Facilitating a transition to zero emission new housing in Australia: Costs, benefits and direction for policy.

This thesis is submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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Statement of Authorship

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

Trivess Moore

13th of August 2012
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List of publications from research

**Journal Articles**


**Peer Reviewed Conference Papers**


This thesis was undertaken under a larger Australian Research Council funded project entitled ‘Lifetime Affordable Housing in Australia: Integrating environmental performance and affordability’. The project ran for three years from 2008–2011.

In addition to the funding provided by the Australian Research Council, the following industry partners were involved in the project, providing both funding and wider resources; RMIT University, UniSA, VicUrban (now Places Victoria), Building Commission (Victoria) and the Land Management Corporation (South Australia).

The aim of the Lifetime Affordable Housing in Australia project was to provide essential research to underpin policy enabling Australia to provide high performance urban housing within current and future economic and environmental limits. As a result of the research, for the first time, policy makers are able to draw on systematic research which quantifies and analyses the costs and environmental savings for different stages and types of housing provision throughout the housing life cycle.

The project was developed around four key themes:

- Theme 1: Housing life cycle costs and benefits
- Theme 2: Locational efficiency costs and benefits
- Theme 3: Affordability implications
- Theme 4: Policy and transition mechanisms

This thesis primarily addresses themes 1 and 4, although it also begins to address theme 3. A number of elements outside the scope of this thesis were addressed by the Research Fellow and two other PhD Scholars who were also working on this project.

Information on the wider project can be found at http://www.rmit.edu.au/cfd/laha
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Abbreviations

BAU – Business as usual
CBA – Cost-benefit analysis
CO$_2$-e – Carbon dioxide equivalent
CSIRO – Commonwealth Scientific and Industrial Research Organisation
EU – European Union
kW – kilowatt (unit of power measurement)
kWh – kilowatt hour (unit of power measurement across time)
MJ – mega joule (unit of energy measurement)
Mt – mega tonne (unit of measurement)
NPV – Net Present Value
NZ – New Zealand
PV – photovoltaic
RE – renewable energy
SHW – solar hot water
m$^2$ – square metres (unit of area measurement)
STT – socio-technical transitions
t – tonne (unit of weight measurement)
UK – United Kingdom
USA – United States of America
Vic – Victoria
ZEH – zero emission house/housing
Definitions

Accumulated costs – Total costs across the set time-horizon and includes all capital, maintenance, replacement and yearly energy costs or savings.

Business as usual (BAU) – The normal course of activity. In this case, the continuation of existing policy approaches.

Cost-benefit analysis (CBA) – A process for evaluating and comparing impacts of policies by systematically analysing total cost inputs against total expected outcomes (benefits) of various policy options compared to a BAU approach. The analysis turns inputs and outputs into a common metric to allow comparison.

Energy costs – The cost to the household of consumed onsite operational energy (gas and/or electricity, including renewable energy).

Renewable energy (RE) – Energy which is derived from natural resources such as sunlight, water and wind.

Star – The common unit of overall energy performance for a dwelling in Australia, as rated against Building Code of Australia requirements. For example, 6 star.

Zero emission house (ZEH) – A house that has the capacity to generate all energy consumed in the dwelling across a calendar year through renewable energy technologies. This definition includes all greenhouse gas emissions produced by energy consumed by the household within the property boundary, including energy used for heating, cooling, hot water, lighting, cooking and appliances.
Abstract

Mitigating the impacts of climate change is perhaps the greatest challenge facing mankind. It has been calculated that reductions of greenhouse gas emissions of up to 90% of 1990 levels are required by 2050 to limit the impacts from anthropogenic climate change. Accordingly, projected responses to this challenge would require all sectors to reduce greenhouse gas emissions. The residential sector in Australia, and globally, has been identified as being a significant contributor to greenhouse gas emissions. Moreover, it has been found to have favourable cost-benefit ratios to address these emissions. Many countries, including Australia, have now introduced minimum energy performance standards for new housing which aim to limit energy consumption and, in turn, greenhouse gas emissions. However, it is projected that current policies fall short of achieving significant greenhouse gas emissions reductions.

A facilitated regulatory transition to zero emission new housing (ZEH) by 2020 is being attempted in several advanced economies. Despite international efforts, the realisation of ZEH as a minimum building standard in Australia remains elusive. This thesis aims to address a lack of empirical evidence regarding the costs, benefits and practical policy implications of a ZEH transition in the Australian context. In order to do this a mixed methods approach has been applied.

Firstly, the costs, benefits and practical requirements for a facilitated regulatory transition to ZEH in Australia were evaluated. Secondly, existing new housing energy performance policies from Australia, the EU and USA were analysed to identify policy implementation gaps, key trends and current knowledge. A socio-technical transitions framework was utilised to analyse the progress to ZEH.

Results show that ZEH is economically and environmentally feasible for the dominant new housing form in the state of Victoria, Australia. However, there are currently significant gaps within the Australian policy context which must be addressed if a facilitated regulatory transition to ZEH is to occur. The research highlights that without a significant re-think of current approaches, Australian housing energy performance policies risk falling further behind standards of comparable advanced economies. This risks locking current and future occupants into unnecessary environmental impacts and high operational costs across the life-span of the house. In addition, findings indicate the applicability of a socio-technical transitions framework in analysis of ZEH transitions and policy development recommendations are presented.
Chapter 1: Introduction

‘…..the future of human prosperity depends on how successfully we tackle the two central energy challenges facing us today: securing the supply of reliable and affordable energy; and effecting a rapid transformation to a low-carbon, efficient and environmentally benign system of energy supply. What is needed is nothing short of an energy revolution’ (IEA, 2008b, p. 37).

1.1 Climate change, energy and housing

Limiting the impact from human induced climate change is perhaps the most critical issue currently facing mankind (Garnaut, 2008; Stern, 2007). The scientific consensus is that a reduction in global greenhouse gas emissions of up to 90% of 1990 levels by 2050 is required to limit climate change impacts (Garnaut, 2008; IPCC, 2007a). The consumption of fossil fuels has been calculated to contribute up to 85% of annual anthropogenic greenhouse gas emissions (IPCC, 2007b).

In 2008, 81% of global energy production was generated from fossil fuels; this was made up of oil (33%), coal (27%), and gas (21%) (IEA, 2010c, p. 80 Table 2.1). Nuclear energy contributed 6% of total energy generation, with the remaining 13% generated through renewable energy technologies (IEA, 2010c, p. 80 Table 2.1). Total global energy demand is projected to increase at 1.4% per annum from 2008–2020 (IEA, 2010c, p. 78), highlighting the significant challenges ahead in transitioning to a low carbon energy future.

In Australia where this thesis is principally focused, the present federal government is committed to reducing greenhouse gas emissions to 80% below 2000 levels by 2050 (Australian Government, 2011). It has been identified that a significant proportion of this reduction will be required to come from changes to energy production, with the energy sector the largest greenhouse gas emitter in Australia (Australian Government, 2010a; Wood et al, 2012). However, a recent Australian Government (2010a) report has identified that without further policy interventions, greenhouse gas emissions in Australia are projected to increase by 24% above 2000 levels by 2020, with (stationary) energy emissions increasing by 33% across the same time period (Figure 1). This means that it will become increasingly difficult and costly to meet the 80% greenhouse gas emission reduction target by 2050 if further interventions are not implemented in the near future (Garnaut, 2008).
In Australia 95% of total primary energy supply is currently generated from fossil fuels (coal 37%, oil 35%, gas 23%) (Schultz & Petchey, 2011). The remaining 5% of total primary energy supply is generated from renewable energy, which is less than the global average of 12% (IEA, 2010c). In terms of Australian electricity generation, renewable energy accounts for 8%, with fossil fuel energy accounting for 92% (Schultz & Petchey, 2011). These statistics highlight the significant challenge it will be to transition to a low carbon energy future in Australia, where fossil fuel energy production is the dominant energy paradigm.

Globally, the built environment, which includes the housing sector, is a significant contributor to anthropogenic climate change, primarily through increasing demand for fossil fuel energy. Energy consumed in the built environment accounts for 40% of worldwide energy use and one third of greenhouse gas emissions (Kolokotsa et al., 2011; van Lente et al., 2011). Specifically the residential sector is responsible for consumption of 14% of total delivered energy (EIA, 2011). In Australia, the residential sector is responsible for 12% of total final energy consumption and 13% of greenhouse gas emissions (Schultz & Petchey, 2011; Wang, Chen, & Ren, 2010).

