers being able to be located remote from the cooling demand. Centralisation facilitates the use of cooling towers to water cool the chillers, increasing the COP.

3.2.3.5 Cooling Towers

Larger chillers, particularly those used in multi-storey buildings rely on cooling towers to help reject heat out of the building. A cooling tower is a heat-rejecting device that uses evaporative cooling to reject heat from a water-cooled chiller or process. Cooling towers work by blowing air through a wet chamber causing evaporation and cooling, cooling warm water from the condenser (chiller) down typically around 29°C. Energy is consumed in the fan and the water pumps that circulate the water between the tower and the chiller. Water is also lost through evaporation. Many
cooling towers operate with a constant-fan speed regardless of the heat-rejection load. Energy savings can be achieved through the installation of a VSD to the fan motor, with the fan speed to vary in response to demand. The power required to run a pump or fan is proportional to the cube of the speed. This means that if 100% flow requires full power, 75% flow requires 42% of full power, and 50% flow requires 12.5% of the power, thus even small reductions in fan speed result in significant savings in power. The VSD itself consumes a small amount of power. However, when combined with an appropriate control system, significant savings can be made by adjusting the fan speed to meet the required demand. VSDs can also extend equipment life and reduce maintenance requirements by allowing a ramped start up rather than the abrupt start up and high starting torque associated with single-speed drives. VSDs are a relatively inexpensive retrofit to cooling towers.

Further energy savings within the chilled water system can be made by adjusting the condenser water temperature to maximise chiller efficiency at partial load. This strategy can deliver large energy savings at chiller part load, which is the primary operation setting of most chillers, however, it can result in increased water consumption.

In hot humid conditions, effectiveness can be degraded to the point where the cooling tower is a net consumer of energy, i.e., the heat rejected is less than the fan and pump energy required. In such situations, using the low-humidity, pre-cooled exhaust air from the building can be an important strategy to maintain efficiency (see ‘Heat Recovery’ below).

### 3.2.3.6 Absorption Chillers

Cooling can also be provided by absorption chillers which convert heat, typically hot water into cooling. Absorption chillers have much lower COPs than electric chillers with single-effect absorption chillers that utilise hot water less than 100°C, having COPs around 0.7, and double-effect hot water absorption chillers that require higher water temperatures achieving COPs of 1.0-1.1.

### 3.2.3.7 Air handling systems

**General description.** Air handling systems are responsible for moving air around buildings, delivering fresh outside air into the building, removing air contaminants and often providing conditioned air to heat and/or cool the air within the building. Air handling systems typically include outside air intakes and exhausts, fans to move the air, hot and/or cooling coils/radiators and ductwork to deliver the air around the building. When no heating or cooling is required the primary purpose of air handling systems is to ventilate the building, providing outside air and removing pollutants. The major determinants of energy consumption in this operating state are the pressure losses through the duct system and the efficiency of the fan motor.

**Improving efficiency.** For existing buildings modifying the existing ducting to improve the efficiency of the system can be logistically and cost prohibitive due to the integrated nature of ducting into the space. However, significant reductions in energy consumption can be achieved through ensuring the appropriate amount of air is being moved through the system. In many older buildings, fans operate at constant speed regardless of the ventilation, heating or cooling requirements of the building. Through the use of VSD on fans, efficient utilisation of outside air and monitoring of air quality in the space, fans speeds can be optimised to allow large fan-energy savings (as noted a 25% reduction in fan speed delivers a 42% energy saving) while maintaining air quality and conditions.

**Fresh air and return air.** When heating or cooling is required, a combination of outside air and return air from the building is blown over radiator coils containing hot/cold water or refrigerant to condition the air entering the space. Savings in the amount of hot or cold water can be achieved through the optimisation of the mixture of outside and return air. For example, buildings that have large outside air intakes can utilise cooler outside air to cool the building when conditions are appropriate. Alternatively, if outside conditions are unfavourable, then outside air can be restricted to the minimum required for ventilation and conditioned air from the building can be mixed with outside air to provide appropriate temperatures and air quality. In many older buildings, the outside air intakes are sized for minimum fresh air only, restricting the potential of utilising favourable outside air conditions for conditioning of the building. The use of outside air for conditioning is described as economy cycle. Buildings with the ability to bring in significant amounts of outside air also utilise night purge cycles, which is the process of introducing cool night-time air to flush accumulated heat out of the building reducing the cooling requirement for the next day, thus improving comfort and reducing peak cooling demand. The effectiveness of night purging is influenced by the thermal mass of the building. Buildings with economy systems consistently require less energy and provide improved indoor air quality. The re-use of return air can be sometimes improved by UV treatment.

**Set points.** Another approach to reducing the heating and cooling energy requirement is optimisation of building temperature set-points, for example raising summer cooling set-point from 22°C to 23°C can reduce cooling energy by around 6%. Many buildings operate at a fixed set point year round which does not take into account the different occupancy clothing between summer and winter. Also a widening of heating and cooling set points reduces the incredibly wasteful occurrence of heating and cooling systems fighting each other to maintain tight temperature set points.
3.2.3.8 Air Distribution Systems

There are a large number of configurations for air handling and distribution systems. In older buildings constant-volume air handling systems are common. In many cases these systems can be modified to variable-volume systems, through the addition of VSDs to fans and integration into the building automation system. In simple systems, where hot and cold air is delivered to zones at a constant volume, air volumes can be adjusted based on the heating, cooling and ventilation requirements, with reduced volumes supplied when conditions are appropriate. One configuration found in older buildings is the hot and cold duct systems where hot and cold air streams are generated at the air handling unit, which are distributed around the building in separate ‘hot and cold ducts before being mixed at the delivery point to deliver the required air temperature. This system is inherently inefficient requiring both hot and cold air to be generated and increasing friction losses by forcing air through two sets of ducts. Such systems can be retrofit to quasi-variable air volume (VAV), through the addition of VSDs to the air handling units and reconfiguration of heating cooling coils and field mixing boxes. This upgrade removes the need to simultaneously generate hot and cold air and can reduce the total volume of air required to condition the building. In many buildings, further reduction in fan power consumption can be achieved through upgrading of belt-driven fans with high-efficiency direct drive-motors (efficiency >90%). This reduces the belt/pulley/bearing/guard losses, typically >5% of motor energy.

3.2.3.9 Variable Air Volume

More modern buildings commonly utilise VAV air handling systems. A typical configuration for a VAV system is a central air-handling unit with a VSD-controlled fan and cooling coils. Based on the requirements of the building, variable volumes of air are supplied into the building spaces, with VAV boxes in rooms or zones that control the amount of air entering the space using a damper and a pressure sensor. VAV boxes can include heating coils or electric reheat, for reheating of cooled air or heating of the area. A well-designed and operated VAV system allows for the optimisation of the amount of air being delivered to the space, minimising the fan energy required, with very low volumes of air (very low-energy consumption) possible when conditions are appropriate. VAV systems typically allow flexible and effective utilisation of economy cycles.

FIGURE 3.21
Components of a central air-conditioned systems [Energy Efficiency & Renewable Energy (US DoE)]
3.2.3.10 Fan-Coil Units

Another conditioning element commonly used in modern buildings is the fan-coil unit. Cold and/or hot water or refrigerant is distributed throughout the building where many small fans blow either ducted fresh air from a central air-handling unit or air drawn directly from the room over heating/cooling coils to deliver conditioning to the space. Fan-coil units can deliver effective conditioning to buildings and provides flexibility where there is significant variation in conditioning requirements within the building. Fan-coil units readily facilitate the use of occupancy sensors to allow the turn down or switch off of individual fan-coil units when the area is unoccupied. As it is more efficient to pump liquid than gas, fan coil units can reduce the energy required to condition a space by reducing the amount of air that needs to be pumped around a building, whilst still moving the required amount of thermal energy. Due to the reduced duct work requirement, retrofitting of fan coil units can be less invasive than other options. A disadvantage to this approach is that the reduced volumes of air reduces the effectiveness of economy cycles, which in temperate climates can result in increased cooling requirements compared to VAV systems.

3.2.3.11 Displacement Ventilation/Underfloor

Another air distribution/conditioning method being utilised in modern buildings is under-floor displacement ventilation, where air is delivered through vents in the floor and then drawn off at ceiling level. The advantage of this system is the effective turn over of air, with stale warm air rising up and being removed. Another advantage is that heated air is delivered at floor level where occupants are, allowing low-pressure air distribution. These systems are commonly used with exposed slabs, which can provide thermal mass to help moderate temperatures and reduce peak demand. Many displacement systems use radiant cooling in the form of chilled slabs or chilled beams, which provide cooling at ceiling level, reducing the volume of air that needs to be moved to condition the space. Also chilled slabs can be pre-cooled to reduce peak demands. Retrofitting of underfloor distribution systems is only possible where there is sufficient floor to ceiling height to accommodate the raised floors.

3.2.3.12 Natural/passive Ventilation

Passive/natural ventilation or mixed-mode ventilation is also utilised in commercial buildings, most commonly in smaller buildings or buildings specifically designed for this purpose. The advantages of utilising natural ventilation is that it reduces the reliance on fans for ventilation and allows direct use of favourable outside air conditions. Unfortunately unless a building has been designed to incorporate natural ventilation, retrofitting is typically complicated and often has limited success if it is not mechanically assisted, ‘mixed-mode ventilation’. Passive ventilation has great potential to reduce HVAC energy requirements if ideal outdoor conditions prevail, however, when outside conditions are outside of those acceptable for comfort, for example in the peak of summer, the difficulty of maintaining sufficient control over passive ventilation systems can result in increased conditioning energy consumption.

3.2.3.13 Heat Recovery

A major source of energy loss from buildings is the exhaust of conditioned air. Optimising the volume of air moving through the building is a crucial first step to minimising these losses. An additional option is the installation of a heat exchanger or enthalpy exchanger to capture some of the energy invested in the exiting conditioned air and provide it to the incoming air. Heat exchangers can take many configurations, such as a series of metal plates where the exiting air is in contact with one side of the metal and the incoming air the other, allowing the transfer of sensible heat between the two air streams. Other methods use wheels containing heat-absorbing materials, liquids and/or desiccants to allow the exchange of energy between and humidity between incoming and outgoing air. For example, in summer when cool dry air is exhausted from the building, a heat exchanger or enthalpy wheel can be cooled and/or dried by the outgoing air and then used to cool and dry the incoming air, reducing the amount of cooling required to reach set point. The introduction of a heat-recovery system increases the fan energy of the system, and can add additional pumping energy where a heat-exchanging fluid is used. It also requires the exhaust air and fresh air to be co-located or for an additional pumping system to transfer the energy between the two air systems. Therefore it is important that the volume of air being conditioned is optimised to reduce fan losses.

3.2.4 Integration

For all air-handling systems in existing buildings the major challenge is their integration into the building fabric, making large overhauls expensive and often invasive. That being said, significant savings can be achieved through modification and optimisation of the existing systems to improve occupant comfort and reduce fan energy.

3.2.4.1 HVAC control upgrades

In larger buildings, HVAC systems are often centrally controlled by a building automation system. The advantages of building automation systems is the ability to coordinate and monitor plant including the ability to schedule the operating times of plant and equipment. For many older buildings it is not uncommon for HVAC equipment to be only locally controlled, which often results in extended or 24-hour operation. The installation of central control into
these buildings can result in large energy savings due to reduction in unnecessary operation of HVAC equipment and allow greater control over heating and cooling set points. In buildings with outdated or limited central control systems, upgrading of the control to modern direct digital control, with improved operating strategies such as those discussed above and optimised time scheduling can reduce HVAC energy consumption by over 40% in poorly operating buildings. A modern control system allows integration of all elements of the system and implementation of more efficient control strategies some of which have been discussed above. Control upgrades also typically deliver improvements in indoor environmental quality. Modern Control systems can also be integrated with occupancy sensors (also coupled to lighting) to switch off or turn down areas when not occupied. Enthalpy controls and equipment that can recover latent heat in humid exhaust air, especially from special facilities such as aquatic centres can be big energy savers.

3.2.5 Case studies with costs

5-10 year-old building HVAC re-commissioning: Total building energy savings of 27% were achieved in a ten-story, 25,600m² GFA office building, through recommissioning and tuning in 2010. The program of works included updating of HVAC control strategies and minor repair and maintenance of dampers and valves. The recommissioning process was conducted over six months at a cost of $96,000 (primarily recommissioning and tuning labour costs), with the measured energy savings equivalent to annual financial savings of approximated $192,000, meaning the project paid for itself in less than six months.

15+ year-old building HVAC control upgrade: Total building monthly energy consumption was decreased by as much as 43%, in a four-story, 6,750m² GFA university research building through a building automation control upgrade and re-tuning. The building had been in operation since 1976, under the control of a pneumatic building automation system. This outdated control system was upgraded to an integrated direct digital system along with the repair of jammed air dampers and upgrading of a range of valves for a total cost of just under $210,000. In addition to the large energy savings the new control system delivered more reliable and controllable conditions within the facility. The measured annual energy savings are equivalent to annual financial savings of $87,000, giving the project a simple pay back of 2.4 years.

Chiller upgrade examples. It is expected that chiller upgrades will occur in line with existing plant end of life, which is typically at 15-20 years. As such many buildings greater than 15 years-old would have chillers due for replacement. It is anticipated that boiler replacement with heat pumps would be equivalent to the cost of equivalent sized air cooled chillers. For smaller buildings, using direct expansion units, a VRV systems could be used for heating and cooling, allowing the chiller and boiler upgrade to be achieved together, for approximately twice the cost of replacing the direct expansion system, with the additional benefits of greater control flexibility. For larger buildings a series of VRV systems could replace a chilled- or hot-water system for heating and cooling at a cost premium for replacing the water lines with refrigerant lines (see example in Table 3.11).

<table>
<thead>
<tr>
<th>Old plant configuration</th>
<th>Average CoP</th>
<th>Capacity</th>
<th>Estimated annual energy savings (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two electric chillers and an absorption chiller-gas boiler system</td>
<td>2</td>
<td>660</td>
<td>320</td>
</tr>
<tr>
<td>Absorption chiller powered from gas boiler</td>
<td>0.45</td>
<td>470</td>
<td>1268</td>
</tr>
<tr>
<td>Air-cooled chiller</td>
<td>1.6</td>
<td>720</td>
<td>350</td>
</tr>
<tr>
<td>Air-cooled chiller</td>
<td>1.6</td>
<td>720</td>
<td>380</td>
</tr>
<tr>
<td>Water-cooled chiller</td>
<td>2.3</td>
<td>172</td>
<td>600</td>
</tr>
</tbody>
</table>
4 Electrical Appliances and Services

4.1 Lighting

This section describes and quantifies the current use of electrical energy for lighting in Australia. It then describes how lighting energy use can be reduced by more than 90% in some applications, primarily by installing currently available light-emitting diode (LED) technology. Australia-wide, the electrical energy savings possible with the recommended upgrades is approximately 20 TWh per year, which is greater than the amount of electricity produced by one continuously operating Hazelwood (Latrobe Valley, Victoria)-sized coal-fired power station.

The other advantages of LEDs are described, such as the reduced maintenance effort required for changing light bulbs, given that LEDs can last more than 50 times longer than other currently used types of lighting (i.e. incandescent lighting including halogen incandescents).

4.1.1 The problem: ineffective and inefficient lighting

Lighting consumes approximately 13% of household electrical energy, 30% of the electrical energy used in commercial buildings, and up to 80% in some retail premises.

Inefficiency. Traditional lighting technologies such as the incandescent globe and halogen downlights convert up to 98% of the electrical energy into heat. Illustrating this, the outside surface of a halogen bulb can reach temperatures of over 300°C.

Halogen downlights. Halogen lights are a form of incandescent light filled with a halogen-based gas that allows operation at higher temperatures than traditional incandescent lights. Inappropriate installation of ceiling-recessed halogen downlights has led to a significant increase in house fires. The unwanted heat generated by lighting often has to be removed from living and working spaces by expending more energy on air conditioning. This consequential impact adds to the strain of providing electricity at peak demand times.

Draught-inducing. As discussed above in Draught-proofing, recessed halogen downlights present additional energy problems because they usually allow draughts.

Ceiling-recessed halogens are inappropriate for general room illumination because they are designed to be directional spotlights with a narrow beam angle. This means that many halogens are required to illuminate any given room to the same extent as a single omnidirectional light globe suspended from the ceiling or used with a floor or table-mounted lamp. Certain rooms in Australian homes are often lit using electrical energy in excess of 25W/m² of floor area, whereas from 2011 new homes are specified not to use electrical energy for lighting in excess of 5W/m².

Recognition of the poor performance of traditional incandescent and halogen lighting led to a lighting regulation in Australia in 2009 that requires a minimum performance standard. Unfortunately, the current Australian performance standard falls far short of what can be achieved with available LED technology; however, it has led to an increased use of compact fluorescent lighting (CFLs).

Although significantly more energy efficient than traditional incandescent and halogens, consumers have perceived CFLs to have negative features such as a delay in reaching full brightness, inappropriate light colour, dimness, inability to be dimmed, vibration or noise generation, and mercury content. Due to the limited future scope for significant improvement in fluorescent technology, some lighting manufacturers such as Philips have discontinued research on compact fluorescents in favour of greater research into LEDs.

With the latest LED technology, lighting energy densities of less than 2W/m² can be achieved (see Appendix 4 Residential Case Study).

The 2009 Australian lighting performance standard still allows halogen lights to be sold and their use continues to grow. Halogen downlights are popular largely because of low ceilings, light quality and other aesthetic reasons, and also because of a lack of understanding of the energy costs involved with their operation. Halogens have long been marketed as “low-voltage” devices, which many buyers confuse with low energy use.

4.1.2 The solutions: ZCA Buildings Plan recommendations

According to the United Nations International Panel on Climate Change (IPCC), lighting energy use can be reduced by 75% to 90% compared to conventional practice through:

- use of daylighting with occupancy and daylight sensors to dim and switch off electric lighting
- use of the most efficient lighting devices available
- use of such measures as ambient/task lighting,

This plan recommends the incorporation of the following as building retrofits:

- replacement of traditional incandescent, halogen incandescent and fluorescent lighting with LEDs
- lighting sensors and controls in commercial and institutional buildings, with growth in this area projected to be 20% per year through to 2020.
increased daylight levels in big box retail and shopping centres, coupled with daylight dimming capability

- better selection of luminaires producing appropriate illumination levels (a luminaire is a lighting unit consisting of one or more electric lamps with all of the necessary parts and wiring)
- additional switches for downlights so that fewer are controlled from any single switch.

This plan does not propose altering the current mix of lighting types (e.g. lamp versus downlight) for existing buildings. Although the introduction of LEDs is likely to drive the invention of new luminaires, this plan does not recommend specific types of luminaires. Instead, this plan applies the derived efficacy of LED products to all luminaire types while delivering the necessary illumination level for occupant use.

For new buildings, this plan recommends minimal use of downlights in favour of omnidirectional lamps that better use lighting energy. Downlights should be used only where focused directional lighting is required such as for displaying feature items.

The following sections provide detailed information about LED lighting technology.

### 4.1.3 LED lighting technology

LEDs are available now as a lower-energy lighting solution with superior economic return for nearly every lighting need. The rapid development and global deployment of the LED has led some commentators to predict the near total demise, within as little as ten years, of all other types of lighting technologies used in applications ranging from street lighting to commercial lighting to residential. Figures 3.22 and 3.23 illustrate examples of currently available LED lights that are being deployed.

LEDs are semi-conductors that produce light when electric current flows across a diode and releases energy in the form of photons. LED bulbs or lamps consist of an LED package which is made up of one or more LEDs, electrical connections and a module that contains an assembly of LED packages on a circuit board. An LED package may include optical, thermal, mechanical and electrical components, a driver, a connecting base, a heat sink to dissipate heat and other components. Figure 3.24 shows some of these components.

LEDs are also being manufactured as a complete luminaire: the complete light fitting that connects to the electricity supply and Diffuses and directs the light output.

LEDs have been used in electronics and vehicle lighting for decades. However, high power white-light LEDs suitable for general illumination are a relatively new development. Led by funding from the US Department of Energy (US DOE),
LED performance has improved over the last 40 years consistent with Haitz’s Law. This “law” states that every decade the cost per lumen (a unit of useful light emitted) for LEDs falls by a factor of 10, and the amount of light generated per LED package increases by a factor of 20.

In recent years, the rate of LED development has exceeded even Haitz’s Law. The US DOE chart below (Figure 3.25) shows the trajectory of improvement of LED energy efficiency compared with other technologies.

A measure of lighting performance is luminous efficacy: the amount of light emitted, or luminous flux measured in units of lumens, divided by the electrical power input to the light. This is specified as lumens per watt, signified as lm/W.

In August 2011, Philips won the US DOE Bright Tomorrow Lighting Prize (L Prize) with a replacement for the 60 W incandescent bulb: a 9.7 W, 910 lumen, warm white bulb with a lifespan of 25,000 hours and efficacy of 93.4 lm/W. Significant further improvement is expected with the US DOE (Figure 3.25) supporting a realistic goal of reaching 200 lm/W by 2025. In December 2012, CREE announced an LED lighting package (not a full luminaire) able to produce 186 lm/W under certain conditions.

4.1.4 LED benefits – compared with other lighting technologies

LEDs have many benefits when compared with other types of lighting technologies:

- **High energy efficiency** – projected to be the highest of any lighting technology within 10 years
- **Quality and colour of light** – colour rendering index (CRI, ability of a light source to produce the true colour of a lighted object) and correlated colour temperature (CCT, representing “warmness” of a light source) similar to incandescent lighting. LED light characteristics can also be varied across a wide range of colours for various applications.
- **Versatility** – LEDs can be used as a replacement for nearly all lighting types and applications
- **Reliability and lifespan** – up to 100,000 hours (or more than 20 years if used 13 hours per day), allowing lighting maintenance and replacement that is less costly, more predictable and less intrusive
- **Safety** – cooler to the touch than incandescents (including halogen incandescents), reducing the risk of burns and fires
- **Improved compatibility** with ceiling insulation
• **Dimming ability** – LEDs work well with sensors and dimmers (although not all products are dimmable)
• **“Instant-on”** – no flicker or delay in achieving full brightness
• **No mercury in LEDs**, so few toxicity issues upon disposal
• **Directionality** – LEDs are less dependent on reflectors, so less light is lost in the fitting.

### 4.1.5 LED energy reduction potential

Table 3.12 shows the energy consumed by typical conventional lighting types compared with LED-based lighting replacements.

The LED replacements recommended in this plan have a colour rendering index (CRI) above 80 for residential and commercial applications. Warm-white lamps are specified for residential applications, neutral-white for most commercial applications and cool-white for warehouse/industrial applications. For the modelling undertaken for this plan, an LED efficacy of 150 lm/W was used to reflect the average value achievable for lighting installed over the next 10 years.

Analysis by Beyond Zero Emissions indicates that Australia-wide, the electrical energy savings possible with a complete lighting upgrade is approximately 20 TWh per year, which is equivalent to the amount of electrical energy that could be produced by one continuously-operating Hazelwood (Latrobe Valley, Victoria)-sized coal-fired power station.

#### 4.1.6 LED costs and economics

LED lighting costs have fallen rapidly in the last few years. This has been driven by the US DOE initiated programs, more efficient design and higher than expected demand through “big box” retail stores in America.

Prices for LED lights remain relatively high in Australia but are falling fast. An example of the price difference between Australia and the US is the 12W A19 Philips LED bulb. At the US department store Home Depot, this bulb retails for US$23. The same bulb retails in Australia for AU$58 (as at January 2013). However, this price in Australia is 25% less than it was one year before.

#### Table 3.12 LED energy reduction potential

<table>
<thead>
<tr>
<th>Examples of conventional lighting type to be replaced with LEDs</th>
<th>Applications</th>
<th>Light output – midpoint of a range of values (lm)</th>
<th>Non-LED Lighting Typical electrical power requirement (W)</th>
<th>Luminous efficacy (lm/W)</th>
<th>LED electrical power requirement (W)</th>
<th>LED Lighting Electrical energy reduction achieved with LEDs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional incandescent (Type A, originally commercialised by Thomas Edison)</td>
<td>Residential</td>
<td>800</td>
<td>60</td>
<td>13</td>
<td>4.0</td>
<td>93%</td>
</tr>
<tr>
<td></td>
<td>Residential</td>
<td>1,100</td>
<td>75</td>
<td>15</td>
<td>5.5</td>
<td>93%</td>
</tr>
<tr>
<td></td>
<td>Residential</td>
<td>1,600</td>
<td>100</td>
<td>16</td>
<td>8.0</td>
<td>92%</td>
</tr>
<tr>
<td>Halogen MR16 GU10 (240 volts)</td>
<td>Residential</td>
<td>900</td>
<td>50</td>
<td>18</td>
<td>4.5</td>
<td>91%</td>
</tr>
<tr>
<td>Halogen MR16 GU5.3 (12 volts)</td>
<td>Residential</td>
<td>263</td>
<td>20</td>
<td>13</td>
<td>1.3</td>
<td>94%</td>
</tr>
<tr>
<td>Linear fluorescent T8 (one inch diameter)</td>
<td>Commercial</td>
<td>2,700</td>
<td>40 (36 without ballast)</td>
<td>68</td>
<td>14.0</td>
<td>65%</td>
</tr>
<tr>
<td>Linear fluorescent T5 (5/8th inch diameter)</td>
<td>Commercial</td>
<td>2,200</td>
<td>32 (28 without ballast)</td>
<td>69</td>
<td>11.0</td>
<td>66%</td>
</tr>
<tr>
<td>High-pressure sodium (a type of high-intensity discharge light or HID)</td>
<td>Outdoor area lighting, street lights</td>
<td>15,000</td>
<td>150</td>
<td>100</td>
<td>75.0</td>
<td>50%</td>
</tr>
<tr>
<td>Metal halide (a type of high-intensity discharge light or HID)</td>
<td>Commercial, industrial, public spaces</td>
<td>10,500</td>
<td>150</td>
<td>70</td>
<td>53.0</td>
<td>65%</td>
</tr>
</tbody>
</table>

Note: LED performance assuming performance of 200 lm/W, assumed to be readily available before 2020.
The US DOE projects that the price of LED lamps will fall from US$30/kilolumen currently to US$10/kilolumen in 2015 and US$5/kilolumen by 2020.24 McKinsey projects that LEDs will take a 70% share of general lighting by 2020. For homes, replacing halogens with LEDs can pay back the money invested in as little as six months.

4.2.1 Induction Cooktops
The induction cooktop has been commercially available since the 1970s. Induction cooktops operate by using electricity to produce magnetic fields. These magnetic fields pass through the ceramic-glass surface and enter cookware (pots/pans). The magnetic field penetrates ferrous metal in the cookware, causing the bottom of the cookware to heat up and act as the heat source for the food to be cooked.

The cooktop itself does not become a “hot-plate” – it heats only incidentally from contact with the bottom of the heated cookware.

4.2.2 Benefits
The benefits of induction cooktops are compared with radiant heat electrical cooktops (including ‘ceramic’ and solid plate) and gas cooktops in 3.14.

Note: Electrical cooktops, induction and non-induction alike, have peak power requirements which may require a wiring upgrade for some installations.

4.2.3 Demand-Reduction Potential
Electric induction cooktops are approximately 50% more efficient at heating a pot/pan than gas. Replacing gas cooktops with induction will lead to a halving of energy demand from cooktop use. Induction cooktops are also 10% more efficient than standard electric cooktops, so additional energy savings would be available if these were replaced. In commercial kitchens, the adoption of induction cooktops will have the added benefit of reducing demand for space cooling due to the reduction in waste heat. The exhaust requirements can be significantly reduced allowing for quieter working environments and customer areas.

4.2.4 Implementation Recommendations

<table>
<thead>
<tr>
<th>Common name of cooktop</th>
<th>Power-source</th>
<th>Technology for heating</th>
<th>Surface options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induction</td>
<td>Electricity</td>
<td>Electromagnetic induction</td>
<td>Ceramic-glass top</td>
</tr>
<tr>
<td>Ceramic</td>
<td>Electricity</td>
<td>Radiant heat</td>
<td>Ceramic-glass top</td>
</tr>
<tr>
<td>Solid plate</td>
<td>Electricity</td>
<td>Resistive heating</td>
<td>Exposed solid plates</td>
</tr>
<tr>
<td>Gas hob</td>
<td>Gas</td>
<td>Direct flame</td>
<td>Gas burners</td>
</tr>
</tbody>
</table>

4.2 Cooking
This section shows how cooking can be made a zero emissions activity by using electric rather than gas appliances. Options to improve energy efficiency are described. These options allow for substantial reductions in the actual energy load that needs to be transferred from gas to electrical infrastructures. The following sections examine the efficiency measures available to cooktops and ovens in more detail.
### TABLE 3.14
Comparison of Cooktop Technologies

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
<th>Induction cooktops</th>
<th>Radiant heat electric cooktops</th>
<th>Gas cooktops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsiveness</td>
<td>How quickly does the delivered heat change when a control is adjusted?</td>
<td>Immediate</td>
<td>Not immediate</td>
<td>Immediate</td>
</tr>
<tr>
<td>Efficiency</td>
<td>How efficiently is supplied energy converted into heat in the cookware? [104]</td>
<td>Approximately 84% efficient</td>
<td>Approximately 75% efficient</td>
<td>Approximately 40% efficient</td>
</tr>
<tr>
<td>Precision</td>
<td>How precisely can the temperature be controlled?</td>
<td>Highest (usually 10 or more settings)</td>
<td>Medium (often only 4 settings)</td>
<td>Lowest (Mainly visual estimation)</td>
</tr>
<tr>
<td>Consistency</td>
<td>Heat distributed evenly in pot/pan?</td>
<td>Even heat</td>
<td>Less-even heat</td>
<td>Less-even heat</td>
</tr>
<tr>
<td>Hazard</td>
<td>Risk of burns from cooktop surface</td>
<td>Lowest</td>
<td>Mid</td>
<td>Highest</td>
</tr>
<tr>
<td>Health</td>
<td>What emissions are produced by this type of cooktop?</td>
<td>None</td>
<td>None</td>
<td>NO₂, CO, CO₂ and other waste gases</td>
</tr>
<tr>
<td>Waste heat</td>
<td>How much waste heat is emitted into the kitchen?</td>
<td>Least</td>
<td>Low</td>
<td>Most (more than 60%)</td>
</tr>
<tr>
<td>Cleaning</td>
<td>What is the ease of cleaning?</td>
<td>Easiest Can be wiped immediately after cooking as the plate is not hot and does not bake spills onto the surface.</td>
<td>Harder – and more finicky unless ceramic-glass.</td>
<td>As the hot surfaces can bake spills onto the surface, cleaning is more difficult and requires waiting until the surface has cooled down</td>
</tr>
<tr>
<td>Installation into benchtop</td>
<td>How easy is it to install in a benchtop?</td>
<td>Easiest. Induction cooktops are generally thinner than other types of cooktop</td>
<td>Easy</td>
<td>Moderate. Typically heaviest.</td>
</tr>
</tbody>
</table>

![Diagram of Induction Cooktop](image)

**FIGURE 3.26**
Operation of an induction cooktop. [Damar]
The ZCA Buildings Plan recommends the replacement of all gas cooktops with electric. In residential buildings, the proposed cooktops are induction, so as to provide those households with gas cooking with an equivalent cooking experience. Existing electric cooktops will be replaced as part of a natural replacement cycle (when they reach their end of life).

In non-residential buildings, a standard electric cooktop is sufficient for slow cooking, but if immediate responsiveness is required induction cooktops are necessary. Therefore, in non-residential buildings a mixture of induction and electric ceramic cooktops are proposed.

4.2.5 Costs

Induction cooktops have come down substantially in cost in Australia with the arrival of low-cost options, such as the Ikea model priced at $699 in 2013. Prices are expected to fall further as volumes increase and they shift from being marketed as high-end luxury products to general use. In comparison, radiant heat electric cooktops start at around $400 for ceramic glass top or $350 for solid plate hobs. Gas cooktops start at $200.

4.2.6 Specific product issues

Cookware

Induction cooking requires cookware – pots and pans – with a ferrous (iron) content.

