Hybrid Buildings: Pathways for greenhouse gas mitigation in the housing sector

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EXECUTIVE SUMMARY

Hybrid buildings are defined here as residential buildings that have the capacity to supply, in total, the annual operating energy requirements of their occupants by utilising locally generated (low or zero emission) energy sources. Operating energy includes energy for heating, cooling, lighting and domestic appliances (built-in and plug-in). At times when energy is generated surplus to its occupants’ immediate demands, energy is supplied to the grid and if the dwelling is unable to generate sufficient energy for autonomous operation, energy is received back from the grid.

Project scope

The aim of the Hybrid Buildings project is to develop virtual prototypes of hybrid buildings and assess their potential for becoming the principal agent for achieving significant reduction in the carbon footprint of Australia’s current and future residential building stock.

The challenge is to develop domestic housing which combines design for energy efficiency (building plus appliances) with local energy generation via a range of micro-generation options (including non-renewables such as gas combined heat and power as well as renewables-based technologies linked to solar photovoltaics, wind turbines, solar thermal hot water, ground source heating/cooling and hydrogen fuel cells).

The focus is on a carbon-based eco-efficiency analysis of alternative configurations of a hybrid building, where variations in performance are explored across different types of residential structure (detached, medium density, high-rise) and floor area, different energy ratings of the shell, the number and mix of domestic appliances in use and the type of distributed generation technology employed. The most prospective intervention points for delivering carbon neutral and zero carbon residential development are identified.

Context

The residential sector has been identified as the most prospective for significant reductions in energy use in Australia (McKinsey & Co., 2008) and clearly there are multiple routes to effect this reduction; principal among these are energy efficiency and technology substitution for energy generation. The Energy Efficiency and Greenhouse Working Group (2003) estimated that energy consumption improvements of 15% to 35% could be achieved under the conservative assumptions that only existing technology was used and that the change would pay for itself within four years. Using more optimistic assumptions of new technology application and longer payback periods, energy reductions exceeding 70% were shown to be viable.

There is uncertainty about the role that building and household-oriented energy efficiency initiatives and new low emission and renewables-based distributed energy generation industries can play in achieving Australia’s greenhouse emissions targets within the Carbon Pollution Reduction Scheme (CPRS), which currently does not have specific sector targets. Australia does not currently have a national policy focusing on carbon neutral buildings or developments, unlike other countries such as the United Kingdom (Department of Communities and Local Government, 2006) which are actively pursuing such policies and programs. Under the current CPRS design low cost abatement in one sector of the economy will lower the price of abatement by the economy overall, but some market failures will remain. This will result in some low cost abatement opportunities within the built environment sector not being achieved in the absence of targeted policies or programs. It is in this light that any transition to carbon neutral and zero carbon housing needs to be considered, including whether a ‘zero carbon housing’ target is warranted in Australia.

This project explores the extent to which hybrid buildings can contribute to a de-carbonising of the built environment, as measured by the following key potential outcomes:

- **Net zero energy building**: supplies as much energy to the grid over the course of a year as it uses, without any reference to carbon emissions. This class of building does not preclude use of low emission local energy generation technologies;
• Carbon neutral building: generates sufficient surplus CO$_2$-e free energy over the course of a year that balances any purchase of grid energy (primarily fossil-fuel-based). This recognises the fact that a single dwelling/household may be unable or unwilling to generate sufficient CO$_2$-e free energy to be classed as zero carbon;

• Zero carbon building: uses carbon free energy over the entire year, sufficient in quantity to supply all household energy needs (both dwelling operations and appliances to match any lifestyle). Connection to the grid is primarily in order to supply energy that is surplus to household needs, and for periods of emergency supply when local energy systems may be inoperable.

Metrics
All energy consumed is as metered at the dwelling, whether electricity or gas. The conversion factors for energy used to greenhouse gases (GHGs) emitted are those provided by the state government for usage of delivered electricity and gas in Victoria. All eco-efficiency modelling assumes a carbon price of A$30/tonne which is at the middle level of Garnaut estimates and European ETS prices.

The energy prices used in this study are the 2009 retail prices of a Melbourne energy supplier as regulated by the Victorian state government and published from time to time in the Victoria Government Gazette. Except for one set of future cost scenarios examined in Section 8, rebates and subsidies, including renewable energy certificates, are not included in this study because they are highly changeable and relatively short-lived. Likewise, while feed-in tariffs can affect whether to invest in local energy generation, the current confusion has meant that feed-in tariffs have been largely omitted from this study.

The annual cost used for comparisons of equipment and technologies which have differing lifetimes is the sum of the annual equivalent cost of the purchase and installation costs plus the annual operating costs including energy and maintenance costs.

An indicator of performance used in this study is relative carbon burden in which economic and environmental (CO$_2$-e) costs of a particular configuration of hybrid building are compared, i.e. $ CO_2$-e cost per $1 of asset life cycle cost per year. The definition of the carbon eco-efficiency measure is:

$$\text{Carbon Eco-efficiency} = \frac{\text{CO}_2\text{-e emissions (converted to a carbon cost)}}{\text{Cost of hybrid building (or some component thereof)}}$$

This measure depicts the proportion (percentage) of the total annualised cost of operating a particular category of hybrid building (of which there are several scenarios examined) that can be attributed to the cost of paying for the amount of carbon emissions involved in its operation.

Dwellings
The alternative forms of dwellings investigated were detached single storey, detached two storey, medium density walk-up flat (i.e. middle floor apartment, no lift), and high-rise apartment (i.e. with lift). The alternative performance (heating and cooling) levels of each were 2.5 star performance, representing existing housing stock, 5 star performance, representing current standard, and 7 star performance, indicative of likely future standard.

The available sizes and types of dwellings for which heating and cooling assessments could be made (Tony Isaacs Consulting, 2007a) were typical of their type, i.e. 230, 302, 109 and 110 m$^2$ respectively.

The approach used for estimating heating and cooling loads for each of the three star ratings for each of the four dwelling types were those used in rating operating energy performance of residential building (CSIRO’s AccuRate residential energy rating tool) which models for all day occupancy. Energy used for heating and cooling was provided by the following range of equipment and energy sources: gas ducted heating, electric heating, electric reverse cycle heating, electric cooling, electric evaporative ducted cooling and electric reverse cycle cooling. The efficiencies were obtained from the DEWHA (2008a) report on energy use in the Australian residential sector. Heating and cooling systems plus appliances were common
across detached and medium density dwellings but varied for high-rise apartments, given that, for a majority of such high-rise developments, electricity represents the dominant energy source for space heating and cooling.

**Appliances**
The appliances used in this study were those typically found in dwellings and designed for domestic use.

- **Hot water** – gas storage, gas instant, electric storage and solar thermal;
- **Built-in appliances** – gas cooktop, electric cooktop, electric oven, gas oven, microwave oven, incandescent lighting, halogen lighting, compact fluorescent lighting, LED lighting and common area energy (Class 2 buildings, e.g. high-rise);
- **Plug-in appliances** – refrigerator, freezer, dishwasher, washing machine, clothes dryer, television, computer, home entertainment systems, set top box, games, electric kettle, small miscellaneous and other standby equipment.

For analytical purposes, appliances are characterised in two key respects: operating energy performance, where there is a distinction made between ‘average’ performance (DEWHA, 2008a) and ‘best of breed’, and the range of appliances, differentiating between a ‘basic’ and an ‘affluenza’ set, where an affluenza set of appliances highlights the accumulation of appliances by an increasing proportion of Australian households, e.g. multiple flat screen televisions, refrigerators and lighting, entertainment equipment, pools and spas.

For built-in appliances, a number of alternative scenarios are derived: cooking, where a number of different combinations of appliances are represented (e.g. all gas, all electric, mixture, microwave only) and lighting, where different lighting technologies are featured (e.g. all incandescent, all halogen, all LEDs, or common mix as defined by DEWHA (2008a)).

**Local energy generation**
Local (or distributed) energy generation encompasses a suite of zero and low emission technologies which aim to reduce reliance on a centralised energy supply, reduce emissions and improve energy use efficiency. Local energy generation involves relatively small capacity (<30MW) units typically sited close to the point of consumption (Jones, 2008).

In the present study, both zero emission and low emission local energy technologies are examined. The zero emission technologies considered are solar photovoltaic, wind turbine and solar hydrogen fuel cell. The low emission technologies considered are ground source heat pump (heating and cooling), gas fuel cell and gas reciprocating engine CCHP (heating and cooling). The hot water technologies considered are solar gas boosted and solar electric boosted.

Figure 1 shows the annual CO₂-e generated, saved and produced by the local energy generation technologies. The plant sizes have been set by what is typical of the installations for residential applications, with the result that the capacity of the low emission technologies is much higher as they are designed to be supplied from an external precinct energy supplier close to 100% of locally generated electricity demanded by a typical household.

Payback periods (without consideration of rebates or subsidies) for the various local energy technologies at January 2009 prices are long (20+ years) with only the high capacity precinct installations and solar hot water systems having a payback period about ten years or less. The introduction of a carbon price and a reduction in the future capital costs of local energy technologies (including possible subsidies), which could accompany an increase in local demand and supply, would further reduce a payback calculation, but have not been factored into most analyses, except a final ‘future’ cost scenario which is quite speculative.
Figure 1  CO₂-e from energy used to generate local energy and CO₂-e saved by local energy technologies

Key project questions
This project has been undertaken to respond to four key questions posed by the research sponsors:

1. **What realistic operating energy and GHG performance can be achieved by the building shell?**

For detached single storey dwellings (in Melbourne), a transition from 2.5 to 5.0 star energy rated housing translates to a 56% reduction in annual energy use for heating and cooling (from 65516 MJ/yr to 28894 MJ/yr). A further transition from 5.0 to 7.0 star rated houses saves a further 18% energy. The overall shift from 2.5 star rated housing (considered to be representative of stock built prior to the introduction of home energy ratings in 2004) to 7.0 star rated delivers a 74% reduction in annual energy used for space heating and cooling (from 65516 to 17216 MJ/yr, an energy saving of 48300 MJ/yr per detached dwelling).

The total CO₂-e emissions for buildings together with their appliances are shown in Figure 2, with the medium density dwellings having the lowest emissions. The emissions of the high-rise apartment exceed those of the single storey house, due to the additional energy demand of the common area services and the energy for appliances being primarily sourced from electricity.

With the CO₂-e emissions resulting from the variable energy demands being similar, further analysis on options for local generation for various scenarios of shell efficiency and appliances were restricted to applications involving single storey detached houses, which continue to be the dominant class of housing built in Australia.
2. What realistic energy and GHG performance can be achieved by ‘best of breed’ domestic appliances as part of hybrid buildings?

For domestic hot water heating capable of delivering total household demand, annual energy consumption ranges from 20973 MJ/yr (for gas storage) to 6581 MJ/yr (for solar thermal electric boost). The picture changes completely with respect to CO$_2$-e emissions from hot water heating appliances, where the range extends from 5599 kg/yr (electric storage) to 441 kg/yr (solar thermal gas boost), a reduction of 92%.

Comparison of a basic set of household plug-in appliances that have ‘average’ energy performance versus ‘best of breed’ performance reveals an average annual energy consumption of 9749 MJ/yr as opposed to 6998 MJ/yr, a difference of 28%. In GHG terms, the difference is 3910 kg CO$_2$-e versus 2807 kg CO$_2$-e, also a difference of 28% (due to the fact that all appliances are electric).

For cooking, the GHG implications of different kitchen set-ups range from: 914 kg/yr (all electric), through 327 kg/yr (gas appliances plus microwave) to 259 kg/yr (all microwave), representing a capacity for CO$_2$-e reductions of the order of 72%.

For lighting, the GHG implications of different lighting set-ups range from 15.8 kg/yr for all halogen to 1.7 kg/yr for compact fluorescents (compact fluorescents may have been under-specified (DEWHA 2008a, p 249)), but the indicative potential for CO$_2$-e reductions is of the order of 89%.

The standby energy for the sets of appliances used in this study varies from 14% of total energy consumption for a ‘best of breed’ set of appliances to 17% for a set of appliances with average performance.

3. What realistic energy supply can be achieved by distributed energy generation as part of hybrid buildings?

The annual average energy demand per dwelling in Melbourne (for space heating and cooling, hot water heating plus domestic appliances) is 75 GJ. Local energy generation technology options will provide outcomes generally well short of total energy demand. However, with a reduction in energy demand and a combination of local generation technologies, it is possible to get to net zero energy, carbon neutral and zero carbon solutions. Given the significant number of dwellings across Australia that will be required to reduce their carbon footprint, and with the current glacial rate of change to the proportion of
green energy in the national grid, this study sheds some light on the path that individual property owners and developers might take towards a low or zero carbon future for their housing. The closure of the federal government’s rebate for the domestic installation of solar photovoltaic systems in June 2009 due to over-subscription is indicative of community interest in renewable energy generation technologies. At present, most Australian governments, industries and communities lack the information to make informed decisions across an increasing range of local energy generation and domestic appliance options.

4. **What realistic operating energy performance (and GHG footprint) can be achieved by hybrid buildings (shell + appliances + local energy generation) compared to grid supplied standard (5 star) dwelling with ‘average’ appliances?**

A positive finding overall is that significant GHG reductions can be achieved via all distributed generation technologies examined. Large gas users such as CCHP, however, will find it difficult to deliver carbon neutral and impossible to deliver zero carbon outcomes.

Net zero energy, carbon neutral and zero carbon outcomes have been demonstrated as possible via carefully tailored combinations of local energy generation (providing electricity from renewable sources) to suit low energy demand shell and appliances. This transition is difficult if not impossible with 2.5 star rated dwellings, indicating a necessity for upgrading the energy efficiency of the shell.

The base case house (new 5 star detached, Figure 3), which is representative of new grid connected project homes being marketed at present, generates approximately 9.5 tonnes of CO₂-e annually in order to supply the comfort and amenity expected by Australian households. A transition pathway to zero carbon housing has been demonstrated which is also capable of exporting the excess ‘green’ electricity the hybrid building generates using DG renewable technologies to the grid (thereby removing a further 1.3 tonnes of CO₂-e annually). A net saving of CO₂-e per dwelling of approximately 11 tonnes annually as represented by the zero carbon house is the result.

![Net CO₂-e for Hybrid buildings scenarios](image)

**Figure 3** Net CO₂-e emissions for selected scenarios in transition to zero carbon dwellings

As far as CO₂-e emissions and the AEC costs are concerned, comparison of scenarios 1 and 2 (i.e. worst case versus current project home) reveals a reduction in CO₂-e of 38 tonnes per year and a cost saving of approximately $8000. To transition from the 5 star project home which generates 9.5 tonnes of CO₂-e per year to a zero carbon house incurs an AEC cost...
increase of over $600, excluding subsidies, rebates, carbon price impost and feed-in payments.

This analysis shows the significant benefits more energy efficiency and carbon efficient houses can achieve – at low or negative costs. This strengthens the case for targeted policies and programs to capture these benefits, even if an emissions trading scheme is introduced as such programs will lower the overall costs of a scheme.

Key messages
This report provides information for several million Australian households as well as industry and government to enable their direct participation in winding back unsustainable levels of CO₂-e emissions. Key messages are summarized as:

*Lifestyle-based change is needed to significantly reduce energy demand:* It is argued that policy analysts need to engage with both technology-based and behaviour-based approaches to energy conservation. While this project is primarily focused on the former pathway for energy transition, elements of the study do permit some observations as to the potential energy and GHG savings if society was prepared to wind back consumption in a number of areas, responding to calls for leading ‘a simpler life’.

*Reduce house sizes:* One of these lifestyle changes is related to consumption of housing space. If there were reversion to a simpler style of living that has been advocated (e.g. Trainer, 2008), with floor spaces akin to those of a quarter century ago (i.e. 167 square metres for new private sector houses in 1983 (ABS 1994)) being reflected in new dwelling completions, the average annual savings in CO₂-e could be of the order of 146 thousand tonnes (based on 2007 completions levels of 150000 dwellings, a 25 year difference in average floor area of 72 m², and average CO₂-e emissions per m² of detached housing of 13.5 kg); a saving in CO₂-e of approximately 1 tonne per dwelling per year.

*Reduce appliance consumption:* A second lifestyle area relates to the over-consumption of domestic appliances (‘affluenza’). Evidence suggest that an ‘affluenza set’ of appliances generates an additional three tonnes of CO₂-e per year per dwelling compared to a household operating what could be termed ‘basic set with ‘best of-breed’ performance. With 8.1 million households in Australia in 2006-07 (ABS, 2008b) and assuming one-third of these could be characterised as ‘affluenza households’, there is potential for an annual average national savings in GHG emissions of approximately eight Mt.

*Distributed energy supply costs improve with dwelling efficiency and precinct installation:* The costs required for each appliance, technology or distributed generation unit are initial capital cost, initial installation cost, annual maintenance and annual operating cost. To be able to add a capital cost to an annual cost to obtain a measure of total annual costs, it is necessary to convert the capital costs to an annual cost which is effectively incurred each year over the life of the asset, thus enabling an annual equivalent cost (AEC) to be calculated for technologies of varying lifetimes. Payback period is another useful measure when considering which local generation technology might be cost effective. Most payback periods without a carbon cost (current situation) are long (20+ years) with only the high capacity precinct installations and solar hot water systems having a payback period about ten years or less. The reduction in payback periods when a carbon cost of $30/tonne is added to the energy operating costs are mostly around 20% but if the carbon price doubled to $60/tonne, the reduction in payback periods is in the 30% to 35% range (i.e. as the carbon price rises, the rate of reduction in the payback period declines).

The estimated annual equivalent costs for the various scenarios vary considerably and would have an impact on decisions to implement local generation capacities. The lowest AEC is just over $600 for one of the only scenarios to achieve a zero carbon target.

*Upgrade existing (pre 2003) dwellings to 5-6 star energy performance:* Over 95% of Australia’s housing stock would reflect an (operating) energy rating of 2.5 stars or less. Modelling undertaken in this report suggests that such housing, together with a worst case set of appliances and use, can be responsible for generating levels of CO2-e exceeding 45
tonnes per detached dwelling per year. This class of stock constitutes the greatest challenge for a transition to carbon neutral or zero carbon housing.

A transition of the housing stock built before the 2003 introduction of a national 5 star energy rating system to carbon neutral or zero carbon status will require all of the following interventions:

- An upgrade of the building shell to at least a 5 star rating;
- Utilisation of ‘best of breed’ appliances;
- Application of local energy generation (low emission or zero emission) provided on site or accessed from a local precinct supplier, given the glacial rate at which the national grid is drawing on renewable energy sources.

**Increase medium density housing:** New (single storey detached 5 star) project homes are typically responsible for 9.5 tonnes of CO$_2$-e emissions per year. New double storey detached and high-rise apartments have larger carbon footprints (of the order of 10.9 and 9.9 tonnes respectively per year).

Medium density housing represents the best outcome from a CO$_2$-e emissions perspective (7.4 tonnes per year) and should become the principal vehicle for the intensification of urban development and redevelopment in Australian cities.

**Seek pathways for transitioning 5 star housing to zero carbon status:** Pathways for achieving zero carbon housing for contemporary 5 star project built homes have been identified. In addition to the 5 star energy efficient shell, they require:

- Solar hot water systems;
- ‘Best of breed’ appliances;
- Local energy generation tailored to household demand (but far from the levels required if linked to the requirements of a 2.5 star dwelling).

**A new ‘energy metric’:** CO$_2$-e should become the standard metric for reporting on energy performance in the housing sector.

**An expanded focus for carbon assessment in the housing sector: building shell plus built-in appliance performance:** To date, regulation has been restricted to the operating energy performance of the building shell. Future regulation should include a carbon target for built-in appliances as well as the building shell in order to deliver a more sustainable carbon footprint for the housing sector.

**A new carbon performance assessment tool for the housing sector:** Performance assessment tools need to take into account the appliances and equipment (built-ins at minimum, e.g. hot water heating, kitchen cookware, lighting, space heating and cooling) used in buildings in addition to the building fabric and produce outputs that are verifiable and relatively easy to understand. They also need to be integrated with economic modelling and analysis that enables eco-efficiency assessments to be provided for any building.

**Future steps**

Given the proof-of-concept performance assessments of alternative configurations of hybrid buildings contained in this report, the question that remains is: what will inhibit the diffusion of this innovation within the housing sector?

In this pilot study, eco-efficiency analysis of hybrid buildings was restricted to one of Australia’s eight climate zones established by the Australian Building Codes Board (Zone 6) in order to establish proof of concept. Given geographic variability across all components of hybrid buildings from both an energy supply and energy demand perspective, there would be value in expanding the study nationally.

There are over 7 million detached or medium density dwellings in Australia and each has the potential for increased energy efficiency and utilisation of local energy generation. This study has assessed the feasibility of individual hybrid residential buildings transitioning to zero energy, carbon neutral and zero carbon status. Initiatives are underway to develop precinct-scale local energy generation, e.g. VicUrban at Dandenong, the City of London’s ten Low
Carbon Zones (City of London, 2009), Sustainability Victoria’s Smart Energy Zones and Zero Carbon Precincts, and the Australian Government’s Solar Cities (DEWHA, 2009b), so the relative benefits and speed with which precinct vs parcel-based initiatives can penetrate the established housing markets need to be established quickly.

**Overcoming barriers to diffusion of an innovation: bridging the information gap and engaging with stakeholders**

Hybrid building is currently located at the foot of the innovation-diffusion curve – the concept has been articulated and subjected to a ‘virtual’ performance assessment.

Hybrid buildings will enable a transition to zero carbon housing – a necessary response by the housing sector to GHG mitigation in the 21st century. This transition will require engaging all stakeholders in the housing sector in a 3-stage process of behaviour change that can lift knowledge levels, encourage commitment to and endorsement of the concept leading to the action of taking the new product to the marketplace (Lorenzoni et al., 2007). The material developed by this project is a key element for Stage 1 of this process of transformation: developing awareness, information and knowledge. One of the recurrent themes in concluding sections of energy and greenhouse policy studies (Productivity Commission, 2005; Garnaut, 2008a) is market failure linked to a lack of information on energy efficiency and carbon mitigation options available to the housing sector. Commenting on issues of information shortfalls in the context of GHG mitigation, the Centre for International Economics (2009, p 52) considers that ‘the areas of greatest concern are in the residential/consumer segment than elsewhere, reflecting the challenges that this particular group is likely to face’.

To accelerate uptake will require overcoming several now well recognised barriers characteristic of early responses by key stakeholder groups and issues:

- Rules established by energy regulators around the use of on-site versus off-site generation (e.g. grid and precinct), feed-in tariffs to grid; and the interplay between companies in different segments of the energy generation industry;
- The capacity of the local DG industry (manufacturers, installers, maintainers) to meet demand and help grow the new green economy by creating scale economies for new products and increasing the attractiveness of a community scale energy industry;
- The nature of building and planning regulations developed by state governments for application by municipal governments as they relate to local energy generation;
- Design professionals ensuring the space is available for DG equipment to seamlessly become an established building element in any new or regenerated housing development, ensuring its acceptability to building and planning regulators, builders and consumers;
- The housing industry and its associations have been historically resistant to any innovation that has some up-front capital cost impact on housing (e.g. the announcement of a shift to 6 star ratings was met with a statement from the MBA to the effect that this would cost home buyers an additional $10,000 (Age, 1 May 2009, p 2);
- Housing consumers becoming familiar with the benefits to be derived from energy efficiency and local energy generation to the point where they begin to demand hybrid buildings as the standard product;
- The nature of future carbon costs and how they are assigned across industry and consumer groups.

Behaviour change and institutional change represent key areas for transformation in order to overcome lock-in and path dependency associated with Australia’s current energy regime and its link with an unsustainable level of GHG emissions.
1 INTRODUCTION TO HYBRID BUILDINGS

This report explores opportunities for mitigating greenhouse gas (GHG) emissions from the housing sector in Australia. It is a sector responsible for 20% of the nation’s total GHG emissions (George Wilkenfeld and Associates & Energy Efficient Strategies, 2003) and is a sector whose energy use is forecast to grow by 34% between 2009-10 and 2029-30 (ABARE, 2008, p 66).

The context for this study is challenging:

• Greenhouse induced climate change is now becoming manifest;
• The global financial crisis has provoked uncertainty about the shape of the future economy;
• There is a failure in urban planning and design – involving industry, government and the professions – to innovate in the housing sector.

Consequently, the results from this study address:

• Viability of new pathways for achieving zero energy, carbon neutral and zero carbon futures for the housing sector; and
• Opportunities for creating new business opportunities and employment around energy efficiency and local energy generation for the housing sector.

Hybrid building is proposed as a potential new and innovative response to these challenges, and this report assesses the eco-efficiency of this new class of residential building.

Hybrid buildings are defined here as residential buildings that have the capacity to supply, in total, the annual operating energy requirements of their occupants by utilising locally generated (low or zero emission) energy sources. Operating energy includes energy for heating, cooling, lighting and domestic appliances (built-in and plug-in). At times when surplus energy is generated to its occupants’ immediate demands, energy is supplied to the grid and if the dwelling is unable to generate sufficient energy for autonomous operation, energy is received back from the grid.

1.1 Context

Urban development in Australia continues to be locked into systems of energy, water and housing delivery that are no longer sustainable (Newton et al., 2006; Newton, 2008). Their resilience is being tested in the face of 21st century demands related to urban population growth, urban intensification, climate change, built environment sustainability and the need for a new green economy – all of which are challenging the path dependency still evident in much current government and industry practice. This lock-in is clearly evident in the degree to which new housing as well as major redevelopments continue to be tied to the carbon intensive energy grid that supplies electricity and gas. As such, current patterns of urban development impose a carbon emissions burden on all households – a situation which will become more evident to all when a price is attached to GHG emissions as a result of global attempts to mitigate climate change. It also perpetuates a trajectory of Australian cities and built environments as a principal source of environmental pressure and as insatiable consumers of resources, producing ecological footprints three to four times the world average (Newton 2007).