Total residential energy consumption in Australia increased by 88% between 1973 and 2009 (Schultz & Petchey, 2011), while the total population has increased by only 60% across the same time-horizon (Phillips, Klapdor, & Simon-Davies, 2010). It is projected to increase by another 16% between 2008 and 2020 (DEWHA, 2008b). This increase in total energy consumption translates to an increase in greenhouse gas emissions due to the high carbon intensity of electricity generated in Australia (Garnaut, 2008). While efficiency gains from new appliances and building stock are expected to result in a slight decline in energy use per house to 2020, the absolute level of residential energy consumption is predicted to continue to rise (DEWHA, 2008b).
Chapter 1: Introduction

This expected rise is related to various social and technical factors. Increasing total dwelling numbers, increasing floor size of new houses, decreasing average occupant numbers, an increased proliferation of appliances (including heating and cooling) and easy access to finance is associated with an upward trend on absolute residential energy consumption (ABS, 2009; Newton & Tucker, 2009; Pitt & Sherry, 2010). Household occupant numbers decreased from 3.1 people per dwelling in 1976 to 2.5 in 2006 (ABS, 2008a). Moreover, house size increased from an average floor area of 162.4 m² in 1984 to 248.0 m² in 2009, representing a 52.7% increase (ABS, 2010c). The number of bedrooms also increased from an average of 2.8 per dwelling in 1976 to an average of 3.1 in 2006 (ABS, 2008a). In addition, a predicted 3.3 million new dwellings are to be built in Australia between 2010–2030 (NHSC, 2011). New dwellings built over the next 20 years will represent approximately 27% of the total dwelling stock by 2030.

The current system of housing energy provision in Australia, and globally, is arguably unsustainable in the context of the requirements to mitigate climate change impacts (Horne & Hayles, 2008; Pearce, Markandya, & Barbier, 1989; Smith, 2007). The question arises as to how to address energy use and energy generation in new housing, which has been identified as having substantial capacity to assist with reducing Australian greenhouse gas emissions. This question forms the starting point for this thesis.

1.2 Responses to residential energy use and greenhouse gas emissions

The importance of the built environment in mitigating greenhouse gas emissions has been identified by a number of authors, for example Ding (2008), IPCC (2007a), Jones, Patterson, and Lannon (2007), Newton and Tucker (2011) and Ortiz, Castells, and Sonnemann (2009). The built environment has highly favourable cost-benefit ratios compared to other sectors for cost-effective greenhouse gas emission reduction through a reduction of energy consumption, improvements to energy efficiency and a viable utilisation of low carbon energy sources (Higgins, Foliente, & McNamara, 2011; IPCC, 2007b; Kolokotsa, et al, 2011; van Lente, et al, 2011).

Over recent decades a range of government approaches to addressing energy use and greenhouse gas emissions in the residential sector have been applied in Australia and internationally. Falling broadly under the banner of ecological modernisation, these policy initiatives typically entail technical change designed to lead to desired environmental and economic outcomes (Mol & Sonnenfeld, 2000; Pearce, et al, 1989). Approaches include the provision of rebates for sustainable technology development and resale, the setting of minimum heating and cooling energy standards for appliances and for the thermal energy performance of the building envelope, as well as initiatives to address occupant behaviour (Greene & Pears, 2003). To date these approaches have primarily focused on improving energy efficiency with a more limited focus on energy demand and generation issues (Míguez et al, 2006; Smith, 2007).
The setting of minimum building energy performance standards has arguably had the greatest effect in addressing energy use in new housing (Ekins & Lees, 2008; Horne & Hayles, 2008; IEA, 2010a). Such standards invariably aim to address a market failure preventing improved sustainability in new housing (Beerepoot & Beerepoot, 2007; Choguill, 2007; Clinch & Healy, 2000b; Lee & Yik, 2004; Oikonomou et al., 2009). As a United Kingdom (UK) Government report states:

‘In a perfect world, well informed home buyers, in full awareness of the threat of climate change, would create a strong demand for highly energy efficient homes. House builders would need to build to those standards in order to compete; and this would place an equally strong imperative on the supply chain, thus promoting innovation, development and continuous improvement. The most reluctant suppliers would be driven to participate by the need to deliver for their investors.

In the real world, some home buyers are aware of the value of energy efficiency…but this translates only weakly into buying preferences: it ranks well behind the key requirements for price, size and location…This is insufficient to motivate house builders or, through them, the rest of the market. Over time things will change, as awareness of the threat increases and energy prices rise, but far too slowly to achieve the 2016 target or even come close to it’ (DCLG, 2007c, p. 88).

Furthermore, researchers such as Bergman et al. (2007) and Crabtree and Hes (2009) argue that the building industry is slow to change and that it has historically only done so when required to meet government regulations or to make use of subsidies. In this way minimum energy performance building regulations create a level playing field for all new dwellings to meet set standards, driving both building industry and consumer change (Pickvance, 2009). More broadly, regulations have been identified as a significant driver of reducing greenhouse gas emissions and facilitating an uptake of low carbon energy generation (Wood, et al., 2012).

Various states in Australia have had some form of minimum energy performance requirements in place since 1993 (Building Commission, 2011). These have typically targeted improving heating and cooling energy requirements in new housing, an approach which has been common in other developed countries (Greene & Pears, 2003; Lee & Yik, 2004; Míguez, et al., 2006). These standards have been informed not only by environmental considerations, but by undertaking cost-benefit analysis (CBA) of possible policy outcomes. Minimum energy performance requirements in the Australia context are discussed in detail in chapter 3.
Recent reviews of outcomes in the Australian context have found that minimum energy performance regulations have achieved significant improvements to energy efficiency of the new housing stock. For example, the introduction of the Building Code of Australia minimum energy performance “5 star” standards in Victoria led to a reduction in greenhouse gas emissions of about 20% (Wilkenfeld G & Associates, 2007). Despite this, increasing house floor size and an increase in appliance numbers and use mean that actual greenhouse gas emissions have increased by 6% compared to existing dwellings. However in the absence of the 5 star regulation, energy consumption would have risen by 33% (Wilkenfeld G & Associates, 2007). This increase in total energy and greenhouse gas emissions despite an increase in energy efficiency has also been documented in international research (Güneralp & Seto, 2012).

While it does achieve improvements in energy efficiency, the current approach which focuses primarily on improving heating and cooling energy efficiencies, has significant limitations in that it addresses less than half of household energy consumption in Australia (DEWHA, 2008b). Depending upon local climate and household demographics, the portion of energy use ascribed to household appliances, electronics, lighting and other non-space heating and cooling services is significant, accounting for 50% or more of total household energy consumption. Minimum energy performance regulations typically do not address these aspects. Furthermore there is a failure to consider energy generation and wider social dimensions within the current regulatory approach (Golubchikov & Deda, 2012; Pickvance, 2009).

Examples of these wider social dimensions and benefits include improved occupant health and comfort, reduced living affordability issues, protection from energy price increases, added resale value, and improved social cohesion outcomes through a reduction in social inequity (Golubchikov & Deda, 2012; Jones, et al, 2007; Nevin & Watson, 1998; Vale & Vale, 2000; Wells et al, 2007; Williamson et al, 2009). Some authors such as Golubchikov and Deda (2012) believe that on such social benefits alone there is a case for policy approaches to improve housing sustainability, aside from economic and environmental rationales for doing so.

In recognition of the limitation of current regulatory approaches, several international jurisdictions have begun implementing a range of innovative policy approaches. These policy innovations include attempts to account for environmental, economic and social elements as well as addressing household energy consumption (Cato, 2011; Scorse, 2010). Countries such as the UK have developed pathways to achieve zero emission housing (ZEH) standards based upon these wider considerations (DCLG, 2006a). As a result ZEH standards have become international best practice.

This thesis starts from the ontological position that minimum energy performance regulations will be a significant driver in a transition to ZEH standards.
1.3 ZEH definition

Definitions of sustainable or energy efficient housing differ between policies and academic literature sources (Marszal et al, 2011; Riedy, Lederwasch, & Ison, 2011). Terms such as ‘green’, ‘sustainable’, ‘renewable’, ‘integrated’, ‘solar’, ‘zero emission/energy’, ‘low emission/energy’, ‘design for life’, ‘adaptable’, ‘healthy’, ‘eco’, ‘hybrid’ and ‘autonomous’ have all been used to discuss more environmentally friendly housing (Chiras, 2002; Marszal, et al, 2011; Newton & Tucker, 2011; Riedy, et al, 2011; Torcellini, Pless, & Deru, 2006; Vale & Vale, 2000). All of these terms have slightly different meanings, and even when different authors or organisations use the same term it can be used to mean slightly different things (Torcellini, et al, 2006). Key points of difference between definitions include life cycle boundary differentiations, the application of different assessment methods, and variations in metrics and timeframes (Riedy, et al, 2011).