Some cookware used on radiant heat electric cooktops and gas cooktops is not suitable for use on an induction cooktop as it does not contain an appropriate iron content and will therefore not heat up. To test if cookware is suitable for use on an induction cooktop, a magnet can be held to the base of the cookware – if the magnet and the base are attracted, the cookware is suitable. Any cookware that does not respond to magnetism will need to be replaced with induction-compatible cookware or will need an adaptor which acts as a hot-plate. However, adaptors reduce the benefits of induction cooking.

To optimise efficiency, the size of the cookware should be matched to the induction cooktop’s plates to minimise overlap of the cookware beyond the perimeter of each induction plate.

Woks

When woks with a convex base are used on a flat induction cooktop, not much of the convex base is close to the electromagnetic field and therefore only a small part of the base will heat up. Therefore, a flat-base wok should be used on a flat induction cooktop. Alternatively, a convex-base wok should be used on an induction cooktop with a matching concave indentation. Concave induction cooktops also come in standalone, portable units and are available for non-residential use (5 kW and 8 kW) as well as residential use (3.6 kW). The heating delivered with these units is often superior to gas-powered burners.

Electromagnetic interference

Some cardiac pacemakers are susceptible to magnetic interference from devices such as mobile phones and induction cooktops. Studies have shown that, unless the pacemaker is brought to within approximately 35cm of an in-use induction cooktop, there is no magnetic interference and maintenance of a distance of more than 50cm is recommended. People with pacemakers should be aware of this risk and may choose radiant heat electric cooktops instead.

4.2.7 Electric Ovens

Although electric ovens are around twice as efficient as gas ovens, they are often only 14% efficient and there are some significant opportunities for improving efficiency to as much as 24%.

4.2.8 Technology Benefits

Compared to gas ovens, electric ovens:

- Heat faster
- Offer more consistent heating
- Offer more precise heating measurements
- Have multiple functions (e.g. grill, fans, etc.)
- Have a lower installation price
- Produce lower emissions.

4.2.9 Demand-Reduction Potential

Reducing thermal mass of oven models is one of the simplest changes used to increase oven efficiency. Because energy is absorbed by all oven components during use, reducing the amount of material in the oven will increase efficiency.

Similarly to improving household insulation, improving insulation in oven cavities can significantly reduce the annual cooking energy consumption of both gas and electric ovens. The performance of insulation depends on the thickness, density and thermal conductivity of the oven. With longer cooking times, improved insulation can decrease energy consumption by 5-6%.

Convection ovens are often more energy efficient because they continuously circulate heat throughout the oven cavity with a fan. This continuous circulation allows for faster, more even cooking at lower temperatures, decreasing energy consumption anywhere from 6-20%. For commercial purposes, convection electric ovens can reach up to 70% efficiency, leading to dramatic decreases in energy consumption, and savings.
Zero Carbon Australia Buildings Plan

Heat is lost through glass windows in oven doors faster than through lack of insulation. Ideally, oven doors should possess no glass window to achieve maximum energy savings; however, users of such ovens tend to compensate by more frequently opening the door. Use of low-emissivity glass and three to four layers of glass panels in the oven door improves insulation and efficiency.

Some implementation recommendations listed above require oven replacement. However, replacing leaking door seals allows electric oven users to achieve energy savings with existing equipment.

4.2.10 Implementation Recommendations
Gas ovens should be replaced with high-efficiency electric ovens. The efficiency of existing electric ovens should be improved through either equipment upgrade or replacement.

4.2.11 Costs
Basic multifunction electric residential ovens with double-glazed doors start from approximately $400, triple-glazed from approximately $900 while quadruple-glazed door ovens with improved insulation and even pyrolytic self-cleaning are available from approximately $1500. Details about further insulation are often not provided in manufacturers’ specifications. Non-residential high-efficiency electric ovens can offer an attractive payback related to their frequency of use.

4.3 Electrical Appliances
The energy performance of many types of equipment which contribute to building energy use are regulated by MEPS (Minimum Energy Performance Standards) and energy rating labels. These schemes are discussed in Part 2. Energy performance of some important electrical appliances is described below. Energy use data in this section otherwise indicated. Throughout this section ‘BAT’ refers to best-available technology.

The modelling of residential energy consumption under this plan assumes normal rate of turnover of electrical appliances, and that new and replacement appliances will perform at a level corresponding to today’s best-available. For more information on the, see Appendix 1.
4.3.1 Televisions

Technology Description

The power usage of television sets depends to a large degree on screen size (measured as a diagonal on the screen). Taking typical screen sizes as being in the range 70-130 cm and assuming 10 hours viewing per day, the annual energy consumption is as shown in Table 3.15.

Table 3.15 shows that the larger screen size model consumes twice the energy of the smaller model.

Note that each of the sets in Table 3.15 has the same basic screen technology type – LCD screen with LED backlighting. On the government energy rating website this is called LCD (LED). The best plasma technology models give substantially higher energy consumption. For example, in the 90-110cm range, the most efficient plasma model consumes 322 kWh/annum (almost three times the consumption of the best LCD (LED) model).

From October 2012, the MEPS maximum energy figure is 90.1 + (0.1168 x screen area [cm²]) based on standard AS/NZS62087.2.2. For example, the 70-90 cm best model in Table 3.15 has an energy consumption of 110 kWh/annum. The MEPS limit for its screen size would be 409 kWh/annum. This suggests that the MEPS limit will be considerably higher than the best models, but somewhat lower than the worst of the present models.

Standby energy use is relatively insignificant. Using a typical value of less than 0.3 W, this translates to about 2.6 kWh/annum, which is less than 3% of the total energy consumption of the best performing model.

Technology Benefits

Energy efficient TVs have the benefit of lowering the household’s electricity bill and greenhouse gas production. As listed above the median model in a range consumes over twice as much energy as the corresponding BAT model.

Costs

The costs of televisions vary widely, depending upon the screen size and type.

4.3.2 Household Refrigerators/Freezers

Technology Description

Refrigerators come in many shapes and sizes and their usefulness may depend on the makeup and personal preferences of the household. For example, whether the freezer box is at the top or the bottom of the appliance may be largely a matter of preference. What may be of more concern is their energy usage and the attributes of the refrigerants used namely, their Global Warming Potential (GWP) and their Ozone Depletion Potential (ODP). Another aspect of refrigerator use is the effect on building heating and cooling.

Taking typical refrigerator sizes as being in the range 200-500 L, the annual energy consumption of one-door and two-door models is as shown in Table 3.16.

Interestingly, in the two-door models, the best energy consumption actually goes down slightly as the size increases. The one-door models consume somewhat less energy for a given size than the two-door models. This is most marked in the 200-300L range, where the best one-door model uses 57% less energy.

Technology Benefits

Modern fridges with low-GWP and low-ODP refrigerants have benefits for the environment, as it is inevitable that some refrigerant escapes into the atmosphere over the life of the product. Also, there is the issue of making sure that all appliances are handled appropriately after the end of their working life. Lower energy usage also has benefits in lower running costs and lower greenhouse gas emission from the electricity generation. As demonstrated in Table 3.16, the average model consumes between 12% and 51% more energy than the BAT model.

<table>
<thead>
<tr>
<th>Capacity (L)</th>
<th>Doors</th>
<th>Annual energy consumption (kWh/annum)</th>
<th>Excess of Median over the BAT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BAT model</td>
<td>Median model</td>
</tr>
<tr>
<td>200-300</td>
<td>1</td>
<td>213</td>
<td>310</td>
</tr>
<tr>
<td>300-400</td>
<td>1</td>
<td>226</td>
<td>310</td>
</tr>
<tr>
<td>400-500</td>
<td>1</td>
<td>250</td>
<td>379</td>
</tr>
<tr>
<td>200-300</td>
<td>2</td>
<td>338</td>
<td>394</td>
</tr>
<tr>
<td>300-400</td>
<td>2</td>
<td>329</td>
<td>415</td>
</tr>
<tr>
<td>400-500</td>
<td>2</td>
<td>318</td>
<td>480</td>
</tr>
</tbody>
</table>

Note that the one-door models have limited freezer capabilities (either none, or with an ice maker, or with a short-term freezer compartment).
4.3.4 Domestic Dishwashers

**Technology Description**

The performance of dishwashers depends upon their capacity. Environmental performance depends upon both the energy and water used. Refer to Table 3.18.

**Technology Benefits**

Energy efficient dishwashers have the benefit of lowering the household’s electricity bill and production of greenhouse gases. Lower water consumption is also a benefit.

**Costs**

Many of the models considered in Table 3.18 could not be found in the retail environment. The models found were on the upper end of the price scale retailing for over $1,000.

4.4 Supermarket Refrigeration

Supermarkets are the most energy intense type of commercial building, using about 3.3 GJ/m²/annum\(^{(112)}\) pp 8, and overall about 26 PJ (7.2 TWh) in 2011 \(^{(112)}\) pp 67). This represents about 2.9% of Australia’s overall electricity consumption \(^{(113)}\) pp 15). The single greatest energy use in supermarkets is refrigeration \(^{114,115}\). About three-quarters of the refrigeration energy is lost to air infiltration, mainly because of open cabinets \(^{(114)}\) pp 153). Refrigeration can also have a more direct effect on emissions through refrigerant leakage, which might be in the range of 2-4% \(^{(114)}\) pp 43) of refrigerant charge per annum on very well-maintained systems. More typical leakage might be in the range of 10-30% per annum \(^{(114)}\) pp 150).

4.4.1 Emission and energy reduction measures

A number of possible measures can be taken to lessen the energy and emissive implications of retail refrigeration. A study by the Carbon Trust \(^{117}\), from the UK, lists 32 different measures that have potential to reduce energy use and direct emissions in retail refrigeration systems. Some of those are:

* **Use lower-GWP refrigerants.** Refrigerants such as CO\(_2\) (R774), propane (R290) and ammonia (R717) have much lower global warming potential than the more commonly used hydrofluorocarbons (HFCs). The use of these improved refrigerants would normally require new refrigeration hardware. For more immediate improvements, there are sometimes direct refrigerant substitutes which, while still HFCs, have lower GWP. An example would be replacing the widely used R404A (GWP=3922) with R407A (GWP=2100).

---

4.3.3 Domestic Washing Machines

**Technology Description**

Front-loading washing machines are regarded as more efficient than top-loading machines. Load capacity can vary from 4.5 to 10 kg, and this choice may be governed by the size of the household. If the machine size is too big for the household, it may be inefficient as a lot of washes may be with partly full tubs. A machine size that is too small may lead to multiple time-consuming washes. How environmentally friendly the machines are depends upon the amount of energy and hot and cold water they use. Further, there are many options and cycles that may complicate the comparison of energy and water usage between models. For example, some machines allow a delayed start option which may help consumers avoid critical electricity pricing periods. Also, many machines have automatic load sensing and water-level adjustment which save both water and energy. Finally, many machines do not have a cold wash option and may not take in hot water, but instead use internal heating to obtain wash temperatures (even on “cold” wash cycle).

Table 3.17 notes that the best performers in the 7-8 kg load range usually do not allow a cold wash option. Presumably manufacturers argue that this gives superior wash quality. The best machine that does allow this in the 7-8 kg size range uses 130 kWh of energy (cold wash) and uses of 68 L of water per wash.

(In this case the star rating index is a combination of the energy used, the machine’s spin efficiency and the load size, and so is limited in its ability to encapsulate the machine’s relative merits.)

**Technology Benefits**

Energy efficient washing machines have the benefit of lowering the household’s electricity bill and production of greenhouse gases. Lower water consumption is also a benefit as it will save on the building of dams and desalination plants. Also, if the input water is hot, energy and greenhouse gases have been expended in the production of that water and in many cases the maintenance of that water’s temperature. It is estimated that between 80% and 90% of a machine’s energy use is expended in heating the water \(^{111}\).
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- **Maintenance, training and re-commissioning.** Active measures to improve the plant maintenance can save significant amounts of energy. Examples of improvements are replacement of door seals, leakage detection and correction, cleaning of condensers and evaporators, checking and re-setting temperature set points.

- **Cabinet doors.** Retrofitting glazed doors to open refrigerator cabinets can save significant amounts of energy by reducing infiltration losses. However, the savings are less than might be imagined because of the need to use energy to keep the doors free of condensation. Energy savings of around 30% to 50% (pp 153) are reported. An indirect, but seasonal, benefit of cabinet doors is the reduction in store-wide heating load, since air temperature for customers needs to be maintained. One possible improvement is glass door treatments that resist the formation of water droplets on the glass (pp 31), lessening the need for anti-sweat heaters. Some reports suggest savings as high as 68% are possible.

- **Air curtains.** An alternative way to control infiltration losses is to use a fan-driven curtain of air.

- **Night curtains.** For stores which are closed overnight, the use of retractable night curtains is a simple and proven way to lessen infiltration losses. Energy savings of around 20% are reported (pp 153).

- **Air locks.** Install air locks on supermarket entrances to lessen ingress of moist air, which in turn improves refrigerator efficiency (pp 48) from reduced condensation and frosting.

- **High-efficiency motors and fans.** Refrigeration equipment using high-efficiency motors and fans can save energy. For example, an electronically commutated motor is reported to use 67% less energy than a conventional alternative motor (pp 153). Energy loss in motors and fans gives rise to heat which adds to the work of the system, so the savings go beyond the direct reduction in motor energy.

- **Smart controls.** An example of a smart electronic control that can save energy is ‘defrost on demand’ in freezers. Electric defrost heaters are required to keep evaporator coils ice-free. These heaters typically operate at a fixed, conservative frequency of two to four times per day. If this is too often or not often enough then energy is wasted. Adaptive controls can sense the ice and only defrost when required. Energy savings of about 12% are reported (pp 153).

### 4.5 Standby Power

Inactive electrical devices with power applied will often be drawing non-trivial amounts of so-called standby power. The issue of standby power cuts across many different equipment types and today represents a significant category of energy consumption. In the residential sector, EES and others estimate standby power at about 10% of overall electrical consumption (pp 19). Often the MEPS standards for devices address the active mode but not the standby mode (pp 18).

<table>
<thead>
<tr>
<th>TABLE 3.17</th>
<th>Refrigerator energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size Range</td>
<td>BAT Model</td>
</tr>
<tr>
<td></td>
<td>Energy Consumption (365 washes)</td>
</tr>
<tr>
<td>5-5.5 kg load</td>
<td>200 kWh</td>
</tr>
<tr>
<td>7-8 kg load</td>
<td>180 kWh</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 3.18</th>
<th>Dishwasher energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine Size</td>
<td>BAT Model</td>
</tr>
<tr>
<td></td>
<td>Energy consumption (365 uses)</td>
</tr>
<tr>
<td>12 places</td>
<td>222 kWh</td>
</tr>
<tr>
<td>14 places</td>
<td>225 kWh</td>
</tr>
</tbody>
</table>

Note: Use of rated performance for direct comparison of models and with in-home usage can be misleading because rated energy use is often based on an ‘eco’ mode of use which varies from typical use.
Example: Microwave oven. An example of the significance of standby power can be seen from the following example. Consider a hypothetical domestic microwave oven that uses 3 W in standby and 1 kW when operating. Say that on average it operates for 4 minutes per day. So, the annual active energy used is about 24 kWh. The annual standby energy used is about 26 kWh. Hence an appliance can use more energy in standby than in active operation.

As a rule of thumb, every 11.5 W of standby power used contributes 100 kWh/annum to electrical energy demand. A typical Australian home might have anywhere from 50 W to 200 W of continuous standby power demand from devices including microwave, garage door opener, internet router, stereo, DVD player, television, docking stations, cordless phones, ovens, range hoods, dishwasher, washing machine, printers, hard-wired smoke alarms, rainwater harvesting system, PC, alarm and air conditioner. A home with 200 W total standby power will consume 4.8 kWh/day on this alone, which is more than a well-sited 1 kW PV system would generate anywhere in Australia.

**Good practice and best practice.** For some time good practice has been for devices to consume about 1 W on standby. Many new devices like televisions consume as little as 0.1 W on standby. The energy projections in this report have been based on 1 W standby.

5 Hot Water Systems

In Australia, about one quarter of household energy is used to provide hot water (23% of residential energy use in 2007\(^3\)), amounting to about 33 MJ/day for each household (based on 92 PJ/annum in 2005\(^4\), (7 pp 197) and 7.63 million households\(^{122}\). Most domestic water heating systems in Australia use gas or resistive electric elements \(^5\). With such a substantial amount of energy being used for heating water, by such inefficient means, it follows that there is considerable scope for saving energy in this area.

**Approaches to improved efficiency.** The major strategies for reducing hot water consumption are low-flow shower heads, front-loading washing machines (which require a greatly reduced amount of water), or machines with cold wash cycles. The other approach is to increase the efficiency of hot water generation. Government regulation, mainly through the MEPS scheme (see Part 2), has led to some improved efficiencies in the area of hot water energy use, though this report shows that there is considerable scope to further reduce energy use in this area. There are two high-efficiency technologies which are both readily available and with the potential to significantly reduce energy use, namely solar (thermal, not PV), and heat pumps. (Note the Clean Energy Council includes heat pumps within their definition of solar. This report will treat heat pumps and solar as distinctly separate technologies). Beyond these two broad approaches to designing hot water systems, there are other aspects of the energy efficiency of hot water generation and use, such as temperature control, behaviour, and installation and insulation practices.

**Instantaneous hot water systems.** Instantaneous hot water systems, i.e. systems that require no storage, are widely available and are frequently described as being highly efficient. This report does not consider instantaneous systems as generally suitable in the context of a zero-carbon Australia because:

- **Gas.** Most instantaneous hot water systems operate using fossil methane as a fuel. As discussed in Part 1, appliances requiring gas are not considered in this report; and

- **Electric.** Electric instantaneous boosting uses resistive elements which are a very inefficient way to generate heat. Except for very small units, electric instantaneous systems generally require a very high power and use three-phase wiring which can have adverse peak load implications on the electricity grid if widely used. However, electric instantaneous would be still appropriate in some circumstances, in situations where usage is very low and/or infrequent, then instantaneous systems would avoid an excessive proportion of standing heat loss that would be associated with a storage system. Similarly, if the use of an instantaneous system avoids very long pipe runs, then it would be preferred.
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5.1 Solar Hot Water

Solar hot water systems use solar energy to directly heat water. These systems have been available in Australia for decades, but are currently only used in about 8% of homes. In Australia, demand for new solar hot water systems has declined since a peak in 2009.

Configurations. Solar hot water systems are generally found either with:
- A solar collector along with a horizontal tank, integrated as a single unit (so called close-coupled arrangement); or
- A ground-standing vertical tank connected to a roof-mounted collector with pipes (so called split-system arrangement).
- Close-coupled systems are simpler and require no pump since water can flow between the tank and the collector in a themosiphon operation.

Collectors. There are three general types of solar collector that are commonly used for domestic water heating: evacuated-tube collectors, glazed flat-plate collectors and unglazed collectors. Unglazed collectors are generally only used for pool heating and will not be considered any further for this reason.

Evacuated-tube collectors. Evacuated-tube solar collectors, although more expensive, are the most efficient of the three collector types. The collectors have a row of glass tubes. Each tube has two glass layers with a vacuum between the layers, allowing low heat loss in the manner of a vacuum flask. Within the glass tube is a metal pipe which absorbs the solar radiation and transfers it to the water. Evacuated-tube solar collectors are highly tolerant to frost and over-heating conditions, and retain reasonable performance even when the incident solar energy is sub-optimal.

Flat-panel collectors. Flat-panel solar collectors are simpler and cheaper, but still reasonably efficient. They consist of a dark rectangular collecting surface covered with a glazing element for insulation. Water passes behind the collecting surface allowing heat to pass into the water. Flat-panel collectors are widely used in both split-system and close-coupled configurations.

Boost power. When heating water using the sun, solar systems offset mains energy use. When there is insufficient solar radiation, these systems boost water temperature using mains gas or mains electricity. At these times efficiency is obviously lessened, but on average efficiency is improved.

Ring mains. An increasingly common configuration of hot water uses a pumped ring mains. These promise hot water without delay, but are to be avoided because of a) increased standing losses and b) pump energy required.
the case of conventional electric boosting, a typical system might draw 3.6 kW. As such, a caution about the use of electric-boosted solar is the potential impact on a 100% renewable power grid during times of winter peak demand.

**Technology Benefits**

Compared to conventional gas and electric systems for providing domestic hot water, solar thermal hot water systems have the advantage of using solar energy to reduce mains energy requirements by as much as 90%, and normally by at least 65%.

**Costs**

Solar hot water systems have a higher up-front cost than conventional electric or gas systems. A study by Choice in 2008 revealed indicative costs starting at $3900 installed. This cost is reduced somewhat by government rebates at both state and federal level. The rebate situation is fluid, and eligibility can vary depending on the type of system being replaced.

### 5.2 Heat-Pump Hot Water

**General operation.** Heat-pump hot water services apply the same technology used in a reverse-cycle air conditioner to the heating of water (see Section 3.2.2). They are highly efficient because most of the energy used to heat the water is extracted from the ambient air. These devices are generally capable of reducing hot water mains energy requirements by at least 50% \(^{128}\), and as much as 70%, compared with a conventional electric hot water system. These type of systems have been available in Australia for more than ten years, but currently represent only about 1.7% of installed systems \(^{128}\) Table 19.

**Configuration.** Generally heat-pump hot water services are generally either configured as either:

- **One-piece.** With the evaporator and fan mounted on top of or beside the tank and integrated into a single unit;

- **Split system.** With the heat-pump mechanism in a separate unit plumbed to the tank at installation time.

**Cold-weather operation.** Conventional wisdom has it that heat-pump hot water services are not suitable in cold climates. It is generally true that efficiency of heat-pump systems are more sensitive to ambient temperature than other water heating systems. However the cold-weather performance of many contemporary recent models can be good. The rating and regulation of these systems introduced a new climate zone covering cold climates in 2011. The first list of systems tested against the new test regime for this zone was released by the Clean Energy Regulator in November 2011. The 255 systems on this list include 106 which are tested in the cold-climate Zone 5. The best performing is rated as saving 9.3 kWh/day on average in cold-climate locales, relative to a reference electric hot water service. This is consistent with Pitt & Sherry’s results Table 11 which reported an average 47% energy saving in Canberra. Therefore it is safe to say that an appropriately chosen heat pump system will be suitable, and give good energy savings, even in cold climates.

**Refrigerants.** The global-warming potential (GWP) of refrigerants used in heat pump systems is often very high, which becomes a problem if they leak or are dumped illegally. Some systems are available that use low-GWP refrigerants such as hydrocarbons or CO2.

**Noise.** Heat pump hot water systems generate noise levels...
Part 3: Low Energy Technologies and Strategies

comparable to modern small air-conditioning units. This introduces the need for care in locating units such that any potential annoyance is minimised. For example, locating a unit right next to a bedroom window should be avoided.

Ventilation. These systems depend on sufficient access to ambient air flow. This precludes installation in confined spaces. Minimum clearance from walls needs to be observed. On the other hand, unlike gas systems, there is no flue gas to be vented, so indoor installation, such as in a garage, is viable given sufficient room volume.

Economies of scale. The technology involved in heat-pump hot water systems is well-understood and readily available, but the market penetration is very low. It follows that, if deployed on a much larger scale, such systems would naturally become more affordable and reliable due to simple effects of scale and product maturation.

Technology Benefits

Compared to the alternatives, heat pump-based hot water services have a number of advantages:

- **Continuous recovery.** Unlike solar-only systems, heat pumps can heat water efficiently even when the sun is not shining;
- **Low boost power.** When boosting, heat-pump systems require much lower power levels than electric resistive boosting. In the context of connecting to a renewable-energy grid and winter-time peak demand, this is a significant consideration;
- **High-efficiency.** They typically achieve a coefficient of performance (COP) of 2 or better. This can lead to a large reduction in energy used compared with

![Figure 3.31](image-url)  
**Figure 3.31**  
The internals of a one-piece heat pump system [Quantum]
of a conventional electric or gas system. For a four-person house, the average mains energy requirement is similar to a conventional electric-boosted solar system.

- **Easy installation and location.** Compared with solar, the installation requires much less labour, and the location of the equipment is much less sensitive to local factors such as shading and roof access.
- **No combustion emissions.** When compared to gas hot water units, heat pump systems enjoy the benefit that they do not emit the flue gases. Flue gases can pose problems if not ventilated properly.
- **Consistent load.** Compared with solar, heat pump electrical load is more consistent from day to day, and from season to season.
- **Adaptable load.** Heat pump systems are more flexible about when boosting is delivered, allowing boosting times to be coordinated with available energy sources such as wind.

**Costs**

A survey of the costs of installed heat pump hot water systems in Australia by this report found the average 2013 cost to be between $3500 to $5000 depending on the brand and tank sizes.

As an indication of costs, at the lower end of the scale, a 310 L heat pump unit was quoted as costing $2,604, based on replacement of an existing electric HWS. The rebate situation is mostly the same as for solar hot water.

**Running costs.** A study by Pitt & Sherry reports that using heat-pump hot water systems can lead to considerable savings in operating costs. However this varies greatly with model, location and electricity supply tariff.

### 5.3 Improving Current Practice

Computer modelling of domestic hot water systems has informed this discussion about the relative merit of different ways of improving the energy performance of hot water systems. This is discussed in Part 5.

Collector slope. Raising the slope of solar collectors allows collectors to perform more consistently across the year. For example, in Melbourne (latitude 38°), solar collectors at 15° and at 63° will perform very differently as shown in the study described in Part 5. The steeper collector slope results in a small net reduction in annual yield. However this is outweighed by the flattening of the annual yield. It is common for solar hot water systems to, at times, have surplus energy in summer. Unlike solar PV systems, solar hot water systems cannot utilize their surplus. Indeed surplus summer-time heat gain can be a problem leading to venting and loss of water.

Temperature regulation. The bio-safety requirements in AS/NZS 3500.4:2010 have been finessed and now permit the hot water service to apply a control regime of a periodic sterilising heat pulse. This allows temperatures to be maintained at lower temperatures (say 50 °C) instead of greater than 60 °C, for large amounts of time. This has the potential to reduce standing heat loss.

Insulation. There is considerable scope for hot water systems to have improved insulation, and for the insulation of valves and pipes to be improved. One very simple retrofit improvement is to insulate the pressure relief valve. These valves are normally left exposed, and act as a thermal bridge which allows heat to be lost. Suitable insulation can be achieved with a valve cover, such as the ValveCosy, which are inexpensive and easy to fit as shown in Figure 3.34. In the context of possibly regulating water temperature at 50 °C instead of 60 °C, it becomes important to ensure minimal temperature drop along the pipes to the hot water taps. This can be achieved by applying pipe insulation at or above the minimum standards.

Winter peak demand. Conventional electric-boosted solar systems, even if they can reduce annual energy needs by 65% in southern Australia, still have the problem of high winter peak demand. For example, the system modelled for Melbourne conditions (see Section 5, hot water, Experiment 14) suggests there would be an electric-boost demand of greater than 140 kWh/month for May to August inclusive. Heat pumps under the same circumstances (Experiment 13), have a much flatter peak in demand during winter. Managing winter-time aggregate energy demand is a crucial consideration when adapting to an all-renewable electric supply proposed under the Zero Carbon Australia model. Modelling indicated that in winter time, the mains energy requirement for solar hot water is about double that for heat pump hot water in temperate climate zones.

**Other conclusions**

*Heat pump vs baseline.* Compared to a baseline electric hot water system, the combined effect of improved tank insulation, improved control, and heating with a heat pump reduces the annual energy requirements by about 80%.

*Heat pump plus solar.* Combining heat pump and solar thermal gives the greatest demand reduction, but at considerable cost. This combination is not considered economically viable given that both heat pump and solar thermal can, by themselves provide sufficient levels of demand reduction.

*Heat pump plus PV.* Modelling results (see Part 5, Hot water, Experiment 13) suggest that 1 kW of PV capacity in Melbourne could provide more electricity than the heat pump needs all year round (on a net monthly basis). Given the low incremental price of 1 kW of capacity on a house that is already buying PV, this suggests that the best solar technology for hot water may be about 1 kW of extra PV capacity for these households.
5.4 Domestic Hot Water Implementation Recommendations

In tropical northern Australia, for sites with good solar access, simple thermosiphon electric-boosted solar systems are preferred on the basis that they can provide at least 85% energy savings, and the boost demands are not a challenge to the electric supply. For the rest of Australia, heat pump hot water systems are preferred on the basis that they are affordable and efficient, and the seasonal variation in boost energy is kept to a minimum. These considerations are summarised in the table below.

Extra PV. Electrical energy demand of hot water can be offset by including additional photovoltaic (PV) systems. Modelling suggests that, in even in southern Australia in winter, one additional kilowatt of PV capacity fully offsets the entire hot water boost requirement (demand and generation averaged across each month). Given the greatly improved affordability of solar PV, and the ability of surplus generation to be used for other things or exported to the grid, we consider that heat pump plus solar PV represents the best value way of providing hot water in a zero-carbon Australia.

FIGURE 3.32
A 'one-piece' heat pump hot water service. [Quantum]

FIGURE 3.33
A 'split-system' heat pump hot water service. [Siddons]

FIGURE 3.34
A valve cover reduces heat loss from the tank’s pressure relief valve. [Valve Cosy]
6 Residential Building Energy Management

This section describes the present state of energy management in residential buildings. It then describes ZCA Buildings Plan recommendations which include widespread use of smart electricity metering, web portals, in-home displays, and certain appliance controls. The application of these technologies is projected to reduce average annual energy consumption in Australian residences by 6.6% or approximately 3.7 TWh/annum.

6.1 The Problem: Limited Information and Limited Control

The ability of Australian homeowners and tenants to reduce energy consumption, especially at peak electricity demand times, is limited by a lack of information. Such information must indicate when, where, and how much energy is being consumed directly by the household. Some examples include residents being unaware of:

The cost of stand-by electricity being used in their home every day and night,

The cost of running an old and inefficient second refrigerator,

The cost of leaving appliances turned on when not in use - such as lighting, computers or televisions,

The relative amounts of energy used by different electrical appliance technologies such as halogens versus LED lights, plasma versus LCD televisions, or heat pump versus radiant heaters,

The cost of running electricity-intensive appliances such as refrigerative air conditioners, pool pumps or clothes driers,

The cost savings possible by shifting electricity use to different periods of a day or week.

The disproportionately high cost of supplying electricity at peak demand times has been described by the Productivity Commission who state, for example, that “around 25% of retail electricity bills reflect the cost of system [electricity network and supply] capacity that is used for less than 40 hours a year (or under 1% of the time)”. Even in instances where residents are aware of how much electricity an appliance uses, the ways that energy can be controlled is generally limited to:

- Manual intervention by the resident.
- The use of simple timers.
- Adjusting thermostats for room temperature control.
- Standby power controllers.

More sophisticated methods of controlling energy, based on real-time information, are not yet widely used in Australia. However as described in the next section, trials have shown the value of applying currently-available residential building energy management technologies.

6.2 The Solutions: Zca Buildings Plan Recommendations

Technologies now exist that merge information and communication methods into residential building energy management systems. These can assist residents to reduce peak and average energy use.

As shown in Figure 3.35, these technologies include:

- “smart” electricity meters that transmit near real-time electricity consumption data,
- web portals displaying energy use information, as measured by the smart meter and transmitted to and recorded by the electricity supplier (typically for half-hourly or hourly intervals),
6.2.1 Smart Electricity Metering

A key enabling technology for residential building energy management is the smart meter. This section describes the various types of electricity meters. (Smart metering can also be applied to other utilities such as water and gas.)

Traditional spinning-disk type accumulation meters record a cumulative amount of electricity energy. They can measure net electrical flow from-the-grid (importing) minus to-the-grid (exporting). Such bi-directional meters, as a minimum, are necessary when there is on-site generation such as rooftop solar photovoltaic systems.

Traditional accumulation meters cannot give any indication of when electricity has been consumed or generated. On the other hand, most modern digital electricity meters go further and log electricity flows over fixed time intervals. These are known as interval meters. For example, if the designated measurement interval is 30 minutes and the billing period

Even more comprehensive and sophisticated centralised home automation systems are under development and deployment globally. However because of the nascent state of those advanced systems, they are not recommended as part of this Plan.