1.2 Hybrid buildings

Hybrid buildings constitute a pathway to de-carbonising the housing stock, enabling a winding back of urban ecological footprints and providing a basis for the generation of low emission or renewable energy from urban areas. They represent a means for delivering a transition to net zero energy housing, carbon neutral housing and zero carbon housing.
Other pathways to carbon neutrality for buildings identified by Twinn (2008) include site autonomy, on-site carbon neutral, net zero carbon, green tariffs, near-site carbon zero, and carbon offsetting among others. Overarching treatments of energy transitions more generally can be found in van den Bergh and Bruinsma (2008), Droege (2006, 2008) and Newton (2008).

There is a growing literature in this area, and a recent compendium of definitions (summarised by Marszal & Heiselberg, 2009) has provided an opportunity to locate hybrid buildings as a delivery mechanism for three levels of residential building performance where energy and GHG emissions constitute the sole environmental criteria for consideration:

- **Net zero energy building**: supplies as much energy to the grid over the course of a year as it uses, without any reference to carbon emissions. This class of building does not preclude use of low emission local energy generation technologies;

- **Carbon neutral building**: generates sufficient surplus CO₂-e free energy over the course of a year that balances any purchase of grid energy (primarily fossil-fuel-based). This recognises the fact that a single dwelling/household may be unable or unwilling to generate sufficient CO₂-e free energy to be classed as zero carbon;

- **Zero carbon building**: uses carbon free energy over the entire year, sufficient in quantity to supply all household energy needs (both dwelling operations and appliances to match any lifestyle). Connection to grid is primarily in order to supply energy that is surplus to household needs, and for periods of emergency supply when local energy system may be inoperable.

An energy efficient building is assumed to be a key component in each of these scenarios.

Local energy is supplied by a number of distributed generation technologies, both low emission and zero emission. Depending upon the particular configuration of the hybrid building ‘assembled’ (Table 1.1), it has the potential capacity to deliver all three levels of residential building performance mentioned above, involving distributed generation as a new, innovative building component. Local energy generation technologies examined include those that can operate autonomously for a single residential property (e.g. photovoltaics) or can supply energy to individual dwellings from a generation unit that has the capacity to serve a precinct.

The investigations of this study range over the dimensions shown in Table 1.1.

### Table 1.1 Dimensions of the Hybrid Buildings project

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling types</td>
<td>One each of a common detached (one and two storey) house, medium density dwelling (no lift) and high-rise apartment (with lift) – each design has their performance assessed using the FirstRate software</td>
</tr>
<tr>
<td>House size</td>
<td>Typical common floor area for each dwelling type</td>
</tr>
<tr>
<td>Household</td>
<td>Energy consumption for a typical household in each dwelling type</td>
</tr>
<tr>
<td>Standards</td>
<td>5 star house and appliances (where available) and best available</td>
</tr>
<tr>
<td>Energy use in the domestic sector</td>
<td>Breakdown of usage categories as available – average consumption for typical household using available energy efficient appliances</td>
</tr>
<tr>
<td>Local generating technologies</td>
<td>Portfolio of practical local energy technologies</td>
</tr>
<tr>
<td>Scale of distributed generating technologies</td>
<td>Single dwelling to multiple dwellings up to about a group of 100, i.e. medium density cluster or high-rise and community scale (not suburb size)</td>
</tr>
<tr>
<td>Appliances</td>
<td>One example of a typical available appliances for each dwelling type, e.g. heater, air conditioner (or fan), refrigerator, dishwasher, washing machine, audio-visual and computer as a ‘basic set’</td>
</tr>
<tr>
<td>Climate zone</td>
<td>Australian Building Codes Board Climate Zone 6, Mild temperate (Shui et al., 2009); a zone that accommodates Melbourne</td>
</tr>
</tbody>
</table>
1.3 Project scope and objectives

The aim of the Hybrid Buildings project is to develop virtual prototypes of hybrid buildings and assess their potential for becoming the principal agent for achieving significant reduction in the carbon footprint of Australia’s current and future residential building stock.

The challenge is to develop a holistic approach which combines design for energy efficiency (building plus appliances) with local energy generation via a range of micro-generation options (including non-renewables such as gas combined heat and power as well as renewables-based technologies linked to solar photovoltaics, wind turbines, solar thermal hot water, ground source heating/cooling and fuel cells).

Household behaviour, floor area, climate zone and set of appliances have been constrained to a representative example of each. The role of different structural building materials is also not assessed here as all dwellings are designed to the same level of energy performance.

The focus for this project is on a carbon-based eco-efficiency analysis of alternative configurations of a hybrid building, which identifies the most prospective intervention points for delivering carbon neutral and zero carbon residential developments and where variations in performance are explored across:

- different types of residential structure (detached, medium density, high rise) and floor area;
- different energy ratings of the shell,
- the number and mix of domestic appliances in use, and
- the type of distributed generation technology employed.

Specific (contractual) assessments examine:

- What realistic (practical, environmental, cost) operating energy performance can be achieved by the building shell;
- What realistic (practical, environmental, cost) energy performance can be achieved by ‘best of breed’ domestic appliances as part of hybrid buildings;
- What realistic (practical, environmental, cost) energy supply can be achieved by distributed energy generation as part of hybrid buildings; and
- What realistic (practical, environmental, cost) operating energy performance can be achieved by different configurations of hybrid buildings (1-3 above combined) compared to grid supplied standard (5 star) dwelling with average appliances.

To the extent possible with available data, the study also comments on the feasibility of the housing sector transitioning to carbon neutrality or zero carbon solely on the basis of technological innovation in design and energy systems as opposed to behaviour change involving lifestyle and associated patterns of consumption.

Additionally, while a search for key leverage points is a central feature of this study, they need to be seen as part of a much larger process of urban system transformation — in this case, from centralised fossil-fuel-based energy supply to local, renewables-based distributed generation (see Newton, 2008).
1.4 Issues for stakeholders in a carbon constrained world

One of the principal ways in which the 21st century will differ from the 20th century is in relation to the pervasive influence that issues of global warming and climate change will have on the decision-making processes of a wide spectrum of stakeholder groups ranging from households to governments and industries.

Climate change has been classed as a ‘wicked’ public policy challenge (Australian Public Service Commission, 2007, p 2) in that it represents an issue highly resistant to resolution and one where there are no quick fixes or simple solutions:

‘Climate change is a pressing and highly complex policy issue involving multiple causal factors and high levels of disagreement about the nature of the problem and the best way to tackle it. The motivation and behaviour of individuals is a key part of the solution as is the involvement of all levels of government and a wide range of non-government organisations’.

Climate change has also been termed a ‘diabolical’ policy problem (Garnaut, 2008b, p xviii):

‘Climate change presents a new kind of challenge. It is insidious rather than (as yet) directly confrontational. It is long term rather than immediate, in both its impacts and its remedies. Any effective remedies lie beyond any act of national will, requiring international cooperation of unprecedented dimension and complexity. While an effective response to the challenge would play out over many decades, it must take shape and be put in place over the next few years. Without such action, if the mainstream science is broadly right, the Review’s assessment of likely growth in global greenhouse gas emissions in the absence of effective mitigation tells us that the risks of dangerous climate change, already significant, will soon have risen to dangerously high levels.’

The implications of global warming and climate change are becoming increasingly clear. The Intergovernmental Panel on Climate Change (2007) and Steffen (2009) have outlined a trajectory in global warming that accompanies increasing levels of CO₂-e concentration in the atmosphere, e.g. atmospheric CO₂-e concentrations are estimated to rise from 352 ppm in 1990 (a baseline for many global forecasts and mitigation agreements such as Kyoto) to a level in excess of 500 ppm by 2100. Without restricting CO₂-e emissions, the IPCC’s most conservative forecast associated with a continuation of ‘business as usual’ practices is a rise of four degrees Celsius by 2100. Australia would be among the most severely impacted nations if such a scenario eventuated (Hennessy, 2008; Spratt & Sutton, 2008). Such an outcome would constitute a 21st century ‘tragedy of the commons’ capable of triggering societal collapse (Diamond, 2005; Lynas, 2008).

The climate mitigation responses to date by key stakeholder groups are summarised below.

1.4.1 Government

Governments at all levels in Australia have developed or are in the process of developing a number of mitigation and adaptation strategies linked to climate change. Foremost among these from the perspective of mitigation is the federal government’s Carbon Pollution Reduction Scheme (CPRS) (2008) which has a long-term goal of reducing Australia’s emissions by 60% below 2000 levels by 2050 and a medium-term 2020 target range of between 5% and 15% reduction below 2000 levels, the latter being conditional on global agreements linked to the UN Climate Change Conference in Copenhagen at the end of 2009. The current preferred mechanism for the government implementing its emissions reduction scheme is via a cap and trade mechanism which covers approximately 75% of the nation’s emissions. Given the contentious nature of a number of elements of the CPRS, the House of Representatives on 19 February 2009 announced an inquiry into the relative merits of emissions trading versus other schemes including carbon taxes and product performance regulation. A Senate Inquiry on Climate Policy was launched on 11 March 2009. Issues examined include:

- The adequacy of a lower target than the 80% recommended by the Garnaut Climate Change Review (2008b, p xxx) for effective mitigation of GHG emissions and climate change;
• The relative effectiveness of a cap and trade as opposed to a carbon tax approach, the latter being seen as more transparent, a simpler process to implement and less liable to become the basis of the next major global financial investment bubble;

• The exclusion of the built environment as a target for emissions reduction, notwithstanding the fact that its buildings are linked to approximately one third of all GHG emissions and that McKinsey & Co. (2008, p 13) identify buildings as representing six of the top seven targets in order of least-cost CO$_2$e abatement (also see ASBEC CCTG, 2008 for additional evidence of the potential for the built environment to contribute significantly to any national target for GHG abatement). There is a school of thought that holds the view that while cities can be seen as a principal villain in relation to GHG emissions and are most at risk from climate change, they are best placed to tackle it (Newton, 1997).

In this context there is now some uncertainty about the role that building and household-oriented energy efficiency initiatives and new low emission and renewables-based distributed energy generation industries can play in achieving Australia’s GHG emissions targets within the CPRS, including speculation that they ‘will simply subsidise big industrial polluters’ (Millar, 2009, p 1).

Australia also has potential opportunities to actively pursue policies and programs to deliver carbon neutral built environments similar to other countries. For example, the UK has instituted building regulations to achieve net zero carbon performance for all new housing after 2016 (Department of Communities and Local Government, 2006). The UK code defines a zero carbon home as one with ‘zero net emissions of carbon dioxide from all energy use in the home’ (i.e. all domestic appliances in addition to those energy uses that are currently part of building regulations such as space heating and cooling), analogous to the concept of hybrid buildings. Internationally, the IEA have recently established a Net Zero Energy Building project (International Energy Agency, 2009), as has Canada (Net-Zero Energy Home Coalition, 2009).

This study has at least three contributions for government:

• It focuses on potential opportunities for government policy and ensures that any performance assessment of hybrid buildings is eco-efficiency based, thereby ensuring that it can be effectively examined against other carbon mitigation alternatives to more clearly identify where the key intervention points for government could lie. Historically governments have focused on enhancing the energy efficiency of the building shell, but more recently there have been a number of initiatives surrounding incentives for uptake of renewable energy technologies such as solar hot water heating and photovoltaic systems; and more recently in the context of increases in energy prices, the provision of energy efficient appliances to disadvantaged households (McNicoll 2009) and installation of ceiling insulation for houses.

• It provides the basis for subsequent research (via focus groups and interviews with key stakeholders) on the extent to which current building and urban planning regulations may be improved to facilitate the entry of hybrid buildings into the marketplace.

• It will inform the energy regulators regarding the future supply of feed-in energy from dwellings as well as likely levels of demand by households for energy from the grid in the context of delivering a future carbon neutral or zero carbon housing sector.

### 1.4.2 Industry

For the building industry (design professions and contractors particularly), the prospect of integrating a new building object – local energy generation/distributed generation technologies – into the design of a residential dwelling represents a new challenge, particularly as it has been found that architects designing buildings with renewable energy systems need to take account of their particular requirements at an earlier stage of the design process than with conventional energy supplies (New Energy Focus, 2009). However with an examination of the efficacy (in eco-efficiency, regulatory and market acceptability
terms) the Hybrid Building offers a new innovative product (both at single dwelling unit and at precinct scales).

For the energy generation industry, the emergence of local (distributed) generation technologies offers the basis for a transition from the highly energy-inefficient and greenhouse gas polluting fossil-fuel-based centralised electricity generators to an energy system that is capable of being based on renewables and reducing peak demand on the grid (and a consequent postponing or elimination of need for construction of additional new centralised power stations).

This study offers the following contributions to industry:

- An ability to compare the annualised cost-benefit of hybrid buildings against traditional offerings in the housing market;
- A comparative performance of distributed generation (DG) technologies in the housing context, and
- Information about the future supply of feed-in energy from dwellings as well as likely levels of demand by households for energy from the grid.

1.4.3 Households and the community

In the future, Australia's households will be required to play a more significant role in reducing their carbon footprint than has previously been the case. When viewed in per capita terms, Australia’s GHG emissions are among the highest in the world (Figure 1.1) and represent a metric that is used somewhat erroneously against ‘the Australian resident’ (due to the fact that it results from the nation’s total emissions from all sources and sectors divided by the total population). In some respects, however, it is a measure of the ‘embodied energy’ of the nation’s population if we accept the proposition that our population draws upon the common wealth that our economy generates from involvement in fossil fuel exports and energy-intensive industries.

![Figure 1.1 Per capita GHG emissions, 2005](image)

Sources: Department of Climate Change (2008c) and International Energy Agency (2007)

**Figure 1.1 Per capita GHG emissions, 2005**

There is little evidence to suggest that either households or individual members of Australia’s population have a good understanding of their level of energy use or their carbon footprint (refer to any number of calculators on the internet), and what the principal contributors are to their level of consumption.

Awareness, knowledge and understanding of one’s level of consumption (of any product or resource) and its impact on the state of the environment represent the first phases of a 4-stage model of behaviour change, according to Voronoff (2005, also see Figure 1.2) that leads to the development of a particular level of concern, which again is a precursor to some action and change in behaviour on the part of an individual or household.
This study provides a clear statement of facts surrounding energy use and greenhouse gas generation in the housing sector, with particular reference to:

- Greenhouse intensity of different sources of energy (type of energy household's buy);
- Significance of the energy rating of the building shell;
- Influence of floor area on energy use;
- Contribution of built-in heating and cooling appliances to total energy use;
- Relative consumption of energy by different sets of domestic appliances; and
- Extent to which a household can become energy self-sufficient, greenhouse neutral or zero carbon via local energy generation.

The principal issues which affect the key stakeholders in the energy use and generation sectors are summarised in Table 1.2.

### Table 1.2 Stakeholder issues

<table>
<thead>
<tr>
<th>Participant</th>
<th>Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design/building industries</td>
<td>Cost/benefit of embracing hybrid buildings against traditional offerings and a market for delivery</td>
</tr>
<tr>
<td>Government</td>
<td>Most cost-effective way to provide incentives or regulations to derive greatest overall efficiency of energy use within the current and future housing stock</td>
</tr>
<tr>
<td>Energy generators</td>
<td>Cost/benefit of embracing local energy suppliers</td>
</tr>
<tr>
<td></td>
<td>Assessing the impacts of carbon cost schemes</td>
</tr>
<tr>
<td></td>
<td>Exploration of methods to reduce peak demand cost</td>
</tr>
<tr>
<td>Energy distributors</td>
<td>Impact of individual dwellings as local energy generators (including gross versus net energy prices)</td>
</tr>
<tr>
<td></td>
<td>Impact of precinct energy providers (including large-scale systems)</td>
</tr>
<tr>
<td></td>
<td>Knowledge of local generation options to assist decisions on what role distributors might play</td>
</tr>
<tr>
<td>Manufacturers</td>
<td>Comparative advantages of, and market for, each local generation technology in terms of eco-efficiency at single dwelling and precinct scale</td>
</tr>
<tr>
<td></td>
<td>Cost/ benefit for property developers installing specific local generation capabilities</td>
</tr>
<tr>
<td>Single property owner/occupier</td>
<td>At what cost point would they be prepared to invest in more efficient shell, appliances and one or more local generation technologies to reduce energy costs and resultant emissions</td>
</tr>
<tr>
<td></td>
<td>Peak energy is not a consideration unless there is 'smart' metering and differential payments for energy consumed and generated at different times of the day</td>
</tr>
</tbody>
</table>


2 CONTEXT

2.1 Energy generation and use in Australia and Victoria

Renewable energy represents less than 5% of total energy consumed in Australia. Principal contributors are: wind (35%), solar water heating (21%), hydro (15%), landfill gas (11%) and bagasse (10%) (ABARE, 2008, p 52). In Victoria only 2% of energy supply is from renewable sources (Sustainabilty Victoria, 2008, Figure 2.1).

![Victorian primary energy consumption (PJ) by fuel in 2004-05](image)

Source: ABARE (2006)

Figure 2.1 Victorian primary energy consumption (PJ) by fuel in 2004-05

A principal reason for the low penetration of renewable energy generation is the fact that they are currently not as cost-effective as conventional technologies (Graham et al., 2008). Indeed, Australia ranks 24th of 27 OECD countries in relation to the (low) cost of electricity (ABARE, 2008, p 44). This is largely due to the fact that it is well endowed with abundant low-cost and accessible supplies of coal. Also, environmental externalities associated with electricity supply (mostly linked to CO₂-e emissions) are currently not incorporated in generation costs and consumer pricing, as well as the absence of environmental objectives in the rules for operating the national electricity grid. Australia also lags the rest of the developed world in terms of the percentage of local (distributed) energy generation in the overall mix (Jones, 2008).

Australia’s Mandatory Renewable Energy Target (MRET) scheme was first established in 2001 when its objective was to ensure the uptake of renewable energy by a commitment to ensuring that 20% of electricity supply comes from renewable sources by 2020 (Department of Climate Change, 2008b). By contrast, California has a 20% renewables target by 2010, which increases to 33% by 2020 (PBS, 2009).

2.2 Residential energy use: Trends and forecasts

In 2009-10 the residential sector consumes 12% of the total energy used in Australia which totals 3822 PJ. Residential sector demand is forecast to grow from the current 442 PJ to almost 600 PJ by 2030 (ABARE, 2008). Independent modelling of residential energy consumption by DEWHA (2008a, p ix) suggests a continued increase in per capita consumption from 17 gigajoules (GJ) in 1990 to 20 GJ in 2020, an approximate 20% increase.

Electricity represents the principal form of energy used by the residential sector now and in the future (DEWHA, 2008a, Figure 7), which explains the relatively higher contribution that the sector makes to greenhouse gas emissions. And the forecast is for an increase in demand for electricity in this sector (see Figure 2.2).
The residential sector has been identified as having the greatest prospect for achieving significant reductions in energy use (Figure 2.3), and clearly there are multiple routes to effect this reduction. Energy efficiency and technology substitution are principal among these. The Energy Efficiency and Greenhouse Working Group (2003) estimated that energy consumption improvements of 15% to 35% could be achieved under the conservative assumptions that only existing technology was used and that the change would pay for itself within four years. Using more optimistic assumptions of new technology application and longer payback periods, energy reductions exceeding 70% were shown to be viable.

This leaves a gap that needs to be closed in a transition to zero carbon housing.
2.3 Residential greenhouse gas emissions: Trends and forecasts

CSIRO’s Global Carbon Project (2008a) has revealed that the annual mean growth rate of atmospheric CO2-e was 2.2 ppm per year in 2007 (up from 1.8 ppm in 2006), and above the 2.0 ppm average for the period 2000-07. The average annual mean growth rate for the previous 20 years was about 1.5 ppm per year. This increase brought the atmospheric CO2-e concentration to 383 ppm in 2007, 37% above the concentration at the start of the Industrial Revolution (about 280 ppm in 1750).

As is evident from Table 2.1, current levels of CO2-e in the atmosphere lock-in warming in the order of 1.3 to 1.7 degrees Celsius, with prospects for greater warming as concentrations up to 450 ppm and beyond are forecast. According to Hennessy (2008, p 31):

‘Stabilising global warming at 1.3-1.7 degrees Celsius relative to the year 2000 would require stabilising CO2-e equivalent concentrations at 445 to 490 ppm between 2100 and 2150.’

This would require a 50% to 85% reduction in emissions by 2050.

<table>
<thead>
<tr>
<th>Global warming relative to 1750</th>
<th>Global warming relative to 2000</th>
<th>CO2-e concentration by 2100-50</th>
<th>CO2-e equivalent concentration by 2100-50</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0-2.4°C</td>
<td>1.3-1.7°C</td>
<td>350-400 ppm</td>
<td>445-490 ppm</td>
</tr>
<tr>
<td>2.4-2.8°C</td>
<td>1.7-2.1°C</td>
<td>400-440 ppm</td>
<td>490-535 ppm</td>
</tr>
<tr>
<td>2.8-3.2°C</td>
<td>2.1-2.5°C</td>
<td>440-485 ppm</td>
<td>535-590 ppm</td>
</tr>
<tr>
<td>3.2-4.0°C</td>
<td>2.5-3.3°C</td>
<td>485-570 ppm</td>
<td>590-710 ppm</td>
</tr>
</tbody>
</table>

Source: Hennessy (2008; extracted from Intergovernmental Panel on Climate Change (2007, Table SPM-5))

Australia is the world’s fourth-ranked per capita emitter of greenhouse gases – at 25.6 tonnes/per capita ahead of USA and Canada (Baumert et al., 2005), and with total CO2-e emissions projected to grow by 45 Mt CO2-e between 1990 and the Kyoto target period (2008-12) to 599 Mt (Department of Climate Change, 2008c), the nation is faced with a significant challenge of finding the most eco-efficient pathways for reducing the carbon intensity of its production and consumption landscapes.

Australia’s emissions come from a variety of sources (Table 2.2). Net emissions across all sectors totalled 576.0 million tonnes of carbon dioxide equivalent (Mt CO2-e) in 2006. The largest single source of direct emissions is the electricity, gas and water economic sector, accounting for 35.5% of Australia’s emissions.

### Table 2.2 Australia’s direct GHG emissions by economic sector, 1990, 2006

<table>
<thead>
<tr>
<th></th>
<th>Emissions Mt CO2-e a,b</th>
<th>Change in emissions (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1990</td>
<td>2006</td>
</tr>
<tr>
<td>All Sectors</td>
<td>552.6</td>
<td>576.0</td>
</tr>
<tr>
<td>Primary Industries</td>
<td>258.9</td>
<td>188.3</td>
</tr>
<tr>
<td>Agriculture, Forestry and Fishing</td>
<td>226.8</td>
<td>136.2</td>
</tr>
<tr>
<td>Mining</td>
<td>32.1</td>
<td>52.1</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>65.1</td>
<td>69.3</td>
</tr>
<tr>
<td>Electricity, Gas and Water</td>
<td>136.3</td>
<td>204.5</td>
</tr>
<tr>
<td>Services, Construction and Transport</td>
<td>48.9</td>
<td>59.5</td>
</tr>
<tr>
<td>Residential</td>
<td>43.5</td>
<td>54.5</td>
</tr>
</tbody>
</table>

a) Estimated under the Kyoto Protocol reporting provisions.  
b) Carbon dioxide equivalent, CO2-e.  

Source: Department of Climate Change (2008d)
In this analysis the residential sector emissions are confined to those linked directly to the dwelling and represent approximately 9.5% of the nation’s total. In the analysis by George Wilkenfeld and Associates & Energy Efficient Strategies (2003), 19.5% of total (end-use) emissions are allocated to the residential sector by including a household’s transport-related emissions to those of operating the dwelling and its appliances.

2.4 Innovation-based responses to climate change

Significant innovation is required for a sustainability transformation of the residential sector of our cities. They need to be able to draw from a pipeline of innovative technologies, products and processes relating to key infrastructures – water, energy, transport, communications and buildings – that can be substituted as existing applications show signs of failure. Newton (2007; also see Newton & Bai, 2008) has proposed a 3-horizon system of innovation capable of application to technology, design, urban development and behaviour change. In relation to innovation (see Figure 2.4),

- **Horizon 1** innovations are those where the technology is commercially available and has a demonstrated level of performance in cost and environmental terms that is superior to products currently in the marketplace and where there should be immediate substitution: the compact fluorescent tube and energy rated appliances are classic examples.

- **Horizon 2** innovations are those where there are examples in operation but not widespread, such as hybrid cars or ‘water-wise’ urban design. They are associated with better-performing processes or products which have an opportunity to be applied more broadly, but where there may be need for some examination of how they would perform in particular locations or settings. An example is 7+ star energy rated dwellings.

- **Horizon 3** innovations are those which for the most part reside in research laboratories as prototypes, but whose sustainability impact can be truly transformational. The challenge is to get a real-world application so their performance can be assessed, and if field performance matches the promise of the laboratory, then they become Horizon 2 innovations and should be adapted more widely. The solar hydrogen fuel cell is a good example of a Horizon 3 innovation, as are integrated urban water systems and eco-industrial complexes.

Hybrid buildings represent an opportunity for integrating innovations from across all three horizons, from the incremental Horizon 1 to the more transformative Horizons 2 and 3. The first steps towards the Horizon 2 and 3 futures need to be put in place now, otherwise there is the prospect of getting ‘caught short’ and having to pursue suboptimal solutions - particularly as the window of opportunity for making a successful sustainability transition in the 21st century in relation to energy is beginning to close rapidly.

Examples of energy innovation across the three horizons include:

- **Horizon 1**: compact fluorescent lighting, 5 star rated buildings, gas-boosted solar hot water heating;
- **Horizon 2**: LED lighting, 7+ star rated buildings, photovoltaic local electricity generation;
- **Horizon 3**: smart lighting (sensors), 10 star energy rated buildings, solar-hydrogen fuel cell.