For the purposes of this thesis the focus is on zero operational emissions as the performance standard, which is now recognised as international best practice (Australian Government, 2010c; DCLG, 2006a; Kolokotsa, et al, 2011). Again there is a range of definitions presented in the literature and within policy documents for ZEH (Riedy, et al, 2011). Some ZEH definitions only cover energy use from built-in appliances within a dwelling; including energy for heating, cooling, lighting, hot water and cooking, while others include all energy consumed within a dwelling.

In this thesis, ZEH is defined as housing which has the capacity to generate all energy consumed in the dwelling across a calendar year through renewable energy technologies (Marszal, et al, 2011). This definition includes all emissions produced from energy consumed by the household within the property boundary, including energy used for heating, cooling, hot water, lighting, cooking and appliances. This definition aligns with the initial definition introduced in the UK’s Code for Sustainable Homes and with the wider requirements to achieve significant greenhouse gas emission reductions in order to mitigate climate change impacts (DCLG, 2008b; McLeod, Hopfe, & Rezgui, 2012; Pitt & Sherry, 2010).

The definition is based upon a ‘net’ generation principle, whereby times of renewable energy generation offset times where renewable energy is not being generated (due to technology or climatic limitations) but energy is still being consumed. The analysis undertaken in this research assumes that across a year, energy generation and energy consumption balance each other out. This approach also allows for fluctuations in renewable energy generation outputs across different climatic seasons. For example, solar photovoltaic output in winter will be typically less than in summer.

In the wider context of environmental sustainability, authors such as Lorek and Spangenberg (2001) and Dey et al (2007) define other significant household emissions including from water
consumption, transport, food, materials and construction processes related to the residential home. Performance standards which include these elements, such as the autonomous house (Vale & Vale, 2000), adhere to more ecologically stringent performance standards than the definition of ZEH used in this research. For example, the autonomous house requires all resources (energy and water) to be collected and disposed of on site, with no connection to centrally provided energy and water infrastructure, arguably reducing wider environmental impacts. Furthermore, some researchers such as Vale and Vale (2009) and Clune, Morrissey, and Moore (2012) argue that there are other critical elements such as reducing house size and improving housing design which should be implement in the development of low-carbon housing.

This thesis acknowledges that there are numerous other important factors related to emissions originating in the residential sector, including that individual dwellings are part of a larger housing system. However this research is focussed on the physical house and the energy generation and consumption required within an individual house of typical (2010) design and shape during operation by the occupants. Other research undertaken as part of the Lifetime Affordable Housing in Australia research project, under which this thesis sits, has addressed some of these wider sustainability concerns. For example, the impact of transport and location on the affordability and sustainability of housing was investigated (Irvine, 2009).

1.4 ZEH performance

Pickvance (2009) identifies that there are four primary sources of environmental impacts from housing:

- location of the dwelling,
- construction process and raw materials,
- technical features of the dwelling, and
- activities of the household that take place in the dwelling.

Of these, technologies and their use by occupants in complex socio-technical systems determine the final energy consumption of the dwelling, rather than solely the physical building itself (Bergman, et al, 2007). For example, embodied energy within the material used for construction represents 10–20% of total energy consumed and greenhouse gas emissions produced across the life of a typical house in a temperate climate zone (Pullen, 2000). The remaining 80–90% of emissions across the life of a dwelling occurs during the operational phase, from energy used for space heating, cooling, cooking, lighting, hot water and appliances (van Lente, et al, 2011), highlighting the importance in addressing operation energy consumption, although consideration of embodied energy should not be neglected. While embodied energy is important, the focus of this thesis is on
greenhouse gas emissions from the operational phase of the dwelling, as these present a significant contributor to greenhouse gas emissions from the residential sector.

Drawing upon the principles presented by the common energy hierarchy (Figure 2), a starting assumption of the research reported in this thesis is that ZEH is most efficiently and cost effectively achieved by firstly reducing overall energy demand including the application of energy efficiency improvements to the building envelope and behaviour change initiatives. Once these options have been exhausted, the addition of renewable energy technologies ensures that the reduced energy demand can be met in a sustainable low-carbon manner (DCLG, 2007c; Kolokotsa, et al., 2011; Vale & Vale, 2000; Zhu et al., 2009). This is the approach undertaken in the UK in their development of ZEH standards as outlined in the following:

‘Our view is that the best approach is to require the highest practicable standards of energy efficiency as a first, not a final, recourse. Ideally, remote generation should be taken into account only for discretionary energy uses or on sites where distributed energy generation is, for local or environmental reasons, not feasible’ (DCLG, 2007c, p. 93).

![The energy hierarchy](image)

Figure 2: The energy hierarchy, based upon McLeod, et al (2012) and WMRA (2009).

The technical and design requirements to build ZEH are well established. These elements include aspects of dwelling design; house size and orientation, insulation for floors, walls and ceilings, double/triple glazed windows, weather stripping, external blinds, eaves and the incorporation of renewable energy systems (Boardman et al., 2005; Edwards & Turrent, 2000; Kats, 2009; Mithraratne, Vale, & Vale, 2007; Morrissey & Horne, 2011; Morrissey, Moore, & Horne, 2011; Vale & Vale, 2000; Zhu, et al., 2009). Houses in Australia are typically not built with a full consideration of these elements, leading to unnecessarily high energy demand for heating and
cooling (Peterkin, 2009). Notable ZEH examples include the AusZEH project in Australia and the Vales autonomous house and the Hockerton Housing project, both from the UK (Pitt & Sherry, 2010; Smith, 2006; Vale & Vale, 2000).

1.5 Requirement for significant change

While the technical and design requirements for building ZEH are known, a change from the current model of housing design, construction and use of energy to a ZEH paradigm requires significant innovation and a change in both policy and practice, as described by wider socio-technical transitions (STT) theory (Smith, 2007). STT theory is focused on addressing deep structural changes to wider social elements (such as regulations, networks, markets, infrastructure and consumer practices) and technical elements necessary to underpin ‘major technological transformations in the way societal functions such as transportation, communication, housing and feeding, are fulfilled’ (Geels, 2002, p. 1257). Chapter 4 will discuss STT in detail.

A departure from current practice to an STT approach presents significant challenges to actors and stakeholders in this sphere, including decision-makers, industry practitioners and consumers. As articulated by Bergman et al. (2007, p. 9):

‘there is much evidence that the mainstream building sector…has practices and a culture which are incompatible with sustainability on various levels, and that sustainability issues require not only a technological shift in the building industry, but a complete paradigm shift: changes in structure, communication, strategy and actors’.

As already stated, there is a shift amongst a number of international jurisdictions towards ZEH standards for all new dwellings. Jurisdictions such as the EU and California have regulated to achieve this by 2020, while in the UK, a timetable has been set to meet this standard by 2016 (CPUC, 2011; DCLG, 2006a; European Commission, 2010). These ZEH standards contain mandated improvements to building envelope thermal efficiencies, the inclusion of renewable energy technologies and wider social dimensions. Taken collectively, these approaches are:

‘something of a revolution in the way new homes will be designed and constructed, and the ways in which energy, and the services that it provides, will be delivered’ (Monahan & Powell, 2011, p. 290).

Such policy initiatives represent the framework for a more comprehensive housing and energy policy approach, moving beyond the previous focus on improved heating and cooling thermal performance. Significantly, these transitions are being driven by innovation and development of previous minimum energy performance standards.
One government report in the UK acknowledges how significant a challenge it will be to transition to ZEH:

‘Achieving zero carbon by 2016 will be an outstanding achievement, leapfrogging Britain from among the European also-rans to world leadership in the field. It presents a major business opportunity, as well as a significant contribution to mitigating climate change. Advancing from the small handful of zero carbon homes currently being built to 240,000 homes a year within nine years will challenge everyone connected with the industry, including house builders themselves, product manufacturers, energy suppliers, designers, surveyors, planners, insurers, regulators and house buyers themselves. There are major risks which the market, on its own, will not resolve’ (DCLG, 2007c, p. 88).