As described in the following sections, this Plan recommends the installation of these technologies in Australian residential buildings. Roll out of these technologies is also recommended in many respects by the Council of Australian Governments (COAG) who, based on work done by the Australian Energy Market Commission and Productivity Commission, voiced “a commitment to make it easier for retailers to offer innovative products to give consumers the choice to have such things as smart metering, in-home displays, and time-of-use-pricing so they may better manage their energy use and reduce costs”.

FIGURE 3.35
Recommended technologies for Residential Building Energy Management
is every 90 days, then the account at each bill will be based on 4,320 intervals.

Interval meters enable electricity to be sold at different prices (tariffs) for different blocks of time within the day (eg night versus day) or different days with the week (weekday versus weekend). This is known as time-of-use (TOU) pricing.

Smart meters (see Figure 3.36) are interval meters that can communicate with electricity supply companies and with in-home displays (IHDs). Communication with electricity suppliers enables remote meter reading and remote control. Communication with in-home devices provides building residents with real-time information about electricity flows and also allows control of electrical appliances.

Smart meters have been installed as part of solar city trials in, for example, Perth and Adelaide. Victoria’s roll out of smart meters for homes and businesses is due to be complete by the end of 2013. As recommended by COAG, the other Australian states and territories also intend to make smart meters more available to residential electricity consumers.

6.2.2 Web Portals

The interval data measured and transmitted by smart meters and recorded by electricity suppliers can be made available to home owners and tenants over the internet. This is known as a web portal. Residents are assigned a login and password by their energy retailer and/or electricity distribution company. Residents can then log-on to the web portal which displays their electricity usage over time, as well as associated billing information.

Figure 3.38 shows how a web portal appears on a computer screen. The two bar charts show, for hourly periods, the amount of electricity imported to and exported from a home for two different days.

Advice about how to save electricity can be incorporated into the web portal, as well as comparative electricity used by neighbours in the same postcode area. This comparative analytical capability has been shown to help residents to change their behaviour.

6.2.3 In-home Displays (IHDs)

In-home displays (IHDs) are stand-alone devices that allow home owners and tenants to view their energy use in nearly real-time. Older technology current-clamp type IHDs have been available in Australia for some time; however, that type of IHD does not communicate directly with the electricity meter and has limited accuracy. State-of-the-art IHDs communicate wirelessly with smart meters, as shown schematically by Figure 3.36. Figure 3.37 shows one commercially-available IHD with smart meter communication capability.
IHDs communicate with smart meters via a low-power, short-range wireless communications protocol known as the ZigBee Smart Energy Profile (SEP), a widely-used standard. A number of jurisdictions (e.g., France and the United Kingdom) are combining installation of IHDs with their smart meter programs. As of 1 March 2012, Victoria included IHDs as a prescribed activity in the Victorian Energy Saver Incentive (ESI) scheme. This effectively subsidises IHD purchases.

Some features of in-home displays that have been set as minimum specifications in the United Kingdom and Victorian schemes are listed below:

- near real-time feedback (less than 30 seconds lag),
- at least 45 days of usage history,
- indicative cost data in cents per kilo-watt hour and accumulated cost,
- numerical and non-numerical displays,
- data communications security,
- power draw of no more than 0.6 watts,
- battery replacement not required within five years.

An additional feature of many mid to high-range IHDs is the ability to receive messages and alerts.

IHDs have the ability to assist energy consumers to understand their instantaneous whole-of-house electricity usage. Referring to an IHD, a resident can manually switch appliances on and off in order to understand electricity consumption. IHDs can also assist residents in becoming aware of standby power loads or the energy use of “forgotten” appliances.

IHDs can convert energy-use data into an indicative cost by applying the resident’s electricity tariff. Tariff complexities such as different prices for different times of the day (known as “peak”, “off-peak”, or “shoulder”) can make it difficult for consumers to understand how their energy use patterns impact their electricity bills. The design of an IHD aims to mitigate this problem by providing an easy-to-understand view of the resident’s expected electricity bill.

FIGURE 3.38
Web portal. [T. Forcey]
6.2.4 Smart Appliances and Demand-Response-Enabling Devices (DREDs)

Given the high cost of supplying electricity at peak times [130], this Plan recommends the installation of technologies known as smart appliances or demand-response-enabled devices (DREDs). Such appliances can be directly controlled by the energy supplier under agreed circumstances such as at times of peak electricity demand. This is known as Direct Load Control (DLC). In this situation, the electricity supplier might turn off, cycle, or adjust the electricity draw of the appliance. The electricity customer can be compensated via a rebate known as a critical peak rebate tariff.

Appliances can be controlled via smart plugs or via a wireless Home Area Network (described below). Smart plugs involve the appliance being directly wired into a specially-provided electrical socket that can be controlled by the electricity supplier.

Successful trials have been conducted into controlling devices such as pool pumps [135], and air conditioners [140]. For those appliances, and also for water heaters and electric vehicle charging, further investigation into the installation of these technologies is under-way [148] as recommended by COAG [136].

The Energy Supply Association of Australia was reported as expecting that a significant impact could be made on peak demand with as little as one-in-forty homes being involved with Direct Load Control devices. Residents might be invited to participate on an “opt-in” basis.

6.2.5 Automated Energy Control Via a Home Area Network (HAN)

A local area network (LAN) allows communication between digital devices deployed in the home such as computers and printers. A home area network (HAN) extends that concept to smart meters, in-home displays, and smart appliances or DREDs.

Smart appliances, communicating via the wireless ZigBee protocol, can be programmed to automatically respond to signals sent from the energy supplier and potentially the resident. For example, the energy supplier might send a critical peak signal through to the HAN (via the smart meter) informing that a critical peak event is occurring. A smart appliance such as a pool pump could respond to that signal by stopping or reducing its electricity use during the critical period and returning to full operation later in the day.

Architectures that use HAN technology to reduce or time-shift electricity demand include “static” and “dynamic” home energy management. Static home energy management is set up by the resident in order to reduce their electricity bill by appropriately responding to a tariff structure. Dynamic home energy management is similar to static but can also respond to energy supplier requests.

6.3 Benefits

This section summarises the benefits in reducing average-annual and peak energy use that can be achieved by deploying the recommended residential building energy management technologies.

6.3.1 Reducing Average-Annual Energy Use

Global studies of energy-use-feedback technology trials found energy savings of 2% to 20% [149, 150, 151, 152]. Feedback that is more real-time and granular allows the greatest savings.

Figure 3.39 shows energy savings ranging from 3.8 to 12% depending on the type of feedback [150].

A recent study by Accenture [147] examined 76 global feedback trials (including seven Australian trials) and five other studies and found the following key trends particularly relating to IHDs:

- Consumers respond positively to IHDs,
- Consumers measurably reduce energy consumption in response to feedback, ranging from two to 20%,
- IHDs drive energy consumption reduction in isolation from other feedback types,
- Dynamic (flexible) pricing tends to drive load-shifting behaviour, whereas feedback reduces overall energy use,
- On-going education has a negligible effect on the behaviour of IHD users,
- Energy saving behaviour persists over time. This is especially the case with IHDs which appear to have a stimulating effect on helping consumers to understand their consumption patterns and to lock-in new habits.

The Accenture study concluded that for Victoria “IHDs could reasonably provide an average-annual energy reduction of 6.6%” As a result the Buildings Plan conservatively assumes that the deployment of IHDs, along with the full suite of recommended residential building energy management technologies, will result in average-annual electricity savings of 6.6% throughout Australia.

6.3.2 Reducing peak energy demand

Flexible pricing alongside the provision of energy information, and even more so alongside automated response, enables the shifting of demand from peak times to
other times. One study reviewed the effect of different pricing schemes and associated feedback mechanisms on peak demand and found that peak demand in the home could be reduced by over 30% if flexible pricing schemes and automation of energy appliances were implemented. Smart meter infrastructure means it is also possible for smart appliances to be able to respond by varying their demand according to grid situation.

A mid-range IHD costs approximately $100.

Based on the recognised economy-wide benefits and broad government support, for the Plan-recommended residential energy management technologies, this Plan assumes that Smart Meters and IHDs will be common in Australia within ten years. Therefore their cost is considered a business-as-usual expense that is not factored into Plan costings.

### 6.4 Costs and Economics of Plan Recommendations for Residential Building Energy Management

The expenditures required to realise the above average-annual energy savings are largely associated with the costs to install smart meters and IHDs.

In Victoria, the smart meter rollout is costing more than $700 per meter, with further ongoing operating costs of $20-30 per year. According to the Productivity Commission, the market for smart meters is maturing and prices are declining.

Smart meter installation involves safety checks. The overall cost of the roll out includes the incidental rectification of many safety issues. Hence there are indirect, but hard-to-quantify, benefits through avoided incidents such as electrical fires and electrocutions.

---

**Figure 3.39**

Average household electricity savings for different feedback types [Accenture 147]
7 Commercial Building Energy Management

Once a building has been designed and built (or been retrofitted) for energy efficiency, there is still a large potential for wasted energy if the facility is not managed well. Facility management personnel do not always have the skills or incentives to optimise facility performance. Priorities of Facility Managers are usually focussed on keeping tenants and building owners satisfied – which does not necessarily include minimising energy use. Similarly, the tools available to a Facility Manager to better manage energy use are often limited. A fully functional Building Management & Control System (BMCS) and/or Energy Management System (EMS) may not be available. If a BMCS is installed, it may not be geared toward optimisation of energy use.

Buildings which are not well managed from an energy perspective generally exhibit consistent energy consumption increases, or ‘drift’ in the order of 5% per year due to issues such as ageing equipment, non-optimal operation, sensor failures and schedules / set-points slowly deviating from optimum levels. In order to minimise or even eliminate this increase, information management systems are required – as well as the skills to operate them. This is contrary to a common opinion that saving energy requires large once-off capital investments. Significant energy savings are possible by simply optimising operation of existing equipment.

7.1 The Facility Management Profession

The Facility Management Association of Australia (FMA Australia) defines facilities management as the effective operational management of buildings. The areas of operations that are managed under facilities management include strategic operational planning, general maintenance and environmental performance. Facilities management can be undertaken by professionals and organisations. The role of facilities managers in energy management is continuously evolving, with newly-realised potential and therefore large scope for development. For example, not only do facilities managers influence the technical operations of buildings, they can also influence how the building is used by educating and influencing tenants on their behaviour and energy consumption.

CONTINUOUS OPTIMISATION VS ONE-TIME ENERGY EFFICIENCY IMPROVEMENTS

Typical Consumption Increasing 5% p.a.

One-Time Fix

Typical Consumption Increasing 5% p.a.

Savings 3-4% p.a.

Continuous Optimisation Increasing 1-2% p.a.

0 1 2 3

Years

Energy Consumption (J per annum)

FIGURE 3.40

How a building’s energy consumption typically increases over time under BAU and after a retrofit with ongoing optimisation
Part 3: Low Energy Technologies and Strategies

7.3 Benefits

Some of the main incentives for building managers to implement better energy management are:

1. Improvement of corporate image
2. Level of support and interest from building owner and tenants
3. Individual concern for the environment
4. Company energy management policy
5. Increase in star rating (NABERS)
6. Access to expertise, information, funding and resources
7. Financial savings from reduced capital and operational expenditure budgets
8. Cost savings from reduced energy consumption

Through adequate training, management staff will acquire skills to improve communication between stakeholders, increase awareness and aid in improving company culture or company policy. Professionals such as managers are in a position to advise clients and therefore, with improved energy knowledge, they can influence priorities or goals of decision makers which may otherwise conflict with energy management objectives.

Implementing the recommendations will help to develop a national database on energy usage across all building sectors and to improve the nationwide lack of information and data on commercial floor space, energy use and potential savings.

7.4 Energy Demand Reduction Potential

The LEHR study indicated that it is possible for buildings to achieve 20-30% emissions savings through improved management alone, with NABERS energy improvements of greater than 1.3 stars.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>NABERS Energy Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings with an efficiency training program</td>
<td>0.5 Stars</td>
</tr>
<tr>
<td>Buildings where manager reports higher level of energy efficiency knowledge</td>
<td>1.3 Stars</td>
</tr>
</tbody>
</table>

Facilities Managers must increase awareness for all stakeholders to understand the potential savings incurred by increasing energy efficiency through increased capacity for environmental services and reporting to specified and meaningful performance targets.

7.2 Non-Technical Management, Training and Skills

Non-technical management involves all communication between stakeholders, behavioural management, direction of operations budget and information or resource sharing. Training and skills refers to the higher education and qualifications required of facilities managers. This report is proposing to substantially improve the focus on energy consumption across building managers and to specifically provide necessary training to give FMs the knowledge to act on energy efficiency.
7.5 Implementation Recommendations

Increasing energy efficiency through better energy management strategies in the built sector can be tailored and classified by building rather than industry. It is common for facilities managers to manage a particular building type which may be used in a range of industries. Some general management improvements that can be implemented across all sectors nationwide are:

- All buildings must have clear identification of energy performance targets.
- Management must meter and report to targets and ensure performance data is publicly available.
- A national target or benchmark applicable to all sectors to allow for comparison between buildings.
- Internal energy management schemes to enhance engagement of all staff and stakeholders.
- Mandatory energy efficiency training for all facilities managers in C and D Grade Office Buildings.
- Training which is tailored and applied across all building sectors.

Studies show that energy efficiency training programs or specific vocational training in energy efficiency produce a greater improvement than a generic qualification.

Trained Facility managers help stakeholders to understand changes in day-to-day programs. Training must be targeted to the knowledge and skills of the building occupants with feedback, incentives and disincentives to promote support and uptake of initiatives. Such training can also lead to promotion of internal energy management initiatives, benchmarking and reporting schemes.

7.6 Costs and Economics

Benchmark training programs include: Vocational Graduate Certificate in Energy Efficiency for Facilities Managers, Australia.

If this was implemented nationwide it would have costs as outlined in Table 3.22.

<table>
<thead>
<tr>
<th>Training</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIRAH/FMA Australia Members</td>
<td>$7,920</td>
</tr>
<tr>
<td>Non Members</td>
<td>$9,600</td>
</tr>
</tbody>
</table>

These results indicate that buildings perform better if facilities managers have training and skills in energy efficiency.

The training of 1,000 personnel does not include all facilities managers in Australia however represents a sample of training for managers located in or responsible for C- and D-Grade office buildings.

7.7 Technical Tools – Energy Management Systems

The ZCA Buildings Plan proposes wide scale adoption of Energy Management Systems (EMS). A well-implemented EMS with appropriately skilled operators and support services is able to ensure that building operation is energy-efficient and problems are identified and addressed before their effects contribute significantly to energy use.

An EMS can range in complexity from basic smart metering, web portals and in-building displays (the same as those proposed for residential buildings and suitable for small commercial buildings) to highly complex systems with dozens of networked sub-meters and active diagnostics and communications.

The Figure below shows the architecture of a sample EMS. It comprises a number of metering devices connected via serial link, Ethernet, or wireless links, to a computer that is able to log the data, process it and report the results in various formats. This computer may physically reside on-site or be located off-site (possibly provided as a cloud Internet service). Processing captured energy data identifies patterns of usage and provides benchmarks for facility operation. Additionally, when usage is outside expectations, alerts can be generated. Facility Managers and other equipment operators can act on the computed findings and alerts to take action to reduce energy and water use in their building.

Currently building owners often use consultants to improve their operating efficiencies and achieve a target NABERS or similar rating. Good around the clock management is often neglected. With an EMS, the performance of a building is constantly assessed and data provided to enable benchmarking against past consumption patterns. Providing useful, actionable data provides an opportunity for buy-in from key stakeholders including building occupants and can even bring about a communal sense of ownership in achieving any efficiency targets set.

<table>
<thead>
<tr>
<th>Training</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nationwide Implementation of Training</td>
<td>$8,424,000</td>
</tr>
<tr>
<td>700 Facilities Managers (members)</td>
<td>$5,544,000</td>
</tr>
<tr>
<td>300 Facilities Managers (non-members)</td>
<td>$2,880,000</td>
</tr>
<tr>
<td>Total 1000 Facilities Managers in Australia</td>
<td>$8,424,000</td>
</tr>
</tbody>
</table>
Consumption data and alerts can be communicated by technologies such as e-mail or SMS in addition to being logged within the system. The data is available in a variety of formats to suit different segments such as Engineering, Management and Public.

Commercially available EMSs vary widely in their cost, architecture, implementations and features. A selection of commercially available systems includes:

- The Pulse tool from Green Buildings Alive (http://greenbuildingsalive.com/)
- Honeywell Energy Manager and the “Attune” Services Suite from Honeywell (https://buildingsolutions.honeywell.com/HBSCDMS/attune/)
- The Edge Intelligent System from EP&T (http://www.eptglobal.com/)
- Noesis Energy (http://www.noesisenergy.com/)
- OzGreen Energy (http://ozgreenenergy.com.au/)

![Example EMS architecture. (SQ Electric)](image)

**FIGURE 3.41**

Sample screen from the Pulse Tool [Buildings Alive Pty Ltd]

**FIGURE 3.42**
One example of a non-traditional approach to an EMS is the Pulse tool from the Australian company Green Buildings Alive (www.greenbuildingsalive.com). “Pulse tracks the patterns of electricity use in office buildings and provides timely and actionable feedback to their operators”. http://www.greenbuildingsalive.com/datatools/. It collects data from the electricity provider or sub-meters on-site and from the Bureau of Meteorology in 15 minute intervals and uses it to display historical trends and to make future energy predictions. It uses regression analysis to process the variances from the statistical mean. It then uses a messaging/email tool to send daily messages to the building operator. The predictive formulae used to do the regression can be updated by an administrator.

Honeywell’s AttuneTM Web Dashboard provides a similar service and can be scaled up to a complete Building Optimisation service.

Another innovative approach is that provided by USA-based Noesis Energy http://www.noesisenergy.com. Noesis provides free and paid service models to buildings and energy professionals. It has created a social network approach where building owners can interact and collaborate on solutions as well as comparing facility performance. At the time of writing, energy use must be manually imported into the tool in Australia.

Another local Australian startup, OzGreen Energy (http://www.ozgreenenergy.com.au/), provides custom metering hardware with wireless communications combined with cloud based services to give near real-time based data allowing alarms and thresholds to be set.

It should be noted that many, generally larger, buildings already have Building Management & Control Systems (BMCS) installed which provide EMS-type functionality to varying degrees. If a building has a BMCS installed, it is recommended that energy management features be utilised and customised to their full extent, or that a separate EMS be installed to run in parallel with the BMCS.

7.8 Benefits

A well-implemented EMS with appropriately skilled operators and support services can ensure that building operation is energy-efficient and issues are identified and addressed before they contribute significantly to energy use. Benefits include:

- Reduced energy consumption reduction
- Reduced peak energy demand reduction
- Drawing attention quickly to important issues through prioritised alarms (eg faulty sensors or actuators causing excessive equipment operation)
7.11 Costs and Economics

EMS systems range from straight out purchase models where all equipment and software is installed on site to subscription hosted services and various hybrid models.

A base building EMS with 12 sub-meters is expected to cost $30,000 and around $75,000 for 30 sub-meters.

Costs available online from Eaton indicate the ranges for components as outlined in Table 3.23.

Payback times are quite short. Anecdotal evidence suggests that on small buildings the payback time for a capital purchase EMS could be between three and five years. With large consumers of energy, payback time could even be less than one year. Paybacks vary with energy prices and as energy prices increase, paybacks become even better.

7.12 Other Service Upgrades

7.12.1 Building Management and Control Systems

Most large buildings have some form of building automation system installed. For example a Building Management and Control System (BMCS) aims to automate the operation of building services. Smaller facilities usually have a certain amount of automation, but this is often in the form of ‘islands of control’ based around individual pieces of equipment. In larger facilities, a complete BMCS will centralise the monitoring, operations and management of a building to achieve more efficient operations (“Engineering Manual of Automatic Control for Commercial Buildings”, Honeywell, 1997). A BMCS monitors conditions, and centralises the collection of data and control of set-points and other factors in the building. Depending on the building, a BMCS may encompass only basic Heating, Ventilation and Air Conditioning (HVAC) operation, or everything from lighting, security, fire, transport (elevators

7.9 Energy Demand Reduction Potential

Results of a properly implemented EMS with skilled operators can vary widely, but are usually expected to be in the order of 5% to 15% energy savings, with some cases resulting in energy savings of up to 40%.

7.10 Implementation Recommendations

It is proposed that properly installed and configured Energy Management Systems be installed in all buildings over 2,000 m² with high-quality automated reporting, and accompanied by skilled operators/analysts. For building size above 2,000 m² it is difficult to physically see and feel what is happening throughout the building, and thus an intelligent system is required to centralise control, data collection and reporting. In buildings below this size, it is recommended that at minimum, smart-metering be installed with web-based access to reporting and an in-building energy display.

<table>
<thead>
<tr>
<th>EMS Component</th>
<th>Cost per unit</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wireless Sensors</td>
<td>$100 to $300</td>
<td></td>
</tr>
<tr>
<td>Wireless Thermostat Controller</td>
<td>$170</td>
<td></td>
</tr>
<tr>
<td>Power Meter</td>
<td>$1000 to $10,000</td>
<td>Eaton IQ150 Meter costs $1200</td>
</tr>
<tr>
<td>Wireless Gateway</td>
<td>$1000 and $3000</td>
<td>The gateways are designed with an integrated web server to enable browser-based remote system management. It usually consists of a radio module with an incorporated antenna.</td>
</tr>
<tr>
<td>Software</td>
<td>$10,000</td>
<td>Varies significantly depending on supplier.</td>
</tr>
</tbody>
</table>
8 Onsite Electricity Generation

8.1 Solar Photovoltaic Generation (PV)

8.1.1 Overview

Australians are installing rooftop solar photovoltaic (PV) systems on a large scale, with households leading the way. In the two years from the end of 2010 to the end of 2012, the proportion of private dwellings with a solar PV system rose from 3% to 10%, or one million households. Solar PV systems make an effective long-term investment, as cuts in component prices have offset recent reductions in government incentives. As the cost trend continues, solar PV systems will become even more affordable.

The ZCA Buildings Plan calls for an accelerated uptake of solar PV, reaching a full uptake on suitable buildings by 2023. In practice some suitable buildings will remain bare due to owners’ preferences; the size of this group is difficult to predict. This plan assumes that any shortfall in uptake will be compensated for in other areas, such as shading car parks, facades, roads or irrigation channels.

8.1.2 The Proposed Solution: Technologies or Strategies Employed – Solar PV

The Australian solar PV industry has grown rapidly since 2008 and has proven the techniques to install rooftop solar PV systems in large numbers. For example during calendar year 2012, Australians installed 336,000 systems, totalling 974 MW of new on-site generation capacity. In 2012 the industry employed more than 15,000 people.

Solar panels are made up of semiconductor solar cells which convert light-energy (photons) from the sun directly into electricity using the photovoltaic effect.

The Buildings Plan proposes the use of grid-connected systems, generating electricity on-site to offset consumption within the building. Solar panels mounted on the roof generate direct current (DC) electricity, and an inverter converts this to alternating current (AC) at 240 volts. If the solar system is not producing enough electricity to run the whole building, the balance is purchased from the grid, as usual. If on-site generation exceeds consumption, the inverter feeds it into the electrical grid via the building’s meter. The electricity distributor then transports this excess energy to supply electricity consumers nearby. The electricity grid sees solar PV as reduced demand. The Buildings Plan requires little more technical innovation in the solar PV field, as it requires no new technology.
Part 3: Low Energy Technologies and Strategies

8.1.3 Benefits

Solar PV systems:

- Allow Australians to achieve net energy independence by generating their own electricity.
- Enhance behaviour change, through incentives to cut electricity consumption.
- Provide attractive long-term investment returns that are low-risk and probably not treated as taxable income.
- Are safe, long-lasting and almost maintenance-free.
- Reduce wholesale electricity prices, by cutting daytime demand.
- Avoid electricity network capacity upgrades by reducing maximum demand.

Financial benefits are not restricted to building owners. Solar financing schemes already common in the USA allow investors to receive dividends from capital invested over many roofs.

8.1.4 Energy Demand–Reduction Potential

Over the last few years, the uptake of Solar PV has consistently out-paced published forecasts. Solar PV’s potential is huge, being able to supply all of the annual energy required by homes and some of that required by non-residential buildings, after the retrofits detailed elsewhere in this plan.

8.1.4.1 Current Picture

The average size of currently installed solar PV systems is 2.5 kW, which equates to around 13 190 W solar panels (typical in 2013). A system of this size generates approximately 3,500 kWh of energy per year, offsetting about half of a typical household’s electrical energy consumption.

Installations are increasing in size; the average in January 2011 and April 2013 were 2.28 kW and 3.8 kW respectively. As of May 2013, the total installed capacity of solar PV systems was over 2.5 GW.

In the financial year 2011-2012, solar PV systems generated 1,702 GWh, offsetting approximately 0.9% of total electrical energy consumption. (Ch 3, p 1) This equates to approximately 1.3% of 2020 household energy consumption pre-retrofit.

8.1.4.2 Future Picture

The ZCA Buildings Plan includes an accelerated uptake of solar PV, resulting in 100% of suitable buildings hosting a system by 2023. The total roof area covered by solar panels will be 204 square kilometres. For comparison, this is approximately 15% of the footprint of all buildings or ten times the total area covered by private swimming pools.

At full solar PV uptake, a typical house’s solar PV system will be rated at 4.5 kW, which equates to around 18 solar panels. With this level of solar PV uptake, residences will host systems rated in total at 31 GW and will generate on-site...
The optimum tilt angle for solar panels increases with distance from the equator. Grid-connect systems should ideally be tilted slightly less than the angle of latitude for the installation site, to maximise generation during summer. On the other hand, off-grid systems should be tilted at an angle greater than latitude to maximise generation during winter when sunlight is scarce. Where the roof’s tilt is within about 20° of the ideal angle, the expense of a tilt frame may not be justified – a better return on this money may be obtained from additional panels instead. Even a near-flat installation may be best suited in the case of large flat roofs, to avoid adjacent rows of panels being shaded.

One example of current best-available technology (BAT) solar panel is SunPower’s E20 Series 250 W module. Its high conversion efficiency of 20% allows more generation from the same roof space. However where roof space is not at a constraint, lower-efficiency panels are currently more cost-effective.

Current inverters reach operating efficiencies of 95-98%. Inverters above 3 kW typically contain more than one Maximum Power Point Tracker, allowing solar panels to be mounted in different orientations on the roof. Since the quality of components varies widely, building owners should check the reputation of installers and component brands, to avoid potential future performance issues.

It is recommended that billing be conducted on a net basis. Within each half-hour billing interval, solar PV generation should be netted off consumption, effectively credited at the consumption tariff rate. This contrasts with gross billing, in which such generation receives the feed-in tariff (currently lower than the consumption tariff, typically). Bills should clearly itemise the solar PV system’s generation.

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8.1.5 Specific Implementation Recommendations

As noted above, this plan proposes that grid-connected solar PV systems be installed on all suitable buildings.

For maximum generation throughout the year, panels should be oriented between north-east and north-west. Shading even a part of the system cuts output dramatically. Building owners should check the path of shadows cast by nearby trees and buildings for summer/winter and morning/evening. It is also important to consider future tree growth and likely building activity.

Patterns of building electricity consumption should also be considered. If occupants rely on late afternoon air-conditioning, a west-facing system may be effective to offset this consumption. Deployed on a larger scale, this technique trims afternoon and evening peak demand on the grid, postponing costs from additional network and generation capacity.

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Patterns of building electricity consumption should also be considered. If occupants rely on late afternoon air-conditioning, a west-facing system may be effective to offset this consumption. Deployed on a larger scale, this technique trims afternoon and evening peak demand on the grid, postponing costs from additional network and generation capacity.

The optimum tilt angle for solar panels increases with distance from the equator. Grid-connect systems should ideally be tilted slightly less than the angle of latitude for the installation site, to maximise generation during summer. On the other hand, off-grid systems should be tilted at an angle greater than latitude to maximise generation during winter when sunlight is scarce. Where the roof’s tilt is within about 20° of the ideal angle, the expense of a tilt frame may not be justified – a better return on this money may be obtained from additional panels instead. Even a near-flat installation may be best suited in the case of large flat roofs, to avoid adjacent rows of panels being shaded.

One example of current best-available technology (BAT) solar panel is SunPower’s E20 Series 250 W module. Its high conversion efficiency of 20% allows more generation from the same roof space. However where roof space is not at a constraint, lower-efficiency panels are currently more cost-effective.

Current inverters reach operating efficiencies of 95-98%. Inverters above 3 kW typically contain more than one Maximum Power Point Tracker, allowing solar panels to be mounted in different orientations on the roof. Since the quality of components varies widely, building owners should check the reputation of installers and component brands, to avoid potential future performance issues.

It is recommended that billing be conducted on a net basis. Within each half-hour billing interval, solar PV generation should be netted off consumption, effectively credited at the consumption tariff rate. This contrasts with gross billing, in which such generation receives the feed-in tariff (currently lower than the consumption tariff, typically). Bills should clearly itemise the solar PV system’s generation.
8.1.6 Costs

Electricity generated by solar PV is now cheaper than the typical Australian residential retail electricity tariff (“socket parity”), and is drawing closer to the average wholesale electricity price (“grid parity”). The Levelised Cost of Electricity (LCOE) generated by solar PV in 2012 was approximately 15 c/kWh, while residential retail tariffs are typically above 20 c/kWh \(^{168}\).

The cost of electricity from solar PV will continue to decrease. The Australian Bureau of Resources and Energy Economics (BREE) expects the solar PV LCOE will drop by 41% between 2012 and 2020, which equates to an average annual decline of 6.3%. \(^{169}\) pp71

For 5kW solar PV systems, the 2013 actual installed cost per watt is $1.98 post-rebate, which equates to $2.13 pre-rebate \(^{170}\). Allowing for price drops, the average installed cost per watt excluding rebates will decline to $1.11 over the 10-year period, with a mid-point of $1.54. Technology advances over the implementation period are captured by specifying best currently available technology, the 20% efficient Sunpower E20 series module.

The cost of installing a typical home’s 4.5 kW system is $6,930 excluding rebates. At an average installation rate of 2.8 GW per year, the average annual investment required during the ten-year plan is $4.3 billion (excluding rebates). This is similar to the $3.8 billion invested in 2011 \(^{171}\). For comparison, Australians spend approximately $1.5 billion each year on private swimming pools (including maintenance and building new pools).

8.1.7 Product Development

The following developments hold the promise to increase the utility and cost-effectiveness of solar PV systems. They are not included in modelling, which makes the Buildings Plan conservative in this respect.

8.1.7.1 Time-Shifting On-Site Generation with Battery Storage

As noted below on smart grids, batteries can be used to smooth peak demands within a building or across the grid. When used as part of a solar PV installation, electricity in excess of consumption can be stored for use later, or to be fed into the grid at times of higher price. For example, Germany introduced subsidies in May 2013 to encourage the uptake of grid-connected battery storage \(^{172}\). Large-scale uptake is dependent on further battery cost reductions.
8.1.7.2 BIPV

Building Integrated Photovoltaic (BIPV) refers to photovoltaic or solar cells that are integrated into the building envelope, for example, roof, walls and windows. In addition to generating electricity, BIPV can also provide structural stability, thermal insulation, shading, natural lighting, and protection from water and other elements. BIPV product development has been ongoing for the past 30 years, but uptake has been slow in comparison to conventional rack-mounted PV due to its higher installation cost per-kW. BIPV has the potential to increase Australia’s total solar PV generation, but has not been specified in this plan.

8.1.7.3 Barriers to Implementation

When installing a solar PV system, building owners face barriers and risks outside their control. To sustain an accelerated uptake of solar PV, Australia must mitigate these barriers.

Connection approval. The local electricity distributor may reject the application to install solar PV because it is unable to manage additional electricity fed into its network.

Distribution network constraints. Generation may be restricted by over-voltage in the street’s power lines.

Council restrictions. Planning rules such as heritage overlays preclude visible installations on many buildings.

Building ownership. In multi-occupancy buildings such as apartment blocks, it is difficult to fairly apportion installation investment and returns.

Tenancy arrangements. Landlords may expect little return from installing a system, since their tenant is the direct beneficiary.