Sustainability within the domestic/housing sector could be further enhanced by extending the hybrid building concept to incorporate vehicle-to-grid (V2G) – another potential form of distributed generation electricity supply (Spaccavento, 2009; Dennis & Thompson, 2009) but outside the scope of this project.
Figure 2.4  Three horizons of urban technological innovation

Although examining the barriers to take-up across the three horizons of innovation is also beyond the scope of this project, a Three Horizons Model of Behaviour Change, following Voronoff (2005) and Hopkins’ (2008) model of human transition – namely, head (i.e. knowledge), heart (i.e. concern) and hands (i.e. action) – is also applicable in the context of hybrid buildings, for example:

- **Horizon 1**: understanding the level of awareness, information and knowledge that different stakeholder groups have of a particular issue (e.g. climate change) and technology (e.g. hybrid buildings);
- **Horizon 2**: determining the level of understanding and concern that an organisation or community has about that issue or technology;
- **Horizon 3**: where the organisation or community (or household) develops a sense of responsibility and undertakes actions that reflect a change in behaviour in order to address a particular issue or challenge.

This project provides the basis for a follow-up study on behaviour change as a result of the information assembled in this report and the basis for engagement with several key stakeholder groups through a transitions arena process (after Loorbach, 2007).
3 PERFORMANCE ASSESSMENT

3.1 Energy and greenhouse metrics

A variety of metrics for measuring consumption of energy and GHG emission is available but the principal ones used are energy (electricity) in MJ/yr (for comparison purposes rather than kWh/yr), energy (gas) in MJ/yr, electricity generation and gas emissions in kg CO2-e/yr.

CO2-e is an abbreviation of 'carbon dioxide equivalent' and is the internationally recognised measure of greenhouse emissions (see Townsville City Council, 2009 for a clear description). Different gases have different capacities to heat the atmosphere and this is referred to as their global warming potential (GWP). These gases are called greenhouse gases and include carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4), perfluorocarbons (PFC), hydrofluorocarbons (HFC) and sulphur hexafluoride (SF6).

CO2-e is the standard for GWP, assigned a GWP = 1. Examples of GWPs include 21 for methane, 271 for nitrous oxide, 6,000 to 9,000 for perfluorocarbons, 1,000 to 10,000 for hydrofluorocarbons and 23,900 for sulphur hexafluoride. CO2-e is not a potent GHG compared to the others but, because it is produced in such huge quantities, its effect on the atmosphere dwarfs all the other GHGs combined. For simplicity, greenhouse emissions are reported as though they were equivalent to a given volume of CO2-e. The CO2-e, for example, of emissions from a landfill producing 100 tonnes of methane would be recorded as 2,100 tonnes CO2-e.

In this report, all energy consumed is as metered at the dwelling, whether electricity or gas. This is termed ‘delivered energy’. The conversion factors for energy used to GHGs emitted are those provided by the state government for usage of delivered electricity and gas in Victoria (Sustainable Energy Authority Victoria, 2002, p 6). For Victorian electricity, 1 MJ of delivered energy consumed for heating and cooling produces 0.4 kg CO2-e and for Victorian gas, 1 MJ of delivered energy consumed for a similar end use produces 0.052 kg CO2-e. For green power, there are zero emissions.

Efficiency of the appliances, particularly in converting delivered energy to heat, significantly affects the amount of energy consumed to produce the desired result and is often called Co-efficient of Performance (COP). For example, delivered electricity is very efficiently turned into heat in a radiator (effectively 100% (DEWHA, 2008a, Table 71, p 22)) while delivered gas only produces about 61% for a gas space heater (DEWHA, 2008a, Table 74, p 225) of its energy as heat in typical appliances. The COP can be greater than 100%, e.g. for cooling by a reverse cycle air conditioner, it is 311% (DEWHA, 2008a, Table 67, p 218).

3.2 Carbon pricing

Carbon pricing involves the assignment of a market price to the amount of carbon emission from an activity, which could include the production of electricity from fossil fuels, manufacturing, agriculture and transport among many others. Introduction of carbon pricing, either as a carbon tax or an emissions trading scheme (see Sadler et al. (2006) and Pearce & McKibbin (2007) for an elaboration on the two approaches), is recognised as one of the more effective ways to reduce levels of GHG generation via the market. The European Union was among the first to create a carbon price signal through an Emissions Trading Scheme in 2005. By December 2008, one tonne of CO2-e was trading around 24 Euro (A$45) (http://www.heren.com/). Modelling for Garnaut's Climate Change Review (2008b) has suggested an international carbon price of between US$20 and $35 per tonne CO2-e in 2013 (A$30-50). The Allen Consulting group (2008) indicate a feasible carbon price range of A$10 to A$40 tonne CO2-e out to 2018. Bristow's (2008) estimates for Canada range from Can$20 in 2009 to Can$50 in 2018.

In this study our eco-efficiency modelling assumes a carbon price of A$30/tonne which is at the lower level of Garnaut estimates and European ETS prices (the starting price could be lower).
3.3 Costs

Dwelling-related energy costs are often quite a small component of a household budget. The National Institute of Economic and Industry Research (2007) have also found that energy demand is relatively unresponsive to change in price. Increases in domestic electricity prices in Australia have been relatively small and incremental, and also operate off a low base compared to energy prices in other countries (ABARE, 2009). What is unclear, however, is the impact on and response by households to the introduction of a carbon price. To date, carbon costs have been an externality and have not been internalised into the price of a product or service, as with the carbon eco-efficiency metric in this study. This eco-efficiency metric establishes the extent to which a carbon impost contributes to the total annualised costs of operating a particular configuration of hybrid building (shell + appliances + distributed generation).

3.3.1 Approaches to costing

The costs required for each appliance, technology or distributed generation unit are:

- Initial capital cost;
- Initial installation cost;
- Annual maintenance;
- Annual operating cost.

All but the capital and installation costs are annual.

Annualised capital costs

To be able to add a capital cost to an annual cost to obtain a measure of total annual costs, it is necessary to convert the capital costs to an annual cost which is incurred each year over the life of the asset. Alternatively, the annual equivalent cost can be considered as the annual payment to pay off a loan (equal to the capital cost) over the life of the asset at a specified interest rate.

This is known as the annual equivalent cost (AEC) which is defined as:

\[
AEC = c \frac{i(1+i)^n}{(1+i)^n - 1}
\]

where

- \(i\) = discount (interest) rate
- \(n\) = number of years
- \(c\) = capital cost

Example

- \(c\) = $1000
- \(n\) = 10 years
- \(i\) = 5%

Then \(AEC = 1000 \frac{0.05(1+0.05)^{10}}{(1+0.05)^{10} - 1} = 129.50\)

Payback period

In a Canadian study (Bristow, 2008) that sought to assess the relative attractiveness of distributed generation technologies to different stakeholder groups (homeowners, commercial property, small business and investors), the focus was primarily on the economics of the different options. Key among the metrics was 'payback period' which is important in influencing consumer behaviour and has to be addressed by households when considering the option to purchase local energy technologies.
Payback period is the ratio of capital expenditure to the annual savings obtained by investing in the technology. The savings investigated in this study for local generation options were the cost of the energy (electricity and gas) saved less the cost of any energy utilised in operating the technology. Subsidies for capital and/or operating expenses were not included.

**Price of energy**
To date, energy producers have not been required to internalise a number of significant environmental costs associated with generating supply, most notably in relation to GHG emissions. It is clear that the true price of energy is set to rise – the uncertainty is, by how much.

The energy prices used in this study are the 2009 retail prices of a Melbourne energy supplier as regulated by the Victorian State Government and published from time to time in the *Victoria Government Gazette*.

**Subsidies and rebates**
Subsidies and rebates prove difficult to factor into eco-efficiency models since they can be extremely short-lived. The ABC’s *7.30 Report* of 5 May 2009 pointed to seven different federal schemes in 10 years involving household incentives for green energy. One of the most recent changes involved a decision of the current government to discontinue its $8,000 rebate to households installing photovoltaic systems (*Age*, 18 December 2008); instead; responsibility has been shifted to electricity retailers to increase their solar subsidies in the light of federal government legislation that will require retailers to buy 20% of their power from renewable energy providers by 2020.

In determining costs, particularly capital costs, the real cost has been taken as the cost to the customer plus adding back subsidies, e.g. the cost of installing a photovoltaic system is the cost as advertised plus the federal government rebate (e.g. $8,000) plus the value of the renewable energy certificates (RECs) which are commonly signed over to the energy supplier. Rebates, subsidies and RECs have not been considered in most analyses in this study, as capital rebates are considered essentially a government incentive to bring forward investments.

**Feed-in tariffs**
A feed-in tariff is a premium rate paid for electricity fed back into the electricity grid from a designated renewable electricity generation source like a rooftop solar photovoltaic system or wind turbine (Energy Matters, 2009). Feed-in tariffs can affect whether to invest in local energy generation and, at present, feed-in tariff regulations for renewable energy exist in over 40 countries around the world. Australia has state-run schemes but no national program. The current modelling excludes this factor in most scenarios, given current variability.

### 3.3.2 Annual cost
For this study, the annual cost is the sum of the annual equivalent cost of the purchase and installation costs, plus the annual operating costs including energy and maintenance costs. To reinforce that the annual cost includes the annual equivalent cost of capital, this annual cost is referred to as annual equivalent cost (AEC) throughout this report.

### 3.4 Carbon eco-efficiency
Carbon eco-efficiency in its narrowest sense can be seen as an instrument of sustainability analysis that links environmental and financial performance and attempts to provide a quantitative measure of their relativities in a product, process or system. There is a process involved in undertaking an eco-efficiency analysis that comprises several steps or tasks that are documented in this report. There is also a need to derive an *eco-efficiency metric* that is capable of delivering an integrated performance assessment of both environmental and economic costs of a particular product, in this case, a hybrid building. The measure of eco-efficiency performance used in this study is *carbon-based* in which economic and
environmental (CO\(_2\)-e) costs of a particular configuration of hybrid building are compared, i.e. $CO\(_2\)-e$ cost per $1 of asset life cycle cost per year.

The definition of this measure, termed a *Relative Carbon Burden Indicator*, is:

\[
\text{Relative Carbon Burden Indicator} = \frac{\text{CO}_2\text{-e emissions (converted to a carbon cost)}}{\text{Cost of hybrid building (or some component thereof)}}
\]

The Relative Carbon Burden Indicator depicts the proportion (percentage) of the total annualised cost of operating a particular category of hybrid building (of which there are several scenarios examined) that can be attributed to the cost of paying for the amount of carbon emissions involved in its operation. The higher the percentage, the greater is the need to identify the source of the carbon intensive element(s) and substitute to a low or zero carbon alternative. It is a measure of the strength of impact on the annualised cost of operating the heating and cooling of a dwelling, water heating and the full range of appliances once a price for carbon is established and CO\(_2\)-e costs are internalised in the price of future goods and services.

As such, the eco-efficiency metric could be of considerable value as an aid to strategic decision making on the part of consumers, manufacturers of building products (including distributed generation technologies) and governments in clarifying where the most effective points for intervention and substitution reside (Huppes & Masanobu, 2005). Its weakness has been found to be linked to the relatively high costs of new technologies (ranging from LED lighting to solar hydrogen fuel cells) reducing the impact that carbon pricing makes on this indicator and may mislead for ‘bleeding edge’ technologies. The results of these analyses can be found in Appendix A: Relative carbon burden indicator.

Eco-efficiency analysis can be situated, however, in a broader context that involves concepts such as decoupling and eco-innovation, both of which can be connected to the emerging opportunity offered by hybrid buildings.

*Decoupling* is a concept championed by the OECD (2002) that seeks to promote and monitor attempts to break the link between ‘environmental bads’ and ‘economic goods’. It is deemed to occur ‘when the growth rate of an environmental pressure is less than that of its economic driving force over a given period’ (p 1). In the case of housing, for example, decoupling could be said to be occurring when the environmentally relevant variable – in the present case, CO\(_2\)-e emissions – is stable or decreasing while the economic driving force – in the present case, demand/consumption of more housing space and domestic appliances – is growing.

The concept of *eco-innovation* is currently being examined as a response to the key 21st century challenges of a growing carbon constrained and resource constrained world (Newton & Bai, 2008). In the European Union (2009, p 14) it is receiving attention as a process for:

\[
\text{'the creation of novel and competitively priced goods, processes, systems, services and procedures designed to satisfy human needs and provide a better quality of life for everyone with a whole-life-cycle minimal use of natural resources (materials including energy and surface area) per unit output, and a minimal release of toxic substances.'}
\]

It is a concept related both to technology development (at any stage of its life cycle) as well as those related human elements involving behavioural and lifestyle change. The present phase of this study is firmly centred on establishing the most eco-efficient class of hybrid building (the technology bundle) as a precursor for a subsequent study of stakeholder (government, industry and consumer) attitudes to this innovation in housing.
3.5 Multi-factor analyses

A graphical representation of all the key performance metrics for hybrid buildings (Figure 3.1) permits a more effective comparative analysis of the competing options that emerge, given that different stakeholder groups tend to assign higher weightings to particular metrics than others.

![Figure 3.1 Key performance metrics for hybrid buildings](image)

3.6 Energy and carbon calculator for hybrid building scenarios assessment

All the calculations for the tables and charts in this report were done using an Excel spreadsheet, specially set up to facilitate scenario selection. Each of the categories of dwellings, heating and cooling, hot water, cooking, plug-in appliances and common area services were set up in separate blocks to enable index selection from a series of drop-down selection options on the scenario worksheet (Figure 3.2). Results were displayed in tables and charts which could be copied into this report as required.

Dependencies such as heating and cooling for different dwelling types and sizes were linked to automatically adjust demand and similar links provided adjustment to demands for energy and resulting CO2-e emissions when technologies such as ground source heat pumps and gas CCHP provided energy for multiple uses such as heating and hot water as well as electricity generation.
Scenarios

LOAD SET
Regeneration

Chart y axis plot
CO2-e: total

Scenario A
Case 1

Dwelling type
House: detached single storey

Star rating
2.5 Star

Space heating and cooling
Heating/cooling: gas ducted and electric evaporative

Hot water
Hot water: gas - storage

Cooking appliances
Cooking: gas cooktop, electric oven, microwave

Lighting
Lighting: average mix

Appliances
Appliances: best-of-breed basic

Common area services
Common services: none

Local generation
Ground source heat pump - 14kW thermal
Solar - Photovoltaic: 1500W
Local generation - none

Figure 3.2 Scenario options selection in spreadsheet

3.7 Policy analysis

It is clear that energy-efficiency initiatives alone will not be sufficient to deliver zero carbon in the residential sector. It is unclear, however, at what point such initiatives become eco-inefficient and other options need to be brought into play. Figure 3.3 illustrates this point, with particular reference to the contribution that local (renewable) generation needs to take in relation to delivery of housing that is zero energy or zero carbon.

The Net Zero Approach:

- Integrated Solar Design
- Energy Efficiency—Shell+Appliances
- Renewables: Solar thermal/PV/Wind etc
- Low Emission Energy: CHP/Biomass etc
- Load/Grid Management

Source: Adapted from Riley (2008)

Figure 3.3 Net zero approach to carbon neutral housing
Clearly there are multiple hybrid building scenarios that need to be assembled to examine the extent of environmental benefit (in relation to GHG mitigation) and cost associated with each. As the Centre for International Economics (2009, p 9) argues: ‘The test of any policy, therefore, is not whether it has economic costs, but rather the level of environmental benefit it has for that cost.’ More broadly, policy analyses need to engage with both technology-based and behaviour-based approaches to enable a transformation to green housing within a timeframe that avoids significant climate change. For this study we are in a position to examine the effects from five cells of the matrix (highlighted) shown in Table 3.1.

### Table 3.1  Policy options for greening the residential sector

<table>
<thead>
<tr>
<th>Policy Focus</th>
<th>Domain Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovation in Technology &amp; Design</td>
<td>Building</td>
</tr>
<tr>
<td>7+ energy star rated</td>
<td>Appliances</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
</tr>
<tr>
<td>Householder Behaviour Change</td>
<td>Local renewable energy generation</td>
</tr>
<tr>
<td>Smaller floor space</td>
<td>Fewer appliances/lighting, simpler life</td>
</tr>
</tbody>
</table>

#### 3.7.1 Targets

Benchmarks or targets are typically assigned as a guide to performance of some asset or activity.

**Targets for products**

In some instances targets are enshrined in legislation, requiring demonstration of performance prior to gaining a permit to build, as is the case with the energy rating of residential buildings (Shui et al., 2009) which was introduced into the Building Code of Australia in 2003 for housing and 2005 for multi-storey residential buildings. The current rating for residential buildings is predominantly 5 stars with a decision on 30 April 2009 to advance to 6 stars by 1 July 2011 (Age, 1 May 2009, p 1) which reduces operating energy requirements to approximately 100 MJ/m² (Figure 3.4). The use of a per square metre basis for rating means that larger dwellings that conform to the required rating consume more energy than an equivalently-rated smaller dwelling, i.e. the rating is not related to total energy demand, a potential shortcoming in encouraging lower overall energy consumption.

![Melbourne star rating bands](image-url)  

Source: Delsante (2007), extract from AccuRate energy rating software provided to authors

**Figure 3.4  Residential heating and cooling star ratings for Melbourne**

29
However, regulation of performance is normally not viewed as best practice and is typically introduced to eliminate the perpetuation of worst practice (Figure 3.5).

Figure 3.5 Encouraging leading practice improvement in Australia

With regard to the performance of the residential building shell, it has been established for some time (Horne et al., 2005) that Australia’s current 5 star standard was of the order of 2 to 2.5 stars below comparable average international levels of performance for housing. It is expected that a 7 star performance standard will be introduced into a future BCA as the new target and as such our modelling of hybrid buildings will include both the existing and likely new standard.

Energy ratings for household white goods have been around for some time and, although they do not cover all household items, they do serve as a guide to energy efficiency of a particular appliance. Over time, the average rating and subsequent energy performance of the appliances has been improving (DEWHA, 2006).

Targets for human activities

From time to time in the face of particular challenges, governments will institute regulations that relate directly to specific human activities. Examples relate to the maximum speed that vehicles can be driven on different streets or in different areas, and the specific hours that residents are permitted to water their gardens during periods of water shortage. In other instances, governments will engage in public campaigns designed to encourage a change in behaviour on the part of a population, e.g. the black balloons advertisements designed to educate the public about domestic sources of GHG emissions and the155L campaign, also communicated through the mass media and designed to encourage Melbourne households to reduce their daily water consumption to less than 155 litres per person per day.

In the future there could be a public campaign designed to encourage households to limit their greenhouse gas emissions per day to some nominated level. As energy comprises many different sources, each with their own greenhouse gas intensity (see above), this would become a slightly more complicated exercise, but not insurmountable. In the presentation of results from the scenario modelling where levels of greenhouse gas emission are used as a key performance indicator, the Melbourne metro average of CO₂ emissions could be
employed as a datum against which performance of different Hybrid Building options could be examined. In the first instance, there would be a need to set some target with the consequence that the house energy rating scheme would need to include a requirement that houses larger than an acceptable size must achieve a higher per square metre energy performance.

Table 3.2 shows the 2007 data for those Melbourne metropolitan municipalities for which adequate data was available. Energy and CO₂-e emissions resulting from such energy consumption are also shown for Melbourne metropolitan municipalities in Figure 3.6 and Figure 3.7.

### Table 3.2 Average dwelling electricity and gas consumption by selected Melbourne municipalities

<table>
<thead>
<tr>
<th>LGA</th>
<th>Energy (kWh)</th>
<th>Energy (MJ)</th>
<th>CO₂-e (kg)</th>
<th>CO₂-e (kg)</th>
<th>Total (MJ)</th>
<th>Total (CO₂-e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glen Eira (C)</td>
<td>4639</td>
<td>16699</td>
<td>6698</td>
<td>53263</td>
<td>2754</td>
<td>69962</td>
</tr>
<tr>
<td>Greater Dandenong (C)</td>
<td>4919</td>
<td>17710</td>
<td>7103</td>
<td>50602</td>
<td>2616</td>
<td>68311</td>
</tr>
<tr>
<td>Wyndham (C)</td>
<td>5131</td>
<td>18471</td>
<td>7409</td>
<td>49964</td>
<td>2583</td>
<td>68435</td>
</tr>
<tr>
<td>Frankston (C)</td>
<td>5149</td>
<td>18535</td>
<td>7435</td>
<td>49590</td>
<td>2564</td>
<td>68125</td>
</tr>
<tr>
<td>Kingston (C)</td>
<td>5404</td>
<td>19453</td>
<td>7803</td>
<td>49528</td>
<td>2561</td>
<td>68981</td>
</tr>
<tr>
<td>Whitehorse (C)</td>
<td>5240</td>
<td>18665</td>
<td>7567</td>
<td>50206</td>
<td>3000</td>
<td>76885</td>
</tr>
<tr>
<td>Casey (C)</td>
<td>5386</td>
<td>19391</td>
<td>7778</td>
<td>59412</td>
<td>3072</td>
<td>78803</td>
</tr>
<tr>
<td>Latrobe (C)</td>
<td>5960</td>
<td>21456</td>
<td>8606</td>
<td>48071</td>
<td>2485</td>
<td>69527</td>
</tr>
<tr>
<td>Knox (C)</td>
<td>5565</td>
<td>20032</td>
<td>8035</td>
<td>62587</td>
<td>3236</td>
<td>82620</td>
</tr>
<tr>
<td>Monash (C)</td>
<td>5719</td>
<td>20588</td>
<td>8258</td>
<td>59882</td>
<td>3096</td>
<td>80469</td>
</tr>
<tr>
<td>Melbourne (C)</td>
<td>6543</td>
<td>23556</td>
<td>9449</td>
<td>38113</td>
<td>1970</td>
<td>61670</td>
</tr>
<tr>
<td>Boroondara (C)</td>
<td>6154</td>
<td>22155</td>
<td>8886</td>
<td>61727</td>
<td>3191</td>
<td>83882</td>
</tr>
<tr>
<td>Mornington Peninsula (S)</td>
<td>6841</td>
<td>24629</td>
<td>9879</td>
<td>48433</td>
<td>2504</td>
<td>73062</td>
</tr>
<tr>
<td>Bayside (C)</td>
<td>6530</td>
<td>23507</td>
<td>9429</td>
<td>60368</td>
<td>3121</td>
<td>83876</td>
</tr>
<tr>
<td>Manningham (C)</td>
<td>6218</td>
<td>22384</td>
<td>8979</td>
<td>69679</td>
<td>3602</td>
<td>92063</td>
</tr>
<tr>
<td>Stonnington (C)</td>
<td>7248</td>
<td>26093</td>
<td>10466</td>
<td>51069</td>
<td>2640</td>
<td>77162</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>5790</strong></td>
<td><strong>20845</strong></td>
<td><strong>8361</strong></td>
<td><strong>54394</strong></td>
<td><strong>2812</strong></td>
<td><strong>75239</strong></td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td><strong>743</strong></td>
<td><strong>2676</strong></td>
<td><strong>1074</strong></td>
<td><strong>7713</strong></td>
<td><strong>399</strong></td>
<td><strong>8028</strong></td>
</tr>
</tbody>
</table>

Source: Julian Smith, personal communication

Currently average household GHG emissions amount to approximately 11.2 tonnes per year, with a standard deviation of more than 1 tonne. Indeed, households in some municipalities consume 2 tonnes CO₂-e above the metropolitan average.

It our presentation of results from scenario modelling we use levels of greenhouse gas emissions as a key performance indicator – here the Melbourne metro average of CO₂-e emissions is employed as a datum against which performance of different hybrid building options can be examined.
Figure 3.6 Annual household energy consumption by municipality in 2007

Figure 3.7 Annual household CO₂-e emissions from energy consumption by municipality in 2007
4 SHELL

4.1 Characteristics of the residential housing stock

For this study the three key features of the housing stock required to be understood as a context of energy and greenhouse analysis are:

- **Dwelling type.** Newton et al. (2000) have established that there is measurable variation between detached and medium density housing in relation to operating energy use (also, see review by Rickwood et al., 2008). It should be noted that in this study, dwelling type influences on heating and cooling have been ‘controlled out’ as an influencing factor by having all types of dwelling conform to specified energy star ratings;

- **Floor area.** Floor area is a factor in energy use due to heating and cooling requirements to deliver occupant comfort. What constitutes occupant comfort is also a variable factor but is controlled here via the occupant-related assumptions in AccuRate. All heating and cooling is based on the net conditioned floor area (NCFA). For single detached houses, the NCFA can be as low as 75% of the gross floor area;

- **New dwelling completions.** All energy ratings are currently restricted to new construction or major renovations; and

- **Occupancy.** The number of persons per dwelling will affect level of energy use. The average household size decreased from 2.69 to 2.51 persons per household in period 1994-95 to 2005-06 while the average dwelling size increased over this period from 2.88 to 3.06 bedrooms per dwelling (ABS, 2007). The average occupancy rate is assumed to be 2.5 per dwelling.

4.1.1 Dwelling types

The intensification of development in Australia’s urban areas remains a slow-moving process. Re-urbanisation is occurring at higher densities (Newton, 2008, 2009) in inner cities, but suburbanisation continues to be the dominant process for delivery of new housing and the detached house features prominently as the type of dwelling currently occupied (Table 4.1).

<table>
<thead>
<tr>
<th>Dwelling Structure</th>
<th>Number of Dwellings 2001</th>
<th>% of Total 2001</th>
<th>Number of Dwellings 2006</th>
<th>% of Total 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separate house</td>
<td>5,327,309</td>
<td>75.3</td>
<td>5,472,521</td>
<td>76.6</td>
</tr>
<tr>
<td>Medium density</td>
<td>1,356,689</td>
<td>19.2</td>
<td>1,380,765</td>
<td>19.3</td>
</tr>
<tr>
<td>High-rise</td>
<td>198,626</td>
<td>2.8</td>
<td>210,949</td>
<td>3.0</td>
</tr>
<tr>
<td>Other, not stated</td>
<td>189,578</td>
<td>2.7</td>
<td>79,861</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7,072,202</strong></td>
<td><strong>100.0</strong></td>
<td><strong>7,144,096</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>


4.1.2 Floor area

Figure 4.1 shows the average floor area of new residential dwellings from 1986-87 to 2006-07. This increased from 162.1 m² to 212.1 m² over this time, an increase of 30.8%. New houses increased from 176.9 m² to 239.2 m² (35.2%), while new ‘other residential” dwellings increased from 104.7 m² to 140.6 m² (34.3%).
Figure 4.1  Average floor area of new residential dwellings, Australia

Table 4.2 shows a steady growth in the average floor area of new houses in recent years following the fall in 2001-02. Between 2002-03 and 2006-07, the average floor area of new houses increased by 10.0 m² (4.4%) and the average floor area of new ‘other residential’ dwellings increased by 3.9 m² (2.8%), although it has decreased over the last two years. The total average floor area of new residential dwellings increased by 4.3 m² (2.1%) over the same period, despite a small decrease in 2004-05.