1.6 Innovation of policy in the Australian context

While a paradigm shift may be underway in selected international jurisdictions, housing energy performance policy innovation in Australia remains limited (Horne & Hayles, 2008; Pitt & Sherry, 2010). There has been an alleged failure in Australia to ‘sustain any significant initiatives in the carbon-reduction process since the introduction of the energy-relating scheme for new homes in 2003’ (Newton & Tucker, 2011, p. 35). Such research suggests that the delivery of energy efficient housing in Australia continues to be locked into a regime which is unsustainable, given the size of the task to tackle greenhouse gas emissions.

In particular a lack of information for policy makers, the building industry and consumers has been identified as a significant market failure in Australia (Newton & Tucker, 2011). In this context, mandatory minimum energy performance standards have acted as a significant driver of energy improvements in housing. Research reporting failures in the Australian housing market in improving the energy performance of new housing stock (Crabtree & Hes, 2009) is also matched with similar market failures reported internationally (Clinch & Healy, 2000b; DCLG, 2007c; Lee & Yik, 2004).

The current minimum energy performance regulations in Australia address heating and cooling energy efficiency, with a focus on the thermal performance of the building envelope. Authors such as Newton and Tucker (2011) argue that building energy regulations should also include requirements for built-in appliances. Such a change in focus would mean that energy efficiency in the dwelling would shift from a consideration of approximately 30% of total energy consumed, to 70% of total energy consumed. In Australia, efforts to develop more wide ranging and comprehensive energy performance regulations have faced significant opposition (HIA, 2009; MBAV, 2008).
Chapter 1: Introduction

Since the introduction of minimum energy performance requirements for new housing in Australia there has been ongoing debate regarding the future direction of these standards. Typically, the debate centres on a perceived trade-off between affordability and sustainability, with affordability more frequently given priority (Morrissey, et al, 2011; Pitt & Sherry, 2010; Pullen et al, 2010). The cost of housing has risen faster than incomes in Australia in recent years (Yates, 2008) and any additional capital costs for improved sustainability outcomes, frequently typified by long payback periods, is cited as a potential concern for policy makers and home owners (Pitt & Sherry, 2010). Most at risk from increasing capital housing costs are low income earners and first home owners. This is a point which is strongly argued by key building industry associations who are typically against any changes which add to costs or which may hamper the sale of dwellings. Sustainability features are seen as adding costs in this context (HIA, 2009; MBAV, 2008). A comparable debate has been reported in other jurisdictions, including in the UK (Pickvance, 2009).

The development of minimum energy performance standards for new housing, along with wider debates on affordability/sustainability debate have been informed by cost-benefit information in Australia, as internationally. However, the focus of these cost-benefit debates has frequently been on the additional capital costs involved, rather than on through-life affordability of the dwelling, including longer-term energy savings and energy security benefits (Morrissey & Horne, 2011; Newton & Tucker, 2011; Wells, et al, 2007).

In Australia in 2012, ZEH is off the immediate or near term policy agenda. Newton and Tucker (2011, pp. 35, 47) state one reason for this:

‘…there is a market failure related to provision of the information necessary for informed policy or investment decisions…it is timely to question whether the scope of current building regulations is now sufficient in the face of 21st-century challenges relating to climate change’.

A significant gap in analysis remains a lack of empirical research into the lifecycle cost implications of increased energy efficiency at the household level, and an interpretation of the wider practical implications of this analysis in terms of a transition to a low carbon housing future.
1.7 Research questions
To address the problems presented in this chapter, and based upon identified gaps discussed in more detail in chapters 2–4, the following question and sub questions are presented to guide the research reported in this thesis:

What is the cost-benefit feasibility of, and policy requirements for, a transition to ZEH in Australia?

Sub question 1: What are the through-life costs and benefits of ZEH performance standards for owner-occupied new home buyers?

Sub question 2: What implications arise from through-life costs and benefits of ZEH, both in practical and policy dimensions?

Sub question 3: What actions may facilitate a transition to ZEH through minimum housing energy performance regulation in the Australian context?

In addressing these research questions, this thesis presents evidence and analysis to contribute to knowledge regarding ZEH standards in Australia. In addition, the thesis aims to address the applicability of STT theory to facilitate a transition to a low carbon housing future.

The research is based upon empirical research directly relevant to Victoria, Australia. It will be of primary benefit to policy developers of minimum housing energy performance standards in Victoria, Australia; however the outcomes are applicable to Australia more broadly, and may be applicable to other jurisdictions or areas of policy development where a transition to a low carbon future is targeted. In particular a number of critical requirements for future policy development of minimum housing energy performance requirements are identified and analysed for the Australian context. Furthermore the critical application of STT in this research will contribute to the emerging field of STT.

1.8 Thesis outline
This thesis is organised into 9 chapters which are briefly outlined below.

The current chapter, chapter 1, introduced the research problem with which this thesis is concerned, and placed this problem within a wider context. In doing so, a set of research questions were presented to address the knowledge gaps identified.

Chapter 2 provides a review of the current approach to policy development by governments in Australia. This review presents the various steps typical of the policy development cycle. In particular the increasing importance of the evidence base to inform policy development is
discussed. Typically this evidence base has taken the form of a CBA. A review of micro
economics, market failures and the role of CBA is undertaken to conclude the chapter.

Chapter 3 begins by briefly presenting policy responses to environmental issues since the 1970s.
Following this, a range of responses to housing energy performance policy internationally and in
Australia are explored and critiqued. The review highlights the importance of a regulatory approach
to addressing minimum energy performance requirements in new housing. In this context, the role
that evidence, and in particular CBA, has played in the development of current minimum housing
energy performance policy in the international and Australian context is reviewed.

Drawing upon the requirements to achieve significant greenhouse gas emission reductions across
every sector, chapter 4 discusses that in addition to favourable cost-benefit evidence, a facilitated
regulatory transition to ZEH requires significant policy innovation. A more comprehensive
transitions approach is presented in the emerging theory of STT. This theory is discussed in detail,
including the relevance of applying such an approach to achieve ZEH in Australia.

Building upon the discussion presented across chapters 1 to 4, chapter 5 presents the research
design applied in this research. The chapter begins by reiterating the research questions and
discussing the scope of the study. The methods applied in this research are then presented. A two
phase mixed methods research design was employed. Phase 1 addresses the costs and benefits of
implementing ZEH to assess the feasibility of such a standard. In doing so the
affordability/sustainability debate is addressed. Phase 2 consists of an international policy analysis
applying an STT framework. In doing this, strengths, gaps and limitations of policy documents in
Australia and selected international case studies are assessed to determine if there are policy levers
which could be applied in the Australian policy context.

Chapter 6 presents the results of phase 1 of the research. The costs and benefits of ZEH are
presented in terms of the additional capital costs involved as well as a consideration of through-life
costs and benefits. The data is compared to a Business as Usual (BAU) scenario. Results presented
include accumulated economic savings, household economic impact, net present value and
environmental benefits.

The results from phase 2 are presented in chapter 7. A summary matrix with the data from the STT
framework policy analysis is presented across the various case study jurisdictions, with the detailed
matrix presented in the appendix. The chapter then presents key results for each case study; the
United States of America (USA), the State of California, EU, UK, Australia and the State of
Victoria. The chapter concludes by providing a comparison across the case studies to highlight
similarities and differences, in particular to the Australian policy context.
Chapter 8 discusses the results presented in chapters 6 and 7, and looks at the three sub research questions, addressing each in turn. The chapter draws back to the key literature presented in chapters 1–4. The discussion then draws upon each sub question to discuss the overall research question and the implications from the research.

Chapter 9 provides a conclusion to the thesis by drawing up all the literature and data presented in the preceding chapters. In doing so it addresses the research problem and subsequent research questions introduced in chapter 1. In addition, it presents a discussion of the implications of the research for future policy development of housing energy performance policy in Australia.
Chapter 2: Policy development and the role of evidence

Chapter 1 explored the issues surrounding current energy consumption trends in the Australian residential sector. Specifically, the increasing consumption of fossil fuels and related climate change impacts were presented as one of the most critical issues currently facing mankind. In order to mitigate climate change impacts, a significant reduction of anthropogenic greenhouse gas emissions of up to 90% of 1990 levels is required. For the Australian residential sector, ZEH was presented as part of a possible solution to address these issues.

As stated in chapter 1, minimum housing energy performance has been typically addressed through policy approaches. Before this can be addressed in detail (chapter 3), this chapter investigates the nature of policy; what exactly is policy, how it is developed and by whom. The chapter begins by discussing these concepts with a focus on policy development in the Australian context. Chapter 3 will then build upon this analysis with a review of housing energy policy development, prospects and alternative approaches.