Electricity tariffs. The electricity distributor might reduce the value of energy offset by the solar PV system, by shifting charges from energy into the fixed daily charge.

Relocation. Building owners may not recoup the value of the solar PV system upon selling the property.

Feed-In Tariff uncertainty. Some feed-in tariffs are subject to revision with little notice.

For further information on network constraints, please see below on smart grids.

8.1.7.4 Other Implementation Options

Off-grid installations. In locations served by a connection to the grid, it is possible to disconnect and install an off-grid solar PV system with battery storage. However, the cost of such a system is many times more than a grid-connected system without battery storage and is currently uneconomical. Also any production exceeding battery capacity is wasted as it cannot be fed into the grid. Hence, grid-connected systems are specified in this plan.

Adjustable frames. Adjustable frames allow solar panels to be dynamically oriented to face the sun, on either one or two axes, increasing electricity production. Tracking mechanisms are available for automation. However, adjustable frames add complexity and must be strong enough to withstand high winds. Since it is generally more advantageous to use simple fixed frames and increase the number of solar panels, adjustable frames are not specified in this plan.

Micro-inverters. Solar PV installations typically include one or more central string inverters, which convert the direct (DC) current created by solar panels into 240 volt alternating current (AC) suitable for powering appliances and feeding back into the grid. A recent innovation in inverter technology is the introduction of micro-inverters. Micro-inverters are built into each solar panel and convert the output of each panel into 240 volt AC in-situ, eliminating the need for a string inverter. Micro-inverters have the potential to increase yield by reducing the impact of shading, and facilitate installation on small roof surfaces, but are currently more expensive than string inverters. This is likely to change in future if micro-inverters are deployed in volume. For these reasons, micro-inverters are not specified in this plan.

8.2 Micro Wind

Wind turbines convert kinetic energy from the wind into mechanical energy and then into usable electrical energy. Large wind turbines are suitable for wind farms in rural areas and for offshore locations. Micro wind is the term used to describe a turbine of 20 kW or less according to the BWEA (British Wind Energy Association) 173.

To generate power in areas close to buildings and people, two characteristics of urban wind need to be considered: the lower mean annual wind speed compared with rural areas, and the more turbulent flow 174. Many studies of wind generation in urban environments have recorded a lack of wind resource available at the desired location despite a reported mean annual wind speed which would have been sufficient. This is partly because of the huge variation in wind resource from site to site, and partly because most of the turbines used in the studies were mounted either on the ground or on residential roofs which are close in height to other obstacles blocking the wind’s path 175. Therefore to take full advantage of the wind resource available, wind turbines should be mounted as high as possible, such as on the roofs of central business district (CBD) office buildings, and each potential site should be properly evaluated prior to installation.
In summary, to get the best power output in an urban area, the evaluation should cover:

- the wind resource in that area,
- choice of site,
- turbine choice.

Additionally, to mount turbines on CBD buildings, the evaluation should also cover:

- wind loads,
- size of the turbines themselves, to ensure the desired building will be able to withstand the turbines on the roof.

8.2.1 Selected Micro Wind Technology

The desirable choice for a micro wind turbine is one which can be roof-mounted, performs well in turbulence, and has passed stringent safety and performance standards. An example of such a micro wind turbine is the Quiet Revolution turbine (qr5), because these have been proven in the field, are rooftop mounted, designed for turbulence and to operate with minimal vibration, as well as being the only vertical axis micro wind turbine which has been approved for the Microgeneration Certification Scheme (MCS).

The qr5 turbine is a 6 kW peak power rated Vertical Axis Wind Turbine (VAWT) with a helical blade design. There are approximately 150 of these turbines currently operational in the UK, the Netherlands, Germany and Australia.

The power curve below shows that the peak output occurs at 16 m/s and the energy curve shows the relationship between annual delivered energy and annual mean wind speed.

8.2.2 Micro Wind Installation Process

Rooftop qr5 installation is relatively simple, with turbines installed in the ‘mast down’ position without the need for additional support structures. Installation and maintenance activities require a clear and level working platform. With a generally smaller plan area than a Horizontal Axis Wind Turbine (HAWT), VAWTs are favourable in the context of rooftop mounts in CBD areas, although many HAWT turbines have been successfully installed on rooftops.

Electronics and control equipment can be wall-mounted in the building plant room or floor-mounted externally in a weatherproof cabinet. The space requirement for control panels and the grid metering board is relatively minor. Grid connection involves installation by an approved electrician and the use of an approved inverter as minimum requirements in Victoria. A three-phase grid connection is required, and electronics and control equipment must be located within 85 m of the turbine.
8.2.3 Micro Wind Benefits

- Wind Turbine systems generate electricity that can be consumed on-site
- Allows for greater energy generation than solar photovoltaic on buildings with a good wind resource
- Is a visible sustainability measure, which could be used by a company to promote their green credentials
- Wind turbines operate day and night, whenever it is windy

8.2.4 Micro Wind Implementation

Recommendations

To properly assess the wind resource at each potential site this report considered an entire 3D model of the wind resource in the area and surrounds. Where the wind resource was found to be sufficient, a wind load analysis was undertaken to see how many turbines can fit onto the building with an adequate safety margin. This process was undertaken using the Melbourne CBD area, demonstrating that there is potential for substantial wind power from CBD buildings. The modelling is discussed in detail in Part 5, Section 3.2 “Executive Summary of CBD Wind Project” and in Appendix 3.

This analysis concluded that there was enough wind resource on suitable buildings to accommodate 269 turbines in the Melbourne CBD area generating 2.3 GWh of energy

Figure 3.48 shows that annual delivered energy at mean annual wind speeds below 5 m/s is 4 MWh or less which is not enough to power a ten-person office. On a wind site with a mean annual wind speed between 5 m/s and 8 m/s, the qr5 will generate up to 15 MWh/annum. This is equivalent to the electrical needs of a 20- to 30-person office (ie for lights, computers, servers, printers, faxes and phones). Demand reduction potential also depends on the efficiency of the turbine in converting mechanical energy into electrical. Recent advances in the design of the qr5 quiet revolution turbine have already improved the efficiency (see Figure 3.49 for comparison), and projections for the next decade are for further efficiency improvements up to 25%.

ENERGY AND POWER CURVES FOR THE QUIET REVOLUTION ’QR5’ TURBININES

![Energy and Power Curves](image-url)
per annum. However it is the view of this report that the relatively lower cost of solar PV makes micro wind a less attractive option and therefore the report considers micro wind to only be financially viable in a limited number of cases.

8.2.6 Micro Wind Product Development

Historically, noise levels are a key concern associated with wind turbines operating in population centres. However, the qr5 turbine generates low noise, owing to the low tip speed ratio (because the turbine tips are relatively close to the axis of rotation). A number of independent studies have established that background noise levels in urban environments typically reach rates equal to or greater than turbine noise levels.

8.2.5 Micro Wind Costs

The cost estimates below were derived from discussions with Maxim Renewables, the distributor for qr5 turbines in Australia. Installation of other micro wind turbines would lead to different costs, but Table 3.24 is indicative of the expected costs for the installation of any turbines with a similar power output.

The average installation cost is currently about $10,000 per turbine, with the actual cost heavily dependent on installation type. However significant economies of scale are available by installing multiple turbines at a particular location. Based on initial CFD and structural analysis, a single building will incorporate seven turbines on average, resulting in an estimated cost of $4,000 per turbine. Where such placement of turbines on top of load bearing columns is not possible, steel grillages may be used to support the incorporation of multiple turbines on an existing roof.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Installation Cost</th>
<th>Installation Cost with Grillage</th>
<th>Total Cost (w/o Grillage)</th>
<th>Total Cost (with Grillage)</th>
<th>Annual Maintenance Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current retail price, single unit</td>
<td>$36,500</td>
<td>$10,000</td>
<td>$18,000</td>
<td>$46,500</td>
<td>$54,500</td>
</tr>
<tr>
<td>Price for 250-500 units</td>
<td>$27,000</td>
<td>$4000</td>
<td>$12,000</td>
<td>$31,000</td>
<td>$39,000</td>
</tr>
<tr>
<td>Price for 500-1000 units</td>
<td>$25,000</td>
<td>$4000</td>
<td>$12,000</td>
<td>$29,000</td>
<td>$37,000</td>
</tr>
</tbody>
</table>

FIGURE 3.49
Quiet Revolution turbines [Quiet Revolution]

TABLE 3.24
Projected turbine unit costs (AUD) for large-scale rollout
9 Smart Grid

Smart grid technology improves the management and robustness of power distribution. This becomes increasingly important because this plan envisages:

- very high use of distributed generation through (mainly) solar panels on residential and commercial buildings and
- use of electricity for all mains energy requirements.

This section describes the upgrades to the electricity network that will support the other elements described in this Plan. These technologies (collectively dubbed the “Smart Grid”) are currently commercially available and indeed are being planned, trialled and deployed in electricity networks around the world, including Australia. They will enable a safe, reliable and efficient electricity supply, and their initial capital costs are recouped through greater quality of supply and lower operational costs of the future electricity network.

Some challenges that the conventional electricity network will need to handle and this Plan provides solutions to are:

- Power quality supply complications due to high percentage of power from small generation sources. It has already been reported by some distributors that high uptake of roof-mounted solar panels is causing instability with voltage control in some areas of their networks. The existing electricity grid (transmission and distribution networks) was predominantly built for the bulk generation and transmission of electrical power to domestic and industrial end users. These systems were designed to operate efficiently, safely and stably in this manner and did not consider the potential for embedded generation at a large scale essentially reversing the direction of power flow.

- Improved forecasting of demand and supply required. As more intermittent generation is added to the electricity system, the forecasting methodologies, data and tools used by engineers must improve at various time scales. Otherwise, engineers would not be able to dispatch the appropriate power into the network from generation plants.

9.1 Proposed Solution

Smart Grid Australia defines a smart grid as “an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies”. In other words, a smart grid will be able to handle the dynamic nature of an electricity network saturated with renewable, distributed generation, using the following elements (the precise technology employed in a given part of the network would be based on specific conditions at the site):

Dealing With Very High PV Penetration

There is a view that very high penetrations of grid-connected renewable energy represent a costly problem for the electricity network, in particular that grid stability and frequency control will be compromised. However, this plan takes the view that very high PV penetrations in conjunction with smart grid technologies enable a decentralised, highly reliable, safer and more fault-resistant electricity system. The likely immediate consequences of very high penetrations of PV are:

Winter peak. Electricity grid demand currently is highest on hot summer afternoons and evenings. These summer peak load events are likely to cease being the biggest because of a) the abundant solar radiation experienced in hot weather and b) reduced heating and cooling demands arising from the initiatives described in this report. As a result the future peak demand is likely to be experienced on winter mornings and evenings.

Surplus power events. With the imagined levels of PV deployment, there will be periods where there is surplus generation across the grid.

Low average centralised generation. Centralised generators will on average provide much lower levels of power as more generation is produced on-site.

Curtailment. Actively stopping or limiting some generation will be required at some times. Smart grid ‘demand-response’ infrastructure will provide the means of doing this.

Studies of High PV Penetration Scenarios. Studies performed already suggest that high levels (in the order of 35%) of wind and solar can be tolerated without compromising grid stability. With some investment in highly dispatchable power sources such as pumped hydro, up to 80% of wind and solar can be tolerated. Other reports, such as those from BZE in 2010, UNSW in 2012 and AEMO in 2013 all model different scenarios of 100% renewable power in Australia. All suggest 100% renewable scenarios are technically feasible while maintaining current levels of reliability. The 2013 AEMO study specifically considered operational issues arising from solar PV intermittency and concluded that their “operational review has uncovered no fundamental limits to 100 percent renewable that can definitely be foreseen at this time”.

Further research into operational considerations are ongoing (eg CSIRO in June 2012, and the IEA as part of their Photo-Voltaic Power Systems Programme and will continue to refine the operational changes required.

Other Grid Case Studies. Other networks around the world already include very significant amounts of intermittent renewable generation, and are robust enough to handle them. Germany as at May 2013 has over 30GW of installed solar capacity, with a peak demand of 60GW.
Grid monitoring. Sensors placed across the grid to enable the network operator to monitor electricity flow.

Volt-var control. Capacitor banks, load tap changers and voltage regulators used to inject power into the grid appropriately to stabilise voltage levels and increase real (useful) power.

Electricity storage. Fixed batteries and other technologies such as refrigeration control to "store" electricity during times of excess generation and discharge during times of excess demand.

Curtailment. Curtailment of export and of demand as last resorts to protect the electricity grid.

Smart inverters, which can provide volt-var control capabilities for the grid, have been considered as future opportunities due to not being commercially available and tested at present but they have strong possibilities in the future.

9.2 Benefits

The benefits of smart grids include their ability to cope with the fundamental changes in demand that are likely, as well as benefits to grid reliability, stability and GHG emissions in their own right.

Other benefits are not directly related to the goals of the Buildings Plan, but are ancillary benefits that are enabled by the implementation of these measures – for example in network reliability, operational cost reductions, improved asset management, etc. These benefits have not been included in this analysis, but for completeness have been briefly mentioned below:

1. Fault Location, Isolation and Service Restoration (FLISR). The process of discovering and remediating network faults, could have a positive impact on network reliability, and therefore reduce the number, frequency and duration of outages experienced by customers. This could be enabled by installing additional automated switchgear (such as circuit breakers and sectionalisers) to dynamically re-route power in the event of faults, as well as software algorithms to use information from the sensors to locate faults more accurately.

2. Dynamic ratings of assets. This could improve asset utilisation and maintenance schedules. It would reduce future capital expenditure by allowing existing assets to be run closer to their maximum capacity. The implementation of improved asset management systems and ratings algorithms, utilising the information provided by the sensors, would be required to enable this.

9.3 Implementation Recommendations

Figure 3.50 depicts a smart grid, with the elements that this plan covers highlighted with green and orange stars.

The following are the smart grid elements to be implemented:

1. Sensors on selected points on the medium voltage (MV) and low voltage (LV) networks. These sensors capture information such as current, voltage, reactive power and phase angles, which is used to monitor the "health" of the network and make decisions on modifying the network in real-time. They will be placed on each distribution substation (where a transformer switches from the MV to the LV network), and at key locations on the MV network.

2. Smart meters to capture information at the house level, as well as record electricity demand and supply for the home for billing purposes. They also enable a last resort curtailment of electricity exported into the network.

3. Fixed distributed storage will be used in key locations in the electricity network to "soak up" excess energy during periods of high local generation and low demand, and release that stored energy during periods of high demand and low local generation. This will flatten the load profile of the system by addressing local peaks and troughs. The storage would typically comprise a secure, weather-proof battery with localised intelligence as well as communications to a central command centre to drive charge / discharge behaviour. A battery will be deployed at key distribution substations where significant and variable electricity demand / production is occurring (e.g. PV production and electric vehicle charging). A much larger battery will also be deployed at some zone substations.

4. Capacitor banks they yield improvements in the efficiency of the electricity grid and can reduce power losses. Capacitors are devices which can store and discharge energy at high rates for short periods of time. Capacitor banks can be switched on and off remotely by the utility and will be placed at strategic locations on the MV network. They will improve power factor and flatten out voltage levels on particularly long feeder lines.

5. Low voltage regulators will be used to assist in providing localised fast response dynamic low voltage regulation. This equipment is currently available and can be comms-enabled for remote switching and can then be used to smooth out flicker impacts and assist in energy conservation by reducing voltage at the bottom of the regulatory voltage band. These will typically be pole-mounted and used at selected points in the LV network close to the source of intermittent generation (e.g. a number of large solar PV installations).
6. Remote controlled transformer tap changers will be used to remotely control voltage levels on the MV network and parts of the LV networks. These devices will be installed at substations (zone substations on the MV network and distribution substations on the LV network) and can drop voltage delivered into the network if voltage peaks are detected, for example due to the injection of power into the network from distributed generation. They can also be used similarly to low voltage regulators to assist in energy conservation by reducing voltage to the bottom of the regulatory voltage band.

7. Utility IT upgrades will be required to take advantage of the additional information provided by the smart grid and make the appropriate switching / charging decisions. This will involve upgrades to the existing DMS systems as well as new systems to manage meter data and sensing data. The specific implementation will depend on the utility involved, however both energy retailers and distributors will require system upgrades. These have been implemented outside of Australia and a number of system integrators and IT vendors have developed IT solutions that can be used.

The above technologies would enable the electricity network to support the very high penetration of PV as envisaged by this Plan, as well as make the network more robust in its own right.
**On the horizon.** The following technologies are on the horizon, but have not been included into the current plan as they are emerging technologies that are not yet commercially available. These can be implemented as they become commercially available:

1. In-home energy storage can be implemented just as distributed energy storage is implemented at distribution substations. This report takes a wait-and-see approach to storage. It should be deployed if it the price is right, and costs are dropping rapidly. Government incentives for in-home energy storage commenced in Germany in 2013[185], and a NZ energy retailer has already commenced a bundled offering of PV with battery storage[186]. It is reasonable to assume, therefore, that energy storage will be widely available within five years.

2. Intelligent inverters are now available that can run in power-factor-control or voltage-control modes. This functionality is now disabled in Australia and there is a general lack of information as to their ability to positively impact voltage levels in the LV network by, for example, mitigating the impacts of flicker. A number of trials worldwide are currently testing the efficacy of this functionality in areas of high intermittent generation. Results from these trials are expect be available in the next few years and will be continuously fed back into inverter design and manufacture, leading to inverters that can locally support LV voltage and power factor correction in the grid. Existing PV inverters in Australia have technology to automatically switch off if voltage spikes or drops are detected.

### 9.4 Costs

There are different technological solutions that can be applied, and the specific solution will be decided by local conditions. To estimate the potential costs of such a solution, we have developed three potential scenarios:

**Worst case.** This scenario makes worst-case assumptions regarding the level of upgrades required to the electricity network. It assumes that there are many local areas where changes in peak electricity demand cannot be moderated through pricing mechanisms and hence will require transformer upgrades. It assumes worst-case levels of IT upgrade requirements and of equipment to be rolled out.

**Medium case.** This scenario makes middle of the road assumptions on upgrade levels required. It assumes that in many areas pricing signals will be able to be used to reduce peak electricity demand (as has been found to be successful in many global pilots and trials) and manage some excess generation.

**Best case.** This scenario assumes behavioural change due to pricing signals and customer education. It assumes that the cost of IT upgrades will be on the low side, and that the level of equipment upgrades throughout the grid is focussed on key areas. Other areas have changed demand profiles due to changed customer electricity usage.

The estimated cost for the smart grid upgrades ranges from worst-case $22.9b, to best-case $9.5b, with the medium case coming to $13.6b. The per unit costs of each of the elements described in the Plan are itemised as per Table 3.25 below. The full cost modelling can be found in Part 6.

---

**TABLE 3.25**

Projected turbine unit costs (AUD) for large-scale rollout

<table>
<thead>
<tr>
<th>Item</th>
<th>Individual Cost ($ per unit, includes installation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Voltage Sensors</td>
<td>$2,300</td>
</tr>
<tr>
<td>Medium Voltage Sensors</td>
<td>$3,450</td>
</tr>
<tr>
<td>Energy storage (zone substation-size)</td>
<td>$1.2m</td>
</tr>
<tr>
<td>Energy storage (distribution substation-size)</td>
<td>$46,000</td>
</tr>
<tr>
<td>Capacitor banks</td>
<td>$70,000</td>
</tr>
<tr>
<td>Utility IT upgrades</td>
<td>$75m per utility</td>
</tr>
<tr>
<td>LV regulator upgrades</td>
<td>$3,450</td>
</tr>
<tr>
<td>Zone Substation upgrades</td>
<td>$50m per substation</td>
</tr>
<tr>
<td>Load Tap changers upgrades</td>
<td>$2,300</td>
</tr>
<tr>
<td>Terminal station upgrades</td>
<td>$50m per station</td>
</tr>
</tbody>
</table>
10 References


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Part 3: Low Energy Technologies and Strategies

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# Part 4: Zero Carbon Buildings Proposals

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<td>References</td>
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</table>
1 Overview

Part 4 describes the process used to establish each building category, using building type and climate zone locations to make recommendations for various retrofit measures.

Six case studies illustrate the retrofits. These explain how the specific building efficiency improvements can reduce energy demand to the point where renewable energy sources can cost-effectively supply the remaining demand.

2 Building Stock Segmentation

Buildings were grouped into Residential or Non-Residential Buildings. Non-residential buildings where further sub-grouped into: Retail; Office; Education; Accommodation; Cafes and Restaurants; Pubs and Clubs; Hospitals; Museums and Galleries; Libraries; Cinemas; Universities; Warehouses; Prisons; and Aged Care.

Various government and industry bodies use different classification codes to group different industry sectors. The most commonly used classification code is the Australian and New Zealand Standard Industrial Classification (ANZSIC)\(^1\). This system groups businesses and public services together according to similar activities. The Australian building construction and design industry typically refers to the Building Code of Australia Classification Code\(^2\). Table 3.1 groups the relevant categories of these two codes together and relates them to the categories used in the Buildings Plan building categories.

Buildings have different uses, energy demands, equipment and hardware installed, architectural styles, and ages and therefore require different approaches and measures. Multiple studies and workshops involving professionals and specialists from the built environment industry in Australia were undertaken by the Buildings Plan. The outcome of this work was the segmentation of the building stock into representative types, according to factors affecting energy performance and construction types. The focus of this work was to establish characteristics that could allow direct thermodynamic modelling of residential, retail, office, and education buildings to provide detailed estimates of the potential energy savings available from retrofit. The remaining building categories where not sub-categorised and modelled and thus were considered at only a high level.

These representative types are separate categories to which the entire building stock can be broadly approximated. For example all office buildings built between 1980 and 2000 with floor to ceiling curtain wall façades and centralised air-conditioning are expected to perform consistently enough to be grouped into a single category.

2.1 Residential

Residential buildings are defined as being places of residence. They include detached houses, apartments, terraces and so on, but exclude buildings such as hotels, hostels and nursing homes. Within this residential category, the building stock is sub-categorised according to the method adopted by Energy Efficient Strategies as outlined in their 2008 report, Energy Use in the Australian Residential Sector 1986 - 2020\(^3\). Broadly the factors determining the segmentation of the residential stock into representative types are:
### TABLE 3.1

Building categories as defined by ZCA, BCA and ANZSIC

<table>
<thead>
<tr>
<th>ZCA Title</th>
<th>Building Code of Australia class</th>
<th>ANZSIC classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accommodation (and residential part of Prisons)</td>
<td>Class 3:</td>
<td>H Accommodation and Food Services</td>
</tr>
<tr>
<td></td>
<td>a residential building, other than</td>
<td>44 Accommodation</td>
</tr>
<tr>
<td></td>
<td>a building of Class 1 or 2, which</td>
<td></td>
</tr>
<tr>
<td></td>
<td>is a common place of long term</td>
<td></td>
</tr>
<tr>
<td></td>
<td>or transient living for a number</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of unrelated persons, including—</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(a) a boarding house, guest house,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>hostel, lodging house or backpackers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>accommodation; or (b) a residential</td>
<td></td>
</tr>
<tr>
<td></td>
<td>part of a hotel or motel; or (c)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a residential part of a school; or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(d) accommodation for the aged,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>children or people with disabilities;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>or (e) a residential part of a health-care building which accommodates members of staff; or (f) a residential part of a detention centre.</td>
<td></td>
</tr>
<tr>
<td>Office</td>
<td>Class 5:</td>
<td>J Information Media and Telecommunications</td>
</tr>
<tr>
<td></td>
<td>an office building used for</td>
<td></td>
</tr>
<tr>
<td></td>
<td>professional or commercial</td>
<td></td>
</tr>
<tr>
<td></td>
<td>purposes, excluding buildings</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of Class 6, 7, 8 or 9:</td>
<td></td>
</tr>
<tr>
<td>Retail and Food Retail (Cafes and Restaurants,</td>
<td>Class 6:</td>
<td>G Retail Trade</td>
</tr>
<tr>
<td>Pubs and Clubs)</td>
<td>a shop or other building for the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sale of goods by retail or the supply</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of services direct to the public, including— (a) an eating room, café,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>restaurant, milk or soft-drink bar;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>or (b) a dining room, bar area that</td>
<td></td>
</tr>
<tr>
<td></td>
<td>is not an assembly building, shop</td>
<td></td>
</tr>
<tr>
<td></td>
<td>or kiosk part of a hotel or motel;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>or (c) a hairdresser’s or barber’s shop,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>public laundry, or undertaker’s establishment; or (d) market or sale</td>
<td></td>
</tr>
<tr>
<td></td>
<td>room, showroom, or service station.</td>
<td></td>
</tr>
<tr>
<td>ZCA Title</td>
<td>Building Code of Australia class</td>
<td>ANZSIC classification</td>
</tr>
<tr>
<td>--------------------</td>
<td>----------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Warehouse</td>
<td>Class 7b — for storage, or display of goods or produce for sale by wholesale.</td>
<td>F Wholesale Trade 33 Basic Material Wholesaling 34 Machinery and Equipment Wholesaling 35 Motor Vehicle and Motor Vehicle Parts Wholesaling 36 Grocery, Liquor and Tobacco Product Wholesaling 37 Other Goods Wholesaling 38 Commission-Based Wholesaling I Transport, Postal and Warehousing 46 Road Transport 47 Rail Transport 48 Water Transport 49 Air and Space Transport 50 Other Transport 51 Postal and Courier Pick-up and Delivery Services 52 Transport Support Services 53 Warehousing and Storage Services</td>
</tr>
<tr>
<td>Laboratory and Factory</td>
<td>Class 8: a laboratory, or a building in which a handicraft or process for the production, assembling, altering, repairing, packing, finishing, or cleaning of goods or produce is carried on for trade, sale, or gain.</td>
<td>C Manufacturing 11 Food Product Manufacturing 12 Beverage and Tobacco Product Manufacturing 13 Textile, Leather, Clothing and Footwear Manufacturing 14 Wood Product Manufacturing 15 Pulp, Paper and Converted Paper Product Manufacturing 16 Printing (including the Reproduction of Recorded Media) 17 Petroleum and Coal Product Manufacturing 18 Basic Chemical and Chemical Product Manufacturing 19 Polymer Product and Rubber Product Manufacturing 20 Non-Metallic Mineral Product Manufacturing 21 Primary Metal and Metal Product Manufacturing 22 Fabricated Metal Product Manufacturing 23 Transport Equipment Manufacturing 24 Machinery and Equipment Manufacturing 25 Furniture and Other Manufacturing</td>
</tr>
<tr>
<td>Hospital</td>
<td>Class 9a — a health-care building, including those parts of the building set aside as a laboratory; or</td>
<td>Q Health Care and Social Assistance 84 Hospitals</td>
</tr>
<tr>
<td>Education</td>
<td>Class 9b — an assembly building, including a trade workshop, laboratory or the like in a primary or secondary school, but excluding any other parts of the building that are of another Class; or</td>
<td>P Education and Training 80 Preschool and School Education</td>
</tr>
<tr>
<td>Residential</td>
<td>[a] Class 1a — a single dwelling being—</td>
<td>ANZSIC Codes don’t include residential buildings</td>
</tr>
<tr>
<td></td>
<td>[i] a detached house; or (ii) one of a group of two or more attached dwellings, each being a building, separated by a fire-resisting wall, including a row house, terrace house, town house or villa unit; or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Class 2: a building containing 2 or more sole-occupancy units each being a separate dwelling.</td>
<td></td>
</tr>
<tr>
<td>Aged Care</td>
<td>Class 9c — an aged care building</td>
<td>86 Residential Care Services</td>
</tr>
</tbody>
</table>
Part 4: Zero Carbon Buildings Proposals

The last major survey of housing characteristics done in 1986 and ABS4602 “Environmental Issues: People’s Views and Practices” (now called “Environmental Issues: Energy Use and Conservation”). It also included estimates based on stock renovations using BIS Shrapnel survey data, a retirement function and an adjustment for annual increases in insulation penetration and level.

In order to estimate the energy consumption of the residential sector the full dataset was sub-categorised according to the dominant building types and attributes with the defining parameters involving thermal performance, e.g. construction types, orientation, air infiltration, etc.

In order to capture the differentiating characteristics of residential building types the following subset was chosen:

1. Detached single storey
2. Detached double storey
3. Semi-detached dwelling
4. Low rise flat (1 - 4 storeys)
5. High rise flat (5 or more storeys)
6. Performance based dwelling

The performance based dwelling chosen reflected minimum compliance requirements for national and state based building schemes, predominantly minimum star ratings under NATHERS, which corresponds to a specific performance level for space conditioning loads.

2.1.1 Location

The description of the climate regions chosen for the residential thermodynamic analysis can be found in Part 5, Section 2 “Residential”. More information is also available in Appendix 2.

The Energy Efficient Strategies analysis involved the selection of a subset of ten climate zones from a total of 69 available in the AccuRate modelling software. These ten climate zones were selected for their ability to give reliable estimates for households in Australia. These climate zones were grouped according to heating and cooling loads and their separate results were used to map back onto the remaining 59 climate zones.

Based on the approach adopted by Pitt and Sherry in the “The Pathway to 2020 for Low-Energy, Low-Carbon Buildings in Australia: Indicative Stringency Study” a decision was made to further group these zones into the following five climate regions for the purpose of developing retrofit packages:

<table>
<thead>
<tr>
<th>BCA Zone number</th>
<th>Characteristics</th>
<th>Designated AccuRate Climate Zone (to represent group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cooling Dominated - Humid</td>
<td>Darwin [1], (Townsville [5])</td>
</tr>
<tr>
<td>2</td>
<td>Low Demand</td>
<td>Brisbane [10]</td>
</tr>
<tr>
<td>5</td>
<td>Balanced Moderate Demand</td>
<td>Mascot [56], (Adelaide [16])</td>
</tr>
<tr>
<td>6</td>
<td>Heating Dominated</td>
<td>Tullamarine [60], (Melbourne [60], Moorabin [62])</td>
</tr>
<tr>
<td>7</td>
<td>Heating dominated High demand</td>
<td>Orange [65], (Canberra [24])</td>
</tr>
</tbody>
</table>

2.1.2 Type

The housing stock model was developed by EES in line with their original 2008 work. Their stock model was developed from a range of ABS data sets, including the

Each building type was further sub-categorised by wall and floor construction formats, which have a significant bearing on the space conditioning loads.

Brick homes represent nearly 70% of the entire stock. Nearly 90% of the stock uses one of just 4 wall types - brick veneer, double brick, timber and fibrocement. Using these statistics and aggregating like wall types into single categories, EES adopted the following wall types - light weight, brick veneer, heavyweight.

2.1.3 Construction formats (Wall/Floor)

The floor types were sorted into only two categories, timber and concrete, with concrete being set as on slab.

2.1.4 Insulation Provisions

The building stock was further sub-categorised according to the penetration of ceiling and wall insulation. No data was available on floor insulation and it was deemed to be a very low percentage of the stock. Therefore the stock was modelled with an assumed zero floor insulation.

Each building sub-type and associated construction format were divided into three additional categories according to
different combinations of insulation. These combinations were: none, ceiling only, and both walls and ceiling.

The building segments with existing added insulation were given a stock average R-rating, rather than attempting to estimate the actual amount of insulation across each construction format and location. For those building categories with wall insulation a figure of R1.5 was assumed. For ceilings a figure of R2.5 was assumed as the stock average. Whilst new installations of ceiling insulation would have a higher R value, the stock average would include reflective foil and loose fill insulation with a fairly low rating.

2.2 Non-residential

Prior to creating any suites of retrofit packages for non-residential buildings, it was necessary to categorise Australia’s building stock on the basis of energy consumption. This process had several stages.

2.2.1 Stage 1: Preliminary Categorisation

Three workshops, and several individual meetings, were held with experts from academia and industry to identify ‘typologies’: groupings of building characteristics (eg function, location, eras of similar construction methods). Council rates data and the segmentation analysis developed for the 1200 Building Stock Segmentation Study by Arup were used as a basis for assessment.