Table 4.2  Average floor area of new residential dwellings

<table>
<thead>
<tr>
<th>Period</th>
<th>New Houses</th>
<th>% Change (a)</th>
<th>New Other Residential</th>
<th>% Change (a)</th>
<th>Total New Residential</th>
<th>% Change (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-01</td>
<td>227.5</td>
<td>2.6</td>
<td>132.6</td>
<td>0.9</td>
<td>204.4</td>
<td>2.0</td>
</tr>
<tr>
<td>2001-02</td>
<td>221.2</td>
<td>-2.8</td>
<td>134.7</td>
<td>1.5</td>
<td>201.7</td>
<td>-1.3</td>
</tr>
<tr>
<td>2002-03</td>
<td>229.2</td>
<td>3.6</td>
<td>136.7</td>
<td>1.5</td>
<td>207.8</td>
<td>3.0</td>
</tr>
<tr>
<td>2003-04</td>
<td>235.0</td>
<td>2.5</td>
<td>143.0</td>
<td>4.6</td>
<td>211.0</td>
<td>1.5</td>
</tr>
<tr>
<td>2004-05</td>
<td>238.4</td>
<td>1.4</td>
<td>143.7</td>
<td>0.5</td>
<td>210.4</td>
<td>-0.3</td>
</tr>
<tr>
<td>2005-06</td>
<td>242.6</td>
<td>1.8</td>
<td>142.1</td>
<td>-1.2</td>
<td>213.2</td>
<td>1.3</td>
</tr>
<tr>
<td>2006-07</td>
<td>239.2</td>
<td>-1.4</td>
<td>140.6</td>
<td>-1.0</td>
<td>212.1</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

(a) Percentage change from previous year.

Source: ABS (2008a)

4.1.3  Dwelling occupancy

Average household size is projected to continue decreasing to 2.3 persons per household by 2026 based on ABS projections (Figure 4.2).

Of greater significance for this study is the occupancy level for different dwelling types, as this has a direct link to energy use (Table 4.3).
Table 4.3 Persons per dwelling, Melbourne Statistical Division 2006

<table>
<thead>
<tr>
<th>Housing Type</th>
<th>Average Persons per Dwelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separate house</td>
<td>2.86</td>
</tr>
<tr>
<td>Semi-detached, row or terrace house, townhouse</td>
<td>2.13</td>
</tr>
<tr>
<td>Flat, unit or apartment</td>
<td>1.80</td>
</tr>
<tr>
<td>Separate house and semi-detached</td>
<td>2.76</td>
</tr>
<tr>
<td>Semi-detached and flat or unit</td>
<td>1.90</td>
</tr>
</tbody>
</table>

Source: Table B31 Dwelling Structure, Basic Community Profile, ABS Census (2006)

It is also worth noting the extent to which housing is under-occupied (Newton, 2010), providing a significant proportion of the total dwelling space that is heated and cooled.

4.1.4 Dwelling completions

Since the beginning of this century, an average of approximately 150,000 new dwelling completions have occurred each year (Table 4.4) – the principal vehicle by which the energy efficiency of the housing sector as a whole is enhanced. It has been estimated (Building Commission of Victoria, pers. comm., 2009) that by 2050, around 55% of Victoria’s houses will still pre-date the 5 star building standard introduced for new housing in 2003. This constitutes a major challenge to improving the overall energy and greenhouse performance of the housing sector.

Table 4.4 Dwelling completions, Australia

<table>
<thead>
<tr>
<th>Year</th>
<th>Houses</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>85,056</td>
<td>34,003</td>
<td>119,059</td>
</tr>
<tr>
<td>2002</td>
<td>105,589</td>
<td>36,848</td>
<td>142,437</td>
</tr>
<tr>
<td>2003</td>
<td>106,383</td>
<td>42,742</td>
<td>149,125</td>
</tr>
<tr>
<td>2004</td>
<td>107,034</td>
<td>50,277</td>
<td>157,311</td>
</tr>
<tr>
<td>2005</td>
<td>106,187</td>
<td>52,062</td>
<td>158,249</td>
</tr>
<tr>
<td>2006</td>
<td>95,474</td>
<td>45,755</td>
<td>141,229</td>
</tr>
<tr>
<td>2007</td>
<td>103,567</td>
<td>43,857</td>
<td>147,424</td>
</tr>
</tbody>
</table>

Note: This is the sum of each quarter for the year.
Source: Australian Bureau of Statistics, 8752.0 Building Activity, Australia, Table 37. Number of Dwelling Unit Completions by Sector, Australia
4.2 Residential building

The alternative forms of dwellings investigated were:

- Detached single storey;
- Detached two storey;
- Medium density walk-up flat (i.e. middle floor apartment, no lift); and
- High-rise apartment (i.e. with lift).

The alternative performance (heating and cooling) levels of each were:

- 2.5 star performance, representing existing housing stock;
- 5 star performance, representing current standard; and
- 7 star performance, indicative of likely future standard.

The initial thoughts for this study were to have as few variables as possible among the dwelling types, e.g. each would have a floor area of approximately 250 m$^2$ area but the available sizes and types of dwellings for which heating and cooling assessments could be made (Tony Isaacs Consulting, 2007a) were typical of their type, i.e. 230, 302, 109 and 110 m$^2$ respectively of the forms listed above. The characteristics of the different types of dwellings employed in the energy modelling are shown in Table 4.5. The net conditioned floor area (NCFA) is that proportion of the floor area of the dwelling which is heated and cooled (or air conditioned) as used in the star rating procedure. The characteristics are for a 5 star dwelling.

Table 4.5 Dwelling characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Detached single storey</th>
<th>Detached two storey</th>
<th>Medium density walk-up flat (no lift)</th>
<th>High-rise apartment (with lift)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation</td>
<td>North</td>
<td>North</td>
<td>East</td>
<td>South</td>
</tr>
<tr>
<td>Floor area (m$^2$)</td>
<td>230.0</td>
<td>301.7</td>
<td>108.8</td>
<td>120</td>
</tr>
<tr>
<td>Net conditioned floor area (NCFA) (m$^2$)</td>
<td>172.5</td>
<td>237.3</td>
<td>108.8</td>
<td>109.9</td>
</tr>
<tr>
<td>Bedrooms</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>External wall area (m$^2$)</td>
<td>179.4</td>
<td>263.2</td>
<td>74.8</td>
<td>48.1</td>
</tr>
<tr>
<td>Shared wall (m$^2$)</td>
<td>0.0</td>
<td>0.0</td>
<td>66.4</td>
<td>89.4</td>
</tr>
<tr>
<td>Floor type</td>
<td>Slab</td>
<td>Slab ground/ timber first</td>
<td>Slab</td>
<td>Slab</td>
</tr>
<tr>
<td>Wall type</td>
<td>BV</td>
<td>BV</td>
<td>Concrete</td>
<td>Concrete</td>
</tr>
<tr>
<td>Roof type</td>
<td>Tiled</td>
<td>Tiled</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>Glazing – amount (% NCFA)</td>
<td>25.7%</td>
<td>22.1%</td>
<td>28.3%</td>
<td>26.5%</td>
</tr>
<tr>
<td>Insulation – ceiling</td>
<td>R3.0</td>
<td>R2.0</td>
<td>None$^1$</td>
<td>None$^1$</td>
</tr>
<tr>
<td>Insulation – walls</td>
<td>R1.5</td>
<td>R2.0</td>
<td>None$^1$</td>
<td>None$^1$</td>
</tr>
<tr>
<td>Insulation – floor</td>
<td>None</td>
<td>None</td>
<td>None$^1$</td>
<td>None$^1$</td>
</tr>
<tr>
<td>Heating/cooling profile</td>
<td>All day occupancy</td>
<td>All day occupancy</td>
<td>All day occupancy</td>
<td>All day occupancy</td>
</tr>
<tr>
<td>Cost – Capital (house only)</td>
<td>$165,337</td>
<td>$223,681</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>Service life (years)</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

$^1$ Floors and ceilings shared with adjacent units.

Based on this information for a 5 star rated dwelling, changes were made to achieve 2.5 and 7 star ratings. The building details are controlled by the need for a particular star rating, i.e. there are many combinations which can achieve the same star ratings. However, it was impossible to reduce the ratings for medium density and high-rise dwellings to a low of 2.5 without a bad redesign. The focus of this study is the energy demand and use so how the star ratings are achieved have no impact on the outcomes. The more important factor is how the chosen dwellings represent the housing stock (see Section 4.1).
4.2.1 Detached single storey
The detached single storey dwelling used for assessing heating and cooling demand was based on that from a study by Tony Isaacs Consulting (2007a) as shown in Figure 4.3.

Source: Tony Isaacs Consulting (2007a)

Figure 4.3 Detached single storey dwelling

4.2.2 Detached two storey
The detached two storey dwelling used for assessing heating and cooling demand was based on that from a study by Tony Isaacs Consulting (2007a) as shown in Figure 4.4.

Source: Tony Isaacs Consulting (2007a)

Figure 4.4 Detached two storey dwelling
Medium density walk-up flat (no lift)
The medium density walk-up flat used for assessing heating and cooling demand was based on that from a study by Tony Isaacs Consulting (2007a) as shown in Figure 4.5.

4.2.3 High-rise apartment (with lift)
The medium density walk-up flat used for assessing heating and cooling demand was based on that from a study by Tony Isaacs Consulting (2007a) as shown in Figure 4.6.

4.3 Space heating and cooling
The approach used for estimating heating and cooling loads for each of the three star ratings for each of the four dwelling types assumed the following:

- The heating and cooling loads were for the occupancy profile associated with the most common usage of the four dwelling types. Assessments were made using CSIRO's AccuRate engine for all day occupancy;
- Energy used for heating and cooling were provided by a range of equipment and energy sources as described below. The efficiencies were obtained from the DEWHA (2008a) report on energy use in the Australian residential sector;
• Annual energy costs were determined from heating and cooling demand and 2009 tariffs for electricity and gas provided by a Melbourne retail energy supplier (Victorian Government, 2009);

• Emissions from energy use were based on data from Victorian energy sources available on the website of the Sustainability Energy Authority Victoria (2002).

4.3.1 Heating – gas ducted
The annual energy consumed was calculated from the heating demand estimated from AccuRate and multiplied by the inverse of the Co-efficient of Performance of the technology (1.905), i.e. the overall gas in MJ required by average gas heating appliances to produce 1 MJ output heating energy, taking into account duct losses (DEWHA, 2008a, Table 75, p 226).

4.3.2 Heating – electric
The annual energy consumed was calculated from the heating demand estimated from AccuRate and multiplied by the inverse of the Co-efficient of Performance of the technology (0.278), i.e. the electricity in kWh required by average electric resistive space heating appliances to produce 1MJ output heating energy (DEWHA, 2008a, Table 71, p 222).

4.3.3 Heating – electric reverse cycle
The annual energy consumed was calculated from the heating demand estimated from AccuRate and multiplied by the inverse of the Co-efficient of Performance of the technology (0.084), i.e. the electricity in kWh required by average electric reverse cycle ducted heating appliances to produce 1MJ output heating energy, taking into account duct losses (DEWHA, 2008a, Table 73, p 224).

4.3.4 Heating – electric – shared services
The annual energy consumed was calculated in the same manner as that for electric heating in Section 4.3.2.

4.3.5 Cooling – electric
The annual energy consumed was calculated from the cooling demand estimated from AccuRate and multiplied by the inverse of the Co-efficient of Performance of the technology (0.143), i.e. the electricity in kWh required by average electric cooling appliances to produce 1MJ output cooling, taking into account duct losses (DEWHA, 2008a, Table 69, p 220).

4.3.6 Cooling – electric evaporative ducted
The annual energy consumed was calculated from the cooling demand estimated from AccuRate and multiplied by the inverse of the Co-efficient of Performance of the technology (0.019), i.e. the electricity in kWh required by average electric evaporative cooling appliances to produce 1MJ output cooling (DEWHA, 2008a, Table 70, p 221).

4.3.7 Cooling – electric reverse cycle
The annual energy consumed was calculated from the cooling demand estimated from AccuRate and multiplied by the inverse of the Co-efficient of Performance of the technology (0.090), i.e. the electricity in kWh required by average electric reverse cycle heating appliances to produce 1MJ output cooling (DEWHA, 2008a, Table 67, p 218).
4.4 Analysis

4.4.1 Dwelling energy demand

The results of the AccuRate assessments to determine heating and cooling demands are shown in Table 4.6. The star ratings are nominally 2.5, 5 and 7 stars and the area used to determine usage per square metre is the total floor area.

<table>
<thead>
<tr>
<th>Star rating (actual)</th>
<th>Detached single storey</th>
<th>Detached two storey</th>
<th>Medium density walk-up flat (no lift)</th>
<th>High-rise apartment (with lift)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Star rating (actual)</td>
<td>2.4 5.1 6.9 2.4 5.1 7.0 2.5 5.1 7.0 2.5 5.5 7.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating (MJ/m²/yr)</td>
<td>348.0 144.5 77.6 308.3 128.9 66.6 N.A. 144.1 66.8 N.A. 141.1 83.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling (MJ/m²/yr)</td>
<td>31.8 23.0 22.2 34.3 20.9 18.0 N.A. 32.5 29.0 N.A. 5.0 3.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (MJ/m²/yr)</td>
<td>379.8 167.5 99.8 342.6 149.8 84.6 N.A. 176.6 95.8 N.A. 146.1 86.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.7 and Figure 4.7 show the annual heating and cooling demands for each of the four dwelling types when rated as approximately 2.5, 5 or 7 stars in Melbourne using CSIRO’s AccuRate. As the star rating system is on the basis of MJ/m² (see Table 4.6), the dwelling with the largest area (detached two storey) requires the most heating and cooling energy for the same star rating. The size of the non-conditioned floor area makes no impact on the star ratings as energy consumption is assumed to be zero. The higher the star rating, the lower the energy demand, but the relationship is not linear, with the energy demand dropping by about half for each 2 star increase in star rating (Figure 4.7). The values in the last line of Table 4.6 are effectively the marginal increase in energy demand per 1 m² of additional total floor area.

Heating demand is many times the cooling demand for all cases and the 2.5 star dwellings require about four times the energy of the 7 star dwellings for the Melbourne climate zone. The relative ratios of heating to cooling demand would be considerably different in tropical and hot dry climate zones. Note that energy ratings are based on total energy demand with the relative differences in heating and cooling not having any impact on the star rating. The very low cooling demand for high-rise apartments is due to the mass of the concrete walls and that the dwelling is surrounded on all but the window side by other dwellings assumed to be at the required temperature (i.e. no heat flows between dwellings).

<table>
<thead>
<tr>
<th>Star rating</th>
<th>Detached single storey</th>
<th>Detached two storey</th>
<th>Medium density walk-up flat (no lift)</th>
<th>High-rise apartment (with lift)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Star rating</td>
<td>2.4 5.1 6.9 2.4 5.1 7.0 2.5 5.1 7.0 2.5 5.5 7.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating (MJ/yr)</td>
<td>60030 24926 13386 73160 30588 15804 N.A. 15678 7268 N.A. 15507 9144</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling (MJ/yr)</td>
<td>5486 3968 3830 8139 4960 4271 N.A. 3536 3155 N.A. 550 396</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (MJ/yr)</td>
<td>65516 28994 17216 81299 35548 20075 N.A. 19214 10423 N.A. 16057 9540</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Dwelling heating and cooling demand

Figure 4.7  Heating and cooling demands for 2.5, 5 and 7 star detached single storey, detached two storey, medium density walk-up flat and high-rise apartment

4.4.2  Dwelling energy, CO$_2$-e emissions and eco-efficiency by technology

Table 4.8 shows the annual energy demand and CO$_2$-e for a 5 star single storey detached dwelling. While the total energy demand and CO$_2$-e are different for the 2.5 and 7 star single storey dwelling (and also different for the other three dwelling types), the relative performances of the heating and cooling technologies are very similar for all star rating and dwelling type combinations. Each of the measures is also shown individually in Figure 4.8 and Figure 4.9. Electric shared services for the high-rise have the same energy and CO$_2$-e per square metre as electric heating.

Table 4.8  Heating and cooling consumption for a 5 star detached single storey dwelling

<table>
<thead>
<tr>
<th>Technology</th>
<th>Heating</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas ducted</td>
<td>Electric</td>
</tr>
<tr>
<td>Energy: total (MJ/yr)</td>
<td>47674</td>
<td>24936</td>
</tr>
<tr>
<td>CO2-e: total (kg/yr)</td>
<td>2498</td>
<td>10002</td>
</tr>
<tr>
<td>Costs: total AEC ($/yr)</td>
<td>$873</td>
<td>$1,487</td>
</tr>
</tbody>
</table>

In terms of energy consumed, the gas ducted heating systems use the largest annual amount of energy (Figure 4.8) but, in terms of CO$_2$-e emissions, electric heating produces 3 to 4 times as much as the gas ducted heating (Figure 4.9) because of the inefficiencies of converting fossil energy into electricity and back again to heat energy. The high Coefficient of Performance for evaporative cooling means little energy is required but it does use substantial amounts of water. As shown earlier, the energy demand for heating far exceeds the demand for cooling in the Melbourne climate zone.
Figure 4.8  Energy demand by heating and cooling technologies for a 5 star single storey dwelling

Figure 4.9  Annual CO₂-e emissions by heating and cooling technologies for a 5 star single storey dwelling
4.4.3 **Key message: Building shell – heating and cooling**

Australia has a large stock of existing housing (over 7 million dwellings). Data on new dwelling completions (Table 4.4) indicates a gross addition of 147,000 on average each year between 2001 and 2007. There is considerable scope for innovation with both existing and new stock in relation to design and technology as well as across-the-board behaviour change.

**Innovation (Technology and design)-induced potential for emissions savings**

The difference in greenhouse gas emissions from a 2.5 star and a 5 star detached single storey dwelling is 3.5 tonnes/year (for a 7 star compared to a 2.5 star house, the amount is 4.6 tonnes/year). For two storey houses, medium density dwellings and high-rise units the respective figures are in Table 4.9.

Table 4.9 Annual CO$_2$-e emissions by dwelling type for gas ducted heating and evaporative cooling

<table>
<thead>
<tr>
<th></th>
<th>CO$_2$-e emissions (kg/dwelling)</th>
<th>CO$_2$-e emissions (kg/m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.5 star</td>
<td>5.0 star</td>
</tr>
<tr>
<td>Detached single storey</td>
<td>6105</td>
<td>2608</td>
</tr>
<tr>
<td>Detached two storey</td>
<td>9208</td>
<td>4679</td>
</tr>
<tr>
<td>Medium density walk-up flat (no lift)</td>
<td>4679</td>
<td>2010</td>
</tr>
<tr>
<td>High-rise apartment (with lift)</td>
<td>4726</td>
<td>1989</td>
</tr>
</tbody>
</table>

Given that approximately 150,000 new dwellings have been completed each year since the nationwide house energy rating scheme (NatHERS) was introduced in 2003, CO$_2$-e savings over the subsequent four years have been of the order of 525,000 tonnes per year (based on an averaging of detached single and two storey stock).

A shift to 7 star ratings would deliver additional annual CO$_2$-e savings from the housing sector (for heating and cooling) of approximately 4.5 tonnes/dwelling/year compared to that of the bulk of the existing (assuming average 2.5 star rated) stock which equates to annual savings of 675,000 tonnes from new housing construction.

**Behaviour (Lifestyle)-induced potential for emissions savings**

The average increase in floor space across all new dwellings constructed between 2001 and 2006 was 11.5 square metres. This equates to an average increase of 1,748,000 square metres per year, based on levels of new dwelling completions during this period (Table 4.4).

As a result of this lifestyle-induced increase in floor space (household size has declined and levels of under-occupancy have increased), approximately 23.6 thousand tonnes of additional CO$_2$-e are being emitted per year in order to heat and cool the extra floor space, based on average emissions rate across detached housing of 13.5 kg per m$^2$ per year (see Table 4.9).

If there were a reversion to a simpler style of living that has been advocated (e.g. Trainer, 2008), with floor spaces akin to those of a quarter century ago (i.e. 167 square metres for new private sector houses in 1983 (ABS, 1994)) being reflected in new dwelling completions, the average annual savings in CO$_2$-e could be of the order of 146 thousand tonnes (based on 2007 completions levels of 150,000 dwellings, a 25 year difference in average floor area of 72 m$^2$, and average CO$_2$-e emissions per m$^2$ of detached housing of 13.5 kg).

With Australia’s most recent greenhouse gas inventory (Table 2.2) indicating that the nation’s residential sector was generating 54.5 Mt of CO$_2$-e per year in 2006, an innovation (technology and design-based) intervention (e.g. adopting a 7 star rating for operating energy for housing) together with a behaviour-based lifestyle change (e.g. winding back floor space to turn of the century levels) could mitigate a significant volume of national greenhouse gas emissions – of the order of 800,000 tonnes/yr.
5 APPLIANCES

5.1 Introduction to appliances

The appliances used in this study are those typically found in dwellings and are designed for domestic use, as shown in Table 5.1.

<table>
<thead>
<tr>
<th>Appliance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hot water</strong></td>
</tr>
<tr>
<td>Hot water – gas – storage</td>
</tr>
<tr>
<td>Hot water – gas – instant</td>
</tr>
<tr>
<td>Hot water – electric</td>
</tr>
<tr>
<td>Hot water – solar thermal</td>
</tr>
<tr>
<td>Hot water – shared services</td>
</tr>
<tr>
<td><strong>Built-in appliances</strong></td>
</tr>
<tr>
<td>Cooktop – gas</td>
</tr>
<tr>
<td>Cooktop – electric</td>
</tr>
<tr>
<td>Oven – electric</td>
</tr>
<tr>
<td>Oven – gas</td>
</tr>
<tr>
<td>Microwave oven</td>
</tr>
<tr>
<td>Lighting</td>
</tr>
<tr>
<td>Common area energy (Class 2 buildings)</td>
</tr>
<tr>
<td><strong>Plug-in appliances</strong></td>
</tr>
<tr>
<td>Refrigerator/freezer</td>
</tr>
<tr>
<td>Dishwasher</td>
</tr>
<tr>
<td>Washing machine</td>
</tr>
<tr>
<td>Clothes dryer</td>
</tr>
<tr>
<td>Television</td>
</tr>
<tr>
<td>Computer</td>
</tr>
<tr>
<td>Home entertainment systems</td>
</tr>
<tr>
<td>Set top box</td>
</tr>
<tr>
<td>Kettle – electric</td>
</tr>
</tbody>
</table>

For analytical purposes, appliances are characterised in two key respects:

- Operating energy performance, where there is a distinction made between ‘average’ performance (DEWHA, 2008a) and ‘best of breed’. This allows exploration of how technological innovation can assist with winding back energy use and CO₂-e emissions;
- Range of appliances, differentiating between a ‘basic’ and an ‘affluenza’ set. An affluenza set of appliances reflects recent commentaries on consumption (Hamilton & Denniss, 2005) that highlight the accumulation of appliances by an increasing proportion of Australian households, e.g. multiple flat screen televisions, refrigerators and lighting, pools and spas.

For built-in appliances, a number of alternative scenarios are derived:

- Cooking, where a number of different combinations of appliances are represented, e.g. all gas, all electric, mixture, microwave only;
- Lighting, where different lighting technologies are featured, e.g. all incandescent, all halogen, all LEDs, common mix as defined by DEWHA (2008a) (see Table 5.4).
5.2 Hot water

5.2.1 Demand
The estimates for hot water demand are based on the data in the DEWHA report, where the average usage level is stated as being 110 L of hot water per day per household (DEWHA, 2008a, p 86). However, this usage is more like a per person rate as it does not match with the values in Table 18, p 58 of George Wilkenfeld and Associates & Energy Efficient Strategies (2007) which, for an average household of 2.53 persons, use 198 and 187 litres per day for a weighted average and efficient water use respectively. A water usage rate of 198 L/day per household was used in this study compared to a value of 202 L/day used by DEWHA (2009a). Medium density and high-rise apartments were assumed to have occupancy rates of 1.3 persons with a consequent reduction in demand for hot water to 60% of average. It was assumed that 1 L of hot water supplied requires an energy input of 188 kJ (DEWHA, 2009a).

The annual energy consumed for an average household in Melbourne was calculated for each hot water technology by multiplying the annual hot water demand by an energy efficiency factor which represents the average purchased energy per litre required to provide 1 L of hot water over a year. The factors were obtained from the model developed by DEWHA (2009a).

5.2.2 Gas storage
The gas storage unit was a typical storage unit with 160 L capacity. The energy efficiency factor for Melbourne was 290 kJ (DEWHA, 2009a) with a 13 MJ per day standby consumption (DEWHA, 2008a, Table 79, p 228).

5.2.3 Gas instantaneous
The gas instantaneous unit has no hot water storage and a typical throughput of about 24 L/min for a 25°C temperature rise. These hot water systems have both a gas standby energy consumption (pilot flame) and electricity consumption for controls. Energy losses are less than those of storage systems. The energy efficiency factor for Melbourne was 262 kJ (DEWHA, 2009) with a 0.4 MJ per day standby consumption and a standby electricity consumption of 5.6 W (DEWHA, 2008a, Table 80, p 229).

5.2.4 Electric storage
The electric storage unit was a typical storage unit with 315 L capacity because it operates on off-peak electricity and needs to hold hot water for about 70% of the day between heating cycles. The energy efficiency factor for Melbourne was assumed to be the same as a gas storage system, i.e. 290 kJ (DEWHA, 2009) with a 1.99 kWh heat loss per day (DEWHA, 2008a, Table 78, p 228).