Further to this, the role of evidence within the context of neo-classical economics and its impact on informing policy development will be explored in this chapter. In particular, the method of CBA has been applied to inform recent housing energy performance regulations internationally and in Australia. Chapter 3 examines the application of CBA to housing energy performance regulations in greater detail.

2.1 Public policy process

The most common type of policy, and that addressed in this thesis, is public policy. Moran, Rein, and Goodin (2008, p. 154) define public policy as:

‘the actions, objectives, and pronouncements of governments on particular matters, the steps they take (or fail to take) to implement them, and the explanations they give for what happens (or does not happen)’.

Public policies shape our world and daily practices by addressing current or potential issues across a range of areas (Althaus, Bridgman, & Davis, 2007). The policy process is an attempt to purposively, systematically and authoritatively address these issues by determining acceptable parameters and behaviours for society (Colebatch, 2002; Dye, 2011; Stewart, 1999). Broad reasons for the use of a policy approach include addressing market failures, preventing monopolies, protecting intangible elements, improving efficiencies, encouraging innovation, addressing resources, curbing undesirable behaviours, and improving societal conditions (Considine, 2005; Scott & Baehler, 2010; Weimer & Vining, 2004). Essentially these reasons indicate the ‘steering’
or ‘facilitating’ role of policy in supporting political-economic frameworks within (in this case) market-based, liberalised economy structures and in directing resources towards maintaining particular forms of social order.

2.1.1 Forms of policy

There are various types of policy, each different in terms of detail, commitment and process. Some examples include (Birkland, 2010; Hogwood, Gunn, & Archibald, 1984; McClelland & Smyth, 2006):

- Broad policy concepts, objectives or areas – e.g. the government stating a desired goal to fix the health care system in Australia.
- An indication of what is, or is to become, normal practice – e.g. banning smoking in public areas and venues.
- A specific commitment to a problem – e.g. a monetary commitment to expand an overcrowded school, or
- A statement of values or guiding principles – e.g. the Greens Party supporting regulation for environmental protection.

In addition, policies come in a range of forms. For example, a policy can be a casual spoken statement, a documented conversation (e.g. a government debate), an official policy document or support provided for research or a program (Moran, et al, 2008). Policy can refer to one of these in isolation or a collection of relevant policy forms, which can cross multiple policy areas (Scott & Baehler, 2010). This allows for a degree of flexibility within the policy development cycle and, in particular, the ability to address a range of issues at different scales (global, national, state, local, individual).

Whatever the form, policies typically contain goals. For these goals to be realised, some form of instrument is required for implementation or further exploration. Policy can be implemented through a range of methods including legislation, practices, symbols, services, values, taxation, rebates, programs, statements, education and networks (Birkland, 2010; Dye, 2011; Hudson & Lowe, 2004; Thomas, 2007). There is no set formula via which policy instruments will successfully work for a particular solution, although common policy approaches have developed over time (McClelland & Smyth, 2006). A combination of approaches may be applied to achieve a desired policy outcome. For example, governments first educated the public about the health dangers associated with smoking before developing regulatory controls (Colebatch, 2002).

Governments will generally consider non-legislative methods to address issues of concern as a first response (Scott & Baehler, 2010). Regulation is often seen as a ‘last resort’. It can be unpopular with the community as regulation may be viewed as unnecessary and adding to workloads.
Chapter 2: Policy development and the role of evidence

(Considine, 2005). In addition, there may be significant costs involved with implementation and monitoring of regulations, which are often passed onto consumers. However, regulation is not always a last resort. Regulation can be applied to expedite processes when there are time constraints or to encourage innovation, for example (Beerepoot & Beerepoot, 2007; Colebatch, 2002; Moran, et al, 2008).

The reliance on regulation for environmental protection, including minimum housing energy performance requirements will be explored in chapter 3.

### 2.2 Policy development cycle

Althaus et al. (2007) describe the typical policy development cycle prevalent in Australia (Figure 3). Similar policy cycle approaches have been identified by others such as Scott and Baehler (2010) and Colebatch (2002). It is not the aim of this thesis to discuss each of these steps, but merely to acknowledge that typical policy development cycles exist and that any exploration and critiques of housing energy performance policies must be undertaken with an understanding of how they have been developed.

![Diagram of the typical policy cycle in Australia](image)

**Figure 3: The typical policy cycle in Australia (Althaus, et al, 2007, p. 37).**

Developing a policy, as shown in Figure 3, includes defining the problem, analysing instruments (including who ‘wins’ and who ‘loses’), selecting the most appropriate pathway/s forward and determining what implementation resources are required. It is a process that is dynamic rather than static. It typically continues to evolve over time as new information comes to hand, technologies
advance, costs reduce, new norms are created or the problem itself changes (Bacchi, 2009; Considine, 2005; Scott & Baehler, 2010).

As Figure 3 shows, the process is a continuous one. This is frequently a consequence of the fact that it is not until after policy has been implemented that unintended loopholes or consequences are, or can be identified (Althaus, et al, 2007; Birkland, 2010; Hogwood, et al, 1984). Within a reflexive governance and dynamic policy framework these consequences can be addressed as the policy evolves. Reflexive governance will be discussed as a part of policy innovation in chapter 4.

It is not always the case that each step in the policy cycle must be addressed to achieve good policy. There are opportunities sometimes to ‘short cut’ the policy process through well-directed policy analysis. Policy analysis can be applied to review policies enacted elsewhere to address similar issues for example and, in particular, can highlight the lessons learnt from those approaches. In this way, analysis can potentially save considerable time and effort in policy development, innovation and implementation, especially when most public policy is developed within the constraints of short-term government policy cycles (Spicker, 2008; Williams & Holmans, 1997). However, ‘short cuts’ in the policy development process must be applied with caution. A carefully considered policy, while not guaranteeing success, will improve the likely chance for a successful outcome (Considine, 2005).

A critical part of the policy development process is the setting of goals and determining the most appropriate methods to achieve these (Colebatch, 2002). This can be a challenging step in the policy development process. The setting of goals and appropriate implementation methods will be dependent upon, and strongly influenced by, underlying values and assumptions on the part of individual policy makers and those underpinning wider societal consensus on specific issues under consideration (Birkland, 2010; Hill & Ham, 1997). The contention around climate change policy is one example where different values and assumptions are held amongst policy actors (Garnaut, 2008).

It is rare for all actors impacted by a policy to have shared goals, values and ideas about implementation approaches (Scott & Baehler, 2010). Ensuring these differences do not curtail the impact of the policy provides a significant challenge for policy makers (Colebatch, 2002). Without a clear and robust purpose and method to implementation, individual policies may have undesired outcomes. The 2009/2010 ceiling insulation scheme rebate in Australia provides a pertinent example of implementation shortfalls of this nature and is explored in more detail in chapter 3 (see section 3.4.1) (Hawke, 2010).

The setting of goals, implementation approaches and the policy process as a whole are strongly informed by the policies and processes that have come before it (Maddison & Denniss, 2009).
Other elements which inform policy developments include recent reviews, reports, academic literature, scenario generation and consultation with clients and experts (Bacchi, 2009; Considine, 1994, 2005; McClelland & Smyth, 2006). Furthermore, outcomes of policy developments are generally set within a boundary of resource and budgetary constraints (Maddison & Denniss, 2009). Addressing all of these policy process considerations can add time and complexity to the policy development process.

Adding further complexity, policy development can involve many actors, including various levels of government, bureaucrats, experts, key interest groups, the general public and sometimes international, national and/or local actors (Moran et al., 2008; Scott & Baehler, 2010). Inevitably, this means that policy development is often a long, contested, complex and dynamic process conducted within existing dominant systems of government and ways of thinking, and regularly challenged from without.

Typically for public policy, the top levels of government will set the broader policy agenda (Colebatch, 2002; Hill & Ham, 1997). Here, the government defines how a particular issue is to be viewed and sets overall objectives or outlines a stance from which to address a particular issue (Hudson & Lowe, 2004). It is then left to bureaucrats or other key participants to develop the methods for implementation and to define what the specific outcomes should be. In the case of health care, ‘patients should wait no longer than an hour to see a doctor’ is an example of a specific and defined policy outcome, within a broader policy agenda of ‘improved health care’.

After the setting of specific policy details and the development of implementation methods, the role of the top levels of government is to sign off on developed measures and to communicate the entire ‘policy package’ to the people it impacts (Moran et al., 2008). Caution must be used in this ‘top down’ approach to ensure that the initial top level of defined objectives are not watered down when the practicality of implementation is encountered (Hudson & Lowe, 2004; Scott & Baehler, 2010). A number of recent Australian government policies (e.g. insulation scheme for existing houses (Hawke, 2010)) have changed substantially or been cancelled mid program, due to difficulties in the development of an implementation method which fitted the broad-level vision for the policy in a timely and economic fashion.