- Louise Honman from Context Architects who specialises in building conservation projects for heritage buildings, provided expert advice on education and retail buildings.
- Sara Wilkinson, expert in commercial building adaptation and an Associate Professor at University of Technology Sydney, gave critical guidance based on her work mapping adaptation (retrofits and renovations) levels in the Melbourne CBD using building permit data.
- Adam Leggett, John Duffin and Mike Rainbow from Arup assisted BZE in the typology exercise.
- Phil Harrington from Pitt & Sherry, and David Moore of Bis Shrapnel provided valuable input as part of their Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia study.

Draft typologies were developed, classified by building function (e.g. Education), age (e.g. 1950 – 1980), and location by Climate zone (see Appendix 2). Typologies included basic detail of building size, location, geometry, fabric, services, and hours of operation.

2.2.2 Stage 2: Review

The draft typologies were presented to a larger workshop, hosted by the University of Melbourne Energy Institute. Thirty four participants from industry, government, and academia took part, including recognised leaders in energy efficiency, sustainable design, and government policy/regulation. The participants were split into groups. Based on their pooled experience, each group was asked to scrutinise a subset of typologies, and to comment on their accuracy and usefulness. The groups were also asked to identify retrofit scenarios that would be “best practice” and commonly implemented for buildings of each typology. Particular focus was given to education, retail, and office buildings, as these were to be used for thermodynamic simulation and to be the basis for extrapolation to other un-modelled building typologies.

2.2.3 Stage 3: Refinement

Following the workshop a range of sources, most significantly the National Exposure Information System (NEXIS) database, were studied to identify any superfluous building typologies, and any areas that had been missed. Building types outside the scope of the Buildings Plan (such as carparks) were removed, and the typologies were finalised as follows:

<table>
<thead>
<tr>
<th>Construction format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightweight/ Timber Floor</td>
<td>Timber or metal framed walls with sheet cladding and suspended timber floor</td>
</tr>
<tr>
<td>Lightweight/ Concrete Floor</td>
<td>Timber or metal framed walls with sheet cladding and a concrete raft slab floor*</td>
</tr>
<tr>
<td>Brick Veneer/ Timber Floor</td>
<td>Brick or block veneer walls, wall frame and a suspended timber floor. Category also includes pre-cast concrete walls with internal framing</td>
</tr>
<tr>
<td>Brick Veneer/ Concrete floor</td>
<td>Brick or block veneer walls, internal timber or metal wall frame and a concrete raft slab floor. Category also includes pre-cast concrete walls with internal framing</td>
</tr>
<tr>
<td>Heavyweight/ Timber Floor</td>
<td>Cavity brick or block or pre-cast concrete and suspended timber floor</td>
</tr>
<tr>
<td>Heavyweight/ Concrete Floor</td>
<td>Cavity brick or block or pre-cast concrete and a concrete raft slab floor</td>
</tr>
</tbody>
</table>

* This type is relatively uncommon.
1. Retail - High Street
2. Retail - Shopping centre
3. Retail - Neighbourhood centre
4. Retail - Detached big box
5. Education - Pre-1940
7. Education - 1970 onwards
8. Office - Pre-1945 Masonry Load Bearing
12. Accommodation
13. Cafes and Restaurants
14. Pubs and Clubs
15. Hospitals
16. Museums and Galleries
17. Libraries
18. Cinemas
19. Universities
20. Warehouses
21. Prisons
22. Aged care

Further information on the non-residential building stock analysis can be found in Part 5.

### 2.2.4 Stage 4: Assessment

To determine the accuracy and coverage of the developed building typologies, a final workshop was held. The building typologies, stock breakdown and preliminary modelled results produced by BZE were compared with the preliminary results from the DCCEE baseline study of commercial buildings in Australia and their energy consumption. A good agreement was found, and the typologies were accepted as being representative of a significant portion of the Australian non-residential building stock.

### 2.2.5 Exclusions

Buildings where the internal industrial process was the dominant consumer of energy were excluded from this study. These buildings will be assessed in the Industrial Process Report, to be completed at a later date. Some building types were not captured in this study due to limited data availability. These include defence, police, fire-fighting and other public order services, transport, and farming related buildings. We recognise this is a short-coming and future work may be required to incorporate these building types.

### 3 Representative Cases

Six case studies are presented within the Buildings Plan. The case studies cover three distinct zones: A climate zone which predominately requires cooling (Brisbane); a temperate climate zone (Sydney); and a climate zone which predominately requires heating (Melbourne).

The cases were based on the building models developed for thermodynamic simulation. The models were created as generic representations of the building typologies presented in Section 1.2. These provide a context for the application of different retrofit packages according to variations in the stock and locations, as well as the indicative energy savings.

#### 3.1 Representative Cases Explained

- In the title, where a climate zone is not specified the retrofit measures proposed are applicable to all buildings within that construction category.
- Assumptions made for the base case for the building thermodynamic modelling by GHD & WSP/Built Ecology is located in the top left box, for further information on this see Part 5.
- The specific climate region to which the energy saving predictions graphed is depicted on the map of Australia.
- The energy savings shown are indicative of expected energy savings for the specific building type with the construction conditions specified in the specific location.

#### 3.2 Retrofits

The following pages shows Case Studies of specific building types within specific climate zones and their energy consumption levels through each stage of the retrofit proposals.
**CASE STUDY RESIDENTIAL: Brick Veneer**

Concrete slab floor. Predominant warming climate.

---

**Base Building Parameters**

- Building Fabric: Brick veneer wall, concrete floor, pitched tile roof
- Insulation: Ceiling only: R2.5 (added).
- Glazing: Single glazed: $U = 6\ \text{W/m}^2\text{K}$; SHGC = 0.8
- Shading: Eaves, no awnings on east or west facing windows
- HVAC: Gas heating, average-performing air conditioning system

---

**Retrofitting Modelling Location**

---

**Lighting**

- Replace all linear fluors and halogen downlights with LED alternatives
- Assumed efficacy of LEDs = 150 lm/W

---

**Fabric Upgrades**

- Insulate roof to R6, insulate walls to R2.5
- Replace windows with thermally broken double glazed units
- Install curtains and pelmets on all windows
- Ventilated downlights to be eliminated; install self sealing exhaust fans
- Full weather sealing on external windows and doors
- External awnings on east and west windows

---

**Space Conditioning**

- Best on the market split system reverse cycle air-conditioners to replace all gas heaters and old air-conditioners. COP >4.6
- 2-3kW for bedroom, 4-5kW for living room
- Wood heating maintained on downward trend
Retrofit Modelling

The graph shows modelling results for each step of the retrofit of a brick veneer house with concrete slab in Melbourne with floor area of 165 m² which currently consumes around 206 MJ/day. Through the retrofitting of lights, fabric upgrades, space conditioning, hot water, cooking and equipment an overall energy reduction of approximately 75% is achieved.

**Hot Water**
- Heat pump to replace all gas instantaneous, gas tank, and electric tank units
- Heat Pump: COP 4
- Water efficiency measures, e.g. low flow shower head

**Cooking**
- Replace gas cooktops with induction electric
- Replace small amount of gas ovens with electric. (Electric is dominant type on market.)

**Energy Monitoring**
- Installation of Smart Meter
- Installation of In Home Display or web portal for real time monitoring of energy consumption
- Meters/switches on individual appliances

**Appliances**
- New replacement appliances must meet best practice energy performance e.g. LED displays, best available fridge, washer, etc.
CASE STUDY RESIDENTIAL: Timber Weatherboard
Suspended timber floor. Cooling dominant climates.

Base Building Parameters
• Building Fabric: Timber walls, timber floor,
• pitched tile roof.
• Insulation: Ceiling only - R2.5 (70% of housing stock)
• Glazing: Single glazed; U = 6 W/m2K; SHGC = 0.8
• Shading: Eaves, no awnings on east or west facing windows
• Hot Water: Electric
• HVAC: Electric heating, average performing air conditioning system

Retrofitting Modelling Location

Lighting
• Replace all A19 incandescent, CFL, halogen, linear fluors, halogen downlights with LED alternatives
• Assumed efficacy of LEDs = 150 lm/W

Fabric Upgrades
• Insulate roof to R6, insulate walls to R2.5, floors R2
• Replace windows with single glazed low-emissivity IGUs with larger openings
• Ventilated downlights to be eliminated; install self sealing exhaust fans
• Full weather sealing on external windows and doors
• External awnings on east and west windows, plus north in tropical climate zones

Space Conditioning
• Best on the market split system reverse cycle air-conditioners to replace all gas heaters and old air-conditioners. COP >4.6
• 2-3kW for bedroom, 4-5kW for living room
• Ceiling fans for improved air circulation without air conditioner
• Wood heating maintained on downward trend
Retrofit Modelling

The graph shows modelling results for each step of the retrofit of a timber weatherboard house in Brisbane of floor area 177m² which currently consumes around 90 MJ/day. Through the retrofitting of lights, fabric upgrades, space conditioning, hot water, cooking and equipment an overall energy reduction of approximately 29% is achieved.

**Hot Water**

- Heat pump replace all gas instantaneous, gas tank units
- Heat Pump: COP 4
- Water efficiency measures, e.g. low flow shower head

**Cooking**

- Replace gas cooktops with induction electric
- Replace small amount of gas ovens with electric. (Electric is dominant type on market.)

**Energy Monitoring**

- Installation of Smart Meter
- Installation of In Home Display or web portal for real time monitoring of energy consumption
- Meters/switches on individual appliances

**Appliances**

- New replacement appliances must meet best practice energy performance e.g. LED displays, best available fridge, washer, etc.
CASE STUDY OFFICE: Pre-1945
Masonry-clad tower.

Base Building Parameters
- Building Fabric: Concrete/masonry walls, concrete slab, concrete roof
- Insulation: None
- Glazing: Single glazed; U = 5.7 W/m2K; SHGC = 0.8
- Glazing extent: 20% (punch hole windows)
- Shading: Minimal
- HVAC: Air cooled chiller, Fan Coil Unit System
- Assumed lighting power density - 17W/m2 (400 lux)

Retrofitting Modelling Location

Lighting
- Replace all A19 incandescent, CFL, halogen, linear fluores, halogen downlights with LED alternatives
- Assumed efficacy of LEDs = 150 lm/W

Fabric Upgrades
- Replacement Double Glazed windows: U = 2; SHGC = 0.64
- Insulate roof to R4 and walls to R2.5
- Draught proofing/air-locks reduce air-infiltration: 1 ACH to 0.1 ACH

Space Conditioning
- Air cooled chiller upgrade: COP ~ 4 (halve energy consumption)
- Boiler replacement with heat pump: COP ~ 4
- Variable speed drives and controls on pumps and fans
- Night purge

Hot Water
- Heat pump to replace all gas instantaneous, gas tank, and electric tank units
- Heat Pump: COP 4
- Water efficiency measures, e.g. low flow shower head

Appliances
- New replacement appliances must meet best practice energy performance e.g. LED displays, low wattage PCs
- Equipment load reduction: 15W/m2 to 3W/m2
- Gas cooking replaced with high efficiency electric (where applicable)

Energy Management
- Installation of Energy Management System with sub-metering
- Provide on-site Facility Managers trained in energy efficiency

Base Building Parameters
- Building Fabric: Concrete/masonry walls, concrete slab, concrete roof
- Insulation: None
- Glazing: Single glazed; U = 5.7 W/m2K; SHGC = 0.8
- Glazing extent: 20% (punch hole windows)
- Shading: Minimal
- HVAC: Air cooled chiller, Fan Coil Unit System
- Assumed lighting power density - 17W/m2 (400 lux)
Retrofit Modelling

The graph shows modelling results for each step of the retrofit of a pre-1945 office building in Brisbane with a net lettable floor area of 1,566m² which currently consumes an average of 3,780 MJ/day of energy. Through the retrofitting of lights, space conditioning, fabric upgrades and appliances an overall energy reduction of approximately 80% is achieved.

### Hot Water
- Heat pump to replace all gas instantaneous, gas tank, and electric tank units
- Heat Pump: COP 4
- Water efficiency measures, e.g. low flow shower head

### Energy Management
- Installation of Energy Management System with sub-metering
- Provide on-site Facility Managers trained in energy efficiency

### Appliances
- New replacement appliances must meet best practice energy performance e.g. LED displays, low wattage PCs
- Equipment load reduction: 15W/m² to 3W/m²
- Gas cooking replaced with high efficiency electric (where applicable)

Demonstrating a series of retro-fit actions as progressive modelling stages and the effects on various components of building energy usage.

### Base Building Parameters
- Building Fabric: Curtain wall, concrete slab, concrete parapet
- Insulation: None
- Glazing: Single glazed; $U = 5.6 \text{ W/m}^2\text{K}$; SHGC = 0.6
- Glazing extent:
  - 1945-1980 - 32% (high spandrel area)
  - 1980-2000 - 73% (full vision glass)
- Shading: None
- HVAC: Constant volume central ducted A/C
- Assumed lighting power density - 12W/m² (400 lux)

### Retrofitting Modelling Location
- Climate modelling

### Lighting
- Replace all A19 incandescent, CFL, halogen, linear fluoros, halogen downlights with LED alternatives
- Assumed efficacy of LEDs = 150 lm/W

### Fabric Upgrades
- Apply solar control film. This will halve solar heat gain
- Insulate roof to R4.5 and walls to R2.5
- Draught proofing/air-locks reduce air-infiltration: 1 ACH to 0.1 ACH

### Space Conditioning
- Water cooled chiller upgrade: COP ~ 6 (halve energy consumption)
- Boiler replacement with heat pump: COP ~ 4
- Replace constant air volume AHU with variable air volume system.
- Variable speed drives and controls on pumps and fans.
- Economy cycle (temperate climates only)
- Night purge

### Hot Water
- Heat pump to replace all gas instantaneous, gas tank, and electric tank units
- Heat Pump: COP 4
- Water efficiency measures, e.g. low flow shower head

### Appliances
- New replacement appliances must meet best practice energy performance e.g. LED displays, low wattage PCs
- Equipment load reduction: 11W/m² to 3W/m²
- Gas cooking replaced with high efficiency electric (where applicable)

### Energy Management
- Installation of Energy Management System with sub-metering
- Provide on-site Facility Managers trained in energy efficiency

---


**Curtain Wall Tower.**
Retrofit Modelling

The graph below shows modelling results for each step of the retrofit of a curtain wall office building in Sydney built between 1980-2000 which currently consumes around 30,845 MJ/day of energy. Through the retrofitting of lights, fabric upgrades, space conditioning and appliances an overall energy reduction of 78% is achieved.

Hot Water
- Heat pump to replace all gas instantaneous, gas tank, and electric tank units
- Heat Pump: COP 4
- Water efficiency measures, e.g. low flow shower head

Energy Management
- Installation of Energy Management System with sub-metering
- Provide on-site Facility Managers trained in energy efficiency

Appliances
- New replacement appliances must meet best practice energy performance e.g. LED displays, low wattage PCs
- Equipment load reduction: 11W/m² to 3W/m²
- Gas cooking replaced with high efficiency electric (where applicable)
Retrofitting Modelling Location

• Building Fabric: Aluminum cladding, raised timber floor, flat metal deck
• Insulation: None
• Glazing: Single glazed; U = 5.7 W/m²K; SHGC = 0.62
• Glazing extent: 20% of facade
• Shading: No external shading
• HVAC: Split system with COP of 2.5
• Boiler: 75% efficiency
• Assumed lighting power density - 255 lux (per GBCA)

Lighting

• Replace all A19 incandescent, CFL, halogen, linear fluores, halogen downlights with LED alternatives
• Assumed efficacy of LEDs = 150 lm/W

Fabric Upgrades

• Fully insulate – Ceiling R4, Floor R2.5, Walls R2.5
• Double Glazing – U-value = 3, SHGC = 0.4
• Install draft proof-measures to reduce air-infiltration from 2ACH to 0.5 ACH
• External shading – install awnings of width 40% of glazing height to north-facing windows, install 300mm fins to east & west facing windows
Retrofit Modelling

The graph shows modelling results for each step of the retrofit of a 72m² education building in Melbourne which currently consumes an average of 99MJ/day of energy. Through the retrofitting of lights, fabric upgrades and space conditioning, an overall energy reduction of ~83% is achieved.

**Space Conditioning**

- Replacement reverse cycle split system air conditioners with units with COP 4.6
CASE STUDY RETAIL: Shopping Centre

Base Building Parameters

- Building Fabric: Concrete wall, concrete slab on ground, flat metal deck roof
- Insulation: roof R1.41, wall R1.26
- Glazing: Single glazed; $U = 5.69 \text{ W/m}^2\text{K}$; SHGC = 0.61
- Skylights: $U = 6.87 \text{ W/m}^2\text{K}$; SHGC = 0.83
- HVAC: Rooftop Packaged Units. Chiller COP 2.3; gas boiler efficiency 75%
- Assumed tenancy lighting power density - 35W/m² (800 lux)

Retrofitting Modelling Location

Lighting

All areas:
- Replace all A19 incandescent, CFL, halogen, linear fluoros, halogen downlights with LED alternatives
- Assumed efficacy of LEDs = 150 lm/W

Fabric Upgrades

Common areas:
- Apply solar control film. This will halve solar heat gain
- Insulation - Roof R4, Wall R2
- Cool Roof paint
- Draught proofing/air-locks to reduce air-infiltration

Space Conditioning

Small retail:
- Replacement high efficiency air-conditioner, COP 4.6

Common areas:
- New air-cooled packaged chiller COP 4 (halve energy consumption)
- Boiler replacement with heat pump COP 4
- Variable speed drives and controls on pumps and fans
- Economy cycle (temperate climates only)
Retrofit Modelling

The graph shows modelling results for the retrofit of a shopping centre in Sydney with a net lettable area of 9,850m² (of which 2,500m² is supermarket) which consumes an average of 58,000MJ/day. Through the retrofiting of the supermarket, equipment, hot water service, lights, fabric upgrades, space conditioning, energy management systems and appliances an overall energy reduction of approx. 63% is achieved.

### Hot Water

- Heat pump to replace all instantaneous and tank units
- Heat Pump: COP 4
- Water efficiency measures, e.g. low flow shower head

### Energy Management

- Installation of Energy Management System with sub-metering
- Provide on-site Facility Managers trained in energy efficiency

### Appliances

- New replacement appliances must meet best practice energy performance e.g. LED displays, low wattage PCs
- Gas cooking replaced with high efficiency electric (where applicable)

### Supermarkets

- Fit doors on display cases - triple glazed with controls to minimise anti-sweat heater energy demand
- All other cost effective measures already implemented in best performing 20% of large supermarket chains
- Total energy demand reduction from 820 kWh/m² to 500 kWh/m²
Other Retail

*High Street Retail*

1. Insulate ceilings and apply cool roof paint
2. Air-curtain or heavy plastic flaps on entrance doorways
3. Draught Proofing
4. LED lighting replacement
5. Upgrade split system A/C, install in correct locations (not immediately above entrance way)
6. Equipment upgrade – computers etc
7. Install smart meter and “In-Home Display”

*Big Box*

1. Cool roof paint
2. Low emissivity solar control film on glazing
3. Insulate walls where practical to R2.5
4. Replace rooftop packaged chiller in warm climates (majority of Big Box operate with evaporative cooling)
5. LED lighting replacement with Lux sensors and dimming for daylight control
6. Energy management system installation

3.3 Non-residential Non-modelled Buildings

The remaining building categories did not have direct thermodynamic simulation and therefore had limited ability to tailor specific retrofit measures. As such, a more conservative approach was taken to the retrofitting opportunities in these categories. The actual measures proposed are drawn from the strategies outlined in Residential, Office, Retail, and Education categories, but with a lower emphasis on HVAC capital works. The table below demonstrates the proposed measures for each “energy end use” and the expected saving from its application. The expected energy savings were based on research from Part 3 and the results of thermodynamic simulation in Office, Retail and Education.

<table>
<thead>
<tr>
<th>End Use</th>
<th>Proposed Retrofit</th>
<th>Expected energy savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office Equipment</td>
<td>Computers, monitors, etc replaced with best practice models</td>
<td>73% (as per 11 W/m² to 3 W/m² in Office category)</td>
</tr>
<tr>
<td>Other Miscellaneous</td>
<td>Small savings from Energy Management System</td>
<td>15%</td>
</tr>
<tr>
<td>Domestic Hot Water</td>
<td>Heat Pump replace existing gas or electric service</td>
<td>~75% (Heat pump COP 4)</td>
</tr>
<tr>
<td>Lighting</td>
<td>LED replacements</td>
<td>78%</td>
</tr>
<tr>
<td>Air handling</td>
<td>VSDs and general maintenance</td>
<td>25% (based on interpretation of modelling results)</td>
</tr>
<tr>
<td>Space Heating</td>
<td>Heat Pump Boiler</td>
<td>~50% (Heat pump COP 4 then derate due to lower heat sources elsewhere in the building)</td>
</tr>
<tr>
<td>Space Cooling</td>
<td>A combination of fabric upgrades, internal heat load reductions, and limited improvements to existing equipment</td>
<td>50%</td>
</tr>
<tr>
<td>Pumping</td>
<td>VSDs and general maintenance</td>
<td>25% (based on interpretation of modelling results)</td>
</tr>
<tr>
<td>Cooking</td>
<td>Induction Cooktops and Electric Ovens</td>
<td>26% (base electric), 63% (base gas)</td>
</tr>
</tbody>
</table>
4 References


Part 5:
Summary of Modelling Findings

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1 Overview

Part 5 describes original computer modelling and analysis undertaken to investigate the potential reduction in grid energy demand, including the use of distributed generation from solar and wind. The models incorporate some of the technologies that are described in Section 3, and apply them to the various categories of buildings from Section 4.

Part 5 is divided into three main sections. The first models residential buildings energy saving measures and the second does the same for non-residential buildings. The third section models the potential for on-site energy generation with solar panels and micro wind turbines.

More detailed explanation of some of the modelling can be found in the appendices. Where possible, the original computer models and the corresponding data are available for download from http://bze.org.au/resources.

2 Residential

Computer modelling of changes in energy use in Australian homes was undertaken by Beyond Zero Emissions (BZE) and Energy Efficient Strategies (EES). The components of the modelling are as shown in Figure 5.1. The heating and cooling modelling indicated:

1. the space-conditioning energy reductions possible if the proposed retrofits were performed on homes of different construction types and in different locations; and
2. the resulting contribution of heating and cooling energy to the national model.

Similarly the modelling of hot water systems served to:

1. test some hypotheses about the most effective systems; and
2. estimate hot water energy use for incorporation into the national model.

The national home energy modelling is described Section 2.3 with more details at Appendix 1. The heating and cooling modelling is described below at Section 2.1. Hot water modelling is described at Section 2.2, with more details at Appendix 6.

2.1 Home heating and cooling

Modelling of residential building thermal performance was undertaken using simulation software called AccuRate. This estimates the thermal energy required for space conditioning (ie heating and cooling) under standardised operating criteria.

2.1.1 Scope

Space conditioning. The AccuRate modelling considers space conditioning, not other household energy uses such as lighting, appliances and hot water.

Detached homes. To simplify the task of estimating residential energy use we have only simulated a detached three-bedroom house, and extrapolated from this for other residential building types.

Occupancy and set points. Because energy use varies significantly with householder behaviour and with variable weather, the AccuRate approach applies standard climate, occupancy profile and set points for heating and cooling all year round. This is appropriate for comparing dwellings, however it does not represent a realistic pattern of use for most households. In practice the space-conditioning energy demands are over-estimated by a ratio of about 2:1 1. In other words the modelled usage behaviour represents higher use of space conditioning than is typical in most households. This is expected and reasonable because of the conservative nature of the assumptions built into the NatHERS rules. This over-estimation of per-household absolute energy
demand is does not affect the overall results because only relative improvements to heating and cooling energy were fed into the national model.

2.1.2 Building Model

The reference model dwelling is based on one provided by EES and described at Appendix 7. There are six variants of the base model, corresponding to construction type as per Table 5.1.

Modelling previously completed by EES includes a baseline, uninsulated dwelling plus two incremental improvements (identified as Mod levels 1 – 3 respectively). The modelling completed for this report adds two further improvement cases (Mod level 4 and 5 respectively). In addition, Mod level 5 is split into two variants “DG” for double glazing and “SG” for single glazing as described in Table 5.2.

2.1.3 Modelling Cases

The residential building models were tested using AccuRate across ten Australian locales, selected as being sufficiently representative of the entire country. These ten zones were chosen to align with those used by EES. Note, climate zone categorisation is at Appendix 2. See Table 5.3.

2.1.4 Results

Supporting modelling was undertaken to determine the sensitivity to orientation by testing the base model in the four cardinal orientations. The difference was found to be sufficiently small to allow a single orientation for the primary modelling.

TABLE 5.1
Building constructions used in residential modelling

<table>
<thead>
<tr>
<th>House Type</th>
<th>Wall construction</th>
<th>Floor construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weatherboard</td>
<td>Timber</td>
</tr>
<tr>
<td>2</td>
<td>Weatherboard</td>
<td>Concrete Slab</td>
</tr>
<tr>
<td>3</td>
<td>Brick Veneer</td>
<td>Timber</td>
</tr>
<tr>
<td>4</td>
<td>Brick Veneer</td>
<td>Concrete Slab</td>
</tr>
<tr>
<td>5</td>
<td>Cavity Brick</td>
<td>Timber</td>
</tr>
<tr>
<td>6</td>
<td>Cavity Brick</td>
<td>Concrete Slab</td>
</tr>
</tbody>
</table>

TABLE 5.2
Building modification levels used in residential modelling

<table>
<thead>
<tr>
<th>Mod level</th>
<th>Modification description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Baseline, uninsulated</td>
<td>EES level</td>
</tr>
<tr>
<td>2</td>
<td>Mod Level 1 plus:</td>
<td>EES level</td>
</tr>
<tr>
<td></td>
<td>• R2.5 insulation added to ceiling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(This mod level is considered most broadly representative of the current building stock)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mod Level 2 plus:</td>
<td>EES level</td>
</tr>
<tr>
<td></td>
<td>• insulation added to walls to +R1.5 (except, +R1.0 for brick cavity walls)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Mod Level 3 plus:</td>
<td>BZE level</td>
</tr>
<tr>
<td></td>
<td>• ceiling to +R6.0, and walls to +R2.5 (except, walls to +R1.5 for brick cavity walls)</td>
<td></td>
</tr>
<tr>
<td>5DG</td>
<td>Mod Level 4 plus:</td>
<td>BZE level</td>
</tr>
<tr>
<td></td>
<td>• double glazing (except on garage);</td>
<td>Cool climate</td>
</tr>
<tr>
<td></td>
<td>• ventilated downlights eliminated;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• self-sealing exhaust fans fitted;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• weather sealing on external windows and doors;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• curtains and pelmets on all windows.</td>
<td></td>
</tr>
<tr>
<td>5SG</td>
<td>Mod Level 4 plus:</td>
<td>BZE level</td>
</tr>
<tr>
<td></td>
<td>• high-performance single glazing (except on garage);</td>
<td>Warm climate</td>
</tr>
<tr>
<td></td>
<td>• ceiling fans in all living areas and bedrooms;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• ventilated downlights eliminated;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• self-sealing exhaust fans fitted;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• weather sealing on external windows and doors;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• curtains and pelmets on all windows.</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 5.3
Climate zones used in residential modelling

<table>
<thead>
<tr>
<th>AccuRate locale name</th>
<th>AccuRate climate region</th>
<th>BCA zone number</th>
<th>BCA climate description</th>
<th>DG/SG model variant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>16</td>
<td>5</td>
<td>Warm Temperate</td>
<td>DG</td>
</tr>
<tr>
<td>Brisbane</td>
<td>10</td>
<td>2</td>
<td>Warm humid summer, mild winter</td>
<td>SG</td>
</tr>
<tr>
<td>Canberra</td>
<td>24</td>
<td>7</td>
<td>Cool Temperate</td>
<td>DG</td>
</tr>
<tr>
<td>Darwin</td>
<td>1</td>
<td>1</td>
<td>High humid summer, warm winter</td>
<td>SG</td>
</tr>
<tr>
<td>Mascot</td>
<td>56</td>
<td>5</td>
<td>Warm temperate</td>
<td>DG</td>
</tr>
<tr>
<td>Moorabin</td>
<td>62</td>
<td>6</td>
<td>Mild temperate</td>
<td>DG</td>
</tr>
<tr>
<td>Orange</td>
<td>65</td>
<td>7</td>
<td>Hot dry summer, cool winter</td>
<td>DG</td>
</tr>
<tr>
<td>Townsville</td>
<td>5</td>
<td>1</td>
<td>High humid summer, warm winter</td>
<td>SG</td>
</tr>
<tr>
<td>Tullamarine</td>
<td>60</td>
<td>6</td>
<td>Mild temperate</td>
<td>DG</td>
</tr>
</tbody>
</table>

MODELLED REDUCTION IN SPACE CONDITIONING ENERGY

FIGURE 5.3
Home Energy Modelling (simplified)
In the primary assessment modelling (referred to as Phase 2, Experiment 5 in the raw data set), three hundred model runs were performed as follows:

- for each of six house types; and
- for each of ten climate zones; and
- for five building mod levels in each climate zone;
- a single orientation for each house.

As expected, the results indicate substantial reductions in space conditioning energy are possible. It has been assumed in this analysis that Mod level 2 most closely represents the average of today's building stock. Improvements in energy use between Mod level 2 and Mod level 5 vary by locale and construction type as shown in Figure 5.2.

The building types showing the most energy savings due to modifications are Type 1 (weatherboard, timber floor) and Type 2 (weatherboard, slab floor) across all locales. The least savings were seen with Type 5 (cavity brick, timber floor) and Type 6 (cavity brick, slab floor). Energy savings were least in the sub-tropical climates of Darwin and Townsville, and greatest in Sydney, Adelaide and Melbourne. In cavity brick buildings (Type 5 and Type 6), less wall insulation is possible (+R1.5 vs +R2.5) but baseline (Mod level 2) performance is slightly better than the timber-walled constructions. Because of this, the levels of improvement measured are better for timber than for cavity brick. The average improvement across all locales and all building types is 58.7%. The modelling also calculates the NatHERS star rating (described in Part 2) for the dwellings. The improvement in star rating is shown in the Figure 5.4.

### 2.2 Hot water

#### 2.2.1 Executive summary

This section contains the modelling in support of the assessment of domestic hot water in Part 3. Computer modelling of domestic heat pump, and solar hot water (SHW) systems was performed using thermal system modelling software called TRNSYS. The aim was to quantify the energy savings possible using best-available technology and various strategies.

**Setup.** The chosen test system incorporated an evacuated-tube collector, heat-pump boosting and a 340L tank. Demand was assumed to be 140L/day based on measured consumption in the case-study home (see Appendix 4). Optimal alignment and solar exposure were assumed (*ie* north-facing with no shading).

**Findings.** The modelling suggested that, bearing in mind the likely costs, the best general option for energy efficient domestic hot water in temperate Australia is a heat pump unit (*ie* with no solar collector), whereas in northern Australia a conventional solar system is optimal. In addition it was found that about 30% of the energy was lost as standing heat loss. Standing heat loss can be greatly reduced with smaller tank size, with a corresponding increased risk of being caught out with insufficient heated water.

#### 2.2.2 Design approach

The SHWS modelled here, is solar with electric boosting. The intent was to design a system with commercial, off-the-shelf components which would get almost all its heat from the sun. Whereas domestic SHW systems typically achieve 60% – 75% reduction in energy requirements, the intention was to confirm that energy reductions greater than 90% were possible, as had been reported.

The system design had the following broad characteristics, as based on the system described at:\(^3\):

- **Evacuated Tubes.** a 30-tube Apricus solar collector;
- **Heat Pump Boosting.** a 340L Quantum hot water service. The average coefficient of performance (COP) of this unit, according to manufacturer's data\(^4\), is about 2.5 for when \(T_{\text{mean_tank}} = T_{\text{ambient}} + 40^\circ\text{C}\). For use in the hybrid SHWS modelling we have chosen a lower COP than would be appropriate if the system were used without solar input because boosting is required when the COP is least favourable;

#### 2.2.3 Method

Modelling was performed using TRNSYS 16 software\(^5\) with the assistance of Solem Consulting. The model was created using components which come standard with TRNSYS, *ie* no third-party components were used.