5.2.5 Solar thermal electric boost
A solar thermal storage unit has a typical storage capacity of 250-300 L. The conversion efficiency of electricity into heat is very high (98%) and the energy efficiency factor for Melbourne was 91 kJ (DEWHA, 2009) with a 11.99 kWh heat loss per day (DEWHA, 2008a, Table 81, p 230). Thus the electric boosted solar thermal system uses about 35% of the energy required by a fully electric storage system.

5.2.6 Solar thermal gas boost
A solar thermal storage unit within-tank gas boosting has a typical storage capacity of 250-300 L (same as for electric boosted solar thermal). The gas storage unit was a typical storage unit with 160 L capacity. The energy efficiency factor for Melbourne was 118 kJ (DEWHA, 2009) with a 14.2 MJ per day standby gas consumption and 65 kWh per year electricity consumption for pumps (DEWHA, 2008a, Table 83, p 231).
5.2.7 Shared services
The shared services hot water systems can be either electric (if as commonly distributed) or gas (if in individual dwelling units). Whether individually or centrally supplied:

‘Shared services which substitute for equipment in apartments, such as centrally supplied heating, cooling and hot water, also need to be covered, although preliminary analyses suggest that emissions per apartment are similar whether these services are supplied centrally or individually’ (George Wilkenfeld and Associates & Energy Efficient Strategies, 2007, p 8).

For this study, individual gas hot water systems have been assumed for medium density dwellings and electric hot water for high-rise dwellings.

5.2.8 Analysis
Table 5.2 shows the annual energy demand and CO₂-e for a range of domestic hot water systems. The annual energy demand for hot water for an average household does vary by a factor of 3 from electricity boosted solar system to gas storage systems. While the gas energy requirements are higher due to differences in direct conversion efficiencies, the annual CO₂-e emissions are reversed, with the electric storage system having almost 12 times the emissions for gas boosted solar hot water system.

Table 5.2 Energy demand, CO₂-e emissions and eco-efficiency for hot water technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Gas storage</th>
<th>Gas instant</th>
<th>Electric storage</th>
<th>Solar thermal electric boost</th>
<th>Solar thermal gas boost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy: total (MJ/yr)</td>
<td>20973</td>
<td>19270</td>
<td>13958</td>
<td>6581</td>
<td>8534</td>
</tr>
<tr>
<td>CO2-e: total (kg/yr)</td>
<td>1084</td>
<td>1058</td>
<td>5599</td>
<td>2640</td>
<td>441</td>
</tr>
<tr>
<td>Costs: total AEC ($yr)</td>
<td>$543</td>
<td>$492</td>
<td>$549</td>
<td>$752</td>
<td>$536</td>
</tr>
</tbody>
</table>

Figure 5.1 Annual energy demand for hot water technologies
### 5.2.9 Key messages

A more rapid transition to gas boosted solar thermal (GBST) hot water heating is required. Electricity still represents 40% of the current installed stock of hot water heaters in Australia (Figure 5.3) and each electric storage hot water unit generates over 10 tonnes per year of CO$_2$-e compared to less than 1 tonne per year for GBST. Compared to electric, opportunities for CO$_2$-e savings are of the order of a factor of 12 for GBST (significantly more than gas instantaneous with a factor of 1.3 and gas hot water storage heater with a factor of 1.7).

Source: DEWHA (2008a, Figure 26, p 43)

### Figure 5.3  Trends in hot water heating type – Australia
5.3 Cooking

The annual energy consumed by cooking appliances (cooktops, ovens, stoves and microwave ovens) is poorly known (DEWHA, 2008a, p 88). The use of gas for cooktops is increasing and now exceeds the use of electricity (DEWHA, 2008a, Figure 61, p 90). In contrast, electric ovens are much more popular, now exceeding 70% of all ovens (DEWHA, 2008a, Figure 61, p 90). In 2007, the average annual energy use per cooktop was estimated to be 288 kWh/year for electricity and 1.6 GJ/year for gas (DEWHA, 2008a, p 89). In 2007, the average annual energy use per oven was estimated to be 237 kWh/year for electricity and 1.7 GJ/year for gas (DEWHA, 2008a, p 89). Microwave ovens have now a very high penetration level but average usage is quite low and typically 50% of the total energy is standby power (DEWHA, 2008a, p 92). Assumed usage is 50 hours per year with the remainder of the time on standby (DEWHA, 2008a, p 92). All standby electricity has been included as described in the following sections.

5.3.1 Cooktop – gas
Gas cooktops do have, on average, a small standby electricity usage amounting to less than 2 kWh/yr, very small (about 6 MJ/yr) (DEWHA, 2008a, Table 85, p 232) in comparison to the gas usage (1600 MJ/yr) mentioned above.

5.3.2 Cooktop – electric
Similarly, electric cooktops do have, on average, a small standby electricity usage amounting to less than 2 kWh/yr, very small (DEWHA, 2008a, Table 84, p 231) in comparison to the electric usage (288 kWh/yr) mentioned above.

5.3.3 Oven – electric
The efficiency of electric ovens over the past 20 years has been increasing because the energy losses have been reduced so that the Wh/hr have been estimated to have declined from 1000 to 736 in 2008 (DEWHA, 2008a, Table 86, p 232). The standby electricity as listed in the same table is noticeable at about 17 kWh/yr but still considerably less than the annual amount of electricity used for the oven cooking (237 kWh/yr).

5.3.4 Oven – gas
Similarly to cooktops, gas ovens do have, on average, a small standby electricity usage amounting to a noticeable 60 MJ/yr, relatively small (DEWHA, 2008a, Table 87, p 233) in comparison to the gas usage (1700 MJ/yr) mentioned above.

5.3.5 Oven microwave
The efficiency of microwave ovens over the past 20 years has been increasing due to improvements in microwave technology from 45% to 57% (DEWHA, 2008a, Table 88, p 234). The standby electricity as listed in the same table is significant at about 21 kWh/yr in comparison with the annual cooking usage of 50 hours at a power rating of 1373 W (69 kWh/yr).

5.3.6 Analysis
Table 5.3 shows the annual energy demand, CO₂-e and eco-efficiency for a range of domestic cooking appliances. The annual energy demand for cooking for an average household does vary considerably depending on the cooking appliance. While the gas energy requirements are about a factor of 2 higher due to differences in direct conversion efficiencies, the annual CO₂-e emissions are reversed, with the electric cooktop and oven having approximately 3 to 4 times the emissions of the equivalent for gas appliance. The low usage of microwave ovens results in low energy consumption but the CO₂-e emissions are slightly higher than those for gas appliances.
Table 5.3: Energy demand, CO₂-e emissions and eco-efficiency for cooking technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Cooktop – gas</th>
<th>Cooktop – electric</th>
<th>Oven – electric</th>
<th>Oven – gas</th>
<th>Oven – microwave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy: total (MJ/yr)</td>
<td>1606</td>
<td>1043</td>
<td>913</td>
<td>1760</td>
<td>323</td>
</tr>
<tr>
<td>CO₂-e: total (kg/yr)</td>
<td>85</td>
<td>418</td>
<td>366</td>
<td>112</td>
<td>129</td>
</tr>
<tr>
<td>Costs: total AEC ($/yr)</td>
<td>$85</td>
<td>$102</td>
<td>$106</td>
<td>$90</td>
<td>$56</td>
</tr>
</tbody>
</table>

Figure 5.4: Annual energy demand for cooking technologies

Figure 5.5: Annual CO₂-e emissions for cooking technologies
5.3.7 Cooking scenarios

From an energy perspective, gas represents the biggest consumer of delivered energy (Section 3.1) and microwaves the lowest. From a CO₂-e perspective, however, gas and microwaves represent the lowest greenhouse gas emission cooking appliance options currently available.
5.3.8 Key messages
From a solely GHG perspective, cooking with gas is a superior outcome at the present time or until a dwelling can be self-sufficient from electricity-generating local renewables such as photovoltaics. The trends in take-up of gas cooking appliances generally across Australia are a positive sign in this respect (Figure 5.8). Microwave performance is diminished due to a 23% contribution from its standby power component.

Source: DEWHA (2008a, Figure 25, p 43)

Figure 5.8 Trends in cooking energy type – Australia
5.4 Lighting

Lighting energy demand in dwellings is another highly variable energy consumption because of both occupant behaviour and the types of lighting installed. The changes in demand over recent years are from larger dwellings (consumption increasing), use of quartz halogen lights (consumption increasing) and compact fluorescent lights (consumption decreasing) (DEWHA, 2008a, p 62). The proportion of linear fluorescents and LED lighting is small (DEWHA, 2008a, p 62 and Table 162, p 344) with the latter expected to expand in future as costs come down. The approach to lighting was based on the DEWHA data (particularly the data in DEWHA, 2008a, Table 102, p 248 and Table 103, p 249) with living and non-living areas treated separately and aggregated to obtain a total for the whole dwelling. Each type of lighting was evaluated as if the dwelling had only one type of lighting as well as a standard mix (DEWHA, 2008a, Table 162, p 344 and Table 163, p 345). The usage is calculated from the 2008 installed lighting density in (W/m²) (DEWHA, 2008a, Table 103, p 249) which is derived from the light density (Lux) and the product efficiency. The shares of lighting technologies are shown in Table 5.4. The living and non-living areas are split 40% and 60% respectively (DEWHA, 2008a, Table 163, p 345) and used 2 and 0.4 hours per day respectively (DEWHA, 2008a, p 97).

### Table 5.4 Shares of lighting technologies for typical dwellings

<table>
<thead>
<tr>
<th></th>
<th>Living Areas (% of total)</th>
<th>Non-living Areas (% of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent</td>
<td>41.3</td>
<td>88.0</td>
</tr>
<tr>
<td>Quartz Halogen</td>
<td>32.0</td>
<td>4.4</td>
</tr>
<tr>
<td>Linear Fluorescent</td>
<td>2.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Compact Fluorescent</td>
<td>24.1</td>
<td>6.6</td>
</tr>
<tr>
<td>LEDs</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: DEWHA (2008a)

5.4.1 Incandescent
For incandescent lighting, the lighting densities are 16.5 and 11.0 W/m² for living and non-living areas respectively (DEWHA, 2008a, Table 103, p 249). The average lifetime was assumed to be 1000 hours.

5.4.2 Halogen
For quartz halogen lighting, the lighting densities are 32.1 and 18.3 W/m² for living and non-living areas respectively (DEWHA, 2008a, Table 103, p 249). The average lifetime was assumed to be 2000 hours.

5.4.3 Linear fluorescent
For linear fluorescent lighting, the lighting densities are 6.2 and 3.1 W/m² for living and non-living areas respectively (DEWHA, 2008a, Table 103, p 249). The average lifetime was assumed to be 8000 hours.

5.4.4 Compact fluorescent
For compact fluorescent lighting, the lighting densities are 3.3 and 2.2 W/m² for living and non-living areas respectively (DEWHA, 2008a, Table 103, p 249). The average lifetime was assumed to be 6000 hours.

5.4.5 LEDS
For LED lighting, the lighting densities are 5.0 and 3.3 W/m² for living and non-living areas respectively, based on the same light densities as for incandescent lighting and a product efficiency of 36.3 compared to 10.9 for incandescent lighting. The average lifetime was assumed to be 20000 hours.
5.4.6 **Average mix**
The average mix is a weighted proportion of each of the lighting technologies, according to the share of lighting technologies shown in Table 5.4.

5.4.7 **Analysis**
Table 5.5 shows the annual energy demand, CO₂-e and eco-efficiency for a range of lighting types. The annual energy demand for lighting for an average household does vary considerably depending on the type of lighting and the typical light density of the technologies as commonly installed. The halogen lights consume the most electricity for the normal level of lighting used for each type while linear and compact fluorescents and LEDs consume many times less. As energy for all types of lighting is always electricity, the annual CO₂-e emissions are in similar proportions.

### Table 5.5 Energy demand, CO₂-e emissions and eco-efficiency for lighting technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Incandescent</th>
<th>Halogen</th>
<th>Linear fluorescent</th>
<th>Compact fluorescent</th>
<th>LEDs</th>
<th>Average mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy: total (MJ/yr)</td>
<td>21</td>
<td>40</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>25</td>
</tr>
<tr>
<td>CO₂-e: total (kg/yr)</td>
<td>8</td>
<td>16</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Costs: total AEC ($/yr)</td>
<td>$1.15</td>
<td>$2.51</td>
<td>$0.42</td>
<td>$0.33</td>
<td>$1.47</td>
<td>$1.49</td>
</tr>
</tbody>
</table>

![Annual energy demand for lighting technologies](image)

**Figure 5.9 Annual energy demand for lighting technologies**
5.4.8 Key messages
Of all domestic electrical appliances, lighting and televisions constitute the largest consumers of energy in the house (Figure 5.11) both now and in the future.

Both incandescent and halogens can be bracketed as the two leading CO$_2$-e emitters for domestic lighting.

Source: DEWHA (2008a, Figure 24, p 41)
5.5 Plug-in appliances

Plug-in appliances consume a substantial proportion of energy (entirely electricity) in a dwelling with high growth forecast (Figure 5.11), particularly the use of televisions, computers and standby energy. The range of appliances adopted in this study is based on the appliances detailed in the report by DEWHA (2008a) on energy use in the Australian residential sector from 1986 to 2020. The report is also the basis for determining the average annual energy for each appliance.

To determine what might constitute poor and good performers and be able to include such appliances in later scenarios, popular sized appliances were assumed as average. By consulting sales catalogues such as Harvey Norman (2009), high and low energy performers were identified, in addition to often examining the manufacturers’ specification to obtain how much variation from the average energy such appliances might consume. This relative variation was applied to the average annual energy usage obtained from the DEWHA (2008a) tables.

5.5.1 Refrigerator
The average annual energy use by refrigerators in Victoria in 2008 is 436 kWh (DEWHA, 2008a, Table 61, p 213).

5.5.2 Freezer
The average annual energy use by refrigerators in Victoria in 2008 is 355 kWh (DEWHA, 2008a, Table 62, p 213).

5.5.3 Dishwasher
The average annual energy use by dishwashers in 2005 is 144 kWh. This energy consumption value is derived from annual number of loads, 175 (DEWHA, 2008a, p 92) and plug kWh of 0.771 (DEWHA, 2008a, Table 66, p 217) for washes of approximately one hour. Dishwasher standby energy is small, 1 W (DEWHA, 2008a, p 217).

5.5.4 Washing machine
The average annual energy use by washing machines in 2005 is 157 kWh (DEWHA, 2006, Annex A, p 35). Top loading machines use 488 kWh when heating water and only 75 kWh/yr when heating water is excluded (DEWHA, 2008a, p 91 and DEWHA, 2006, Annex A, p 35). They use a much lower 261 kWh when water is heated and are now about 65% of washing machines. Cold washes occur 80% of the time. The average is the weighted average of machine type and cold washes. Washing machines’ standby energy is small, 1.7 W for top loaders and 0.7W for front loaders (DEWHA, 2008a, pp 214-15).

5.5.5 Clothes dryer
The average clothes dryer consumes about 150 kWh in Australia with large variations due to climate (DEWHA, 2008a, p 91) and standby energy is small 0.4 W (DEWHA, 2008a, Table 65, p 216).

5.5.6 Television
Television energy use has been growing to an ever-increasing proportion of household energy use (Figure 5.11) and hours of viewing (2,600 hours per year was used) increasing along with the size of television sets (DEWHA, 2008a, p 61). Larger LCD and plasma televisions will increase the energy demand by at least a factor of two along with additional use of televisions. Average on mode energy consumption is 100 W (DEWHA, 2008a, p 61). Standby energy is 1.7 W (DEWHA, 2008a, Table 89, p 235). The average annual energy use by televisions in 2008 is 275 kWh (DEWHA, 2008a, Table 62, p 213).

5.5.7 Computer
Computer energy use has been growing (Figure 5.11) along with hours of use to 900 hours per year (DEWHA, 2008a, p 55). Computer energy consumption includes monitors, with consumption being 106 W for desktops and 33.7 W for monitors (DEWHA, 2008a, Table 97, p 243). Laptop computers use 30 W (DEWHA, 2008a, Table 98, p 244). The average annual energy use by computers in 2008 is 25 kWh.
5.5.8 Home entertainment systems
Home entertainment systems (in addition to television) have increased in recent years and include DVDs, VCRs and miscellaneous home entertainment. The assumed annual hours of operation was 400 hours (DEWHA, 2008a, p 57) for 2008. The average annual energy use by home entertainment systems in 2008 was 20 kWh (DEWHA, 2008a, Table 92, p 238).

5.5.9 Set top box
Not all dwellings have set top boxes, either for digital television or pay TV. When turned on, the boxes use either 15.5 W (digital TV) or 8 W for pay TV (DEWHA, 2008a, Tables 92 and 93, pp 238 and 239). Usually they are on when the television is on but could be on permanently; the assumed annual hours of operation was 2,600 hours (DEWHA, 2008a, p 97) for 2008. The assumed average energy consumption was the average of the two types of set top boxes: 12 W when on and 5 W on standby (assumed never turned off). The average annual energy use by set top boxes in 2008 was 76 kWh (DEWHA, 2008a, Table 92, p 238).

5.5.10 Games
Electronic games consoles are becoming commonplace in dwellings. The average annual energy use in this category in 2008 is 37 kWh, based on the appliance power and an average use of 300 hours per year (DEWHA, 2008a, Table 95, p 241). Standby energy is 1 W (DEWHA, 2008a, Table 95, p 241).

5.5.11 Kettle – electric
The average annual energy use by electric kettles in 2005 is 135 kWh (DEWHA, 2008a, Table 62, p 213).

5.5.12 Small miscellaneous
Small miscellaneous items include power tools, vacuum cleaners, small kitchen appliances etc. usually used intermittently. The average annual energy use by such equipment in 2008 is 200 kWh (DEWHA, 2008a, p 98).

5.5.13 Standby – other electric
The average annual energy use by a wide range of devices which use standby energy in 2008 is 330 kWh (DEWHA, 2008a, p 98). Standby energy is expected to grow quickly.

5.5.14 Analysis
Table 5.6 and Table 5.7 show the energy and CO\textsubscript{2}-e emissions for annual average usage of each of the appliances.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Refrigerator</th>
<th>Freezer</th>
<th>Dishwasher</th>
<th>Washing machine</th>
<th>Clothes dryer</th>
<th>Television</th>
<th>Computer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy: total (MJ/yr)</td>
<td>1570</td>
<td>1279</td>
<td>517</td>
<td>564</td>
<td>553</td>
<td>990</td>
<td>458</td>
</tr>
<tr>
<td>CO\textsubscript{2}-e: total (kg/yr)</td>
<td>630</td>
<td>513</td>
<td>207</td>
<td>226</td>
<td>222</td>
<td>397</td>
<td>184</td>
</tr>
<tr>
<td>Costs: total AEC ($/yr)</td>
<td>$136</td>
<td>$95</td>
<td>$142</td>
<td>$100</td>
<td>$79</td>
<td>$408</td>
<td>$317</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology</th>
<th>Home entertainment systems</th>
<th>Set top box</th>
<th>Games</th>
<th>Kettle – electric</th>
<th>Small miscellaneous</th>
<th>Standby – other electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy: total (MJ/yr)</td>
<td>72</td>
<td>274</td>
<td>268</td>
<td>486</td>
<td>540</td>
<td>1188</td>
</tr>
<tr>
<td>CO\textsubscript{2}-e: total (kg/yr)</td>
<td>29</td>
<td>110</td>
<td>107</td>
<td>195</td>
<td>217</td>
<td>477</td>
</tr>
<tr>
<td>Costs: total AEC ($/yr)</td>
<td>$296</td>
<td>$30</td>
<td>$117</td>
<td>$38</td>
<td>$70</td>
<td>$61</td>
</tr>
</tbody>
</table>
Figure 5.12 shows the relative proportions of energy consumed per average appliance for each category. The obvious large consumer categories are televisions and refrigerators, with freezers also a large energy consumer when used. Figure 5.12 does NOT show the actual usage relativities by dwellings or household because most dwellings have more than one television and not all dwellings have a freezer, e.g. there are 1.28 refrigerators per household in Victoria and 0.4 freezers (DEWHA, 2008a, p 93). Since all use electricity, the relative CO₂-e profiles are identical to the energy profiles (Figure 5.13 and Figure 5.14). All categories include the standby energy for each appliance but there is an additional standby category for all those small appliances including electric clocks, cordless telephones, mobile phone chargers, battery chargers for hand tools etc.

**Annual energy demand for plug-in appliances**

![Annual energy demand for plug-in appliances graph]

**Figure 5.12  Annual energy demand for plug-in appliances by percentage**

**Annual energy demand for plug-in appliances**

![Annual energy demand for plug-in appliances bar chart]

**Figure 5.13  Annual energy demand for plug-in appliances**
5.5.15 Key messages for appliance set
All domestic appliances contribute tangibly to the carbon footprint of a household, but there are three that stand out: refrigerators, freezers and televisions (together representing over 50% of total).

5.5.16 Plug-in appliance scenarios
Two scenarios are identified for plug-in appliances:

1. Technology-based: average versus ‘best of breed’ energy performance
   
   Comparison is made between a basic set of domestic appliances that are designated as having ‘average’ energy performance by DEWHA (2008a) and the same set classed as ‘best of breed’ in relation to energy efficiency. ‘Best of breed’ data was obtained from a range of sources such as retailers’ offerings and checking on manufacturers' websites to obtain specifications where possible to obtain performance details, as shown in Table 5.8. The comparison indicates the extent to which technological innovation can potentially drive energy efficiency for this class of domestic appliances.

2. Lifestyle-based: basic versus affluenza set of appliances
   
   Comparison is made between the basic set of plug-in appliances as previously defined and an affluenza set which reflects a trend towards the consumption of more plus larger appliances (e.g. TVs, refrigerators). The affluenza set is shown in Table 5.9.

The annual energy and CO2-e emissions for the average, ‘best of breed’, affluenza average mix and affluenza ‘best of breed’ are shown in Table 5.10 and CO2-e emissions in Figure 5.15 (the annual energy demand profile is similar as most energy used in appliances is electricity).
Table 5.8  Comparison of average and ‘best of breed’ appliances

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Average energy performance</th>
<th>‘Best of breed’ energy performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy rating</td>
<td>Household usage factor</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>1195</td>
<td>1.00</td>
</tr>
<tr>
<td>Freezer</td>
<td>973</td>
<td>1.00</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>771</td>
<td>1.00</td>
</tr>
<tr>
<td>Washing machine</td>
<td>454</td>
<td>1.00</td>
</tr>
<tr>
<td>Clothes dryer</td>
<td>1830</td>
<td>1.00</td>
</tr>
<tr>
<td>Television</td>
<td>100</td>
<td>2.00</td>
</tr>
<tr>
<td>Computer</td>
<td>140</td>
<td>1.00</td>
</tr>
<tr>
<td>Home entertainment systems</td>
<td>380</td>
<td>1.25</td>
</tr>
<tr>
<td>Set top box</td>
<td>12</td>
<td>1.00</td>
</tr>
<tr>
<td>Games</td>
<td>95</td>
<td>2.00</td>
</tr>
<tr>
<td>Kettle – electric</td>
<td>370</td>
<td>1.00</td>
</tr>
<tr>
<td>Small miscellaneous</td>
<td>548</td>
<td>0.75</td>
</tr>
<tr>
<td>Standby – other electric</td>
<td>40</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 5.9  Appliance sets for affluenza scenarios

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Affluenza with average performance appliances</th>
<th>Affluenza with ‘best of breed’ appliances</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy rating</td>
<td>Household usage factor</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>1195</td>
<td>2.00</td>
</tr>
<tr>
<td>Freezer</td>
<td>973</td>
<td>1.00</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>671</td>
<td>1.00</td>
</tr>
<tr>
<td>Washing machine</td>
<td>454</td>
<td>1.00</td>
</tr>
<tr>
<td>Clothes dryer</td>
<td>1830</td>
<td>1.00</td>
</tr>
<tr>
<td>Television</td>
<td>150</td>
<td>3.00</td>
</tr>
<tr>
<td>Computer</td>
<td>170</td>
<td>2.00</td>
</tr>
<tr>
<td>Home entertainment systems</td>
<td>380</td>
<td>2.00</td>
</tr>
<tr>
<td>Set top box</td>
<td>12</td>
<td>0.00</td>
</tr>
<tr>
<td>Games</td>
<td>95</td>
<td>2.00</td>
</tr>
<tr>
<td>Kettle – electric</td>
<td>400</td>
<td>1.00</td>
</tr>
<tr>
<td>Small miscellaneous</td>
<td>548</td>
<td>1.00</td>
</tr>
<tr>
<td>Standby – other electric</td>
<td>40</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Table 5.10  Energy demand, CO2-e emissions and annual equivalent cost for plug-in appliances

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy: standby total (MJ/yr)</td>
<td>1643</td>
<td>988</td>
<td>2119</td>
<td>1998</td>
</tr>
<tr>
<td>Energy: operating (MJ/yr)</td>
<td>8105</td>
<td>6010</td>
<td>12442</td>
<td>8953</td>
</tr>
<tr>
<td>Energy: total (MJ/yr)</td>
<td>9749</td>
<td>6998</td>
<td>14560</td>
<td>10951</td>
</tr>
<tr>
<td>CO2-e: standby total (kg/yr)</td>
<td>659</td>
<td>396</td>
<td>850</td>
<td>801</td>
</tr>
<tr>
<td>CO2-e: operating (kg/yr)</td>
<td>3251</td>
<td>2410</td>
<td>4990</td>
<td>3591</td>
</tr>
<tr>
<td>CO2-e: total (kg/yr)</td>
<td>3910</td>
<td>2807</td>
<td>5840</td>
<td>4393</td>
</tr>
<tr>
<td>Costs: total ($/yr)</td>
<td>$2,947</td>
<td>$2,674</td>
<td>$6,397</td>
<td>$3,898</td>
</tr>
</tbody>
</table>
5.5.17 Key messages for ‘best of breed’ and affluenza sets of appliances

As expected, a worst possible scenario from both an energy and a greenhouse gas emission perspective, are households with an affluenza set of appliances that have average energy efficiency rating. These households would generate each year, on average, close to 6 tonnes of CO₂-e, approximately double that of those who operate a basic set of ‘best of breed’ appliances.