While public policy is often developed from top levels of government, the impetus for policy development can come from lower down, including from key actors outside the government (Colebatch, 2002; Hudson & Lowe, 2004). A group of concerned industry actors might come together to negotiate a new standards requirement, for example. Key industry actors may become involved in policy processes for a number of reasons, including to protect their products from other competitors or to ensure the quality and performance standards of their products (Considine, 2005).
However these actors must act within the confines of the current policy regime and therefore may find that there are limitations to their involvement or ability to affect policy change.

Whether a top down or bottom up approach is applied to policy development is critical to the policy process and ultimately the policy outcome (Hudson & Lowe, 2004). For example a bottom up approach may be developed with key actors in support, reducing the chance of resistance to the policy later in the process of implementation. A top down approach may allow for more flexibility in designing the policy and achieving significant outcomes. Similarly a top down approach may facilitate an ease of integration between new policies and old, particularly if policies fall across multiple policy areas (Moran, et al, 2008). Again, there are no fixed rules on when a top down or bottom up approach should be applied, highlighting the complex nature of policy development.

Ideally, any policy development should be undertaken in an orderly fashion, free of bias and external pressures (Althaus, et al, 2007). In a perfect world, policy makers would have access to all available information, or have resources and time available to gather it, and to explore all possible methods to achieve particular goals, including assessing impacts and benefits, as well as opening the discussion to the public before coming to a decision on which policy path to pursue is made (Colebatch, 2002). This process is known as rational policy development (Birkland, 2010; Simon, 1957). It is argued that by following such an approach, a more efficient and effective outcome can be achieved and the risks associated with unplanned elements can be reduced (Scott & Baehler, 2010).

The complexities of policy development, including time and budgetary constraints mean that rational policy development is rarely achieved in practice (Considine, 2005). For example, policy makers often operate without complete information about all aspects of the policy and due to time constraints must make assumptions based upon the best available information (Birkland, 2010). In addition, some assumptions, particularly about human behaviour, can be difficult to predict correctly and can have a significant impact on the outcome of a policy (Bahaj & James, 2007; Gram-Hanssen, 2010; Hudson & Lowe, 2004).

Other issues include the selection of those values and objectives to be used in the policy development process, the accommodation of requirements from key actors and in the case of the environment, addressing intangible aspects such as the value of air quality to society (Althaus, et al, 2007; Hill & Ham, 1997; Hogwood, et al, 1984). Rational policy development has also been criticised for its simple ‘one step after the other’ linear approach from start to finish (Birkland, 2010). The development of successful policy rarely follows such a linear path, as presented in Figure 3 (Maddison & Denniss, 2009).
Due to these difficulties, complete rational policy development is rare (Birkland, 2010). The alternative policy approach is incremental policy development (Considine, 2005; Lindblom & Woodhouse, 1993). For this approach, current policies are taken as the starting point and are progressively ‘adjusted’ in an incremental fashion towards a new goal or outcome (Considine, 2005). Much like rational policy development though, there are a number of criticisms in the literature about this approach.

Criticisms of incremental policy development include views that if the original policy is wrong in the first place, revised iterations of this policy will likely lead to outcomes which are further away from ‘right’ policy direction (Hill & Ham, 1997; Hogwood, et al., 1984). There are also questions about the ability to adapt policy in areas of rapid development. One example is the area of technological innovation and development. Making incremental changes to existing policy approaches may result in quickly out-dated policy mechanisms, which are no longer suitable to achieve the original policy goals (Moran, et al., 2008).

Another criticism of incremental policy development is that key actors can influence small changes in the policy development process itself more easily than they can a rational policy (Hill & Ham, 1997). Potentially key actors can push their own policy agenda, through a series of subtle interventions. The policy debate surrounding the urban growth boundary in Melbourne and Sydney, which was initially set to limit expansion of the city, is one example of this. Through a series of small changes to the boundary at individual points, key influential actors have achieved arguably the same change as a larger policy intervention (Buxton & Goodman, 2008).

Despite these criticisms, there are a number of benefits cited for the use of an incremental policy approach. A series of incremental changes can allow testing of new policy approaches (Maddison & Denniss, 2009). If the changes are successful, further changes can be made. However if changes are shown not to be successful, policy can readily be adjusted back to the original position without incurring significant damage (Hill & Ham, 1997). Another benefit is the ability to adjust as new information or innovation emerges, provided a problematic ‘lock in’ to a poor policy has not already occurred.

Commonly, policy development attempts to combine elements of incremental and rational policy development in a hybrid approach. This approach acknowledges that policy must work within time, budgetary, information and historical constraints, but that elements of rational policy development such as allowing for public consultation can still be addressed. The hybrid approach has been more typical of public policy development since the late 1990s, when evidence-informed policy development became more popular. This developed from a change in government and policy approaches, which were predicated on the idea that evidence can add to the ‘rationality’ of policy...
development (Argyrous, 2010), by providing strong arguments to rationalise why particular policy pathways were adopted or rejected.

This coincided with a general change in policy development; away from a primary reliance on the traditional methods of economics (discussed in section 2.4) and towards a more multi-faceted consideration, including aspects such as social and environmental elements, more commonly known as the triple bottom line approach (McClelland & Smyth, 2006). Such evidence-informed policy development has been most typically applied historically in the health sector, but over the past decade has been adopted in other policy areas (Argyrous, 2010; Gray, 2001).

2.3 Evidence-informed policy development

Evidence is important to the policy development process and it is widely suggested that the use of evidence can help to improve policy outcomes (Cameron et al., 2011; McClelland & Smyth, 2006; Spicker, 2008). The use of evidence, it is argued, attempts to fill information gaps and leads the policy process towards the middle ground between incremental and rational policy development (Althaus, et al., 2007; Mishan & Quah, 2007). However, the provision of evidence itself cannot achieve anything. Analysis is still required on the part of policy makers or actors, the results of which need to be incorporated into action/s (Scott & Baehler, 2010; Spicker, 2008).

The use of evidence is now a feature in the continuous evolution of policy. While increasingly important, the nature of ‘evidence’ use is contested; for example, questions arise as to how evidence is produced, selected, framed, presented, justified and legitimised (Pearce & Barbier, 2000; Shaxson, 2005). There are approaches that can be applied to reduce these issues. For example, by making the evidence and assumptions used clear and explicit so that all actors can understand the basis for policy decisions, the decision making process itself is made more transparent and robust (Shaxson, 2005). In addition, the compiling of evidence from trusted sources can help to clarify contentions when multiple policy participants produce conflicting evidence and arguments (Jacobson & Goering, 2006).

Despite these issues, it is argued that evidence can be used to improve the process outcomes, and the earlier in the policy process that evidence is applied, the stronger policy outcomes will be (Hudson & Lowe, 2004). For example, the provision of new information or evaluation of current methods and previous policy outcomes can provide ‘improved’ context for policies (Mishan & Quah, 2007; Mulgan, 2005). The use of evidence can also be used to defend a policy decision in the face of strong criticism from actors, as has been the case with many environmental policies (Banks, 2009).

Despite the above arguments for evidence-informed policy, not all evidence and outcomes can be calculated, modelled or predicted with accuracy. There are many assumptions imbedded within
policies, particularly those aspects which relate to human behaviours and the environment (Althaus, et al, 2007). Failure to provide complete and unbiased information was presented as a criticism of rational policy development.

A compilation of key strengths and weaknesses of the use of evidence in policy development was undertaken as part of the literature review for this research. A summary of these findings is presented in Table 1 and a number of these strengths and weaknesses will be discussed further in subsequent sections of this chapter.