**Common model parameters.** The following settings were applied to most modelling cases except where indicated:

- Simulation duration: 8,760h (one year) except Experiment 6;
- Simulation time step: 5min;
- Control in line with AS3498 (clause 7.1j), approximated by using 8h boost once per week with set points of 45/55 (except Experiment 5);
- Hot water load: 140L/day, delivered 1/3 at 6:45am, 1/3 at 11:15am, and 1/3 at 8:30pm.
- Solar pump speed: 4L/min;
- Heat pump COP: See Figure 5.5;
- Solar collector area: 4.16m\(^2\);
- Solar collector optical efficiency (A0): 0.452;
- Solar collector efficiency factors (A1/A2): 1.36/0.0039;
- Inlet water temperature: fixed at 10°C in early experiments (3,4); provided by weather model in later experiments (5,6,7,8);
HOME ENERGY MODELLING RESULTS - BY ENERGY

ORANGE

Canberra

Darwin

Tullamarine

Moorabin

Melbourne

Adelaide

Mascot

House Type

Type Wall construction Floor construction

1 Weatherboard  Timber
2  Weatherboard  Concrete Slab
3  Brick Veneer   Timber
4  Brick Veneer   Concrete Slab
5  Cavity Brick   Timber
6  Cavity Brick   Concrete Slab
Settings (continued):

- pipe length in solar circuit: 17m;
- boost electrical power 4,500W;
- Tank volume 340L (except in Experiment 8 where this value is varied);
- Tank loss factor 3.0kJ/h.m²K, which is equal to 0.833W/m²K (except for Experiment 8 where this value is varied)

With the exception of Experiment 6, results are annual aggregates.

Other points to note about the modelling are:

- **Heat pump.** Heat-pump performance characteristics are broadly based on the Quantum 340-11AC3-134. The COP values used in the modelling are based on monthly average temperature and are shown in Appendix 6, based on manufacturer’s test report.

- **Control regime.** The implementation of the AS3498 (clause 7.1j) control regime in the model is very simplistic and conservative. Real-world performance is very likely to achieve slightly higher performance by more carefully choosing when to boost based on the actual time since the threshold of sterility was last achieved.
HOME ENERGY MODELLING RESULTS - BY STAR RATING

ORANGE

CANBERRA

DARWIN

TULLAMARINE

MOORABBIN

MELBOURNE

ADELAIDE

MASCOT
2.2.3.1 Main experimental cases
Refer to Table 5.4 for the main investigative modelling cases. Note: all experimental cases involve the hybrid solar/heat-pump model except where otherwise indicated.

TABLE 5.4

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Investigating sensitivity to changing collector slopes and azimuths</td>
</tr>
<tr>
<td>4</td>
<td>Investigating sensitivity to changes in collector slope with greater precision</td>
</tr>
<tr>
<td>5a</td>
<td>Investigating sensitivity to changes in set-point temperature</td>
</tr>
<tr>
<td>5b</td>
<td>Combining case 4 and 5a to better show changes in set-point compared to normal</td>
</tr>
<tr>
<td>6</td>
<td>Using Case 3 settings, but looking at outputs month-by-month</td>
</tr>
<tr>
<td>7</td>
<td>Using Case 6 settings, but looking at sensitivity to tank size and insulation level</td>
</tr>
<tr>
<td>8</td>
<td>As per case 7, but with more detail for a single locale</td>
</tr>
<tr>
<td>9</td>
<td>Comparing monthly performance with and without solar gain</td>
</tr>
<tr>
<td>10</td>
<td>Estimating monthly average COP</td>
</tr>
<tr>
<td>11</td>
<td>Consolidated data analysis, solar thermal and heat pump</td>
</tr>
<tr>
<td>12</td>
<td>Baseline non-heat-pump electric system only (used in Case 11)</td>
</tr>
<tr>
<td>13</td>
<td>(no hot water model) Estimated PV yield, month-by-month</td>
</tr>
<tr>
<td>14</td>
<td>Successive improvements, excluding heat pump</td>
</tr>
<tr>
<td>15</td>
<td>Comparing performance of heat pump vs solar</td>
</tr>
</tbody>
</table>

HOME ENERGY MODELLING RESULTS
BY STAR RATING

- Type 6: Cavity Brick & Concrete Slab
- Type 5: Cavity Brick & Timber Slab
- Type 4: Brick Veneer & Concrete Slab
- Type 3: Brick Veneer & Timber Slab
- Type 2: Weatherboard & Concrete Slab
- Type 1: Weatherboard & Timber Slab

FIGURE 5.5 (LEFT)
Home energy modelling results - by star rating
FIGURE 5.6
Hot water model as shown in TRNSYS Studio

FIGURE 5.7
ESTIMATED HEAT PUMP CoP

Heat pump CoP

CoP

Month

Darwin
Perth
Sydney
Melbourne
EFFECT OF SUCCESSIVE MEASURES TO IMPROVE HWS PERFORMANCE

MELBOURNE

SYDNEY

DARWIN

PERTH

Baseline

No Heat Pump

U=0.8

No Heat Pump

SP45/55

Heat Pump Only

Heat Pump & Solar (CSO=-10)

Heat Pump & Solar (CSO=25)

FIGURE 5.8
Effect of successive measures to improve HWS performance.
2.2.4 Results

Detailed results of the hot-water-system modelling can be found at Appendix 6. The most important results are summarised below.

The effect of successive improvement measures. This graphs below show a consolidated view of the combined effect of a number of successive measures from a baseline resistive electric hot water system. See Appendix 6. (Experiment 11/12) for more detail. The lines in the graphs correspond as follows:

- **Baseline.** In these graphs the ‘baseline’ values correspond to a conventional resistive-electric hot water service of 340L, with water statically regulated at 60°C;
- **No HP, U=0.8W/m²K.** The baseline system has improved insulation (U=0.8W/m²K);
- **No HP, SP=45/55.** The ‘no HP, U=0.8’ case is further improved with smarter water temperature regulation using 45°C for six days per week, and 55°C for one day per week.
- **HP only.** The ‘no HP, SP=45/55’ is further improved by delivering energy with a heat pump in place of resistive electric;
- **HP + Solar (CSO=10).** The ‘HP only’ case is further improved by adding a 30-tube solar collector which is configured at a slope of 10° less than local latitude (which corresponds in southern Australia to being mounted flush on a typical pitched roof);
- **HP + Solar (CSO=-25).** The ‘HP + Solar (CSO=-10)’ case is further improved by raising the slope of the collectors to 25° more than the local latitude to optimise for winter.

Refer to Figure 5.7, “Effect of successive measures to improve HWS performance” and Figure 5.8, “Annual summary of effect of successive measures to improve HWS performance”.

**Seasonal load of electric-boosted solar vs heat pump.** The analysis presented below strongly suggests that the boost energy requirements for electric-boosted solar are highly seasonal, whereas the boost energy for heat pump hot water systems are more evenly spread through the course of the year. The boost energy requirements in the worst-case month would generally be met or exceeded by 1kW of solar PV capacity. See Appendix 6 (Experiment 15) for more detail. The two cases represented in each graph correspond to:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Minimum exposure period</th>
</tr>
</thead>
<tbody>
<tr>
<td>70°C or greater</td>
<td>1s</td>
</tr>
<tr>
<td>66°C</td>
<td>2min</td>
</tr>
<tr>
<td>60°C</td>
<td>32min</td>
</tr>
<tr>
<td>55°C</td>
<td>6h</td>
</tr>
</tbody>
</table>

Refer to Table 5.5, AS3498 Hot water temperature control.
**Electric-boosted solar.** Conventional storage, electric-boosted solar hot water system, boost energy plus pump energy;

**Heat pump.** Heat pump electric solar hot water system;

In all cases except Darwin, the energy required in the worst-case month (*ie* winter) is reduced by about 60% by using a heat pump system instead of an electric-boosted solar system.

Refer to Figure 5.9 “Monthly boost energy – solar vs heat pump”.

**The effect of steeper collector slope.** Computer modelling was undertaken to study the effect of collector slope on system performance. This study showed that (except for the tropics) the winter-time boost energy requirements were reduced as much as 25%, and generally by about 13%, achieved by tilting the north facing collector at a slope of latitude +30° compared to latitude-10°. The study also showed that solar collectors, perhaps surprisingly, remain very effective (except in the tropics) when mounted vertically and facing north. This raises the possibility of wall-mounted solar collectors when circumstances permit.

**Temperature control.** Computer modelling was undertaken to study the effect of controlling water at lower temperatures in accordance with AS/NZS3498:2009 (Clause 7.1j; see Table 5.5). The modelled system regulated the temperature at 55°C for 8h/week, and at 45°C for the balance of the week. This was compared with a system where temperature was regulated at 60°C seven days a week. This study was applied to five different climate zones. Compared with a fixed 60°C set point, using a 45/55 control regime results in a net energy reduction of about 10% in all locales.

**COMPARISON OF ELECTRICAL BOOST ENERGY REQUIREMENTS FOR SOLAR WATER HEATING VS HEAT PUMP WATER HEATING UNITS**

**Melbourne**

ANNUAL TOTAL:

SOLAR: 975 kWh, HEAT PUMP: 756 kWh

**Sydney**

ANNUAL TOTAL:

SOLAR: 753 kWh, HEAT PUMP: 677 kWh

**Darwin**

ANNUAL TOTAL:

SOLAR: 18 kWh, HEAT PUMP: 502 kWh

**Perth**

ANNUAL TOTAL:

SOLAR: 579 kWh, HEAT PUMP: 673 kWh

*FIGURE 5.10*

Monthly boost energy - solar vs heat pump
TABLE 5.6
Australian energy use in residential buildings (PJ/annum)

<table>
<thead>
<tr>
<th>End use</th>
<th>Energy source</th>
<th>Program year 1</th>
<th>Program year 10</th>
<th>Zero-gas-only year 10</th>
<th>BAU year 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating</td>
<td>LPG</td>
<td>1.9</td>
<td>0.0</td>
<td>0.0</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Electricity</td>
<td>12.8</td>
<td>7.9</td>
<td>21.5</td>
<td>12.6</td>
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<tr>
<td></td>
<td>Mains Gas</td>
<td>75.5</td>
<td>0.0</td>
<td>0.0</td>
<td>78.7</td>
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<tr>
<td></td>
<td>Wood</td>
<td>42.9</td>
<td>17.7</td>
<td>43.1</td>
<td>43.1</td>
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<tr>
<td>Water Heating</td>
<td>LPG</td>
<td>3.7</td>
<td>0.0</td>
<td>0.0</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>Electricity</td>
<td>41.7</td>
<td>45.1</td>
<td>48.9</td>
<td>37.1</td>
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<td></td>
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<td>39.5</td>
<td>0.0</td>
<td>0.0</td>
<td>40.4</td>
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<td>Cooking</td>
<td>LPG</td>
<td>1.9</td>
<td>0.0</td>
<td>0.0</td>
<td>2.2</td>
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<td></td>
<td>Electricity</td>
<td>9.9</td>
<td>13.6</td>
<td>14.2</td>
<td>10.4</td>
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<td></td>
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<td>0.0</td>
<td>0.0</td>
<td>8.7</td>
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<td>Space Cooling</td>
<td>Electricity</td>
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<td>6.0</td>
<td>12.0</td>
<td>12.0</td>
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<td>Appliances</td>
<td>Electricity</td>
<td>106.1</td>
<td>84.0</td>
<td>109.8</td>
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<td>Lighting</td>
<td>Electricity</td>
<td>27.6</td>
<td>4.8</td>
<td>16.5</td>
<td>16.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>385.6</td>
<td>179.1</td>
<td>266.1</td>
<td>376.4</td>
</tr>
</tbody>
</table>

MODELLED AUSTRALIAN RESIDENTIAL ENERGY CONSUMPTION

FIGURE 5.11
Modelled residential energy by usage
**The effect of improved insulation.** Computer modelling was undertaken to study the effect of have better-insulated hot water tanks. Baseline tanks were assumed to have a U value of 1.0W/m²K. These were compared with tanks with varying U values down to 0.28 W/m²K. On small tanks, the improved insulation had little effect. On larger tanks the improvement in annual mains energy requirement was about 16%.

**2.2.5 Conclusions**

- **Energy Reduction.** The modelling performed here indicates that, as a conservative estimate, heat-pump boosted solar hot water will achieve reductions in HWS energy of between 80% and 90% compared with conventional electric systems.
- **Seasonal variability of solar boost.** The boost energy requirements of conventional solar hot water systems are highly variable in temperate zones. If collectors are sized for wintertime conditions then excess summertime solar capacity is wasted.
- **Tropical.** The very low boost energy requirements shown for Darwin suggest that more expensive systems suffer from the law of diminishing returns. So a low-cost solar system would be sufficient.
- **Setpoint control.** The application of a temperature control regime, in accordance with AS3498, can achieve boost energy reduction of about 10% relative to conventional thermostatic control. This consideration is relevant regardless of whether or not the HWS uses solar.
- **Steep collectors.** The mounting of solar collectors at a slope of about latitude+30° has the potential to increase winter solar gain by about 13% relative to more conventional low-slope mounting.
- **High-performance tanks.** The use of well-insulated tanks has the potential to save significant amounts of energy when tank size is more than about twice the average daily usage. A tank loss factor (U value) of 1.0 W/m²K or lower would be desirable.
- **Wall mounting.** In Southern Australia, the performance of collectors when mounted vertically remains high. This opens the possibility of wall-mounting collectors where necessary. This could be particularly useful on multi-story dwellings where suitable north-facing walls are available.
- **Heat pump.** In temperate climates, the energy requirements for heat pump hot water services have much less seasonal variability, and have annual

![Figure 5.12](attachment:image.png)

**Energy Reduction by State**

**ZCA Buildings Plan Program**

<table>
<thead>
<tr>
<th>Australian Capital Territory</th>
<th>Northern Territory</th>
<th>Tasmania</th>
<th>Western Australia</th>
<th>South Australia</th>
<th>Queensland</th>
<th>Victoria</th>
<th>New South Wales</th>
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</thead>
<tbody>
<tr>
<td>400</td>
<td>375</td>
<td>350</td>
<td>325</td>
<td>300</td>
<td>275</td>
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<td>325</td>
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<td>250</td>
<td>225</td>
<td>200</td>
<td>175</td>
<td>150</td>
<td>125</td>
</tr>
<tr>
<td>275</td>
<td>250</td>
<td>225</td>
<td>200</td>
<td>175</td>
<td>150</td>
<td>125</td>
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<td>200</td>
<td>175</td>
<td>150</td>
<td>125</td>
<td>100</td>
<td>75</td>
<td>50</td>
<td>25</td>
</tr>
</tbody>
</table>

**Figure 5.12**

Modelled residential energy by usage
energy requirements comparable to typical solar configurations.

- **Heat pump plus PV.** In temperate climates, the winter-time average energy demand for a heat pump system can be satisfied with about 1 kW of PV generation.

### 2.3 National home energy model

The national home energy model was prepared by Energy Efficient Strategies (EES), and their detailed methodology is presented in Appendix 1. This model takes heating and cooling information from Section 2.1, hot water data from Section 2.2, plus EES’s own data and models on appliance energy, as well as projected growth, and a detailed model of residential building stock. Modelling results indicate the energy reductions, as shown in Table 5.6, for the scenario involving upgrade of all homes in Australia to the Buildings Plan specification over the period 2011-2020 (program years 1 – 10). Although this plan is specifically modelled based on a 2011 start date, the results of the ten-year program can apply to a start date at any time in this decade with approximately the same result.

This model includes the on-trend growth in the number of homes over that selected period. These results should be viewed beside the business-as-usual (BAU) modelling at Part 2 (included in Table 5.6 under the column ‘BAU year 10’).

The modelled results under the ten-year program represent a 54% reduction in total national residential energy consumption. This energy, at year 10, is predominantly electricity (161 PJ/annum, which is 45 TWh/annum). The balance is legacy wood heating (18 PJ/annum) which is showing and on-trend reduction for ten years of the program.

As discussed in Part 3, Section 6.3, the implementation of in-home displays and smart meters in all Australian homes can have the potential to reduce all energy consumption by about 7%. For the purpose of this study we consider this reduction to apply primarily to the “Other Standby”, as real time monitoring and education programs can help households to recognise devices that are consuming lots of energy unnecessarily.

**Zero-gas-only scenario.** An additional scenario was modelled by EES looking only at a program for removing fossil gas usage from residential buildings. This analysis focussed solely on the replacement of gas space heating, gas hot water heating, and gas cooking, with the market-average-performing reverse-cycle air conditioner, a standard electric cook top, and a typical heat pump hot water system. These results are shown in Table 5.6, above under the heading ‘Zero-gas-only year 10’. The removal of gas appliances and their replacement with electric alternatives leads to only a modest (~12%) increase in overall electricity consumption, before PV generation is factored in. Overall under this scenario, there would be a 29% reduction in total residential energy use compared to business as usual (BAU). This suggests a zero-gas-only program could be embarked on first as an interim stage towards the full Buildings Plan.

**BAU demand.** This plan’s modelled decline in residential energy use should be viewed relative to business as usual (BAU). Latest estimates for BAU in 2020 are for a fall of 2.5% in absolute demand over the ten years (see Figures 5.10 and 5.11). Relative to BAU, the reduction in energy use is 52%.

**Independent of PV.** The modelled reduction in energy use is independent of PV generation. The estimated residential PV generation under this plan is about 46 TWh (see...
Section 4.1), which is more than the 44.8 TWh estimated residential energy consumption.

**Per-household energy.** The modelled current-day average per-household energy is 45 GJ/annum, comprising electricity, gas and wood. In year 10 of the program this is reduced to 18 GJ/annum, with gas removed entirely. This is a 60% reduction. The effective reduction would be greater because of the distorting effect on the figures of the (low-efficiency) legacy wood. In other words, homes without wood heating would expect a greater than 60% reduction in supplied energy. This is shown in Figure 5.12. This modelling agrees well with the case study home which achieved a 71% reduction in consumption (76 GJ down to 23 GJ), see Appendix 4.

### 3 Non-residential

#### 3.1 Stock Model

##### 3.1.1 Introduction

The non-residential building sector comprises a wide range of building types and uses. To date there has been very little work done to collect and collate the floor area and energy intensity of non-residential buildings in Australia. This is partially due to the variability of building types and uses, and also the lack of need for detailed information about these building types.

Most recently, the Department of Climate Change and Energy Efficiency released a study ⁶, prepared by Pitt & Sherry, Exergy, and Bis Shrapnel, that estimates the historic and projected energy consumption of each commercial sector, using a bottom-up approach. Although this study includes data that is relevant to the Buildings Plan, it was released in November 2012 and therefore not available when research into non-residential buildings was commenced.

For these reasons Beyond Zero Emissions has developed its own model of the non-residential building stock within Australia based upon public data sources. This section outlines a summary of this research and analysis.

**FIGURE 5.14**

Breakdown of non-residential floor area and annual energy use in baseline year
FIGURE 5.15
Non-residential gas and electricity use breakdown

FIGURE 5.16
End use breakdown of gas and electricity use
3.1.2 Methodology

The non-residential building stock model presented in the Buildings Plan was developed using a bottom up approach. The first step in the development was to research the number of buildings in each category and their total floor areas by state. Once the stock model had detailed floor area information by building type, energy statistics were researched and then extrapolated to state-wide and Australia-wide values using the established floor areas.

A range of resources were used to formulate the stock model. Data from the Australian Bureau of Statistics were used to establish business numbers and other statistics such as employment, visitors or bed numbers. Research was then conducted into building floor areas and was utilised in conjunction with the statistics gathered from the Australian Bureau of Statistics to establish total building floor areas by state \(^7,8,9\). Some of the main sources used to develop the total floor areas include data from the Productivity Commission of Australia \(^10\), the Melbourne Census of Land Use and Employment (CLUE) \(^11\) and the Sydney Floor Space and Employment Survey \(^12\). In addition a significant number of other sources were used including government reports and property databases, land use surveys, company annual reviews and other property-related data sources. A similar approach was utilised to formulate the energy figures. Government reports, NABERs data and individual energy audits were used to establish an energy load per square meter for each building type within each state. The total energy consumption for each building type was then formulated using the previously established building floor areas.

3.1.3 Summary of building categories

The building categories within the non-residential stock model were chosen based on their occurrence, size and the range of retrofit improvement measures that can be implemented. The categories include:

**Retail buildings:**
- High Street Retail
- Neighbourhood Centres
- Shopping Centres
- Big Box Retail

**Office buildings:**
- Built Pre-1945
- Built 1945-1980
- Built 1980-2000
- Built Post-2000

**Education buildings:**
- Built Pre-1940
- Built 1940-1969
- Built Post-1970
- Accommodation buildings
- Hospital buildings
- Warehouse buildings
- University buildings
- Aged Care buildings
- Clubs and Pubs
- Museums and Galleries
- Cafes and Restaurants
- Prison buildings
- Library buildings
- Cinema buildings

An overall summary of the results gathered in terms of total floor area and energy use for each building category is displayed in Figure 5.13. The results show that offices and retail space are the highest energy users within the non-residential building sector. These two categories also have the highest total floor areas.

Figures 5.14 and 5.15 outline the breakdown of gas and electricity across different states and different sectors respectively. This information was used when estimating energy reduction through retrofits or the replacement energy required when fuel-switching.

3.1.4 Breakdown of sources

The analysis of non-residential buildings was performed using multiple data sources. An overview these is outlined in Table 5.7 "Data sources".

For more information on the non-residential model, including a link to the model data files, see Appendix 11.

3.1.5 Estimating energy savings potential

Outside of the work done to develop the non-residential stock model, two different methodologies were used to estimate the energy savings potential for different building categories.

For the dominant building types, including offices, retail and education buildings, thermal modelling was done using the modelling package Integrated Environmental Solutions (IES) Virtual Environment (VE) or IES-VE. The modelling accounted for climate zone weather variations for both before and after energy-related retrofit scenarios. The relative difference from after to before retrofits was used as an estimate of the energy savings potential. The results of this analysis is outlined in the following section 3.2 Energy modelling.

The remaining categories were individually modelled using energy savings estimations for building energy services and also the 2004 study into energy efficiency \(^13\) by EMET Consultants. This report summarises the breakdown of energy used for building services for commercial building categories as defined by ANZSIC classifications. The EMET Consultants report also includes both electricity and gas use, and was used to define energy end use percentages for building services for each of the building categories.

In order to comprehensively model the potential energy savings across different states, the gas to electricity breakdown was ascertained using Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) data. In several categories more detailed gas use information was available and was therefore used in place of ABARE statistics which have a broader scope.
3.2 Energy modelling

3.2.1 Non-Residential Modelling Scope

A wide variety of building types are classified as non-residential and therefore it was necessary to limit the scope of the non-residential modelling. Three key groups have been considered: education, office and retail. Different building types have been modelled within the key groups based on typical constructions and services in different time periods. The modelling was undertaken by WSP Built Ecology and GHD as an in-kind contribution to the Buildings Plan. A summary of the modelled buildings, as described in Part 4, is as follows:

**Education**

Types of education buildings modelled:

- Pre-1940 Construction
- 1940-1969 Construction
- Post-1970 Construction

**Office**

Types of office buildings modelled:

- Pre-1945 Construction
- 1945-1980 Construction
- 1980-2000 Construction

**Retail**

One shopping centre was modelled comprising of common circulation space, retail tenancies, and supermarkets. The results from this work was utilised to estimate energy savings in the other retail categories – Neighbourhood Centres, High St Retail, and Big Box Retail.

### Table 5.7

Data sources

<table>
<thead>
<tr>
<th>Building Category</th>
<th>2012 Floor Area Estimations</th>
<th>2012 Energy Use Estimations</th>
<th>Data Source</th>
<th>Energy Savings Potential</th>
<th>2022 Estimations</th>
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</thead>
<tbody>
<tr>
<td>High Street Retail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neighbourhood Centres</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shopping Centres</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Big Box Retail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office buildings</td>
<td></td>
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<td>Accommodation buildings</td>
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</tr>
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<td>Hospital buildings</td>
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<td>Warehouse buildings</td>
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<td>University buildings</td>
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<td>Aged Care buildings</td>
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<td>Cafes and Restaurants</td>
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<td>Library buildings</td>
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<tr>
<td>Cinema buildings</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
3.2.2 Software

Software used for the non-residential HVAC modelling described in this report is Integrated Environmental Solutions (IES) Virtual Environment (VE).

Virtual Environment is an integrated suite of applications linked by a Common User Interface and a single Integrated Data Model. ModelIT is the application used for input of 3D geometry used to describe the building. Individual ModelIT geometries were modelled for each building type analysed, based on typical dimensions for buildings of each type. Parameters describing the building loads and HVAC systems were entered into the Apache TemplatesSystems application. SunCast was used for solar shading analysis, and ApacheSim was used to perform the thermal simulation.

3.2.3 Climate

Three climate zones were modelled for each building type to analyse the varying effectiveness of different retrofit options for different climates in Australia. The performance of each building was modelled in three climate zones: Brisbane, Melbourne and Sydney. These climate zones, as defined by the Building Code of Australia, capture 70% of Australia’s population. For further information on the climate zones selected refer to Appendix 2.

The climate files used for each model were ASHRAE International Weather Years for Energy Calculations (IWECs). Each IWEC represents a compilation of representative historical weather data. The selection criteria for the IWEC files uses nine weighted weather parameters to determine a representative dataset for energy modelling.

3.2.4 Modelling Methodology

Application of Retrofits Retrofit options were applied to a “base case” building. The “base case” building models were constructed using data and assumptions for existing buildings of each type. The broad characteristics of the base case buildings where set by the Segmentation Analysis as discussed in Part 4. This provides a building model which represents the performance of a typical existing building.

When performing a building renovation, there are roll-on effects due to the interaction of different improvement initiatives. For example, an improvement in lighting efficiency will reduce the internal heat load for a building, meaning that cooling requirements will decrease and heating requirements will increase. Therefore, in general it is preferable for HVAC upgrades to occur after building fabric, shading and lighting upgrades have been implemented so that systems can be sized based on the improved building performance.

Upgrades were modelled sequentially based on the preferable order of the retrofit application. For example, the building fabric upgrades have been modelled prior to the HVAC upgrades. In general, the order of retrofit application throughout the non-residential modelling was as follows:

1. Lighting upgrades
2. Fabric upgrades
3. Services upgrades (HVAC and domestic hot water)
4. Equipment load reduction (were applicable)
**Orientation** Building orientation can have a significant effect on building thermal performance and is also an important factor in assessing how effective different retrofit options are for different buildings. Because the building modelling is based on representative building types rather than actual examples of buildings, the buildings have been modelled as having identical facades to the North, South, East and West. This averaged out the effects of building orientation on the building performance for each building, providing an estimate for the average improvement which can be expected for each option.

### 3.2.4.1 Office

A reference case was determined for each type, as described later in this section. Upgrades were then applied as follows:

1. Lighting upgrade
2. Fabric upgrades
3. Services upgrades (HVAC and domestic hot water)
4. Equipment load reduction

**Office Building Parameters**

Table 5.8 details general parameters which remain constant between the base case and the retrofit case in the office models.

<table>
<thead>
<tr>
<th>Building Parameter</th>
<th>Pre 1945</th>
<th>1945 to 1980</th>
<th>1980 to 2000</th>
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<tbody>
<tr>
<td>Number of stories</td>
<td>6</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Lighting profile</td>
<td>As per Green Star Office V3 / NABERS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occupant density (m² per person)</td>
<td>15</td>
<td>(Pre 1945 Office was set to 10)</td>
<td></td>
</tr>
<tr>
<td>Occupant profile</td>
<td>As per Green Star Office V3 / NABERS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NLA (m²)</td>
<td>1566</td>
<td>9000</td>
<td>9000</td>
</tr>
<tr>
<td>Equipment profile</td>
<td>As per Green Star Office V3 / NABERS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occupant Heat Load</td>
<td>Sensible heat (W) : 70 as per BCA 2012, Section J</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Latent (W) : 60 as per BCA 2012, Section J</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilation (L/s/person)</td>
<td>7.5 as per BCA 2012 (AS1668.2 1998)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature set points</td>
<td>20-24°C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 5.8**

Office building parameters

**TABLE 5.9**

Pre-1945 office

<table>
<thead>
<tr>
<th>Building Parameter</th>
<th>Base</th>
<th>Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Fabric</td>
<td>Wall: Uninsulated curtain wall</td>
<td>Insulate to R3</td>
</tr>
<tr>
<td></td>
<td>Roof: Uninsulated concrete parapet</td>
<td>Insulate to R4.6</td>
</tr>
<tr>
<td>Glazing</td>
<td>U-value 5.6W/m²K</td>
<td>5.6W/m²K</td>
</tr>
<tr>
<td></td>
<td>SHGC 0.6</td>
<td>Apply film: 0.35</td>
</tr>
<tr>
<td>Lighting</td>
<td>12 W/m²</td>
<td>2.67</td>
</tr>
<tr>
<td>Equipment</td>
<td>15 W/m² [BCA]</td>
<td>3</td>
</tr>
<tr>
<td>Glazing extent</td>
<td>32%</td>
<td>32%</td>
</tr>
<tr>
<td>HVAC Description</td>
<td>Central ducted, gas boiler Constant Air Volume AHU</td>
<td>Central ducted, electric boiler (heat pump) Variable Air Volume AHU</td>
</tr>
<tr>
<td>Chiller Efficiency</td>
<td>COP 3.0</td>
<td>COP 6.0</td>
</tr>
<tr>
<td>Boiler Efficiency</td>
<td>Gas, 75% efficient</td>
<td>Elec, IPLV 4.0</td>
</tr>
<tr>
<td>Hot water consumption (L/person/day)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Domestic Hot Water Efficiency</td>
<td>Gas (75%)</td>
<td>Electric, COP=4.0</td>
</tr>
<tr>
<td>Infiltration</td>
<td>Air Changes per Hour (ACH)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.1</td>
</tr>
</tbody>
</table>
The sections below detail the variables used in the base case and retrofits for each of the office building types, i.e. Pre-1945, 1945-1980, and 1980-2000. Note office buildings built after 2000 were not modelled for thermodynamic simulation as management improvements and systems tuning are the main retrofits proposed.

**Pre-1945 Office**

Table 5.9 details variables used to model the base case and retrofits for the Pre-1945 Office building type.

**1945-1980 Office**

Table 5.10 details variables used to model the base case and retrofits for the 1945-1980 Office building type.

**1980 to 2000 Office**

Table 5.11 details variables used to model the base case and retrofits for the Post-1980 Office building type.