5.6 Pools, spas and common area services (Class 2 buildings)

5.6.1 Pools and spas

Pools and spas are high users of energy (mostly gas for heating) and contribute significantly to greenhouse gas emissions of a dwelling (Table 5.11).

Table 5.11 Energy demand, CO₂-e emissions and annual equivalent cost for pools and spas

<table>
<thead>
<tr>
<th>Technology</th>
<th>Pools and spas</th>
<th>Total affluenza appliances</th>
<th>Pool/total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy: total (MJ/yr)</td>
<td>10950</td>
<td>26251</td>
<td>41.7%</td>
</tr>
<tr>
<td>CO₂-e: total (kg/yr)</td>
<td>566</td>
<td>100039</td>
<td>5.6%</td>
</tr>
<tr>
<td>Costs: total AEC ($/yr)</td>
<td>390</td>
<td>1540</td>
<td>25.3%</td>
</tr>
</tbody>
</table>

5.6.2 Common area services

The common area services are generally only relevant to high-rise dwellings but lighting for common area and car parking also applies to medium density dwellings at a reduced rate. Most of the details and information came from a representative example building of 173 apartments on 32 levels with a mix of 1, 2 and 3 bedroom apartments plus 4 bedroom sub-penthouses, and 2 prestige penthouses. The facilities include a heated pool and spa and well equipped gymnasium with sauna.
Tenant electricity was 7300 kWh/year with tenant heating (all electric) based on 80 W/m²/yr and hot water of 6700MJ/yr per apartment, the last two being lower than the average and the first higher for single family dwellings.

Capital and operating costs for the common area services were not available as individual components of the building so the eco-efficiency indicator is not comparable to eco-efficiency values for all other systems and appliances.

**Common area lighting**
Common area lighting was assessed at 10 W/m² of common area which averaged 25 m² per apartment and operated for an average of 6 hours per day.

**Lifts**
Energy consumption for lifts was back calculated from annual costs and electricity rates, resulting in an annual energy use of 500 kWh per apartment.

**Car parking**
Energy consumption for car parks was back calculated from annual costs and electricity rates, resulting in an annual energy use of 88 kWh per apartment.

**Lifestyle (pool, sauna, gym)**
Energy consumption for a heated pool and associated amenities was back calculated from annual costs and electricity rates, resulting in an annual energy use of approximately 11000 MJ per apartment.

### 5.6.3 Analysis
By far the largest energy consumer and CO₂-e emissions is the amenities including a heated pool (about ten times larger) while car parking is the lowest (Table 5.12, Figure 5.166 and Figure 5.177).

**Table 5.12 Energy demand, CO₂-e emissions and eco-efficiency per dwelling unit for common area services**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Common area lighting (MJ/yr)</th>
<th>Car parking (MJ/yr)</th>
<th>Lifts (MJ/yr)</th>
<th>Lifestyle (pool) (MJ/yr)</th>
<th>Total (MJ/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy: total</td>
<td>1971</td>
<td>631</td>
<td>1800</td>
<td>10950</td>
<td>15352</td>
</tr>
<tr>
<td>CO₂-e: total</td>
<td>791</td>
<td>253</td>
<td>722</td>
<td>566</td>
<td>2332</td>
</tr>
<tr>
<td>Costs: total AEC ($/yr)</td>
<td>$101</td>
<td>$32</td>
<td>$92</td>
<td>$164</td>
<td>$390</td>
</tr>
</tbody>
</table>
5.6.4 Key messages
Basic common area services for residents of high-rise apartments (common area lighting, car parking lighting and lifts) can add up to 2 tonnes of greenhouse gas emissions per apartment, with a further half tonne for residents with access to a heated swimming pool.
6 LOCAL/DISTRIBUTED ENERGY GENERATION

6.1 Introduction to local energy generation

Local energy generation or distributed generation (DG) encompasses a suite of zero and low emission technologies (see Figure 6.1) which aim to reduce reliance on a centralised energy supply, reduce emissions and improve energy use efficiency. Local energy generation involves relatively small capacity (<30MW) units typically sited close to the point of consumption (Jones, 2008). The benefits advanced for local generation include:

- Avoiding the construction of expensive transmission and distribution assets to move power from where it is generated at some distance from its customers, together with the associated energy losses that ensue (Jones, 2008);

- Contributing low or zero emission energy to the grid, thereby reducing the amount of power required from the central generators and grid at peak times (and prices) and postponing need for cost of constructing additional generation, transmission and distribution;

- Bringing electricity generation (‘noble energy’) closer to the point of consumption, thereby encouraging households to think more about their use of energy.

Returns from local energy generation include:

- Replacing electricity that would have been purchased from an electricity retailer. Estimates of annual household expenditures on electricity range from $800 in South Australia (Independent Pricing and Regulatory Tribunal, 2007) to $1,200 in Victoria (Morton, 2009). Forecast increases in future prices for grid energy above CPI linked to costs of input factors including a cost on carbon will enhance the economics of local energy generation;

- Exporting electricity to the grid with feed-in tariffs having been established in most jurisdictions. The South Australian gross feed-in tariff, guaranteed for 20 years, will provide the householder operating a 1 kW photovoltaic installation with approximately...
$900 per year if all its power were exported to the grid (currently restricted to photovoltaic). The Victorian government has proposed a net feed-in tariff that would be paid as a credit on electricity bills and not cash. As currently articulated, if the credit is not used within a year (which could be common for energy efficient households with large photovoltaic installations who are not home during the day), it would expire and become a 'profit' for electricity retailers. As Morton (2009) indicates, it would create a perverse incentive for the householder to consume more energy.

Key questions remain, however, as to the eco-efficiency proposition for local energy generation. In particular:

- **Scale.** It is evident that some distributed energy generation technologies are applicable only at scales above that of an individual residential dwelling, e.g. gas reciprocation engine CCHP for a precinct of 30 or more dwellings. An examination of a precinct energy scenario is outside the scope of this study, given the additional local generation technology spread as well as the fact that precincts will likely include mixed use development of residential, commercial and retail customers, each with their own distinctive 24/7 energy demand profiles (Figure 6.2). There is clearly a need for both precinct and individual dwelling options, given the enormity of the challenge to mitigate GHG emissions and the vast stock of existing housing. Indeed, it is apparent that energy futures studies need to be considered across all scales ranging from individual dwelling to precinct to region. While not comparable to the present study in relation to DG technologies, a UK comparison of individual dwelling versus district micro-generation energy technologies identified up to 70% less capital costs for the district scheme (Chow, 2008b). To enable comparison of precinct sized systems with single household systems, several precinct systems are described here on a per dwelling basis (i.e. the total energy generated by a neighbourhood plant is divided by the number of dwellings served);

![Figure 6.2 Gas daily variation during winter – household customers](source: Jemena (2008))
- **Embodied energy.** A full energy accounting of options would need to consider the amount of embodied energy in the DG technologies employed as well as any additional building structure and fabric that may be required to deliver a hybrid building – a factor currently missing from current energy accounting systems (Chow, 2008b);

- **National grid.** A key contribution of a national grid that operates across Australia to a future resilient low emission hybrid energy economy lies in its role as a smart network-based energy ‘storage’ and distribution system capable of directing surplus electricity supplied from DG in real time to customers in regions where it is in demand. Currently, there is a lack of maturity in national electricity market regulation to accommodate all options sought by both resident-suppliers from a single dwelling and community (precinct) energy suppliers, and their counterparts who seek independence from the grid (i.e. the ‘autonomous house’ or precincts that operate a ‘private wires’ or micro-grid networks).

In the present study both zero emission and low emission DG technologies are examined. The zero emission technologies considered are:

- Solar – Photovoltaic;
- Wind – Turbine;
- Solar – Hydrogen fuel cell.

The low emission technologies considered are:

- Ground source heat pump – Heating and cooling;
- Gas fuel cell;
- Gas – Reciprocating engine CCHP – Heating and cooling.

The hot water technologies considered are:

- Solar – Hot water – gas boosted;
- Solar – Hot water – electric boosted.

Details of the various technologies are shown in Table 6.1.
### Table 6.1 Local energy generation data

<table>
<thead>
<tr>
<th>Technology</th>
<th>Zero emissions</th>
<th>Low emissions</th>
<th>Hot Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generation: electricity –</td>
<td>1971</td>
<td>3942</td>
<td>5913</td>
</tr>
<tr>
<td>(kWh/yr/dwelling)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generation: heating –</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(MJ/yr/dwelling)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generation: cooling –</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(MJ/yr/dwelling)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generation: hot water –</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(MJ/yr/dwelling)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generation: total (MJ/yr/dwelling)</td>
<td>7096</td>
<td>14191</td>
<td>21287</td>
</tr>
<tr>
<td>Fuel usage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel usage: electricity</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(kWh/yr)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel usage: gas (MJ/yr)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel usage: total (MJ/yr)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost – Capital ($/dwelling)</td>
<td>17999</td>
<td>33523</td>
<td>49547</td>
</tr>
<tr>
<td>Cost – Installation ($/dwelling)</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Cost – Maintenance ($/kWh)</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Rebates – installation</td>
<td>8000</td>
<td>8000</td>
<td>8000</td>
</tr>
<tr>
<td>($/dwelling)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rebates – RECs ($)</td>
<td>1274</td>
<td>2548</td>
<td>3822</td>
</tr>
<tr>
<td>Rebates – electricity supplied ($)</td>
<td>118</td>
<td>237</td>
<td>355</td>
</tr>
<tr>
<td>Service life (yrs)</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Sources: Reedman, Payne, Badwal, Giddey and Clarke (see Acknowledgements)
N/A: Not applicable
Note: * For 5 star dwelling
6.2 Zero emissions local energy generation

6.2.1 Solar – Photovoltaic

Solar photovoltaic panels provide the most direct method of generating local renewable electricity and can provide enough electricity for the entire needs of a dwelling if a sufficiently large and suitably oriented area (usually on a roof) is available (CSIRO, 2008b), whether in a city or on rural area. In cities, the system is usually a direct feed into the electricity grid with no local storage capability. Solar photovoltaic systems are close to maintenance free with only cleaning of panels a regular task. The type of solar cells is not important in this project as it is the total output and its cost which influence the analysis. Figure 6.3 illustrates a residential photovoltaic system with grid connection.

![Solar photovoltaic system diagram](source: Clean Energy Council (2008, p 8)).

**Figure 6.3 Solar photovoltaic system diagram**

The chosen residential photovoltaic system consists of solar panels rated at about 1500kW on a north facing roof producing approximately 2000 kWh of electricity per annum in Melbourne, including a regulator and inverter with a smart meter connecting the solar panels to the electricity grid (Origin Energy, 2009a). The total cost of the installation is $18,500, of which $8,000 is an Australian government rebate, $1,274 is for Renewable Energy Certificates (RECs), making a net cost to the owner of $9,225. The installation is estimated to produce 1971 kWh of electricity per annum. Any additional income from the net feed-in tariff
in Victoria is too unpredictable and probably small and as such is ignored. The size of residential solar panels installations was averaging about this capacity until the Australian government rebate made it more economically viable to install only 1 kW of panels to achieve the maximum grant of $8,000.

6.2.2 Wind –Turbine
Wind turbines vary considerably in size and it is ‘usually not advisable to mount wind turbines on houses unless they are less than 1 kW’ (CSIRO, 2008b). They can be horizontal axis (such as the large megawatt sized wind turbines) or vertical axis (such as the Savonius and Darrieus types) but the only type readily available in Australia are small horizontal axis turbines (Alternative Technology Association, 2007). The chosen wind turbine is thus a 1 kW horizontal axis turbine. The annual electrical energy output for Melbourne is 1249 kWh (Reedman, 2008). The total cost of the installation is $4,500, of which $306 is for RECs, making a net cost to the owner of $4,192. Annual maintenance is minimal but a 5 yearly service appears to be required and can vary considerably in price (Alternative Technology Association, 2007).

6.2.3 Solar hydrogen fuel cell
Hydrogen as an energy currency, carrier and storage medium may be a key component of the solution to problems of global warming, poor air quality and dwindling reserves of liquid hydrocarbon fuels. Hydrogen is a flexible storage medium and can be generated by the electrolysis of water. It is particularly advantageous if an electrolyser may be simply and efficiently coupled to a source of renewable electrical energy (Clarke et al., 2009). Use of hydrogen as a source of renewable energy is in its infancy but there have been proposals and experiments to use hydrogen as the intermediary between the solar source and the electricity (and heat) used because it can be stored readily. A possible system is shown in Figure 6.4. The photovoltaic input is as described for a 4500 W system (see section 6.2.1 Solar – Photovoltaic). The electrolyser is assumed to operate at 70% conversion efficiency with 20% recoverable as heat. The fuel cell efficiency is assumed to be 40% with another 35% recoverable as heat. Any excess electricity from the photovoltaics (such as when the electrolyser is operating at capacity) is available directly to the appliances. The heat is recovered as hot water boost. The estimated cost is about $80,000 and produces about 1650 kWh of electricity annually together with about 9500 MJ of hot water heating.

![Solar hydrogen fuel cell](image)

Figure 6.4 Solar hydrogen fuel cell
6.3 Low emissions

6.3.1 Ground source heat pump – Heating and cooling
Ground source heat pumps (as shown diagrammatically in Figure 6.5) have been used in a broad spectrum of facilities including domestic housing, hospitals, education facilities, commercial offices and civic buildings, but have not had widespread application despite their environmental benefits over more commonly used air conditioning systems.

As described in Building Design Professions (2004),

*a heat pump is a device which pumps heat from a lower temperature to a higher temperature level. This applies for all refrigeration machines. However, the label 'heat pump' has evolved to define those refrigeration machines which are configured to provide both cooling and heating, commonly referred to as ‘reverse cycle’. The term is unfortunate, as every refrigeration machine pumps heat even if it is in one direction. Ground source heat pumps, as the name implies, are refrigeration machines that provide heating and cooling by using ground water and earth as a medium to reject or absorb heat. This is made possible because ground temperatures are stable, remaining relatively constant throughout the year. During summer when space cooling is required, heat is removed from the building and transferred to the ground. In winter the reverse occurs, with heat being removed from the ground and supplied to the building.*

![Diagram of ground source heat pump](image)

**Source:** Energycore (2009)

**Figure 6.5 Ground source heat pump**

The ground source heat pumps considered in this study are closed loop systems, with the domestic scaled versions having a copper loop, in a 75mm hole which has been drilled to a depth of 30m. Larger scale precinct systems utilise a polyethylene loop in a 150mm hole which has been drilled to a depth of 100m and, while it costs more, the benefits are shared over many dwellings. Domestic scale systems can provide 14 to 21 kW thermal but multiple scale dwellings such as apartments require less heating and cooling so each dwelling only requires about 7 kW thermal capacity. Each system is assumed to be able to provide all the heating, cooling and hot water requirements of a single dwelling. Only in the case of 2.5 star
dwellings would the heating possibly fall short of demand. The overall Coefficient of Performance (COP) is assumed to be 4.

Initial costs are relatively high with a 14 kW thermal system costing about $29,000 (copper holes $10K, heat pump $15K, ducting $3K, water buffer tank $1K), a 21 kW thermal system costing about $43,500 and a 7kW thermal for apartments costing about $22,000 per apartment.

6.3.2 Gas – Fuel cell

There are several types of fuel cell which transform chemical energy into electricity: Alkaline Fuel Cell (AFC), Phosphoric Acid Fuel Cell (PAFC), Proton Exchange Membrane Fuel Cell (PEMFC), TDirect Methanol Fuel Cell (DMFC), Molten Carbonate Fuel Cell (MCFC), and Solid Oxide Fuel Cell (SOFC) (Biegler 2005), each of which has its own particular advantages and disadvantages; All have been demonstrated at a practical scale in their various applications. The PAFC is the most commercially advanced technology, aimed at medium-scale power generation. The PEMFC is favoured for transportation because of its high power density, moderate operating temperature, quick start-up and rapid response to changes in system demand. The DMFC has made a comeback because of the market need in consumer electronics. High operating temperatures and slow start-up mean that both the MCFC and SOFC lend themselves to power generation in larger, continuously operating installations in the tens of kW to several MW range.

The natural gas fuel cell (used as an example in this project) is a SOFC for a single installation serving multiple dwellings. The annual generation is 7490 kWh of electricity and 947 MJ of heat which is not considered as part of the savings due to unknown forms of installation and the costs of a distributed heating system. The costs of installation are $4,000 per dwelling for a precinct sized plant (Reedman, 2008). The plants are run by a service company which owns, maintains and operates the system and charges users for the energy it supplies to them. Ceramic Fuel Cells Ltd (2009) claims electricity is generated at 50% electrical efficiency at the point of use. Additionally, the household can use the heat from the fuel cell for domestic hot water and/or space heating, which increases the total efficiency from the fuel energy up to the 70% used in the example. The Australian Technology Park in Sydney has a 200-kilowatt fuel cell that uses natural gas as a fuel. It supplies power to the park’s medical centres, laboratories and computer systems. This is the first Australian commercial application of such a cell (Australian Academy of Science, 2009).

6.3.3 Gas – Reciprocating engine (Combined heating, cooling and power)

The general approach is an energy system that uses natural gas to generate electricity and recover waste heat, providing an overall energy conversion efficiency of up to 75%, to supply energy to homes, offices and industrial developments (Figure 6.6). The example used in this study is based on an existing installation implemented by GridX Power at Mirvac Group’s Vision Estate in Glenfield (GridX Power, 2009).
The GridX System uses natural gas to power high efficiency generators, supplying electricity to the buildings and the mains grid. The by-product of electricity generation is used for heating and cooling purposes. The size and costs of the plants are determined by the demand and apply on a case-by-case basis. The plants are run by a service company which owns, maintains and operates the system and charges users for the energy it supplies to them.

6.3.4 Solar – Hot water – gas boosted
Solar hot water systems are common throughout Australia but continue to provide only a small fraction of households’ hot water requirements (DEWHA, 2008a, Figure 35, p 51). A typical residential solar hot water system consists of flat plate collectors totalling 3.6 m² on a north facing roof, a 315 L tank and an inline 26 L/min continuous flow gas booster (Origin Energy, 2009b). The efficiency of the gas system was assumed to be 68.5% MJ of hot water per MJ of gas consumed (DEWHA, 2008a, Table 83, p 231). The gas required was 118 kJ/L for the 73900 L of hot water required per annum for a family home. This assumes that the solar system supplies about 55% of the required energy for water heating. An average medium sized household (3 to 4) in Melbourne requires annual energy input of 13861 MJ for 202 L per day (=187 kJ/L) (DEWHA, 2009a). The total cost of the installation is $5,750, of which $2,500 is an Australian government rebate, $1,372 is for RECs, making a net cost to the owner of $1,878. This combination of well established technologies is almost maintenance free, with only occasional cleaning of the panels required.

6.3.5 Solar – Hot water – electric boosted
The efficiency of an electric boosted system was taken to be 98% MJ of hot water per MJ of electricity consumed (DEWHA, 2008a, Table 81, p 230). The electricity required was 91 kJ/L for the 73900 L of hot water required per annum for a family home. This assumes that the solar system supplies about 55% of the required energy. The total cost of the installation is $5,750, of which $2,500 is an Australian government rebate, $1,372 is for RECs, making a net cost to the owner of $1,878.

6.4 Analysis and key messages
Table 6.2 shows the annual energy and CO₂-e generated, saved and produced by local energy generation technologies. Each of the measures is also shown individually in Figure 6.7 and Figure 6.8. The energy generated (mostly electricity) varies according to the size of the local energy generating plant. The plant sizes have been set by what is typical of the installations for residential applications, with the result that the capacity of the low emission technologies is much higher as they are designed to supply from an external precinct energy supplier close to 100% of locally generated electricity demanded by a typical household. Low emission local energy technologies consume significant amounts of energy to deliver electricity and heating (including hot water heating). The advantage of low emission local energy generation rests primarily in the ability to deliver electricity direct from gas in a distributed system (i.e. close to the end consumer).

Solar hot water systems also constitute a class of local energy technologies capable of delivering significant savings in emissions (see Section 5.2).

The zero emission technologies could be configured to supply much more energy per dwelling but such decisions constitute individual household choices influenced by plant size, available space (area and position/access/orientation), costs and rebates.
Table 6.2 CO$_2$-e generated, saved and produced by local energy technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Zero emissions</th>
<th>Low emissions</th>
<th>Hot Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar – Photovoltaic 1500 W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar – Photovoltaic 3000 W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar – Photovoltaic 4500 W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind – Turbine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar hydrogen – Fuel cell</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground source heat pump – 14kW thermal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground source heat pump – 21kW thermal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground source heat pump – 7kW thermal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground source heat pump – shared</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas – Fuel cell</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas – CHP Engine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar – Hot water – electric boost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar – Hot water – gas boost</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Emission saved (kg/yr)                    |                |               |           |
| CO$_2$-e: electricity                     | 2846            | 5692          | 8538      |
| CO$_2$-e: gas                             | 0               | 0             | 0         |
| CO$_2$-e: heating                         | 0               | 0             | 0         |
| CO$_2$-e: cooling                         | 0               | 0             | 0         |
| CO$_2$-e: hot water                       | 0               | 0             | 0         |
| CO$_2$-e: total                           | 2846            | 5692          | 8538      |

| Emissions from consumed fuel (kg/yr)      |                |               |           |
| CO$_2$-e: electricity                     | 0               | 0             | 0         |
| CO$_2$-e: gas                             | 0               | 0             | 0         |
| CO$_2$-e: total                           | 0               | 0             | 0         |

Table contains data for CO$_2$-e generated, saved and produced by local energy technologies.
Figure 6.7  Energy consumed by specific local energy technologies to deliver useable energy

Figure 6.8  CO2-e from energy used to generate local energy and CO2-e saved by local energy technologies
In Figure 6.8, the CO₂-e emissions are based on replacement of the typical technology for heating, cooling and hot water, e.g. gas ducted heating, electric reverse cycle cooling and gas storage hot water. Figure 6.9 shows that, if all the heating, cooling and hot water systems were electric, the saved CO₂-e emissions would be considerably higher, particularly for the ground source heat pump technologies and, to a lesser extent, the gas fuel cell and the gas CCHP engine. However, if the replaced heating, cooling and hot water systems were gas driven, as shown in Figure 6.10, the savings in CO₂-e emissions would be much less, making local energy generation only of marginal benefit (if at all) in reducing CO₂-e emissions.

Payback periods (without consideration of rebates or subsidies) for the various local energy technologies at January 2009 prices are shown in Figure 6.11 for carbon costs of $0, $30 and $60 per tonne and retail energy prices as at January 2009. The performance characteristics of each of the local generation technologies are as listed in Table 6.2. Most payback periods without a carbon cost (current situation) are long (20+ years) with only the high capacity precinct installations and solar hot water systems having a payback period about ten years or less.

The reduction in payback periods when a carbon cost of $30/tonne is added to the energy operating costs are mostly around 20% but, if the carbon price doubled to $60/tonne, the reduction in payback periods is only in the 30% to 35% range, i.e. as the carbon price climbs higher, the rate of reduction in the payback period declines.

Reduction in the future capital costs of distributed generation technologies, which could accompany an increase in local demand and supply, would further reduce the payback period, but have not been factored into these analyses.

Figure 6.9 CO₂-e from energy used to generate local energy and CO₂-e saved by local energy technologies assuming electric sources
**Figure 6.10 CO₂-e from energy used to generate local energy and CO₂-e saved by local energy technologies assuming gas sources**

**Figure 6.11 Payback period of local energy technologies**
7 HYBRID BUILDING SCENARIOS

In this section, several configurations of hybrid buildings are created in order to examine the degree to which they represent an advance over a base case of housing which is representative of over 90% of the existing national stock (i.e. 2.5 star rated), in respect of energy use, GHG emissions, cost and eco-efficiency.

‘Virtual building is the ability to subject a new concept or product – in this instance, hybrid buildings – to a range of performance assessments prior to actual assembly and represents one of the key pathways to the delivery of a more sustainable built environment (Newton, 2009a). The key scenarios for assessment are the extent to which transitions to net zero energy (NZE), carbon neutrality (CN) or zero carbon (ZC) are possible across a range of dwelling, appliance and local energy generation options:

- Grid-based energy supply;
- 5 star stock;
- 7 star stock;
- Regeneration of greyfields housing;
- Technological fix.

Prior to these analyses however, we briefly examine the extent to which dwelling type influences operating energy.

7.1 Does dwelling type matter?

Previous research (Newton et al., 2000; Rickwood et al., 2008) has suggested that type of dwelling (detached versus medium density versus high-rise apartment) confers a degree of variation in operating energy performance, primarily due to factors related to shell type and size (floor area).

In this study, four dwelling types representative of those being currently built (see Section 4.2) were selected for analysis. All performed at an annual operating energy level equivalent to a 5 star energy rating, with different floor spaces reflective of what is typically offered to the market and a mix of building materials.

Operating energy performance of the building shell (heating and cooling) plus appliances was modelled for all four building types (see Table 7.1) under grid supplied energy scenarios to compare energy demands. Heating and cooling systems plus appliances are common across detached and medium density dwellings but vary for high-rise apartments, given that, for a majority of such high-rise developments, electricity represents the dominant energy source for space heating and cooling and cooking.

As shown in Table 7.1 and Figure 7.1, the main differences in energy demand are in space heating and cooling, hot water and lighting, with the apartments all using less than the detached houses. High-rise also has an additional significant common area energy demand for lighting and lifts, while medium density has a small additional energy demand for the common area lighting. The CO2-e emissions for the electricity sourced energy are much higher than for the gas sourced energy appliances (Figure 7.2).