**Table 1: Strengths and weaknesses of using evidence in the policy development process.**

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requires clear problem definition and questions to be explored.</td>
<td>Gathering of evidence can take a significant amount of time.</td>
</tr>
<tr>
<td>Can improve transparency of the policy process and outcomes, which can reduce opposition to the policy.</td>
<td>Some elements are difficult to model, predict or add values to, leading to evidence which is laden with assumptions.</td>
</tr>
<tr>
<td>Can lead to improved efficiency and effectiveness in the policy development process which can lead to more robust outcomes and reduce policy failures.</td>
<td>Can be issues of evidence quality when having to follow ethics and regulations for evidence gathering.</td>
</tr>
<tr>
<td>Can be used to ‘short cut’ the policy process by providing lessons learnt from best practice policies.</td>
<td>Differing methods can lead to conflicting evidence, especially if a certain outcome is being pushed by those providing evidence.</td>
</tr>
<tr>
<td>Can be used to assess the costs, benefits, risks and uncertainties of different policy pathways.</td>
<td>It is easy enough for evidence to be manipulated to tell a desired story.</td>
</tr>
<tr>
<td>In collecting the evidence, a wider range of actors can participate if required.</td>
<td>Evidence across time can be hard to gather as measurements and methods can change or evolve.</td>
</tr>
</tbody>
</table>

Despite the weaknesses of applying evidence in policy development, in recent years it has been a requirement from government at both the state and federal level in Australia to use evidence for new policy development (Building Commission, 2005b; DPI, 2011). Commonly, this evidence takes the form of a CBA, which can be used to compare the micro-economic aspects of various policy solutions, to their expected economic benefits. CBA is a specific method of calculating advantages and disadvantages of a particular course of action in monetary terms. It has its origins in micro-economics, and in particular draws on neo-classical theories of market economics (Cato, 2011). The concept of micro-economics and the CBA concept will be explored in the following sections.
2.4 Micro-economics and market failures: a summary

Neo-classical economics is briefly introduced here as a preface for leading the discussion to the concept of market failures and the application of CBA. For a more detailed discussion of neo-classical economics refer to seminal works by Smith (1999) and Schumpeter (1942).

Neo-classical economics theory holds that competition, or the ‘invisible hand’ of markets, will ensure efficiencies between supply, demand, scarcity and costs, reducing the requirements for direct interventions by governments (Gowdy, 2009; Sloman, Norris, & Garratt, 2010). Within neo-classical economics theory however, there are debates as to how much of a role there is for governments in the marketplace, including how much and what type of regulation is required (Pearce, 1998; Schumpeter, 1942; Smith, 1999). For example, governments might not set specific regulations, but assist with reframing conditions conducive to market innovation, such as the provision of economic rebates for new technologies (Geels, 2012).

Neo-classical economics is specifically concerned with understanding consumer behaviours and choice and attempting to determine the characteristics of rational choice outcomes in the face of limited resources (Polkinghorn, 1979; Tisdell & Hartley, 2008). In essence, the marketplace sets and aims to achieve a certain price for goods or services, determining consumers’ maximum willingness to pay thresholds (Atkinson & Mourato, 2008).

This is based upon three key assumptions about consumers: that consumers use rationality in their decision development, that consumers make decisions which maximise the outcome for themselves and that consumers make these decisions independently, based upon complete information (den Butter & Hofkes, 2006; Weintraub, 2002). These assumptions are strongly contested within the environmental economics literature. Consumers have other motivations, distinct from self-interest and profit maximisation, which are part of the choice process yet are not captured in the above assumptions (Eyre et al, 2011; Hards, 2012; Pearce, 1998). In addition to this, the assumptions fail to address that human wellbeing is not just linked to materialism but to various other factors (Pearce & Barbier, 2000).

Rational choice is the process whereby consumers weigh up the costs and benefits of activities to maximise outcomes (Schwartz, Carew, & Maksimenko, 2010; Vatn, 2005). Generally, the outcome is to provide the best ‘value’ for money. However this notion of value is strongly contested within economics and, in particular, environmental economics literature (Graves, 2007; Pearce, et al, 1989).

The definition of ‘value’ is dependent on a range of factors such as cost, available information, quality, quantity, time, previous choices (Hards, 2012; Pearce & Barbier, 2000; Polkinghorn, 1979). The question of whose ‘value’ is also raised within the literature as intergenerational
considerations are taken (Barry, 1999; Pearce, 1993). Furthermore who does the ‘valuing’ and how this is undertaken is challenged in the literature (Pearce, 1998). A more detailed discussion on ‘values’, including how to determine economic values for non-market elements such as the environment, willingness to pay and environmental economics can be found in the literature of David Pearce (Pearce & Barbier, 2000; Pearce, et al, 1989) and others (Atkinson & Mourato, 2008).

In addition, 'value' might not reflect the true worth of the good or service (the total cost to develop or provide) and may be linked to consumer preferences instead (Pearce, 1998). This can result in undervaluing of things. The environment is often undervalued if ‘value’ is based upon consumers’ preferences to pay for environmental conservation (Guy & Shove, 2000; Pearce & Barbier, 2000). The monetisation of environmental elements to develop markets is heavily contested in the literature, with arguments stating that valuation of environmental elements does not work in practice (Atkinson & Mourato, 2008; Pearce, 1998). In particular critiques of the approach of monetisation of environmental elements claim that such an approach can place environmental conservation at risk if the economic benefits are shown to be too small (Pearce & Barbier, 2000).

Furthermore, the question over private economic preferences informing public policy is raised as an issue within the literature, especially with regards to environmental goods which are typically a public good (Atkinson & Mourato, 2008). Making ‘rational’ choices which include environmental considerations is a more complex process than if choices are solely for private goods or services (Graves, 2007; Pearce, 1993).

Ongoing research is attempting to understand how otherwise ‘rational’ consumers fail, or refuse to consider environmental elements in their decision making (Pearce & Barbier, 2000; Scorse, 2010). Market failures present one option. A market failure is defined as the state when ‘private means contradict the social ends of an efficient allocation of resources’ (Hanley, Shogren, & White, 2001, p. 16). These occur when consumer choice fails to be ‘rational’ within the structures set by the marketplace (Schwartz, et al, 2010). This failure to be ‘rational’ can stem from a number of factors, including that the consumer has incomplete information to make decisions, which can include the impact from externalities (Schwartz, et al, 2010).

Market failures have frequently occurred for environmentally related goods and services, typically due to the issue of externalities (Cato, 2011; den Butter & Hofkes, 2006; Geels, 2012; Graves, 2007; Hanley, et al, 2001; Scorse, 2010). Where the full costs of elements are not contained within the price of particular goods or services for individuals or producers but are borne by society, an externality occurs (Parag & Darby, 2009; Scorse, 2010). Many elements of the environment do not have a market price associated with them and therefore are not considered in or incorporated into current economic structures (Cato, 2011; Geels, 2010; Pearce & Barbier, 2000).
Chapter 2: Policy development and the role of evidence

The market responses to climate change have been described as the largest market failure in history by some commentators (Cato, 2011; Garnaut, 2008; Stern, 2007), resulting from the inability of consumers, including commercial, industrial and residential consumers, to place an adequate price on the environmental, social and inter-generational considerations of carbon emissions (Campbell & Brown, 2003; Hanley, et al, 2001). As Scorse (2010, p. 10) states:

‘If we lived in a world where prices fully captured environmental costs, our entire economies would look vastly different: we would have different modes of transportation, different layouts for our cities and towns, different dietary habits, and consumer goods would likely contain much less toxic material. Prices of environmentally harmful goods would rise and much more R&D would go into alternatives, thereby decreasing their price. In such a world society’s resources would be invested in those things which bring the greatest social value’.

Neo-classical economists believe that environmental market failures such as climate change are best dealt with by market responses (Cato, 2011; Kolk & Pinkse, 2004; Scorse, 2010). Environmentalists disagree saying that once a market has failed, government intervention is required (den Butter & Hofkes, 2006; Goodstein, 2008; Pearce, 1998). Government intervention can be in the form of regulations, rebates, taxation or controlling supply and demand as described earlier in the chapter (Berck & Helfand, 2011; Cato, 2011; Geels, 2010).

Over recent decades, environmentalists have attempted to move ‘sustainability’ debates away from traditional economic structures (Asafu-Adjaye, 2005; Scorse, 2010). For example, Cato (2011) argues that a shift away from the traditional economic practice of overlapping interactions between the economy, environment and society is required. An alternative approach such as that proposed by the theory of green economics (whereby the economy operates within limits of the environment and within society) is argued to represent a more comprehensive approach, which would see improved outcomes for society and the environment (Figure 4).
The application of CBA as a policy development aid across the past decade has been in part informed by the wider move away from using traditional economic structures to deal with environmental concerns (Asafu-Adjaye, 2005; Cato, 2011; Hanley, et al, 2001; Scorse, 2010). This is in part due to the ability of CBA to accommodate perspectives of traditional neo-classical economics whilst also including wider environmental and social elements. The concepts and use of CBA in policy development are discussed below.