### TABLE 5.10

1945-1980 office

<table>
<thead>
<tr>
<th>Building Parameter</th>
<th>Base</th>
<th>Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Building Fabric</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walls</td>
<td>Uninsulated curtain wall</td>
<td>Insulate to R3</td>
</tr>
<tr>
<td>Roof</td>
<td>Uninsulated concrete parapet</td>
<td>Insulate to R4.6</td>
</tr>
<tr>
<td>Glazing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-value</td>
<td>5.6 W/m²K</td>
<td>5.6 W/m²K</td>
</tr>
<tr>
<td>SHGC</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W/m²</td>
<td>12</td>
<td>2.67</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W/m²</td>
<td>15 (BCA)</td>
<td>3</td>
</tr>
<tr>
<td>Glazing extent</td>
<td>32%</td>
<td>32%</td>
</tr>
<tr>
<td>HVAC Description</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central ducted, gas boiler Constant Air Volume AHU</td>
<td>Central ducted, electric boiler (heat pump) Variable Air Volume AHU</td>
<td></td>
</tr>
<tr>
<td>Chiller Efficiency</td>
<td>COP 3.0</td>
<td>COP 6.0</td>
</tr>
<tr>
<td>Boiler Efficiency</td>
<td>Gas, 75% efficient</td>
<td>Elec, IPLV 4.0</td>
</tr>
<tr>
<td>Hot water consumption (L/person/day)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Domestic Hot Water Efficiency</td>
<td>Gas (75%)</td>
<td>Electric, COP=4.0</td>
</tr>
<tr>
<td>Infiltration</td>
<td>Air Changes per Hour (ACH)</td>
<td>1</td>
</tr>
</tbody>
</table>

### TABLE 5.11

Post 1980 office

<table>
<thead>
<tr>
<th>Building Parameter</th>
<th>Base</th>
<th>Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Building Fabric</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walls</td>
<td>Uninsulated curtain wall</td>
<td>N/A (fully glazed)</td>
</tr>
<tr>
<td>Roof</td>
<td>Uninsulated concrete parapet</td>
<td>Insulate to R4.6</td>
</tr>
<tr>
<td>Glazing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-value</td>
<td>5.6 W/m²K</td>
<td>5.6 W/m²K</td>
</tr>
<tr>
<td>SHGC</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W/m²</td>
<td>12</td>
<td>2.67</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W/m²</td>
<td>15 (BCA)</td>
<td>3</td>
</tr>
<tr>
<td>Glazing extent</td>
<td>73%</td>
<td>73%</td>
</tr>
<tr>
<td>HVAC Description</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central ducted, gas boiler Constant Air Volume AHU</td>
<td>Central ducted, electric boiler (heat pump) Variable Air Volume AHU</td>
<td></td>
</tr>
<tr>
<td>Chiller Efficiency</td>
<td>COP 3.0</td>
<td>COP 6.0</td>
</tr>
<tr>
<td>Boiler Efficiency</td>
<td>Gas, 75% efficient</td>
<td>Elec, IPLV 4.0</td>
</tr>
<tr>
<td>Hot water consumption (L/person/day)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Domestic Hot Water Efficiency</td>
<td>Gas (75%)</td>
<td>Electric, COP=4.0</td>
</tr>
<tr>
<td>Infiltration</td>
<td>Air Changes per Hour (ACH)</td>
<td>1</td>
</tr>
</tbody>
</table>
3.2.4.2 Education

A reference case was determined for each education building type modelled, as described later in this section. Upgrades were then applied as follows:

1. Lighting upgrade
2. Fabric upgrades
3. Services upgrades (HVAC and domestic hot water)

**Education Building Parameters**

Table 5.12 details general parameters which remain constant

<table>
<thead>
<tr>
<th>Building Parameter</th>
<th>Pre 1940</th>
<th>1940 to 1970</th>
<th>Post 1970</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of stories</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Lighting profile</td>
<td></td>
<td></td>
<td>As per Green Star Education</td>
</tr>
<tr>
<td>Occupant density</td>
<td></td>
<td>4 (Green Star Education)</td>
<td></td>
</tr>
<tr>
<td>Occupant profile</td>
<td></td>
<td></td>
<td>As per Green Star Education</td>
</tr>
<tr>
<td>Area</td>
<td></td>
<td>One classroom: 72m²</td>
<td>Two classrooms (Ground and Level 1): 144m²</td>
</tr>
<tr>
<td>Equipment loads and profile</td>
<td></td>
<td></td>
<td>As per Green Star Education</td>
</tr>
<tr>
<td>Occupant Heat Load</td>
<td></td>
<td>Sensible heat [W] 70 as per BCA 2012, Section J</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Latent [W] 60 as per BCA 2012, Section J</td>
<td></td>
</tr>
<tr>
<td>Ventilation (L/s/person)</td>
<td></td>
<td></td>
<td>7.5 as per BCA 2012 (AS1668.2 1998)</td>
</tr>
<tr>
<td>Temperature set points</td>
<td></td>
<td></td>
<td>20-24°C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Parameter</th>
<th>Base</th>
<th>Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Fabric</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walls</td>
<td>Uninsulated masonry</td>
<td>Insulate to R2.5</td>
</tr>
<tr>
<td>Floor</td>
<td>Slab and carpet</td>
<td>Same as base</td>
</tr>
<tr>
<td>Roof</td>
<td>Uninsulated concrete</td>
<td>Insulate to R4.0</td>
</tr>
<tr>
<td>Glazing U-value</td>
<td>6W/m²K</td>
<td>New glazing: 3W/m²K</td>
</tr>
<tr>
<td>SHGC</td>
<td>0.62</td>
<td>New Glazing: 0.4</td>
</tr>
<tr>
<td>Lighting</td>
<td>W/m²</td>
<td>As per Green Star Education</td>
</tr>
<tr>
<td>Glazing extent</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Shading</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal</td>
<td>None</td>
<td>Same as base</td>
</tr>
<tr>
<td>External</td>
<td>None</td>
<td>North: 600mm eaves East/West: 300mm fins</td>
</tr>
<tr>
<td>HVAC Description</td>
<td>Gas boiler heating (radiators), split system cooling</td>
<td>New split systems for heating and cooling</td>
</tr>
<tr>
<td>Split System Efficiency</td>
<td>COP 2.5</td>
<td>COP 4.6</td>
</tr>
<tr>
<td>Boiler Efficiency</td>
<td>Gas, 75% efficient</td>
<td>Refer splits above</td>
</tr>
<tr>
<td>Hot water consumption (L/person/day)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Domestic Hot Water Efficiency</td>
<td>Gas (75%)</td>
<td>Electric, COP=4.0</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Infiltration</td>
<td>Air Changes per Hour (ACH)</td>
<td>1.8</td>
</tr>
</tbody>
</table>
### Table 5.14
Education 1940-1970

<table>
<thead>
<tr>
<th>Building Parameter</th>
<th>Base</th>
<th>Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>Uninsulated masonry</td>
<td>Insulate to R2.5</td>
</tr>
<tr>
<td>Floor</td>
<td>Uninsulated raised timber</td>
<td>Insulate to R2.0</td>
</tr>
<tr>
<td>Roof</td>
<td>Uninsulated metal deck</td>
<td>Insulate to R4.0</td>
</tr>
<tr>
<td>Glazing</td>
<td>U-value: 6 W/m²K, SHGC: 0.62</td>
<td>New glazing: 3 W/m²K, SHGC: 0.4</td>
</tr>
<tr>
<td>Lighting</td>
<td>As per Green Star Education</td>
<td>1.7</td>
</tr>
<tr>
<td>Glazing extent</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Shading</td>
<td>Internal None, External None</td>
<td>Same as base, North: 600mm eaves East/West: 300mm fins</td>
</tr>
<tr>
<td>HVAC Description</td>
<td>Gas boiler heating (radiators), split system cooling</td>
<td>New split systems for heating and cooling</td>
</tr>
<tr>
<td>Split System Efficiency</td>
<td>COP 2.5</td>
<td>COP 4.6</td>
</tr>
<tr>
<td>Boiler Efficiency</td>
<td>Gas, 75% efficient</td>
<td>Refer splits above</td>
</tr>
<tr>
<td>Hot water consumption (L/person/day)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Domestic Hot Water Efficiency</td>
<td>Gas (75%)</td>
<td>Electric, COP=4.0</td>
</tr>
<tr>
<td>Infiltration</td>
<td>2</td>
<td>0.5</td>
</tr>
</tbody>
</table>

### Table 5.15
Post-1970 education

<table>
<thead>
<tr>
<th>Building Parameter</th>
<th>Base</th>
<th>Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>Uninsulated aluminium cladding</td>
<td>Insulate to R2.5</td>
</tr>
<tr>
<td>Floor</td>
<td>Uninsulated raised timber</td>
<td>Insulate to R2.0</td>
</tr>
<tr>
<td>Roof</td>
<td>Uninsulated metal deck</td>
<td>Insulate to R4.0</td>
</tr>
<tr>
<td>Glazing</td>
<td>U-value: 6 W/m²K, SHGC: 0.62</td>
<td>New glazing: 3 W/m²K, SHGC: 0.4</td>
</tr>
<tr>
<td>Lighting</td>
<td>As per Green Star Education</td>
<td>1.7</td>
</tr>
<tr>
<td>Glazing extent</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Shading</td>
<td>Internal None, External None</td>
<td>Same as base, North: 600mm eaves East/West: 300mm fins</td>
</tr>
<tr>
<td>HVAC Description</td>
<td>Gas boiler heating (radiators), split system cooling</td>
<td>New split systems for heating and cooling</td>
</tr>
<tr>
<td>Split System Efficiency</td>
<td>COP 2.5</td>
<td>COP 4.6</td>
</tr>
<tr>
<td>Boiler Efficiency</td>
<td>Gas, 75% efficient</td>
<td>Refer splits above</td>
</tr>
<tr>
<td>Hot water consumption (L/person/day)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Domestic Hot Water Efficiency</td>
<td>Gas (75%)</td>
<td>Electric, COP=4.0</td>
</tr>
<tr>
<td>Infiltration</td>
<td>2</td>
<td>0.5</td>
</tr>
</tbody>
</table>
between the base case and the retrofit case in the education models.

**Education Pre-1940**

Table 5.13 details variables used to model the base case and retrofits for the Pre-1940 Education building type.

**Education 1940-1970**

Table 5.14 details variables used to model the base case and retrofits for the 1940-1970 Education building type.

**Education Post-1970**

Table 5.15 details variables used to model the base case and retrofits for the Post-1970 Education building type.

---

### TABLE 5.16

**Shopping centre parameters**

<table>
<thead>
<tr>
<th>Building Parameter</th>
<th>Shopping Centre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of stories</td>
<td>1</td>
</tr>
<tr>
<td>Lighting profile</td>
<td>As per Green Star Retail</td>
</tr>
<tr>
<td>Occupant density</td>
<td>4 (Green Star Retail)</td>
</tr>
<tr>
<td>Occupant profile</td>
<td>As per Green Star Retail</td>
</tr>
<tr>
<td>Area</td>
<td>9840m²</td>
</tr>
<tr>
<td>Equipment loads and profile</td>
<td>As per Green Star Retail</td>
</tr>
<tr>
<td>Occupant Heat Load</td>
<td>70 as per BCA 2012, Section J</td>
</tr>
<tr>
<td>Latent [W]</td>
<td>60 as per BCA 2012, Section J</td>
</tr>
<tr>
<td>Ventilation [L/s/person]</td>
<td>7.5 as per BCA 2012 (AS1668.2 1998)</td>
</tr>
<tr>
<td>Temperature set points</td>
<td>20-24°C</td>
</tr>
</tbody>
</table>

### TABLE 5.17

**Shopping Centre**

<table>
<thead>
<tr>
<th>Building Parameter</th>
<th>Base</th>
<th>Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Fabric</td>
<td>Aluminium clad, R1.25</td>
<td>Insulate to R3.1</td>
</tr>
<tr>
<td>Roof</td>
<td>Uninsulated concrete</td>
<td>Insulate to R4.0</td>
</tr>
<tr>
<td>Glazing U-value</td>
<td>5.7 W/m²K</td>
<td>5.7 W/m²K</td>
</tr>
<tr>
<td>SHGC</td>
<td>0.61</td>
<td>0.32</td>
</tr>
<tr>
<td>Skylights U-value</td>
<td>6.9W/m²K</td>
<td>6.9W/m²K</td>
</tr>
<tr>
<td>SHGC</td>
<td>0.83</td>
<td>0.35</td>
</tr>
<tr>
<td>Lighting: Tenancy W/m²</td>
<td>35</td>
<td>5.3</td>
</tr>
<tr>
<td>Lighting: Circulation W/m²</td>
<td>22</td>
<td>3.75</td>
</tr>
<tr>
<td>Glazing extent</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>HVAC Description</td>
<td>Rooftop package units with gas boiler heating hot water</td>
<td>New rooftop package units (for heating and cooling)</td>
</tr>
<tr>
<td>Packaged System Efficiency</td>
<td>COP 2.3</td>
<td>COP 4.0</td>
</tr>
<tr>
<td>Boiler Efficiency</td>
<td>Gas, 75% efficient</td>
<td>Elec, IPLV 4.0</td>
</tr>
<tr>
<td>Hot water consumption L/person/day</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td>Domestic Hot Water Efficiency</td>
<td>Gas (75%)</td>
<td>Electric, COP=4.0</td>
</tr>
<tr>
<td>Infiltration: Tenancy Air Changes per Hour (ACH)</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Infiltration: Tenancy Air Changes per Hour (ACH)</td>
<td>2</td>
<td>0.1</td>
</tr>
</tbody>
</table>
3.2.4.3 Shopping Centre

A reference case was determined for each education building type modelled, as described later in this section. Upgrades were then applied as follows: 1. Lighting upgrade 2. Fabric upgrades 3. Services upgrades (HVAC and domestic hot water) 3.4. Supermarket upgrades

Shopping Centre Parameters

Table 5.16 details general parameters which remain constant between the base case and the retrofit case in the shopping centre model. Table 5.17 details variables used to model the base case and retrofits for the shopping centre.

Supermarket Upgrades

Given the complex thermal interactions in a supermarket between space conditioning refrigeration, lighting and other equipment, it was not possible to accurately model a supermarket and simulate its performance in IES VE. Instead the supermarket component was added into the shopping centre as a single unit, denoted by a single energy intensity value that was altered post retrofit. A meeting was held between building modellers at GHD and WSP Built Ecology, BZE, and Alan Pears (energy efficiency expert). The meeting evaluated data sets of a large Australian supermarket company and assessed the energy intensity range. It was assumed that the measures implemented in the best performing 20% of supermarkets could be readily implemented across the entire supermarket building stock. This would lead to an overall saving of 35%. Given the data considered in this analysis was over ten years old and that the Buildings Plan is proposing the implementation of air-locks, closed display cases, and LED lighting, it was proposed that a further 20% saving on top of the best performing energy intensity was achievable. The final post retrofit energy intensity was thus 500kWh/m².

Analysis of the annual reports of Woolworths and Coles provided an estimate for the 2011 energy intensity for supermarkets of 860kWh/m². This agrees well with the cited 3.3GJ/m² at Part 3, Section 4.4.

3.3 Results

3.3.1 Retail

FIGURE 5.17 (RIGHT)

Retail results

<table>
<thead>
<tr>
<th>Component</th>
<th>Prior to Retrofit</th>
<th>Post-Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supermarket</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic H/W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ZCA MODELLING RESULTS OF RETROFIT SEQUENCES: OFFICE BUILDINGS

BRISBANE — PRE-1945 OFFICE TYPE

SYDNEY — PRE 1945 OFFICE TYPE

BRISBANE — 1945 - 1980 OFFICE TYPE TYPE

SYDNEY — 1945 - 1980 OFFICE TYPE TYPE

BRISBANE — 1980 - 2000 OFFICE TYPE

SYDNEY — 1980 - 2000 OFFICE TYPE
3.3.2 Office

Figure 5.18 (LEFT)
Office Results
ZCA MODELLING RESULTS OF RETROFIT SEQUENCES — EDUCATION BUILDINGS

**BRISBANE — PRE-1940 — EDUCATION TYPE**

**SYDNEY — PRE-1940 — EDUCATION TYPE**

**BRISBANE — 1940-1970 — EDUCATION TYPE**

**SYDNEY — 1940-1970 — EDUCATION TYPE**

**BRISBANE — 1970-TODAY — EDUCATION TYPE**

**SYDNEY — 1970-TODAY — EDUCATION TYPE**

Below is Figure 5.17. Make 5.18 identical to this file please.
3.3.3 Education

Figure 5.19 (Left)

ZCA MODELLING RESULTS OF RETROFIT SEQUENCE — EDUCATION BUILDINGS

3.3.3 Education

Figure 5.19 (LEFT)
4 Onsite energy generation

4.1 Solar

As discussed in Part 3, the BZE Buildings Plan is based on a comprehensive uptake of solar PV over a ten-year period. The potential installed capacity is calculated by estimating the area of suitable roofs, and the area of solar panels that can fit using specific configurations. Annual energy generation is then estimated, and compared against building energy consumption. For further methodology details, please refer to Appendix 8.

4.1.1 Building Footprint

Residential floor areas for 2011 were obtained from the ABS (Australian Bureau of Statistics). For commercial and industrial footprint, two sources of data are available. First, the Valuer General’s Office of Victoria (VGO) provides floor area statistics for Victoria. Second, NEXIS provides approximate footprint and floor area data for the whole of Australia. For more details refer to Section 3.1.

For institutional buildings, the footprint was calculated by assuming the average number of levels. For hospitals, schools and universities, this was 5, 2 and 2.86 respectively. The results are summarised in Table 5.18.

4.1.2 Suitable Roof space

The most suitable roof surfaces for solar PV generation are those that:

- Are at least 4m² in size,
- Receive at least 4kWh/m²/day of solar radiation on average,
- Have a simple shape, and
- Are at least 2m wide.

There are few studies available analysing what proportion of roof space meets this criteria. However Boroondara and Port Philip councils in Melbourne have done this, using airborne LIDAR data and computer analysis, through a company named Entura. This included calculated shade paths from neighbouring buildings and trees.

On commercial buildings, flat roof surfaces at least 300m² in area and receiving solar radiation of at least 3kWh/m²/day are also considered suitable.

Using the above criteria, the results for the City of Boroondara are shown in Table 5.19 “Proportion Factors of the City of Boroondara”.

The data for Port Phillip is shown in the Table 5.20.

The Proportion factors for the City of Boroondara have been selected, and are used in subsequent analysis throughout Australia. This is a conservative assumption, as this municipality contains many tall trees and older houses with complex roof geometries. Refer to Figure 5.20.

<table>
<thead>
<tr>
<th>State</th>
<th>Residential</th>
<th>CBD Non-Residential</th>
<th>Non-CBD Non-Residential</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW</td>
<td>393</td>
<td>0.56</td>
<td>25.1</td>
<td>418</td>
</tr>
<tr>
<td>VIC</td>
<td>319</td>
<td>0.45</td>
<td>24.4</td>
<td>344</td>
</tr>
<tr>
<td>QLD</td>
<td>279</td>
<td>0.31</td>
<td>16.5</td>
<td>296</td>
</tr>
<tr>
<td>SA</td>
<td>97</td>
<td>0.10</td>
<td>5.2</td>
<td>102</td>
</tr>
<tr>
<td>WA</td>
<td>146</td>
<td>0.14</td>
<td>11.3</td>
<td>157</td>
</tr>
<tr>
<td>TAS</td>
<td>30</td>
<td>0.15</td>
<td>3.0</td>
<td>33</td>
</tr>
<tr>
<td>NT</td>
<td>10</td>
<td>0</td>
<td>0.9</td>
<td>11</td>
</tr>
<tr>
<td>ACT</td>
<td>20</td>
<td>0</td>
<td>1.6</td>
<td>21</td>
</tr>
<tr>
<td>AUSTRALIA</td>
<td>1,293</td>
<td>1.71</td>
<td>88</td>
<td>1,382</td>
</tr>
</tbody>
</table>

Note: This is conservative, since it does not allow for additional building construction during the 10 years of this plan.
4.1.2.1 Usable Space

Since solar panels have discrete sizes and are mounted on racks, solar PV systems cannot cover 100% of the suitable roof area. To identify the usable space, the shapes of 31 typical solar systems were algorithmically matched against each of the Boroondara roof surfaces.

Following the automated processing, a manual desktop inspection of a sample of the automatically selected areas was undertaken to assess accuracy. The automatic process could not generally identify obstructions on the roof (e.g., chimneys or skylights), and some complex roof patterns that would render areas inappropriate for PV solar panels. Manual inspection, using aerial imagery, was considered the most efficient and effective way to account for this limitation.

A standard PV panel used for this analysis is assumed to be 1,665mm x 1,016mm in size, with a rated power of 250W.

The mean value of 62% from this table is used as the residential Usable Space Factor (USF). For commercial buildings, space on roofs is often taken up by plant machinery and cooling towers. Thus a further reduction should be taken into account. We have chosen a conservative estimate of 20% for non CBD buildings.

USF (Non CBD) = 0.8 USF = 50%

In CBD areas, there is also significant shading due to neighbouring buildings. According to a Deakin University study of Melbourne’s CBD district \(^\text{16}\), in a survey of 536

---

### TABLE 5.19
Proportion Factors of the City of Boroondara

<table>
<thead>
<tr>
<th>Type</th>
<th>Floorspace (km²)</th>
<th>Suitable Roofspace (km²)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>8.74</td>
<td>2.06</td>
<td>0.2362</td>
</tr>
<tr>
<td>Commercial</td>
<td>3.11</td>
<td>1.08</td>
<td>0.3470</td>
</tr>
</tbody>
</table>

### TABLE 5.20
Proportion Factors of Port Phillip

<table>
<thead>
<tr>
<th>Type</th>
<th>Floorspace (km²)</th>
<th>Suitable Roofspace (km²)</th>
<th>Proportion Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>3.9</td>
<td>2.3</td>
<td>0.5897</td>
</tr>
<tr>
<td>Commercial</td>
<td>2.6</td>
<td>1.0</td>
<td>0.3846</td>
</tr>
</tbody>
</table>

### TABLE 5.21
Wasted Space Box Plot Results

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Wasted Space</th>
<th>Usable Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>16%</td>
<td>84%</td>
</tr>
<tr>
<td>First Quartile</td>
<td>29%</td>
<td>71%</td>
</tr>
<tr>
<td>Median</td>
<td>34%</td>
<td>66%</td>
</tr>
<tr>
<td>Mean</td>
<td>38%</td>
<td>62%</td>
</tr>
<tr>
<td>Third Quartile</td>
<td>45%</td>
<td>55%</td>
</tr>
<tr>
<td>Max</td>
<td>83%</td>
<td>17%</td>
</tr>
</tbody>
</table>

---

\(^\text{16}\)
### TABLE 5.22

Final roofspace, km²

<table>
<thead>
<tr>
<th>State</th>
<th>Residential</th>
<th>CBD Non-Residential</th>
<th>Non-CBD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW</td>
<td>57</td>
<td>0.03</td>
<td>4.3</td>
<td>62</td>
</tr>
<tr>
<td>VIC</td>
<td>47</td>
<td>0.02</td>
<td>4.2</td>
<td>51</td>
</tr>
<tr>
<td>QLD</td>
<td>41</td>
<td>0.02</td>
<td>2.8</td>
<td>44</td>
</tr>
<tr>
<td>SA</td>
<td>14</td>
<td>0.01</td>
<td>0.9</td>
<td>15</td>
</tr>
<tr>
<td>WA</td>
<td>21</td>
<td>0.01</td>
<td>1.9</td>
<td>23</td>
</tr>
<tr>
<td>TAS</td>
<td>4</td>
<td>0.01</td>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td>NT</td>
<td>2</td>
<td>0</td>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>ACT</td>
<td>3</td>
<td>0</td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>AUSTRALIA</td>
<td>189</td>
<td>0.09</td>
<td>15.14</td>
<td>204</td>
</tr>
</tbody>
</table>

### TABLE 5.23

Panel rated power [MW]

<table>
<thead>
<tr>
<th>State</th>
<th>Residential</th>
<th>CBD Non-Residential</th>
<th>Non-CBD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW</td>
<td>57</td>
<td>0.03</td>
<td>4.3</td>
<td>62</td>
</tr>
<tr>
<td>VIC</td>
<td>47</td>
<td>0.02</td>
<td>4.2</td>
<td>51</td>
</tr>
<tr>
<td>QLD</td>
<td>41</td>
<td>0.02</td>
<td>2.8</td>
<td>44</td>
</tr>
<tr>
<td>SA</td>
<td>14</td>
<td>0.01</td>
<td>0.9</td>
<td>15</td>
</tr>
<tr>
<td>WA</td>
<td>21</td>
<td>0.01</td>
<td>1.9</td>
<td>23</td>
</tr>
<tr>
<td>TAS</td>
<td>4</td>
<td>0.01</td>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td>NT</td>
<td>2</td>
<td>0</td>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>ACT</td>
<td>3</td>
<td>0</td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>AUSTRALIA</td>
<td>189</td>
<td>0.09</td>
<td>15.14</td>
<td>204</td>
</tr>
</tbody>
</table>

### TABLE 5.24

Capacity factors

<table>
<thead>
<tr>
<th>State</th>
<th>Capacity Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW</td>
<td>16.60%</td>
</tr>
<tr>
<td>VIC</td>
<td>15.00%</td>
</tr>
<tr>
<td>QLD</td>
<td>18.58%</td>
</tr>
<tr>
<td>SA</td>
<td>17.96%</td>
</tr>
<tr>
<td>WA</td>
<td>19.36%</td>
</tr>
<tr>
<td>TAS</td>
<td>14.26%</td>
</tr>
<tr>
<td>NT</td>
<td>20.90%</td>
</tr>
<tr>
<td>ACT</td>
<td>17.90%</td>
</tr>
</tbody>
</table>
Note 1. The residential net energy of 13PJ is less than the remaining wood energy of 18PJ (see Table 5.6) in year 10. Hence with this level of solar PV uptake, residential building annual electricity use will be entirely offset by generation.

### TABLE 5.25

Solar PV annual energy generation potential (GWh)

<table>
<thead>
<tr>
<th>State</th>
<th>Residential</th>
<th>CBD</th>
<th>Non-CBD</th>
<th>Total Non-Resi</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW</td>
<td>13,634</td>
<td>7</td>
<td>1,026</td>
<td>1,033</td>
<td>14,667</td>
</tr>
<tr>
<td>VIC</td>
<td>9,999</td>
<td>5</td>
<td>901</td>
<td>906</td>
<td>10,905</td>
</tr>
<tr>
<td>QLD</td>
<td>10,839</td>
<td>4</td>
<td>753</td>
<td>758</td>
<td>11,597</td>
</tr>
<tr>
<td>SA</td>
<td>3,637</td>
<td>1</td>
<td>230</td>
<td>231</td>
<td>3,868</td>
</tr>
<tr>
<td>WA</td>
<td>5,900</td>
<td>2</td>
<td>538</td>
<td>540</td>
<td>6,440</td>
</tr>
<tr>
<td>TAS</td>
<td>895</td>
<td>2</td>
<td>106</td>
<td>107</td>
<td>1,003</td>
</tr>
<tr>
<td>NT</td>
<td>458</td>
<td>0</td>
<td>44</td>
<td>44</td>
<td>502</td>
</tr>
<tr>
<td>ACT</td>
<td>735</td>
<td>0</td>
<td>68</td>
<td>68</td>
<td>804</td>
</tr>
<tr>
<td>AUSTRALIA</td>
<td>46,098</td>
<td>21</td>
<td>3,666</td>
<td>3,687</td>
<td>49,785</td>
</tr>
</tbody>
</table>

Solar PV energy generation compared to building energy consumption, pre- and post-retrofit. All energy types are included except wood.
Panel area and rated power was obtained for several commercially-available panels. The average panel area required to deliver 1kW of rated power was 6.39m². Since the efficiency of available panels is continually improving, an allowance was made for development over the ten-year period, reducing the area for 1kW of rated power to 6.13m² or 4.1% smaller than the current area. This corresponds to 163W/m².

### 4.1.2.4 Total On-site Potential Capacity

The total capacity, in kilowatts, for a full solar PV uptake is obtained by dividing the roof area by the panel performance factor, as shown in Table 5.23.

---

**TABLE 5.26**

Annual PV Generation Potential and Building Energy Consumption [PJ/annum]

<table>
<thead>
<tr>
<th>Building Type</th>
<th>PV Generation Potential</th>
<th>Consumption pre-retrofit</th>
<th>post-retrofit (gross)</th>
<th>post-retrofit (net of PV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>166</td>
<td>386</td>
<td>179*¹</td>
<td>13*¹</td>
</tr>
<tr>
<td>Non-Residential</td>
<td>13</td>
<td>175</td>
<td>98</td>
<td>85</td>
</tr>
<tr>
<td>Total</td>
<td>179</td>
<td>561</td>
<td>277</td>
<td>98</td>
</tr>
</tbody>
</table>

---

**SOLAR PV UPTAKE**

**FIGURE 5.22**

Cumulative installed capacity by year.
4.1.4 Energy Generation Potential

The total annual solar PV energy generated is the rated system power multiplied by the capacity factor, as shown in Table 5.25.

4.1.5 Net Energy Consumption in Buildings

The net grid energy required by buildings is the consumption less the PV generation. Using the residential data from Section 3.1 and non-residential data from Section 3.3, Table 5.25.
5.26, shows the PV generation potential in context with the energy use by buildings.

Solar PV systems on non-residential buildings will be rated in total at 2GW and will generate approximately 4TWh/annum. The total for both building categories is 33GW and 50TWh/annum. Energy import consumption by non-residential buildings will be reduced by 13%. Refer to Figure 5.21.

Future demand for electricity was detailed in Beyond Zero Emissions’ Stationary Energy Plan, totalling 325TWh/annum. That report included only 10TWh of distributed solar PV generation, equating to 3% of demand. This plan’s updated figure of 50TWh equates to 15% of demand.

4.1.6 Installation Rates

To reach full solar PV uptake by 2023, Australia’s solar industry will need to exceed the previous yearly record of solar PV generating capacity installed, which was 974MW in 2012. Figure 5.22 shows an indicative installation path over the ten-year period.

Over the ten years, 31GW of solar PV is installed, averaging 2.8GW per year. At no point does the increase in annual installations exceed 1GW, which first occurs as annual installation rises from 1GW in 2014 to 2GW in 2015. The solar industry has proven its ability to achieve such jumps previously, with 2010 and 2011 amounting to 361% and 202% of the previous year, respectively.

After full solar PV uptake is achieved, rooftop solar PV sales and installation will slow, being limited to sites such as new constructions and upgrades and replacement of existing systems. However, further growth potential exists in other locations, such as above unroofed carparks, and over irrigation channels and dams. The workforce may also transition to large-scale solar PV farms to supply domestic or export demand.
Part 5: Summary of Modelling Findings

4.2 Micro Wind

4.2.1 Introduction

Recent developments in small-scale wind turbine technology and rising electricity prices have led to a renewed interest in the potential for micro wind power generation in urban areas. Traditionally, micro wind generation has received mixed reviews, mostly stemming from an inadequate wind resource at chosen sites combined with the hitherto limitations of micro wind turbines in terms of dealing with relatively high turbulence and their inefficiency in turning mechanical energy into electrical.

Previous unsuccessful installations of micro wind turbines have, in the majority, been at residential roof top heights using horizontal axis wind turbines. To take advantage of the increased wind resource at height and considering the increased turbulence in urban areas, this study has considered the viability of vertical axis micro wind turbines on top of commercial CBD buildings in Melbourne. Given that the commercial viability of any micro wind investment is highly dependent on accurate resource estimation, adequate financial return on investment and compliance with building regulations, these are all considered in this study.

The viability of turbines installed on top of Melbourne’s CBD buildings was assessed, where viability is defined in terms of:

- whether an adequate wind resource exists,
- whether a potential site can withstand additional loads from installed turbines, and
- whether there is a return on investment at least equal to an average residential rate of return.

While similar international studies for rooftop mounted turbines have been performed, the location-dependent nature of the resource calls for detailed local analysis. A more complete write up of this investigation can be found at Appendix 3.

4.2.2 Methodology

The viability of wind turbines on CBD buildings in Melbourne was calculated using the following methodology:

- An analysis of micro wind turbines on the market which can be installed in Australia was undertaken.
- The wind resource in Melbourne CBD has been calculated using computational fluid dynamics (CFD), a faster and cheaper alternative to anemometers on each building, to produce a 3D wind resource map. A geometric model of Melbourne CBD was made,
divided up into strips and CFD simulations were run using those strips for three wind directions; N+NW (resolved in the NNW orientation), W+SW (resolved in the WSW orientation) and S+SE (resolved in the SSE orientation). These wind directions orientated at NNW, WSW and SSE were chosen as they align closely with the orientation of Melbourne’s CBD district, as well as covering 76% of Melbourne’s annual wind. When taking into account that 7% of the remaining 24% is defined as calm, we cover 81% of the wind distribution in Melbourne’s CBD with those directions (wind speeds are taken from the CBD Bureaus of Meteorology anemometer averaged over 30 years). Refer to Figure 5.23.

A preliminary site evaluation has been undertaken to determine the maximum number of turbines which can be installed on a given building given wind resource and load constraints. This was done via a dynamic wind load analysis; the wind load for which each building was designed – and the lateral load and moment created by the installed turbines – were calculated to get an estimate of the loads involved.

The commercial viability of the turbine investment has been assessed, via internal rate of return (IRR) and levelised cost of energy (LCOE) calculations; a number of scenarios have been modelled based on varying policy, cost and technical parameters, incorporating the policies in UK, and Germany.

To get an idea of the numbers of turbines required for an Australia-wide roll out of micro wind in CBD areas and the potential power they could generate, a very simple extrapolation was undertaken using the building distribution of Melbourne. That is calculating the proportion of wind turbines over the total number of buildings and then subsequently the average power output per turbine (for Melbourne).