The total gross energy consumption for the high-rise apartments is approximately half that of the two storey detached house (Figure 7.3), with the apartments having a much lower energy demand than the detached houses. However, when CO2-e emissions are considered (Figure 7.4), the relativities change dramatically, with the medium density being the lowest and the emissions of the high-rise exceeding those of the single storey house and being within 10% of those of the two storey detached house, due to the additional energy demand of the common area services and the energy for appliances being more electricity sourced.
With the CO₂-e emissions resulting from the variable energy demands being similar, further analysis in the following sections on options for local generation for various scenarios of shell efficiency and appliances has been restricted to applications involving single storey detached houses, which continue to be the dominant class of housing built in Australia.

When considering the emissions per unit area of dwelling (Table 7.2), the heating and cooling demand is approximately the same for all dwelling types as they are all approximately 5 star rated and the rating scheme is based on the energy demand per unit area for net conditioned floor area. The appliance energy per unit area of dwelling is much higher for the smaller area dwellings as the reduced occupant consumption does not compensate for the reduction in floor area and, in the case of the high-rise, the increased use of electricity as the energy source.

Table 7.1  Case study set for dwelling types of typical floor area and appliances in the market

<table>
<thead>
<tr>
<th>Selection</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling type</td>
<td>Detached single storey</td>
<td>Detached two storey</td>
<td>Medium density</td>
<td>High-rise</td>
</tr>
<tr>
<td>Star rating</td>
<td>5 Star</td>
<td>5 star</td>
<td>5 Star</td>
<td>5 star</td>
</tr>
<tr>
<td>Space heating and cooling</td>
<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative</td>
<td>Electric reverse cycle</td>
</tr>
<tr>
<td>Hot water</td>
<td>Gas – storage</td>
<td>Gas – storage</td>
<td>Gas – storage</td>
<td>Electric shared services</td>
</tr>
<tr>
<td>Cooking</td>
<td>Gas cooktop, electric oven, microwave</td>
<td>Gas cooktop, electric oven, microwave</td>
<td>Gas cooktop, electric oven, microwave</td>
<td>Electric cooktop, electric oven, microwave</td>
</tr>
<tr>
<td>Lighting</td>
<td>Average mix</td>
<td>Average mix</td>
<td>Average mix</td>
<td>Average mix</td>
</tr>
<tr>
<td>Appliances</td>
<td>'Best of breed' basic</td>
<td>'Best of breed' basic</td>
<td>'Best of breed' basic</td>
<td>'Best of breed' basic</td>
</tr>
<tr>
<td>Common services</td>
<td>None</td>
<td>None</td>
<td>Low rise</td>
<td>High-rise</td>
</tr>
<tr>
<td>Local generation 1</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Local generation 2</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Local generation 3</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Energy used by consumption (MJ/yr)</td>
<td>84866</td>
<td>97619</td>
<td>56916</td>
<td>47700</td>
</tr>
<tr>
<td>Energy generated by local energy generation (MJ/yr)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Energy supplied by grid (MJ/yr)</td>
<td>84866</td>
<td>97619</td>
<td>56916</td>
<td>47700</td>
</tr>
<tr>
<td>CO₂-e emitted by consumption (kg/yr)</td>
<td>9529</td>
<td>10868</td>
<td>7417</td>
<td>9915</td>
</tr>
<tr>
<td>CO₂-e saved by local generation (kg/yr)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CO₂-e net emitted by the grid supply (kg/yr)</td>
<td>9529</td>
<td>10868</td>
<td>7417</td>
<td>9915</td>
</tr>
<tr>
<td>Cost AEC ($/yr)</td>
<td>4958</td>
<td>5332</td>
<td>4266</td>
<td>4321</td>
</tr>
</tbody>
</table>
Figure 7.1  Energy consumption for appliances in project home equivalent dwelling types

Figure 7.2  CO₂-e emissions for appliances in project home equivalent dwelling types
Figure 7.3  Total energy consumption for project home equivalent dwelling types including shell and appliances

Figure 7.4  Total CO₂-e emissions for project home equivalent dwelling types including shell and appliances
Table 7.2  CO₂-e emissions for project home equivalent dwelling types per unit area

<table>
<thead>
<tr>
<th>Dwelling type</th>
<th>Net conditioned floor area (m²)</th>
<th>CO₂-e emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detached single storey</td>
<td>Detached two storey</td>
</tr>
<tr>
<td>Net conditioned floor area (m²)</td>
<td>173</td>
<td>237</td>
</tr>
<tr>
<td>Building heating and cooling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total CO₂-e (kg/yr)</td>
<td>2786</td>
<td>3417</td>
</tr>
<tr>
<td>Total CO₂-e (kg/m²/yr)</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Hot water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total CO₂-e (kg/yr)</td>
<td>1084</td>
<td>1084</td>
</tr>
<tr>
<td>Total CO₂-e (kg/m²/yr)</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Built-in appliances</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total CO₂-e (kg/yr)</td>
<td>2852</td>
<td>3560</td>
</tr>
<tr>
<td>Total CO₂-e (kg/m²/yr)</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>Plug-in appliances</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total CO₂-e (kg/yr)</td>
<td>2807</td>
<td>2807</td>
</tr>
<tr>
<td>Total CO₂-e (kg/m²/yr)</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>All appliances</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total CO₂-e (kg/yr)</td>
<td>5659</td>
<td>6367</td>
</tr>
<tr>
<td>Total CO₂-e (kg/m²/yr)</td>
<td>33</td>
<td>37</td>
</tr>
<tr>
<td>Common area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total CO₂-e (kg/yr)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total CO₂-e (kg/m²/yr)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total dwelling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total CO₂-e (kg/yr)</td>
<td>9529</td>
<td>10868</td>
</tr>
<tr>
<td>Total CO₂-e (kg/m²/yr)</td>
<td>55</td>
<td>46</td>
</tr>
</tbody>
</table>
With knowledge of the great range in carbon signatures for different hot water equipment and built-in domestic appliances (refer again to Section 5) it is timely to question whether the scope of current building regulation — restricted to the shell — is now sufficient in the face of 21st century challenges related to GHG emissions and climate change.
7.2 Grid-based energy scenarios

The base scenario examined is one where the operating energy for the dwelling and all its appliances is supplied by the grid. In the five grid-based scenarios examined, variations in shell performance and appliance efficiency are introduced for a detached single storey house in an attempt to identify the level of potential savings in energy and CO₂-e as well as cost performance. These case studies are defined in Table 7.3.

Several charts follow: total energy demand, local energy generation and net grid energy demand (Figure 7.6), CO₂-e emissions by category (Figure 7.7), rose diagram of energy, CO₂-e, eco-efficiency and annual equivalent costs (Figure 7.8) and annual equivalent cost versus annual CO₂-e emitted by consumption (Figure 7.9).

7.2.1 Key messages

Grid-based scenarios are situations where households are reliant totally upon energy supplied from the grid (currently 95% fossil fuel-based) precluding any transition to a zero energy, carbon neutral, or zero carbon future for the housing sector.

Indeed, in the worst case scenario (case 1) which is characterised by detached single storey housing that is 2.5 energy star rated, has all electric hot water heating, all electric space heating and cooling, all electric kitchen, halogen lighting throughout and an affluenza set of plug-in appliances with average energy ratings, annual CO₂-e emissions are 47 tonnes – more than four times the average for dwellings in Melbourne. This not only comes at a massive cost to the environment but also to the household ($12771/yr), and at a time before the impact of an introduction of carbon pricing for energy becomes evident.

The introduction of more energy efficient shell and appliances (cases 2-5) can be seen to have a significant impact on energy consumption and GHG emissions. For example, a 5 star energy rated dwelling with primarily gas appliances, a mix of lighting and a ‘best of breed’ basic set of appliances – what could be expected to be the ‘norm’ for new project homes – generates approximately 9.5 tonnes of CO₂-e per year. This is less than the Melbourne metropolitan average of approximately 11 tonnes per dwelling but it is far from any of the three key energy transitions being examined (refer to the last three rows in Table 7.3). Clearly, there is potential for these transitions to be rapidly achieved by the introduction of some form of low emission or renewable energy generation within the housing sector.
Table 7.3  Case study set for grid-based energy source

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<tr>
<th>Selection</th>
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<th>Case 3</th>
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<td>Detached single storey</td>
<td>Detached single storey</td>
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<td>Electric heating and cooling</td>
<td>Electric reverse cycle</td>
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<td>Electric cooktop, electric oven, microwave</td>
<td>Electric cooktop, electric oven, microwave</td>
<td>Gas cooktop, electric oven, microwave</td>
<td>Gas cooktop, gas oven, microwave</td>
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<td>Average performance basic</td>
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<td>‘Best of breed’ basic</td>
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<tr>
<td>Energy supplied by grid (MJ/yr)</td>
<td>117894</td>
<td>62309</td>
<td>40540</td>
<td>84866</td>
<td>59274</td>
</tr>
<tr>
<td>CO2-e emitted by consumption (kg/yr)</td>
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<td>24993</td>
<td>16261</td>
<td>9529</td>
<td>7023</td>
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<td>24993</td>
<td>16261</td>
<td>9529</td>
<td>7023</td>
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Figure 7.6  Total energy demand, local energy generation and net grid energy demand (grid-based energy sources only)

Figure 7.7  CO₂-e emissions by category (grid-based energy sources only)
Figure 7.8  Rose diagram (grid-based energy sources only)

Figure 7.9  Annual CO$_2$-e emitted by consumption versus annual equivalent cost (grid-based energy sources only)
7.3 5 star housing scenarios

For the remaining analyses, a base case has been established that is representative of current project home offerings for detached housing (Case 4 in the grid based scenarios and Case 1 in all the following scenarios). The challenge is to seek configurations of hybrid buildings where a local energy generation capacity is incorporated in addition to energy efficiency initiatives that are capable of delivering the most effective energy and carbon transition for housing.

In the five scenarios examined (all 5 star energy-rated single storey detached houses with standard sets of appliances etc.), variations in local generation options are introduced in an attempt to identify the level of potential savings in energy and CO₂-e as well as cost performance. These case studies are defined in Table 7.4.

Several charts follow: total energy demand, local energy generation and net grid energy demand (Figure 7.10), CO₂-e emissions by category (Figure 7.11) and annual equivalent cost versus annual CO₂-e emitted by consumption (Figure 7.12).

7.3.1 Key messages
A pathway to carbon neutral housing is possible for 5 star energy rated dwellings that have the benefit of either a gas fuel cell, a 4500 W photovoltaic system or a ground source heat pump combined with a 1500 W photovoltaic system
<table>
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<tr>
<th>Selection</th>
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<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
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<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative replaced by GSHP</td>
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Figure 7.10  Total energy demand, local energy generation and net grid energy demand (5 star housing scenarios)

Figure 7.11  CO2-e emissions by category (5 star housing scenarios)
Figure 7.12 Annual CO₂-e emitted by consumption versus annual equivalent cost (5 star housing scenarios)

7.4 7 star housing scenarios

For these analyses, the same base case used for 5 star energy rated dwellings has again been established as Case 1. The challenge again is to seek configurations of hybrid buildings where a local energy generation capacity is incorporated to deliver the most effective energy and carbon transition for housing.

In the additional four scenarios examined (all 7 star energy rated single storey detached houses with the same sets of appliances as the previous 5 star energy rated dwellings), variations in local generation options are introduced in an attempt to identify the level of potential savings in energy and CO₂-e as well as cost performance. These case studies are defined in Table 7.5.

Several charts follow: total energy demand, local energy generation and net grid energy demand (Figure 7.10), CO₂-e emissions by category (Figure 7.11) and annual equivalent cost versus annual CO₂-e emitted by consumption (Figure 7.12).

7.4.1 Key messages

A pathway to carbon neutral housing is more readily achievable for 7 star energy rated dwellings that have the benefit of either a gas CCHP system, gas fuel cell, 4500 W photovoltaic system or ground source heat pump combined with a 1500 W photovoltaic system, because the space heating and cooling demand has decreased by about 20000 MJ/yr. The gas CCHP system now joins the other options as a carbon neutral option with the other local generation options increasing their savings in CO₂-e emissions.
<table>
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<tr>
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<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative replaced by GSHP</td>
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<td>Gas cooktop, gas oven, microwave</td>
<td>Gas cooktop, gas oven, microwave</td>
<td>Gas cooktop, gas oven, microwave</td>
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Figure 7.13 Total energy demand, local energy generation and net grid energy demand (7 star housing scenarios)

Figure 7.14 CO₂-e emissions by category (7 star housing scenarios)
7.5 Regeneration of residential greyfields housing

For this analysis, the same base case used for 5 star energy rated dwellings has again been established as Case 1. The challenge is to seek configurations of hybrid buildings where a local energy generation capacity is incorporated to deliver the most effective energy and carbon transition for housing, in this instance, from stock built before the introduction of a minimum operating energy standard (5 star system). This stock has been termed greyfields housing and represents the occupied, ageing, technologically, physically and environmentally obsolescent housing; stock which constitutes the majority of housing in Australia (Newton, 2010).

In the additional four scenarios examined (all 2.5 star energy rated single storey detached houses with the same sets of appliances as the previous 5 and 7 star energy rated dwellings), variations in local generation options are introduced in an attempt to identify the level of potential savings in energy and CO₂-e as well as cost performance from a ‘regeneration’ of the existing stock. The regeneration of residential greyfields stock has been identified as one of the most significant challenges for a sustainability transition of cities in the 21st century (Newton, 2010). These case studies are defined in Table 7.6.

Several charts follow: total energy demand, local energy generation and net grid energy demand (Figure 7.16), CO₂-e emissions by category (Figure 7.17) and annual equivalent cost versus annual CO₂-e emitted by consumption (Figure 7.18).

7.5.1 Key messages
Significant savings of CO₂-e are possible by the introduction of DG, ranging between 8 and 16.5 tonnes/dwelling, but are not sufficient to attain NZE, CN or ZC status.
Table 7.6 Case study set for regeneration scenarios

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<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative replaced by GSHP</td>
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<td>Cooking</td>
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<td>Gas cooktop, gas oven, microwave</td>
<td>Gas cooktop, gas oven, microwave</td>
<td>Gas cooktop, gas oven, microwave</td>
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<td>Lighting</td>
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<td>‘Best of breed’ basic</td>
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<tr>
<td>Local generation 1</td>
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<td>Gas – CCHP Engine</td>
<td>Gas – Fuel cell</td>
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Figure 7.16  Total energy demand, local energy generation and net grid energy demand (regeneration scenarios)

Figure 7.17  CO2-e emissions by category (regeneration scenarios)
### 7.6 Technological fix scenarios

For these analyses, the same base case used for 5 star energy rated dwellings has again been established as Case 1. The challenge is to seek configurations of hybrid buildings where combinations of local energy generation capacity are incorporated with a higher performing shell to deliver transitions to one or more of net zero energy, carbon neutral and zero carbon futures.

In the additional four scenarios examined (all 7 star energy rated single storey detached houses but with different space heating and cooling, cooking and appliance set options), variations in local generation options are introduced in an attempt to identify the level of potential savings in energy and CO₂-e as well as cost performance. These case studies are defined in Table 7.7.

Several charts follow: total energy demand, local energy generation and net grid energy demand (Figure 7.19), CO₂-e emissions by category (Figure 7.20) and annual equivalent cost versus annual CO₂-e emitted by consumption (Figure 7.21).

#### 7.6.1 Key messages

Carbon neutrality has been achieved in all cases examined. Net zero energy status exists for Cases 4 and 5 primarily due to utilising local generation technologies which produce sufficient energy of more than one type, e.g. energy for both heating and hot water without using fossil fuels. Zero carbon is also delivered by the hybrid building configurations in Cases 4 and 5.
Table 7.7 Case study set for technological fix scenarios

<table>
<thead>
<tr>
<th>Selection</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling type</td>
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<td>Detached single storey</td>
<td>Detached single storey</td>
<td>Detached single storey</td>
<td>Detached single storey</td>
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<tr>
<td>Star rating</td>
<td>5 star</td>
<td>7 star</td>
<td>7 star</td>
<td>7 star</td>
<td>7 star</td>
</tr>
<tr>
<td>Space heating and cooling</td>
<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative replaced by GSHP</td>
<td>Electric reverse cycle replaced by GSHP</td>
<td>Electric reverse cycle replaced by GSHP</td>
</tr>
<tr>
<td>Cooking</td>
<td>Gas cooktop, electric oven, microwave</td>
<td>Gas cooktop, gas oven, microwave</td>
<td>Gas cooktop, gas oven, microwave</td>
<td>Electric cooktop, electric oven, microwave</td>
<td>All microwave</td>
</tr>
<tr>
<td>Lighting</td>
<td>Average mix</td>
<td>All compact fluorescent</td>
<td>All compact fluorescent</td>
<td>All compact fluorescent</td>
<td>All compact fluorescent</td>
</tr>
<tr>
<td>Appliances</td>
<td>‘Best of breed’ basic</td>
<td>‘Best of breed’ basic</td>
<td>‘Best of breed’ affluenza</td>
<td>‘Best of breed’ affluenza</td>
<td>‘Best of breed’ basic</td>
</tr>
<tr>
<td>Local generation 1</td>
<td>None</td>
<td>Gas – CCHP Engine</td>
<td>Ground source heat pump – 21kW thermal</td>
<td>Solar hydrogen fuel cell</td>
<td>Ground source heat pump – 14kW thermal</td>
</tr>
<tr>
<td>Local generation 2</td>
<td>None</td>
<td>None</td>
<td>Solar – Photovoltaic 1500 W</td>
<td>Solar – Photovoltaic 3000 W</td>
<td>Solar – Photovoltaic 3000 W</td>
</tr>
<tr>
<td>Local generation 3</td>
<td>None</td>
<td>None</td>
<td>Wind turbine</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Energy used by consumption (MJ/yr)</td>
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<td>60976</td>
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<td>48384</td>
<td>37177</td>
</tr>
<tr>
<td>Energy generated by local energy generation (MJ/yr)</td>
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<td>-22218</td>
<td>58668</td>
<td>44851</td>
<td>40515</td>
</tr>
<tr>
<td>Energy supplied by grid (MJ/yr)</td>
<td>84866</td>
<td>83193</td>
<td>7545</td>
<td>3533</td>
<td>-3338</td>
</tr>
<tr>
<td>CO₂-e emitted by consumption (kg/yr)</td>
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<td>7049</td>
<td>9150</td>
<td>12079</td>
<td>7584</td>
</tr>
<tr>
<td>CO₂-e saved by local generation (kg/yr)</td>
<td>0</td>
<td>7899</td>
<td>7277</td>
<td>10662</td>
<td>8923</td>
</tr>
<tr>
<td>CO₂-e net emitted by the grid supply (kg/yr)</td>
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<td>-850</td>
<td>1873</td>
<td>1417</td>
<td>-1339</td>
</tr>
<tr>
<td>Cost AEC ($/yr)</td>
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<td>5104</td>
<td>6868</td>
<td>7000</td>
<td>5551</td>
</tr>
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<td>×</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>CN target</td>
<td>×</td>
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<td>✓</td>
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<td>✓</td>
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<tr>
<td>ZC target</td>
<td>×</td>
<td>×</td>
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<td>✓</td>
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</tr>
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</table>
Figure 7.19  Total energy demand, local energy generation and net grid energy demand (technological fix scenarios)

Figure 7.20  CO₂-e emissions by category (technological fix scenarios)
Figure 7.21  Annual CO₂-e emitted by consumption versus annual equivalent cost (technological fix scenarios)
8 CONCLUSIONS

In transitioning Australia’s energy system to a low carbon future it is critical that the housing sector be engaged in this process, given the significant contribution it makes to end-use energy consumption and GHG emissions.

This study has demonstrated the capacity for housing, whether existing or new, to achieve significant reductions in energy use and GHG emissions, and for both 5 and 7 star rated dwellings with efficient appliances and local energy generation to achieve carbon neutral and zero carbon status. The principal pathway for this is through enhanced energy efficiency of the building shell, use of energy efficient appliances and local energy generation.

By establishing a 2016 zero carbon policy for energy use in all new dwellings and their associated domestic appliances, UK’s Department of Communities and Local Government has instigated a process capable of transforming the housing sector and, in the process create a major new market and industry for on-site renewable local generation technologies. Australia currently lags in this regard, but could become a fast-follower (see McLennan, Magasanik Associates (2007) study of the market for distributed generation in Victoria).

In the current political, economic and environmental contexts surrounding the establishment of carbon pricing, trading and taxing schemes in the lead-up to the United Nation’s Framework Convention on Climate Change in Copenhagen in December 2009, carbon-based eco-efficiency performance modelling will be required to rapidly assess an increasing suite of ‘zero energy/carbon neutral/zero carbon house’ options in order to inform the key stakeholder groups that are integral to delivering a low carbon future for our built environment.

This project has developed performance assessment methods capable of appraising a range of hybrid building options against each other and against available targets.

8.1 Key findings – technology based innovation

1. What realistic operating energy and GHG performance can be achieved by the building shell?

For detached single storey dwellings (in Melbourne), a transition from 2.5 to 5.0 star energy rated housing translates to a 56% reduction in annual energy use for heating and cooling (from 65516 MJ/yr to 28894 MJ/yr). A further transition from 5.0 to 7.0 star rated houses saves a further 18% energy. The overall shift from 2.5 star rated housing (considered to be representative of stock built prior to the introduction of home energy ratings in 2003) to 7.0 star rated delivers a 74% reduction in annual energy used for space heating and cooling (from 65516 to 17216 MJ/yr, an energy saving of 48300 MJ/yr per detached dwelling).

The total CO₂-e emissions for buildings together with their appliances are shown in Figure 8.1, with the medium density dwellings having the lowest emissions. The emissions of the high-rise apartment exceed those of the single storey house, due to the additional energy demand of the common area services and the energy for appliances being primarily sourced from electricity.

With the CO₂-e emissions resulting from the variable energy demands of the different housing types being little different, further analysis on options for local generation for various scenarios of shell efficiency and appliances were restricted to applications involving single storey detached houses, which continue to be the dominant class of housing built in Australia.
2. **What realistic energy and GHG performance can be achieved by ‘best of breed’ domestic appliances as part of hybrid buildings?**

For domestic hot water heating capable of delivering total household demand, annual energy consumption ranges from 20973 MJ/yr (for gas storage) to 6581 MJ/yr (for solar thermal electric boost). The picture changes completely with respect to CO₂-e emissions from hot water heating appliances, where the range extends from 5599 kg/yr (electric storage) to 441 kg/yr (solar thermal gas boost), a reduction of 92%.

Comparison of a basic set of household plug-in appliances that have ‘average’ energy performance versus ‘best of breed’ performance reveals an average annual energy consumption of 9749 MJ/yr as opposed to 6998 MJ/yr, a difference of 28%. In greenhouse gas terms, the difference is 3910 kg CO₂-e versus 2807 kg CO₂-e, also a difference of 28% (due to the fact that all appliances are electric).

For cooking, the greenhouse gas implications of different kitchen set-ups range from 914 kg/yr (all electric) through 327 kg/yr (gas appliances plus microwave) to 259 kg/yr (all microwave), representing a capacity for CO₂-e reductions of the order of 72%.

For lighting, the greenhouse gas implications of different lighting set-ups range from 15.8 kg/yr for all halogen to 1.7 kg/yr for compact fluorescents (compact fluorescents may have been under-specified (DEWHA, 2008a, p 249)), but the indicative potential for CO₂-e reductions is of the order of 89%.

The standby energy for the sets of appliances used in this study varies from 14% of total energy consumption for a ‘best of breed’ set of appliances to 17% for a set of appliances with average performance.

3. **What realistic energy supply can be achieved by distributed energy generation as part of hybrid buildings?**

The annual average energy demand per dwelling in Melbourne (for space heating and cooling, hot water heating plus domestic appliances) is 75 GJ (Table 3.2).

Local energy generation technology options will provide only the outcomes shown in Table 8.1, generally well short of total energy demand. However, with a reduction in energy demand and a combination of local generation technologies, it is possible to get to net zero energy, carbon neutral and zero carbon solutions (Table 7.7). Given the significant number of dwellings across Australia that will be required to reduce their carbon footprint, and with the
current glacial rate of change to the proportion of green energy in the national grid, this study sheds some light on the path that individual property owners and developers might take towards a low or zero carbon future for their housing. At present, most Australian governments, industries and communities lack the information to make informed decisions across an increasing range of local energy generation and domestic appliance options.

Table 8.1  Electricity, heating, cooling and hot water generation for local energy generation technologies

<table>
<thead>
<tr>
<th>Local generation technologies</th>
<th>Electricity (MJ/yr)</th>
<th>Heating (MJ/yr)</th>
<th>Cooling (MJ/yr)</th>
<th>Hot water (MJ/yr)</th>
<th>Total (MJ/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar – Photovoltaic 1500 W</td>
<td>7096</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7096</td>
</tr>
<tr>
<td>Solar – Photovoltaic 4500 W</td>
<td>21287</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>21287</td>
</tr>
<tr>
<td>Wind – Turbine</td>
<td>4494</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4494</td>
</tr>
<tr>
<td>Ground source heat pump – 21kW thermal</td>
<td>0</td>
<td>24926</td>
<td>3968</td>
<td>13861</td>
<td>42755</td>
</tr>
<tr>
<td>Solar hydrogen – Fuel cell</td>
<td>5960</td>
<td>0</td>
<td>0</td>
<td>9622</td>
<td>15582</td>
</tr>
<tr>
<td>Gas – Fuel cell</td>
<td>26963</td>
<td>947</td>
<td>0</td>
<td>0</td>
<td>27910</td>
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<tr>
<td>Gas – CCHP Engine</td>
<td>23967</td>
<td>906</td>
<td>388</td>
<td>0</td>
<td>25262</td>
</tr>
<tr>
<td>Solar – Hot water – electric boost</td>
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<td>0</td>
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<td>13861</td>
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<td>Solar – Hot water – gas boost</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13861</td>
<td>13861</td>
</tr>
</tbody>
</table>

4. **What realistic operating energy performance (and GHG footprint) can be achieved by hybrid buildings (shell + appliances + local energy generation) compared to grid supplied standard (5 star) dwelling with ‘average’ appliances?**

A positive finding overall is that significant GHG reductions can be achieved via all distributed generation technologies examined. Large gas users such as CCHP, however, will find it difficult to deliver carbon neutral and impossible to deliver zero carbon outcomes.

Net zero energy, carbon neutral and zero carbon outcomes have been demonstrated as possible via carefully tailored combinations of local energy generation (providing electricity from renewable sources) to suit low energy demand shell and appliances. This transition is difficult if not impossible with 2.5 star rated dwellings, indicating a necessity for upgrading the energy efficiency of the shell.

All of these transitions come at an additional annual equivalent costs (ranging from approximately $1000 to $2000 per year), but could be expected to be significantly offset once a carbon tax is introduced and a distributed energy generation industry becomes established.

The base case house (new 5 star detached, Table 8.2 and Figure 8.2) which is representative of new grid connected project homes being marketed at present generates approximately 9.5 tonnes of CO₂-e annually in order to supply the comfort and amenity expected by Australian households. A transition pathway to zero carbon housing has been demonstrated which also provides the capacity for removing a further 1.3 tonnes of CO₂-e annually by exporting the excess ‘green’ electricity the hybrid building generates using DG renewable technologies to the grid. A net saving of CO₂-e per dwelling of approximately 11 tonnes annually as represented by the zero carbon house is the result.

As far as CO₂-e emissions and the AEC costs are concerned, comparison of scenarios 1 and 2 (i.e. worst case versus current project home) reveals a reduction in CO₂-e of 38 tonnes per year and a cost saving of approximately $8000 per year. To transition from the 5 star project home which generates 9.5 tonnes of CO₂-e per year to a zero carbon house incurs an AEC cost increase of over $600 per year, excluding subsidies, rebates, carbon price impost and feed-in payments.

This analysis shows the significant benefits more energy efficiency and carbon efficient houses can achieve – at low or negative costs. This strengthens the case for targeted
policies and programs to capture these benefits, even if an emissions trading scheme is introduced as such programs will lower the overall costs of a scheme.
Table 8.2  Case study set for net CO\textsubscript{2}-e emissions for scenarios in transition to zero carbon dwellings

<table>
<thead>
<tr>
<th>Selection</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling type</td>
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<td>Detached single storey</td>
<td>Detached single storey</td>
<td>Detached single storey</td>
<td>Detached single storey</td>
</tr>
<tr>
<td>Star rating</td>
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<td>5 star</td>
<td>2.5 Star</td>
<td>5 star</td>
<td>7 Star</td>
</tr>
<tr>
<td>Space heating and cooling</td>
<td>Electric heating and cooling</td>
<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative</td>
<td>Gas ducted and electric evaporative replaced by GSHP</td>
<td>Electric reverse cycle replaced by GSHP</td>
</tr>
<tr>
<td>Cooking</td>
<td>Electric cooktop, electric oven, microwave</td>
<td>Gas cooktop, electric oven, microwave</td>
<td>Gas cooktop, gas oven, microwave</td>
<td>Gas cooktop, gas oven, microwave</td>
<td>All microwave</td>
</tr>
<tr>
<td>Lighting</td>
<td>All halogen</td>
<td>Average mix</td>
<td>All compact fluorescent</td>
<td>All compact fluorescent</td>
<td>All compact fluorescent</td>
</tr>
<tr>
<td>Appliances</td>
<td>Average performance affluenza</td>
<td>‘Best of breed’ basic</td>
<td>‘Best of breed’ basic</td>
<td>‘Best of breed’ basic</td>
<td>‘Best of breed’ basic</td>
</tr>
<tr>
<td>Local generation 1</td>
<td>None</td>
<td>None</td>
<td>Solar – Photovoltaic 4500 W</td>
<td>Ground source heat pump – 14kW thermal</td>
<td>Ground source heat pump – 14kW thermal</td>
</tr>
<tr>
<td>Local generation 2</td>
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<td>None</td>
<td>Solar – Photovoltaic 1500 W</td>
<td>Solar – Photovoltaic 3000 W</td>
</tr>
<tr>
<td>Local generation 3</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Wind turbine</td>
<td>None</td>
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<tr>
<td>Energy used by consumption (MJ/yr)</td>
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<td>84866</td>
<td>151117</td>
<td>83262</td>
<td>37177</td>
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<td>Energy generated by local energy generation (MJ/yr)</td>
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<td>33726</td>
<td>80954</td>
<td>40515</td>
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<tr>
<td>Energy supplied by grid (MJ/yr)</td>
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<td>84866</td>
<td>117391</td>
<td>2307</td>
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<td>CO\textsubscript{2}-e emitted by consumption (kg/yr)</td>
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<td>9529</td>
<td>12096</td>
<td>8291</td>
<td>7584</td>
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<td>0</td>
<td>9181</td>
<td>8519</td>
<td>8923</td>
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<td>CO\textsubscript{2}-e net emitted by the grid supply (kg/yr)</td>
<td>47289</td>
<td>9529</td>
<td>2915</td>
<td>-227</td>
<td>-1339</td>
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<tr>
<td>Cost AEC ($/yr)</td>
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<td>4958</td>
<td>8363</td>
<td>5994</td>
<td>5551</td>
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</tr>
</tbody>
</table>
In Section 3 (see Table 3.1), it was argued that policy analysts need to engage with both technology-based and behaviour-based approaches to energy conservation. While this project is primarily focused on the former pathway for energy transition, elements of the study do permit some observations as to the potential energy and greenhouse gas savings IF society was prepared to wind back consumption in a number of areas, responding to calls for leading ‘a simpler life’.

One of these related to consumption of housing space. If there were reversion to a simpler style of living that has been advocated (e.g. Trainer, 2008), with floor spaces akin to those of a quarter century ago (i.e. 167 square metres for new private sector houses in 1983 (ABS, 1994)) being reflected in new dwelling completions, the average annual savings in CO$_2$-e could be of the order of 146 thousand tonnes (based on 2007 completions levels of 150,000 dwellings, a 25 year difference in average floor area of 72 m$^2$, and average CO$_2$-e emissions per m$^2$ of detached housing of 13.5 kg).

A second area relates to the over-consumption of domestic appliances (‘affluenza’). Evidence suggest that an ‘affluenza set’ of appliances generates an additional three tonnes of CO$_2$-e per year per dwelling compared to a household operating what could be termed ‘basic set’ of ‘best-of-breed’ appliances. With 8.1 million households in Australia in 2006-07 (ABS, 2008b) and assuming one-third of these could be characterised as ‘affluenza households’, there is potential for an annual average national savings in GHG emissions of approximately eight Mt.
8.3 Key findings - costs

The costs required for each appliance, technology or distributed generation unit are Initial capital cost, initial installation cost, annual maintenance and annual operating cost. To be able to add a capital cost to an annual cost to obtain a measure of total annual costs, it was necessary to convert the capital costs to an annual cost which is effectively incurred each year over the life of the asset, thus enabling an annual equivalent cost (AEC) to be calculated for technologies of varying lifetimes.

The estimated annual equivalent costs for the various scenarios as shown in the tables in Section 7 vary considerably and would have an impact on decisions to implement local generation capacities. The lowest AEC is over $5,000 for one of the only scenarios to achieve a zero carbon target (but it assumes a 7 star house, the cost of achieving same is not included in the costs). The AEC is a useful measure for comparison of the scenarios to determine the most cost effective options.

Payback periods (without consideration of rebates or subsidies) for the various local energy technologies at January 2009 prices are long (20+ years) with only the high capacity precinct installations and solar hot water systems having a payback period about ten years or less. The reduction in payback periods when a carbon cost of $30/tonne is added to the energy operating costs is mostly around 20% but if the carbon price doubled to $60/tonne, the reduction in payback periods shifts to the 30% to 35% range; i.e. as the carbon price rises, the rate of reduction in the payback period declines.

Using the five case studies shown in Table 8.2, three scenarios for future costs (Table 8.3) were assessed to gain some insight into the changing future cost relativities. The scenarios include changes in rebates and subsidies, capital cost multiplier to reflect real reduction in capital costs as technologies become widely available, operating energy cost multiplier to reflect the real increase in the price of energy and a carbon price. Note that the ‘No subsidies’ scenario excludes the existing rebates for installation of solar hot water and wind turbines which were included in all previous scenarios. The results are listed in Table 8.4. The annual equivalent costs of the first two cases (both grid supplied) rise noticeably as the cost of energy and carbon emission costs increase. In contrast, the annual equivalent costs of the last three cases drop as the costs of new technology increase and use of grid energy decreases.

Table 8.3 Alternative future costs scenarios

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<tr>
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<th>No subsidies</th>
<th>Immediate future costs</th>
<th>Longer term future costs</th>
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</thead>
<tbody>
<tr>
<td>Rebates</td>
<td>None</td>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td>Capital costs multiplier for new technology (%)</td>
<td>100</td>
<td>80</td>
<td>50</td>
</tr>
<tr>
<td>Operating energy costs multiplier (%)</td>
<td>100</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Carbon cost ($/tonne)</td>
<td>0</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Sale of surplus electricity to grid</td>
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<td>$0.60/ kWh</td>
<td>$0.60/ kWh</td>
</tr>
</tbody>
</table>

Table 8.4 Impact of alternative future cost scenarios

<table>
<thead>
<tr>
<th>Cost AEC ($/yr)</th>
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<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
</tr>
</thead>
<tbody>
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<td>No subsidies</td>
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<td>4958</td>
<td>9534</td>
<td>6808</td>
<td>6517</td>
</tr>
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<td>Immediate future costs</td>
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<td>5594</td>
<td>7959</td>
<td>5575</td>
<td>4954</td>
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<td>Longer term future costs</td>
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<td>6311</td>
<td>7975</td>
<td>5646</td>
<td>4787</td>
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</tbody>
</table>

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8.4 Key messages

This report provides information for several million Australian households as well as industry and government to enable their direct participation in winding back unsustainable levels of CO$_2$-e emissions. Key messages are summarized as:

*Lifestyle-based change is needed to significantly reduce energy demand:* It is argued that policy analysts need to engage with both technology-based and behaviour-based approaches to energy conservation. While this project is primarily focused on the former pathway for energy transition, elements of the study do permit some observations as to the potential energy and GHG savings IF society was prepared to wind back consumption in a number of areas, responding to calls for leading ‘a simpler life’.

*Reduce house sizes:* One of these lifestyle changes is related to consumption of housing space. If there were reversion to a simpler style of living that has been advocated (e.g. Trainer, 2008), with floor spaces akin to those of a quarter century ago (i.e. 167 square metres for new private sector houses in 1983 (ABS 1994)) being reflected in new dwelling completions, the average annual savings in CO$_2$-e could be of the order of 146 thousand tonnes (based on 2007 completions levels of 150000 dwellings, a 25 year difference in average floor area of 72 m$^2$, and average CO$_2$-e emissions per m$^2$ of detached housing of 13.5 kg); a saving in CO$_2$-e of approximately 1 tonne per dwelling per year.

*Reduce appliance consumption:* A second lifestyle area relates to the over-consumption of domestic appliances (‘affluenza’). Evidence suggest that an ‘affluenza set’ of appliances generates an additional three tonnes of CO$_2$-e per year per dwelling compared to a household operating what could be termed ‘basic set with ‘best of-breed’ performance. With 8.1 million households in Australia in 2006-07 (ABS, 2008b) and assuming one-third of these could be characterised as ‘affluenza households’, there is potential for an annual average national savings in GHG emissions of approximately eight Mt.

*Distributed energy supply costs improve with dwelling efficiency and precinct installation:* The costs required for each appliance, technology or distributed generation unit are initial capital cost, initial installation cost, annual maintenance and annual operating cost. To be able to add a capital cost to an annual cost to obtain a measure of total annual costs, it is necessary to convert the capital costs to an annual cost which is effectively incurred each year over the life of the asset, thus enabling an annual equivalent cost (AEC) to be calculated for technologies of varying lifetimes. Payback period is another useful measure when considering which local generation technology might be cost effective. Most payback periods without a carbon cost (current situation) are long (20+ years) with only the high capacity precinct installations and solar hot water systems having a payback period about ten years or less. The reduction in payback periods when a carbon cost of $30/tonne is added to the energy operating costs are mostly around 20% but if the carbon price doubled to $60/tonne, the reduction in payback periods is in the 30% to 35% range (i.e. as the carbon price rises, the rate of reduction in the payback period declines).

The estimated annual equivalent costs for the various scenarios vary considerably and would have an impact on decisions to implement local generation capacities. The lowest AEC is just over $600 for one of the only scenarios to achieve a zero carbon target.

*Upgrade existing (pre 2003) dwellings to 5-6 star energy performance:* Over 95% of Australia’s housing stock would reflect an (operating) energy rating of 2.5 stars or less. Modelling undertaken in this report suggests that such housing, together with a worst case set of appliances and use, can be responsible for generating levels of CO$_2$-e exceeding 45 tonnes per detached dwelling per year. This class of stock constitutes the greatest challenge for a transition to carbon neutral or zero carbon housing.
A transition of the housing stock built before the 2003 introduction of a national 5 star energy rating system to carbon neutral or zero carbon status will require all of the following interventions:

- An upgrade of the building shell to at least a 5 star rating;
- Utilisation of ‘best of breed’ appliances;
- Application of local energy generation (low emission or zero emission) provided on site or accessed from a local precinct supplier, given the glacial rate at which the national grid is drawing on renewable energy sources.

**Increase medium density housing**: New (single storey detached 5 star) project homes are typically responsible for 9.5 tonnes of CO₂-e emissions per year. New double storey detached and high-rise apartments have larger carbon footprints (of the order of 10.9 and 9.9 tonnes respectively per year).

Medium density housing represents the best outcome from a CO₂-e emissions perspective (7.4 tonnes per year) and should become the principal vehicle for the intensification of urban development and redevelopment in Australian cities.

**Seek pathways for transitioning 5 star housing to zero carbon status**: Pathways for achieving zero carbon housing for contemporary 5 star project built homes have been identified. In addition to the 5 star energy efficient shell, they require:

- Solar hot water systems;
- ‘Best of breed’ appliances;
- Local energy generation tailored to household demand (but far from the levels required if linked to the requirements of a 2.5 star dwelling).

**A new energy metric**: CO₂-e should become the standard metric for reporting on energy performance in the housing sector.

**An expanded focus for carbon assessment in the housing sector: building shell plus built-in appliance performance**: To date, regulation has been restricted to the operating energy performance of the building shell. Future regulation should include a carbon target for built-in appliances as well as the building shell in order to deliver a more sustainable carbon footprint for the housing sector.

**A new energy performance assessment tool for the housing sector**: Performance assessment tools need to take into account the appliances and equipment (built-ins at minimum, e.g. hot water heating, kitchen cookware, lighting, space heating and cooling) used in buildings in addition to the building fabric and produce outputs that are verifiable and relatively easy to understand. They also need to be integrated with economic modelling and analysis that enables eco-efficiency assessments to be provided for any building.

### 8.5 Future steps

Given the proof-of-concept performance assessments of alternative configurations of hybrid buildings contained in this report, the question that remains is: what will inhibit the diffusion of this innovation within the housing sector?

**Need for a national picture**

In this pilot study, eco-efficiency analysis of hybrid buildings was restricted to one of Australia’s eight climate zones established by the Australian Building Codes Board (Zone 6, Figure 8.3 and Figure 8.4) in order to establish proof of concept. Given geographic variability across all components of hybrid buildings from both an energy supply and energy demand perspective, there would be value in expanding the study nationally.

**Parcel or precinct?**

There are over 7 million separate or medium density dwellings in Australia and each has the potential for increased energy efficiency and utilisation of local energy generation. This study has assessed the feasibility of individual hybrid residential buildings transitioning to zero
energy, carbon neutral and zero carbon status. Initiatives are underway to develop precinct-scale local energy generation, e.g. VicUrban at Dandenong, the City of London’s ten Low Carbon Zones (City of London, 2009), Sustainability Victoria’s Smart Energy Zones and Zero Carbon Precincts, and the Australian government’s Solar Cities (DEWHA, 2009b), so the relative benefits and speed with which precinct vs parcel-based initiatives can penetrate the established housing markets need to be established quickly.

Source: Australian Building Codes Board (2008)

Figure 8.3 Map of climate zones of Australia

<table>
<thead>
<tr>
<th>Climate zone</th>
<th>Description</th>
<th>Average 3 pm January water vapour pressure</th>
<th>Average January maximum temperature</th>
<th>Average July mean temperature</th>
<th>Average annual heating degree days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High humidity summer, warm winter</td>
<td>≥ 2.1 kPa</td>
<td>≥ 30°C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Warm humid summer, mild winter</td>
<td>≥ 2.1 kPa</td>
<td>&lt; 30°C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Hot dry summer, warm winter</td>
<td>≤ 2.1 kPa</td>
<td>≥ 30°C</td>
<td>≥ 14°C</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Hot dry summer, cool winter</td>
<td>≤ 2.1 kPa</td>
<td>≥ 30°C</td>
<td>&lt; 14°C</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Warm temperate</td>
<td>≤ 2.1 kPa</td>
<td>&lt; 30°C</td>
<td>-</td>
<td>&lt; 1000</td>
</tr>
<tr>
<td>6</td>
<td>Mild temperate</td>
<td>≤ 2.1 kPa</td>
<td>&lt; 30°C</td>
<td>-</td>
<td>1000 to 1999</td>
</tr>
<tr>
<td>7</td>
<td>Cool temperate</td>
<td>≤ 2.1 kPa</td>
<td>&lt; 30°C</td>
<td>-</td>
<td>2000 to alpine</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Areas defined as “alpine” in the BCA</td>
</tr>
</tbody>
</table>

Overcoming barriers to diffusion of an innovation: bridging the information gap and engaging with stakeholders

Hybrid building is currently located at the foot of the innovation-diffusion curve (Figure 8.5) – the concept has been articulated and subjected to a ‘virtual’ performance assessment.

Figure 8.5 Diffusion of innovation curve

Hybrid buildings will enable a transition to zero carbon housing – a necessary response by the housing sector to GHG mitigation in the 21st century. Progressing this transition will require engaging all stakeholders in the housing sector in a 4-stage process of behaviour change (Figure 8.5) that can lift knowledge levels, encourage commitment to and endorsement of the concept leading to the action of taking the new product to the marketplace. The material developed by this project is a key element for Stage 1 of this process of transformation: developing awareness, information and knowledge. One of the recurrent themes in concluding sections of energy and greenhouse policy studies (Productivity Commission 2005; Garnaut, 2008b) is market failure linked to a lack of information on energy efficiency and carbon mitigation options available to the housing sector. Commenting on issues of information shortfalls in the context of greenhouse gas emission mitigation, the Centre for International Economics (2009, p 52) considers that: ‘the areas of greatest concern are in the residential/consumer segment than elsewhere, reflecting the challenges that this particular group is likely to face’. Transformations of the type envisioned in this report are unlikely to progress, however, without engagement by the key stakeholders involved in the housing energy transitions arena. They include:

- **the distributed energy generation and renewable energy industries.** They offer a range of available technologies, but information shortfalls exist in relation to cost and performance over a scale of applications ranging from building to precinct. As an emerging green industry for the 21st century, distributed generation currently lacks scale economies that can deliver downward pressure on prices and there currently is uncertainty over the attractiveness to households and investors of a community-scale energy industry.

- **energy regulators.** Key here is their attitude towards building and precinct level local energy generation; agreements on gross versus net feed-in tariffs; and the availability of infrastructure that would enable the emergence of an intelligent green grid.

- **the design professions.** Architects need to be aware of the requirements of distributed generation technologies (effectively a new building element) at an earlier stage of the design process than with conventional energy supply. Urban planners also need to be aware of the added space (area) requirements of renewable energy generation compared to the grid (Newton and Mo, 2006).

- **property developers.** Principal uncertainties involve their level of understanding of the benefits and costs of installing specific local energy generation facilities.
• **energy distributors.** This stakeholder group requires knowledge of local energy generation options that can assist their decision-making in what role distributors might play in community-scale initiatives.

• **energy generators.** This centralised, fossil-fuel-based industry is rapidly making assessments of and potential responses to the impacts that carbon pricing will make; as well as examining the most eco-efficient options for meeting peak demand for energy.

• **the housing industry and its associations.** This group has been historically resistant to any innovation that has some up-front capital cost impost on housing. Issues of life-time costing and split incentives represent two key policy areas where the industry sector needs to identify pathways to encourage investment in housing innovation linked to energy.

• **housing consumers.** All consumers need to become more informed about the costs and benefits of energy efficiency and local energy generation as it applies to existing as well as new housing.

• **government.** From an energy perspective, governments need to identify the most cost-effective ways to provide incentives and/or regulate to reduce levels of CO2-e emissions across the built environment. This will involve a re-examination of building codes and planning regulations to the extent that they currently inhibit local energy generation.

Behaviour change and institutional change represent key areas for transformation in order to overcome lock-in and path dependency associated with Australia’s current energy regime and its link with an unsustainable level of GHG emissions.
9 BIBLIOGRAPHY


APPENDIX A: RELATIVE CARBON BURDEN INDICATOR

Eco-efficiency in its narrowest sense can be seen as an instrument of sustainability analysis that links environmental and financial performance and attempts to provide a quantitative measure of their relativities in a product, process or system. There is a process involved in undertaking an eco-efficiency analysis that comprises several steps or tasks that are documented in this Appendix. There is also a need to derive an eco-efficiency metric that is capable of delivering an integrated performance assessment of both environmental and economic costs of a particular product, in this case, a hybrid building. The measure of eco-efficiency performance used in this study is carbon-based in which economic and environmental (CO$_2$-e) costs of a particular configuration of hybrid building are compared, i.e. $ CO_2$-e cost per $1 of asset life cycle cost per year. The definition of this measure, termed a Relative Carbon Burden Indicator, is:

Relative Carbon Burden Indicator =  \( \frac{\text{CO}_2\text{-e emissions (converted to a carbon cost)}}{\text{Cost of hybrid building (or some component thereof)}} \)

The Relative Carbon Burden Indicator depicts the proportion (percentage) of the total annualised cost of operating a particular category of hybrid building (of which there are several scenarios examined) that can be attributed to the cost of paying for the amount of carbon emissions involved in its operation. The higher the percentage, the greater is the need to identify the source of the carbon intensive element(s) and substitute to a low or zero carbon alternative. It is a measure of the strength of impact on the annualised cost of operating the heating and cooling of a dwelling, water heating and the full range of appliances once a price for carbon is established and CO$_2$-e costs are internalised in the price of future goods and services.

As such, the eco-efficiency metric could be of considerable value as an aid to strategic decision making on the part of consumers, manufacturers of building products (including distributed generation technologies) and governments in clarifying where the most effective points for intervention and substitution reside (Huppes & Masanobu, 2005). Its weakness has been found to be linked to the relatively high costs of new technologies (ranging from LED lighting to solar hydrogen fuel cells) reducing the impact that carbon pricing makes on this indicator and may mislead for ‘bleeding edge’ technologies. The results of these analyses for all domestic appliances and equipment are presented below.
A.1 Heating and cooling

Electricity-based technologies have the largest Relative Carbon Burden Indicator values (Figure A.1). Higher values of the indicator mean more of the life cycle cost is attributed to the carbon cost of the fuel. Electricity powered technologies show the largest values even for cooling where the demand is low relative to heating.

Figure A.1 indicates that once a carbon price (in this study assumed to be $30/tonne) is introduced, the relative contribution that this cost component makes to the annualised cost of different heating and cooling technologies ranges from 20% in the case of electric heating to 1% in the case of electric reverse cycle cooling.

![Figure A.1: Relative Carbon Burden Indicator by heating and cooling technologies for a 5 star single storey dwelling](image)
A.2 Hot water

The differences in the CO₂-e emissions are reflected in the Relative Carbon Burden Indicator values, with the electric boost solar hot water system now dropping to be one of the lowest ratios (Figure A.2). The Relative Carbon Burden Indicator provides an indication of the implications of a potential carbon price, and for GBST hot water heaters the impact is minimal. There is significant carbon cost impost for retaining electric hot water storage systems.

Figure A.2 Relative Carbon Burden Indicator for hot water technologies
A.3 Cooking

The differences in the CO$_2$-e emissions are reflected in the energy source, with all three electric appliances (cooktop, oven and microwave oven) now far exceeding the same measure for gas cooking appliances (Figure A.3). From a Relative Carbon Burden Indicator perspective, the gas scenario is most prospective, representing lowest carbon price impost per annual expenditure outlay on cooking appliances (Figure A.4). The poor Relative Carbon Burden Indicator performance of microwaves is due to the relative cheapness of the technology, which accentuates the contribution of the carbon cost embodied in the electricity used in the overall annualised cost equation.

![Eco-efficiency for cooking technologies](image1)

**Figure A.3** Relative Carbon Burden Indicator for cooking technologies

![Eco-efficiency for sets of cooking appliances](image2)

**Figure A.4** Relative Carbon Burden Indicator for cooking scenarios
A.4  Lighting

The differences in the Relative Carbon Burden Indicator are less pronounced, with incandescent lighting being the worst and the LEDs being the best (Figure A.5). When attention is turned to eco-efficiency, both linear and compact fluorescents have a diminished performance, primarily as a result of the relative cheapness of their capital cost versus the carbon cost linked to their operation. When the carbon cost of operating energy is (becomes) the main annualised lifetime cost, the eco-efficiency metric rises, as reflected with the fluorescent lighting as well as the incandescent and halogen products. For LEDs, lifetime capital costs are three times the energy and carbon operating costs. This points to where new cost drivers linked to carbon pricing are likely to exert a significant influence of future relative attractiveness among competing products.

Figure A.5  Relative Carbon Burden Indicator for lighting technologies
A.5 Plug-in appliances

The Relative Carbon Burden Indicator highlights the significance of a standby component as a significant carbon cost impost (Figure A.6). The cheaper appliances are the ones households neglect to consider in the context of energy use and CO₂-e generation, but will be among the most significant bracket to experience the impact of any CO₂-e tax or pricing impost.

Figure A.6 Relative Carbon Burden Indicator for plug-in appliances