### 4.2.3 Main Findings

#### 4.2.3.1 Turbine Selection

Quiet Revolution turbines were selected for the study as they meet stringent independent tests whilst being lightweight and are tested in and designed for urban turbulent conditions.

#### 4.2.3.2 Wind Resource

It has been shown that the choice of inlet velocities greatly affect the calculated velocities obtained and in choosing a conservatively low inlet velocity for each direction, we have demonstrated at the very least there is enough wind resource to power 269 turbines in the Melbourne CBD. In addition the turbulence intensity for the whole CBD area was recorded to be under the 45% limit imposed by the Quiet Revolution turbine. The CFD results were verified with a wind tunnel analysis for two sites in conjunction with a high resolution comparison as well as initial resolution and benchmark tests. Refer to Figures 5.25 and 5.26.

#### 4.2.3.3 Power Generation Potential

Power generation potential was determined to be, on average, 63MWh/annum/building. The total of 269 turbines would generate 2.2GWh of electricity per annum, being 14.6% of the electricity consumption of the City of Melbourne. Of note is that annual power output per building is likely to be marginally underestimated here as the E+NE direction was assumed to be ‘calm’ and therefore not considered in this analysis.

---

**TABLE 5.27**

<table>
<thead>
<tr>
<th>Buildings with suitable wind resource</th>
<th>Sydney</th>
<th>Melbourne</th>
<th>Hobart</th>
<th>Perth</th>
<th>Canberra</th>
<th>Adelaide</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40124</td>
<td>22992</td>
<td>2108</td>
<td>5592</td>
<td>5710</td>
<td>4645</td>
</tr>
</tbody>
</table>

**TABLE 5.28**

<table>
<thead>
<tr>
<th>Turbines required</th>
<th>City</th>
<th>Sydney</th>
<th>Melbourne</th>
<th>Hobart</th>
<th>Perth</th>
<th>Canberra</th>
<th>Adelaide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale Factor</td>
<td></td>
<td>1.75</td>
<td>1.00</td>
<td>0.09</td>
<td>0.24</td>
<td>0.25</td>
<td>0.20</td>
</tr>
<tr>
<td>Number Turbines</td>
<td></td>
<td>471</td>
<td>269</td>
<td>24</td>
<td>65</td>
<td>67</td>
<td>54</td>
</tr>
</tbody>
</table>
4.2.3.4 Feasibility of Installation on CBD buildings

Whilst each building was not individually examined by a structural engineer, we conservatively estimated that a building should be built to withstand at least a 3.5% increase in wind loading from turbines on average. This analysis allowed between one and 20 turbines per building, with an average of seven turbines per building. On a case-by-case basis this could increase, meaning that the number of turbines which could be installed on CBD rooftops in Melbourne could be larger than the 269 figure.

4.2.4 Economic Analysis

A full analysis was carried out on a building-by-building basis for a sample of 36 buildings to assess the commercial viability of turbines. This analysis considered both the Internal Rate of Return (IRR) and the Levelised Cost Of Electricity (LCOE). The general conclusion is that Solar PV tends to give a significantly lower LCOE and higher IRR than micro wind. For example Figure 5.27 compares the LCOE of Solar PV and micro wind on a building-by-building basis. It shows that, for Solar PV, most buildings in the sample give relatively low LCOE (eg 27 of the 36 buildings have LCOE of $0.4/kWh or less). For micro wind, very few of the buildings have a comparably low LCOE (3 out of 36 have LCOE of $0.4/kWh or less).

In the light of the relatively poor economic results for wind, several policy alternatives were considered, to evaluate the impact they would have on the economic attractiveness of turbine investment. The scenarios modelled were:

- A government loan guarantee system
- A 25% reduction in turbine installation and maintenance cost
- A tax break for micro wind investment
- A 25% increase in turbine efficiency
- A Feed In Tariff (FIT) of $0.45/kWh

The results of the analysis indicate that the greatest impact on costs come from unit cost reduction, efficiency gains and FIT. From the analysis, with the cost reductions and efficiency gains likely in the next 5-10 years, the average LCOE would fall to $0.38. However, even with these changes, government support is still required to meaningfully improve the economic prospects of micro wind investment.

Extrapolation Australia-wide. Using our stock model, the number of buildings in the capital cities (which have adequate wind resource) are given in the Table 5.27. Combining these figures to scale with the Melbourne figures and the average number of turbines per building (seven), a crude estimate of the number of micro wind turbines needed Australia wide is shown in Table 5.28.

This comes to a total of 950 turbines Australia wide. Taking the average power generated annually per turbine in Melbourne (8.5MWh/annum) as a guide, up to 8.1GWh/annum could be generated via micro wind in Australia.

4.2.5 Conclusion

The total of 950 CBD micro wind turbines Australia wide could generate about 8.1GWh/annum of electricity at an average levelised cost of $0.61/kWh.

4.3 Comparison between Solar PV and Micro Wind on CBD Rooftops

In Central Business Districts (CBD) of the capital cities, Solar PV and micro wind both present opportunities for onsite generation, as detailed in the sections above. However they are not complementary, as rooftop space is limited and wind turbines create shadows that reduce the output of solar panels. This section compares the relative attractiveness of these two technologies.

Methodology. Since the micro wind analysis focused on Melbourne, this is the natural location for comparison. It was estimated that the Melbourne CBD could host 269 turbines each rated at 6.5kW, for a total CBD installed capacity of 1.8MW. At a cost per turbine of $29,000, the total investment is $7.8 million, or $4.46 per watt. The capacity factor is 14.9%. For Solar PV, systems on rooftops in the Melbourne CBD would be rated at 3.8MW, with a total cost of $5.8 million, or $1.54 per watt. The capacity factor is 15%. If micro wind was used exclusively in the Melbourne CBD at the expense of solar PV, the relative increase in cost would be $2 million, or 35% higher. Installed capacity and annual energy generation would be less than half that if solar PV were used instead.

Conclusion. Due to its cost and output advantage, solar PV is selected in this plan. Nevertheless, when considering a specific building, design and wind speed may favour the use of micro wind instead of (or to complement) solar PV. Where micro wind is more favourable, it will reduce costs and/or increase on-site energy generation compared to Solar PV. In this respect, the solar PV analysis is conservative.
5 References

1. The normal over estimation of space conditioning energy in modelling using NatHERS profiles was confirmed in discussion with Lloyd Harrington of Energy Efficient Strategies


5. “A TRaNsient SYstem Simulation program version (TRNSYS) 16.01.” Solar Energy Laboratory, University of Wisconsin, 2013-06-02, http://sel.me.wisc.edu/trnsys


19. Building-related consumption only. Excludes other activities within buildings, eg manufacturing. This excludes charging electric vehicles.


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1 Introduction

In this part, a comparison is drawn between the costs of business as usual (BAU) and the Zero Carbon Australia Buildings Plan (ZCA-b), in both the residential and commercial sectors. One case study investigating a representative house in Melbourne, and another analysing an office space in Sydney are described.

The ZCA Buildings Plan finds impressive energy efficiency improvements can be achieved while eliminating fossil fuel gas from residential and commercial buildings. By necessity, capital investment is required to upgrade the building stock to achieve these outcomes. However, this investment can be recovered through reduced energy cost, associated with the reduced consumption.

This part analyses the costs associated with the upgrade of buildings, and contrasts it with the BAU case. Whilst there are many benefits associated with the Buildings Plan, only the direct savings on energy costs are considered. Indirect benefits such as health and welfare improvements, whilst important, are not considered here. These indirect benefits could translate into significant indirect economic savings. For example, in the non-residential sector, indirect benefits might include increased productivity, competitive advantage (through enhanced reputation, or consumer preferences for more sustainable products) or increased employee satisfaction and staff retention.

The costs of upgrading the building stock are incurred up front, whilst the direct economic benefits, through lower operating costs, are incurred over time. To compare the cash flows of different options with different time profiles, it is necessary to use a discount rate to convert the future costs into present value terms. The discounted cash flows allow the net present costs to be determined and a legitimate comparison to be made over an extended period.

2 Residential Sector

This analysis compares the net present costs associated with the BAU scenario with the ZCA-b scenario for the residential sector. On-going energy costs (operating costs) and the capital cost requirements are needed to complete the net present cost analysis.

2.1 Operating Costs

The operating costs are derived from energy consumption and energy price projections. The results from the National Home Energy Model (see Part 5) form the basis of the consumption projections used in this calculation. The National Home Energy Model analysis includes a breakdown of energy consumption projection by energy type and state, for both BAU and upgrade scenarios, with energy consumption being predominantly by gas and electricity.

Business as usual energy prices are used in both scenarios. Electricity and gas prices are particularly important inputs to determine this cost.

Electricity

The electricity price is assumed to incorporate a low carbon price as the base case for this analysis. This assumes carbon prices will fall in line with linkage to the European carbon markets in 2015. This scenario also assumes the 2020 renewable energy target is maintained at the current 41TWh per annum.

Both retail and wholesale electricity projections (for each state) were used in the analysis. However, as a conservative measure, any reduction in energy consumption was assumed to reduce overall costs by changes in the wholesale cost only. Retail electricity costs include a range of components (e.g. network cost), that are not necessarily directly reduced by reduced consumption. Some of these costs will still need to be recovered, even with substantial declines in energy (and net energy) consumption, resulting from the implementation of a national retrofit program. The existing tariff structures would be expected to change under such a scenario. Without being prescriptive on what these changes may be, they would allow for the fixed costs to be recovered, and may have more cost reflective variable charges. Whilst there are other variable charges in a typical electricity bill, as a conservative measure, only wholesale costs were considered.

Gas

Like electricity, costs include a range of fixed and variable components. However, unlike electricity, in the Buildings Plan, gas is not required at the end of the transition. Parts of the gas network are assumed to be ‘turned off’ progressively,
Part 6: Economic Analysis

as the retrofit program is rolled out. As such, the costs (both fixed and variable) are expected to fall to zero by the end of the transition.

LPG costs, like gas, are also projected to decline to zero over the transition period. Wood consumption is expected to decrease, but not to zero. Further detail of the energy price projections and assumptions used can be found in Appendix 10, Appendix 11, and in Part 2.

The consumption data were combined with energy price projections to evaluate the operating costs under the two different scenarios discussed. Figures 6.1 and 6.2 illustrate the operating costs under the two scenarios, out to 2030. The Buildings Plan is assumed to be implemented from 2013 onwards, with 2012 prices representing the current costs.

Whilst these data were derived from price and consumption

FIGURE 6.3
projections, they are consistent with data from the Household Expenditure Survey\(^4\), (which estimates the 2009-10 expenditure on Electricity, gas and other fuels to be $14 billion).

2.2 Capital Cost

Implementation of the residential buildings plan requires an investment of $234 billion in total, over the transition period. This includes $157 billion for building retrofits, and a further $77 billion for smart grid upgrades and solar system installation costs. Small cost reductions (15%) were assumed for some of the building components and solar system costs. For current niche industries in Australia – double glazing, wall insulation, solar control film – research was conducted to find the average costs in markets where these industries are mature. This gave the expected costs for implementation under the Buildings Plan. Figure 6.3 illustrates the breakdown of costs by the different retrofit and upgrade components. Further details of the capital cost used, and assumptions can be found in the Appendix 9.

Taken over the implementation period, the annual cost of retrofitting the ZCA component is roughly 40% of BAU annual expenditure on renovations ($31 Billion\(^5\)) as reported for 2010. As a conservative measure, it is assumed that the Buildings Plan is entirely additional to BAU renovations. This is likely to result in a significant overestimate of cost. However it is not possible to decisively and robustly determine which upgrades could be integrated with renovations, and what the cost saving might be. Approximately $2 billion was spent annually on building repairs and maintenance\(^6\), which is assumed to continue under the BAU scenario. Buildings plan repair and maintenance costs have been incorporated within the building retrofit costs.

2.3 Net Present Cost

The net present cost over a 30 year period was evaluated. A three percent (real) discount rate was used. Whilst this is a low discount rate compared with the commercial rate, it is consistent with current home loan rates (in real terms).

Three different scenarios were evaluated. Scenario one compares the net present costs of BAU with that for the retrofit program (ZCA–b) under the same wholesale electricity price assumptions. The second scenario compares the net present costs of BAU with that of the retrofit program, but assuming the wholesale electricity prices are consistent with a “low demand” scenario - a reasonable scenario for the building plan scenario. A third scenario compares net present cost of BAU with that for the complete residential upgrade, including solar installation and smart grid upgrade and assuming ‘low demand’ wholesale electricity prices. In practice, smart grid upgrades costs are likely to be reflected in retail electricity prices. For the purpose of this analysis however, this cost was represented in the capital cost of the retrofit program.

### RESIDENTIAL NET PRESENT COSTS: SCENARIO ONE

**COMPARISON OF NET PRESENT COSTS WITH BASE CASE WHOLESALE ELECTRICITY PRICES**

![Figure 6.4](image1.png)

### RESIDENTIAL NET PRESENT COSTS: SCENARIO TWO

**COMPARISON OF NET PRESENT COSTS, UNDER LOW DEMAND ELECTRICITY PRICE SCENARIO**

![Figure 6.5](image2.png)
Figure 6.4 shows a comparison between the Net Present Costs for Scenario 1. Figure 6.5 shows the comparison for Scenario 2, and Figure 6.6 shows the comparison for Scenario 3.

The Buildings Plan has the same net present cost as the BAU case, under the conservative assumptions used for scenario one. However, this does not include indirect benefits, and is considered a very conservative estimate given the assumptions around electricity prices and capital costs.

When it includes a comprehensive uptake of solar PV (and including smart grid upgrades), the residential buildings plan returns a net present saving of $40 billion. This is a highly conservative value, given the modest capital cost reductions assumed for solar, and given that only wholesale energy costs were assumed to be avoided.

Electricity prices contribute similar net present cost in either scenario (except were solar contributes considerably to household energy consumption). Whilst only BAU electricity prices are presented here, other scenarios (including high carbon price or a 100% renewable energy stationary energy sector, such as that proposed in the ZCA Stationary Energy Plan) result in similar benefits. Wholesale electricity price projections have little impact on the overall relative cost difference between BAU and the residential buildings plan.

**2.4 Example Case: Melbourne Home**

This hypothetical case illustrates the energy and cost savings for a house in Melbourne. The house was assumed to have average ceiling insulation and no wall or floor insulation. It was also assumed to have gas heating, gas hot water and gas cooking, typical of many homes in Melbourne. The floor space was assumed to be 190m², typical for detached homes in Victoria. For a real-world residential case study see Appendix 4.

**2.4.1 Retrofit**

The major retrofit actions included fabric upgrades and replacement of gas services with electric services. Ceiling insulation was assumed to be upgraded. The cost of the various upgrades is listed in Table 6.1.

<table>
<thead>
<tr>
<th>Retrofit upgrades</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Glazing</td>
<td>$10,642</td>
</tr>
<tr>
<td>Insulation</td>
<td>$8,713</td>
</tr>
<tr>
<td>Curtains, Pelmets Awnings</td>
<td>$3,039</td>
</tr>
<tr>
<td>Draught Proofing</td>
<td>$358</td>
</tr>
<tr>
<td>Reverse Cycle A/C Multi Split system</td>
<td>$8,755</td>
</tr>
<tr>
<td>Cooktop</td>
<td>$1,108</td>
</tr>
<tr>
<td>Heat Pump Hot Water Service</td>
<td>$3,968</td>
</tr>
<tr>
<td>Total</td>
<td>$36,582</td>
</tr>
</tbody>
</table>

It should be noted that this scenario, with the full retrofit being applied, is the most costly. Across the residential stock, replacements for heating, hot water and cooking systems are only proposed for existing gas appliances. Furthermore, some houses will already have sufficient ceiling insulation, or good quality single glazed windows suitable for secondary glazing (about half the cost of double glazing).

**2.4.2 Solar System**

A solar system for this home was sized according to principles established in Part 5 Section 4. Based on the suitable and usable area (see Table 6.2), and a solar power density of 163 watts per m², the house was assumed to have a 4.5 kW system. The current installed cost for a system this size in Victoria is $2.30/watt unsubsidised (or $1.76/watt, including SRES subsidy), for a total cost of $10,350. The unsubsidized cost was used as a conservative measure.
REDUCTION IN ENERGY CONSUMPTION RESULTING FROM RETROFIT

![Graph showing energy consumption reduction from retrofit](image)

**FIGURE 6.7**

REDUCTION IN ENERGY CONSUMPTION RESULTING FROM RETROFIT

4.5 KW SOLAR SYSTEM

![Graph showing energy consumption reduction with 4.5 kW solar system](image)

**FIGURE 6.8**
Part 6: Economic Analysis

The net present cost over a 30 year period was evaluated for three different scenarios: BAU, ZCA-b (building upgrade only) and ZCA-b+s (building upgrade plus solar system installation). The discount rate used in the calculation was the current mortgage rate, the typical cost of capital for home owners. Figure 6.11 illustrates the net present costs, per home, for three different scenarios.

By implementing the full retrofit program, this house realizes net present savings of approximately $3,000 dollars over the 30 year period. Incorporating a 4.5 kW solar system increases the savings to over almost $6,000.

This comparison assumes the upgrade is done at today’s costs. No cost reductions were assumed, except for double glazing and wall insulation (due to industry scale up) and conservative assumptions on the value of avoided electricity were used. Even with these assumptions, the upgrade program realizes a net present saving relative to the BAU case. Under a large scale deployment of energy efficiency upgrades, cost reductions could be expected, and higher utility costs might be avoided, resulting in even greater savings.

### 2.4.3 Impact on Energy Consumption

The upgrade results in significant reduction in energy consumption from 206.4 MJ/day to 51.5 MJ/day and completely eliminates gas usage. Figure 6.7 illustrates the impact of the retrofit upgrades on the average daily energy consumption for the Melbourne home. Figure 6.8 illustrates the impact of the retrofit program alongside the installation of a 4.5 kW solar system (and the net impact on daily energy consumption).

### 2.4.4 Annual Utility Bill

The same energy price assumptions were used as in the sector wide residential comparison. Importantly, this includes the assumption that only the wholesale cost of electricity was avoided (for any avoided energy). Figures 6.9 and 6.10 illustrate the difference between utility costs for the Melbourne home under BAU, and after the retrofit. This particular household would avoid over $1500 of utility expenses annually, (increasing to almost $2000 annually, by 2030).

### 2.4.5 Net Present Costs

<table>
<thead>
<tr>
<th>Suitable and usable space for solar PV system</th>
<th>Ratio</th>
<th>Area [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Footprint</td>
<td>-</td>
<td>189.7</td>
</tr>
<tr>
<td>Suitable Roof space</td>
<td>0.23</td>
<td>44.8</td>
</tr>
<tr>
<td>Usable Space</td>
<td>62%</td>
<td>27.8</td>
</tr>
</tbody>
</table>

Figure 6.9
Annual utility costs per home, BAU vs ZCA-b (2013)

Figure 6.10
Annual utility costs per home, BAU vs ZCA-b (2020)
FIGURE 6.11
Comparison of net present cost per home for three scenarios.

FIGURE 6.12 (LEFT) & FIGURE 6.13 (RIGHT)

COMPARISON OF NON-RESIDENTIAL EXPENDITURE FOR ZCA PROGRAM WITH BUSINESS AS USUAL (BAU)
3 Non-residential Sector

This analysis compares the net present cost associated with the Business As Usual (BAU) scenario with the ZCA Buildings Plan (ZCA-b) scenario, for the non-residential sector. As for the residential plan, ongoing energy costs (operating costs) and the capital cost requirements are needed to complete the net present cost analysis.

3.1 Operating Costs

The operating costs are derived from energy consumption and energy price projections. The results from the non-residential stock modelling exercise (Part 5, Section 3) form the basis of the consumption projections used in the following calculations. This analysis included a breakdown of total energy consumption by state under different scenarios. The percentage breakdown of energy use (electricity vs gas) by state was used to determine the gas and electricity consumption under the BAU scenario. Further details on energy consumption projections can be found in the Appendix 5.

Again, BAU energy prices are used in both scenarios. However, in this analysis, commercial utility costs were assumed (which are at a discount relative to retail prices).

3.1.1 Electricity

The same electricity price scenario as the retail analysis was used as the base case for the non-residential analysis using a "low" carbon price linked to the European carbon markets and assuming that the 2020 renewable energy target is maintained at the current 41 TWh per annum. However in this analysis, commercial and wholesale electricity projections (for each state) were used.

A conservative assumption around electricity reduction was also used: any reduction in energy consumption was assumed to reduce overall costs by changes in the wholesale value only. Commercial electricity costs also include a range of components (e.g. network cost) that are not necessarily directly reduced by reduced consumption.

3.1.2 Gas

Gas is also not required in the non-residential sector at the end of the transition. Gas-related costs (both fixed and variable) are expected to fall to zero by the end of the transition, unlike electricity costs. Further detail of the commercial energy price projections used can be found in Appendix 11.

The consumption data were combined with energy price projections to evaluate the operating costs under the different scenarios. Figures 6.12 and 6.13 illustrate the operating costs under the two scenarios – BAU and ZCA-b.

3.2 Capital Costs

The non-residential buildings plan requires an investment of $34.4 billion in total over the transition period. This includes $29.6 billion for building retrofits and a further $5 billion solar system installation costs. Figure 6.14 illustrates the breakdown of costs by the different non-residential building types, and the cost of solar installation. Further details of the capital cost used, and assumptions can be found in Part 5 Section 3.

3.3 Net Present Cost

The net present cost over a 30 year period was evaluated. The costs were evaluated using a low discount rate 5% (real), with sensitivity of analysis at 3% and 7%. This is consistent with the recommended approach for analysing building fabric upgrades and costs (Pitt and Sherry, 2010).
“Pathway to 2020 for low-energy, low-carbon buildings. Indicative stringency study” pp74). The higher discount rate (7%) is reflective of commercial discount rates and cost of capital, whereas the lower discount rate is more reflective of governmental discount rates and cost of capital.

As with the residential analysis, three different scenarios were evaluated. The first scenario compares the net present cost of BAU with the retrofit program under the same wholesale electricity price assumptions (“low carbon price”). The second scenario compares the net present cost of BAU with the retrofit program, but assuming the wholesale electricity prices are consistent with a “low demand” scenario. A final scenario compares the net present cost of the non-residential upgrades (including solar installation), with “low demand” electricity prices.
3.4 Example Case: Sydney Office (1980 - 2000 Curtain Wall Building)

This hypothetical case illustrates the energy and cost savings achievable for an office building in the Sydney CBD. It looks at a curtain wall building (1980-2000 stock), with 9000 m² of lettable area, over 10 levels. The building was assumed to use gas to supply heating services.

### 3.4.1 Retrofit

The cost of the retrofit program for this building type is $1.29 million. This includes the costs of a 9 kW solar system, without subsidy. This solar system sizing was based on Part 5 Section 4, and takes into consideration the impact of shading of surrounding buildings. A breakdown of the cost of the various upgrades is listed in Table 6.3 below.

<table>
<thead>
<tr>
<th>Retrofit upgrades</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low e window film</td>
<td>$46,303</td>
</tr>
<tr>
<td>Insulate ceilings</td>
<td>$32,400</td>
</tr>
<tr>
<td>Draught proofing</td>
<td>$2,000</td>
</tr>
<tr>
<td>New water cooled chiller</td>
<td>$405,000</td>
</tr>
<tr>
<td>Heat pump boiler replacement</td>
<td>$180,000</td>
</tr>
<tr>
<td>CAV to VAV</td>
<td>$450,000</td>
</tr>
<tr>
<td>VSDs</td>
<td>$49,500</td>
</tr>
<tr>
<td>Economy Cycle</td>
<td>$9,900</td>
</tr>
<tr>
<td>EMS</td>
<td>$28,000</td>
</tr>
<tr>
<td>LED Lights</td>
<td>$44,280</td>
</tr>
<tr>
<td>Light Occupancy Sensors</td>
<td>$6,933</td>
</tr>
<tr>
<td>Heat Pump Domestic Hot Water</td>
<td>$17,500</td>
</tr>
<tr>
<td>Solar System</td>
<td>$20,700</td>
</tr>
<tr>
<td>Total</td>
<td>$1,292,516</td>
</tr>
</tbody>
</table>

Under lower discount rates, the non-residential plan returns net savings across the sector, even under the conservative assumptions. A national rollout may be expected to further lower some costs (including PV) and higher utility savings, above wholesale value only, would realize even greater benefits.

Figure 6.15 shows a comparison between the Net Present Costs for Scenario 1. Figure 6.16 shows the comparison for Scenario 2, and Figure 6.17 shows the comparison for Scenario 3.

Even under at relatively high discount rates, the net present cost of the non-residential upgrade plan is similar to BAU. Again, this is considered a very conservative estimate given the assumptions around electricity prices and capital costs (and it does not include indirect savings and benefits). The economics of the non-residential upgrade also improve if compared with a “low demand” energy price forecast, and including solar installation.

Under lower discount rates, the non-residential plan returns net savings across the sector, even under the conservative assumptions. A national rollout may be expected to further lower some costs (including PV) and higher utility savings, above wholesale value only, would realize even greater benefits.

**COMPARISON OF NET PRESENT COSTS, INCLUDING SOLAR INSTALLATIONS, WITH ‘LOW DEMAND’ WHOLESALE ELECTRICITY PRICES:**

**SCENARIO THREE**

**FIGURE 6.17**
3.4.2 Impact on Energy Consumption

The upgrade program results in a reduction in energy consumption from 404.5 MJ/m² per annum to 91.5 MJ/m² per annum (or 112 kWh/m² per annum to 91.5 MJ/m² per annum). The upgrade results in a energy consumption reduction of 77%, and completely eliminates gas consumption. Figure 6.18 illustrates the impact of the retrofit upgrades on annual energy consumption per square meter, for the Sydney curtain wall office building.

3.4.3 Annual Utility Bill

The same energy price assumptions were used as in the sector wide commercial comparison, (including the conservative assumption that only the wholesale cost of electricity was avoided). Figure 6.19 shows the difference between utility costs for the Sydney example under BAU, and after the retrofit, illustrating a utility cost saving of $66,000 annually. This saving increases to above $90,000 per annum over a 30-year period.

3.4.4 Net Present Cost

The net present cost of providing energy over a 30 year period was evaluated. A range of discount rates was used in the calculation from 3-7% (in real terms), as in the sector wide analysis. Relative to the BAU utility costs, this retrofit program achieves an internal rate of return of 5% (in nominal real terms).

This particular retrofit program is assumed to occur in isolation. There are no assumptions on cost reductions (in either building upgrades or solar costs), except for solar control film that could be expected in a national implementation of the Buildings Plan. The reduction in electricity consumption is also assumed to only offset the wholesale electricity consumption. Even with these assumptions, the economics work out quite similar.

The upgrade program is worthwhile at a sector-wide level (see Non-residential Sector analysis). With a national roll out and with targeted government support, this particular retrofit program would also be economically viable at high (7%) discount rates.

![Impact of retrofit upgrades on energy consumption](image-url)
Part 6: Economic Analysis

**ANNUAL UTILITY COSTS FOR SYDNEY**

**BAU VS ZCA 2013**

![Utility Costs Chart](image)

**Figure 6.19**
Annual utility costs, Non-residential BAU vs ZCA 2013

**NET PRESENT COST**

**SYDNEY OFFICE (1980 - 2000 CURTAIN WALL BUILDING)**

![Net Present Cost Chart](image)

**Figure 6.20**
Comparison of net-present costs – non-residential
4 Stationary Energy Plan Implications

The ZCA Stationary Energy Plan specified a ten-year capital expenditure requirement of $370 billion. This plan involved an extensive modelling exercise to determine the technology mix, and ultimately cost of supplying Australia’s energy mix with 100% renewable energy. This modelling exercise was predicated on supplying an annual demand of 325 TWh of electricity, and incorporated conservative estimations of what energy efficiency gains could be made in the commercial and residential sectors. Since then, the comprehensive analysis contained within the Buildings Plan suggests that through efficiency measures alone, demand could be reduced by a further 43.5 TWh. This would, in effect, lower the overall cost Stationary Energy Plan, as less energy generation infrastructure would be necessary.

Whilst remodeling the Stationary Energy Plan is beyond the scope of this study, an estimation of the cost reduction can be made. This can be done by assuming that the overall cost of supplying a unit of electricity (MWh) in a 100%-renewable energy system is constant (and is not affected by absolute total MWh demand). Under these conditions, the capital investment required in the Stationary Energy Plan would be expected to fall by $37 billion.

5 Labour Estimates

In depth estimates of the labour requirements of the Buildings Plan are beyond the scope of this report. Nonetheless, the calculated labour cost of implementing the Buildings Plan can be used as a guide. The total estimated labour cost was found to be $54 Billion over ten years. Assuming a standard tradesperson rate of $60 per hour and an average work week of 38 hours, this labour cost equates to approximately 500,000 job hours over ten years. On a yearly, full-time-equivalent basis this is 50,000 positions.

Further investigation into the resource implications of the ZCA Buildings Plan, including materials and manufacturing capacity, is expected to be undertaken by Beyond Zero Emissions and this could include a detailed analysis of the labour requirements. Such an analysis would assess individual labour sectors and Australia’s current capacity in each of them.
6 References


# Appendices

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</tbody>
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Appendices

Appendix 1 - Residential energy modelling
This is a description of the national residential energy model created by Energy Efficient Strategies (EES). This appendix is principally referred from Part 5 Section 2. This text has been provided by EES.

This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_1.pdf

Appendix 2 - Climate Zone coverage
This describes how the standard BCA climate zones relate to the different climate zones used in this plan. This appendix is principally referred from Part 5.

This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_2.pdf

Appendix 3 - Wind energy study
This is a study undertaken by Vipac on urban wind energy potential. This appendix is principally referred from Part 3 Section 8.2. This text has been provided by Vipac.

This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_3.pdf

Appendix 4 - Residential Case Study
This is a case study of a single home in Melbourne which has been retrofitted along the lines proposed in this plan.

This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_4.pdf

Appendix 5 - Non-residential Stock Model
This describes in more detail the modelling which informs the estimate of non-residential energy consumption. This appendix is principally referred from Part 5 Section 3.

This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_5.pdf

Appendix 6 - Hot water system modelling results
This describes in more detail the modelling performed to a) inform the decision about recommended hot water system type, and b) estimate the hot water energy requirements under this plan. This appendix is principally referred from Part 5 Section 2.2.

This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_6.pdf
Appendix 7 - Reference home model
This describes the set of computer models used as main reference for the assessment of residential energy use. This appendix is principally referred from Part 5 Section 2.1.
This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_7.pdf

Appendix 8 - Rooftop solar resource model
This describes the modelling performed by Entura which informs this plan's estimate of the national roof-top resource available for the installation of solar PV. This appendix is principally referred from Part 5 Section 4.1.
This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_8.pdf

Appendix 9 - Supporting information on Sankey diagram for residential HVAC
This provides supporting information related to the Sankey-style energy flow diagram shown at Part 3 Section 3.1.
This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_9.pdf

Appendix 10 - Retrofit costings
This provides the raw costings data which informs the estimate of retrofit costs in Part 6.
This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_10.pdf

Appendix 11 - Gas price analysis
This provides detail about the analysis of future gas price which informs the business-as-usual case in the economic analysis at Part 2 Section 7 and Part 6.
This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_11.pdf

Appendix 12 - Electricity price analysis
This provides detail about the analysis of future electricity price which informs the business-as-usual case in the economic analysis at Part 2 Section 7 and Part 6. This was provided by Energy Action.
This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_12.pdf

Appendix 13 - Economic Analysis
This provides supporting material which informs the detailed economic analysis at Part 6 which compares business as usual economics, with the cost of undertaking the Buildings Plan retrofit.
This appendix can be found online at http://media.bze.org.au/bp/bp_appendix_13.pdf
The Zero Carbon Australia Buildings Plan will:

◉ Halve Australia’s building energy use

◉ Fully retrofit existing buildings for higher comfort

◉ Install 33GW of rooftop solar

◉ Raise the bar on appliance performance

◉ Protect against rising gas prices

◉ Go gas free by installing highly efficient electric technologies

◉ Give energy freedom to millions of home owners

◉ Create tens of thousands of new jobs