2.5 Cost-benefit analysis

CBA is a process for evaluating and comparing impacts of policies, typically from the point of view of the society rather than that of the individual (Australian Government, 2007; De Rus, 2010; Goodstein, 2008). It is undertaken by systematically analysing total cost inputs against total expected outcomes (benefits) of various policy options compared to a BAU approach (Boardman et al, 2011; Campbell & Brown, 2003; Mishan & Quah, 2007). The analysis turns inputs and outputs into a common metric to allow comparison. Typically, this metric is expressed as value in present day dollar amounts (Commonwealth of Australia, 2006).

The use of CBA to inform policy development is not a new approach; it was first applied for this purpose in the mid-1800s (Pearce, Atkinson, & Mourato, 2006). Governments have had a long history of using CBA to inform policy development. The US Government has required the use of CBA in certain policy developments since the 1930s and it has been a requirement since 1981 to use CBA to inform all new major regulations (Mishan & Quah, 2007; Pearce, et al, 2006; Pearce & Barbier, 2000). In the UK, a change in government in 1997 led to a requirement that the policy...
development process be informed by CBA (Pearce & Barbier, 2000). Similarly, the Australian Government has committed to the use of CBA in current policy development to ‘encourage better decision making’ (Australian Government, 2007, p. 115).

Initially, CBA was more widely used for projects, however in recent decades CBA has been applied increasingly to the policy development process (Pearce, et al, 2006). In both the USA and UK contexts, the application of CBA in the policy development process has arisen from a need for economic efficiencies and to prevent over-regulation (Pearce & Barbier, 2000). However, the use of CBA in the policy development process has not been without issues (Atkinson & Mourato, 2008).

Earlier CBA failed to include wider social and environmental costs and benefits, and the methods of CBA have evolved in response to criticisms (Atkinson & Mourato, 2008). In particular the work by Pearce (Pearce, 1993; Pearce & Barbier, 2000; Pearce, et al, 1989) since the late 1980s, in addition to the Our Common Future report (Brundtland, 1987), has been critical in the development and evolution of environmental CBA. The ability to place a ‘value’ on non-market goods and services, such as the environment, was briefly critiqued in section 2.4, and represents an ongoing criticism of the CBA approach.

The inclusion of values for certain intangible elements has arguably allowed analysis to target wider social and environmental issues with greater accuracy (Pearce, et al, 2006; Scorse, 2010; Stern, 2007). The most significant examples of this wider, more inclusive, type of CBA are the climate change reviews completed by Stern (2007) and Garnaut (2008).

Despite methodological advances, the use of CBA remains contested (Gezelius & Refsgaard, 2007). Ackerman and Heinzerling (2001, p. 1) state that:

‘cost-benefit analysis is a deeply flawed method that repeatedly leads to biased and misleading results…cost-benefit analysis cannot produce more efficient decisions because the process of reducing life, health, and the natural world to monetary values is inherently flawed’.

The undervaluing of environmental elements, which are often critical for the survival of the human race (clean air, water, etc.), is known as the paradox of value (Maurice, Phillips, & Ferguson, 1986).

A review of the literature has identified a number of benefits and critiques of using CBA. These have been summarised and are presented in Table 2.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Critiques</th>
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<tbody>
<tr>
<td>It presents policy makers with quantitative data about potential impacts from regulatory proposal across time.</td>
<td>It assumes it is possible to place a value on things. Where a market does not exist, as is the case for many environmental elements, the process of assigning values can be problematic and contentious.</td>
</tr>
<tr>
<td>It presents data in a common metric, which allows comparison between various policy approaches in order to find the most cost-effective approaches. It sets a level of consistency.</td>
<td>Not every element is able to be defined in terms of a cost or benefit, which can mean important elements are left out of the analysis, resulting in outcomes that are incomplete.</td>
</tr>
<tr>
<td>It requires policy makers to consider positive and negative impacts for wider elements, communities and approaches traditionally not considered in policy development.</td>
<td>Design weakness creates a margin of error - whereby any errors in selected alternative scenarios can impact on the output of the analysis.</td>
</tr>
<tr>
<td>Thinking outside the box can lead policy makers to explore linkages and benefits of other sectors of the economy and government departments allowing for even greater net benefits for society.</td>
<td>Assumptions about costs and benefits are not always made clear and transparent, for what is included as well as what is not included in the analysis.</td>
</tr>
<tr>
<td>It captures costs and benefits of tangible and intangible elements.</td>
<td>Future uncertainty for costs and benefits including what discounting rates to use can lead to inaccurate projections.</td>
</tr>
<tr>
<td>It aids with resource allocation.</td>
<td>It ignores the issue of who suffers as a result of the environmental problems.</td>
</tr>
</tbody>
</table>

While the literature raises a number of concerns about the use of CBA, there are steps which can be taken to minimise the limitations highlighted by CBA critics (Hanley & Shogren, 2005). Figure 5 presents the process chart which is followed by the Australian Government when conducting CBA. This process is similar to those discussed in the wider CBA process literature (Asafu-Adjaye, 2005; Boardman, et al, 2011; Campbell & Brown, 2003; De Rus, 2010; Diakoulaki et al, 2001). Steps such as undertaking sensitivity analysis on results can help to reduce critiques of CBA by testing what impacts differences in key assumptions can have on outcomes (Boardman, et al, 2011).
Figure 5: Process chart for undertaking a CBA (Commonwealth of Australia, 2006, p. 9).

CBA outcomes lead to a determination of the ‘feasibility’ of the analysis options. The concept of feasibility is one that is linked to the broader idea of possibility (Moran, et al., 2008). In other words, is it possible for the proposed policy or scenario to be undertaken? In terms of a CBA it is possible, therefore feasible, when the benefits outweigh the costs of a scenario compared to a BAU approach (De Rus, 2010).

Three broad outcomes are possible for each analysed option: negative, neutral or positive (Mishan & Quah, 2007). For an option to be deemed feasible, the outcome must be positive or, at worse, neutral (Boardman, et al., 2011). Where more than one option is determined to be positive, the analysis can be used to determine which option has the greatest positive benefit for individuals and society. The aim for policy development is to achieve Pareto improvement: where at least some people are better off and no one is worse off (Campbell & Brown, 2003).

Outcomes of CBA, while highlighting the most feasible option, do not determine if this option is the ‘right’ or most appropriate policy approach (Gezelius & Refsgaard, 2007; Peterson, 2009). Wider considerations, as discussed earlier, must be factored in to any policy development process. For example, a CBA found that it would be beneficial for the Czech Republic Government to encourage citizens to smoke. The reasoning being that smokers would die earlier and therefore
reduce health care requirements, pensions and housing requirements for the elderly, saving the government significant money (Ackerman & Heinzerling, 2001; ADLI, 2000). In addition, as stated earlier in this chapter, the monetisation of the environment can lead to outcomes where environmental conservation is not recommended due to benefits being low or ‘negative’. Clearly CBA must be used amongst a range of wider policy development approaches, and with reference to critiques, community values and sensitivities.

2.6 Chapter summary

An understanding of policy and the process through which it is developed is critical to discussions of governance, innovation and purposive change in the context of a low carbon transition. This chapter therefore underpins the review, analysis and discussion in subsequent chapters. The policy development process is complex and there are critical elements to be addressed when developing and implementing a successful policy. This chapter has discussed the importance of evidence to inform the policy development process. Within this context, the increased use of evidence in the policy development process has developed ostensibly to underpin more robust and substantiated policy development.

In order to address wider elements, including the environmental and societal concerns of policy implementation, a broader approach to the use of traditional neo-classical economics has been evolving. In part, this has happened because of market failures, which have arisen when dealing with monetisation of the environment. In order to address these market failures, methods such as CBA have evolved to allow for the inclusion of environmental and social considerations and to inform policy development. Despite this evolution, CBA and its variants continue to be criticised for their narrow framing of utility and values, and for the way in which these are represented through ‘evidence’ in CBA process and results. Despite this, CBA provides a practical tool for informing policy development when applied with considerations of limitations.
Chapter 3: The development of housing energy performance policy

Building upon chapter 2, this chapter explores housing energy performance policy development from Australia and a number of selected international case studies. The chapter begins by presenting an overview of key environmental issues and policy responses since the early 1970s, when energy consumption and efficiency gained prominence on policy agendas globally (Saidel & Alves, 2003; Venn, 2002). Following this, policy approaches for improving and controlling energy utilisation in housing are presented.

Selected international case studies are discussed to develop an understanding of housing energy policy development in advanced economies, including future policy directions. As will become clear throughout the chapter, the focus is on regulatory approaches to addressing housing energy performance, however alternative government approaches such as market mechanisms and social-based programs are also discussed. In clarifying these terms, the Australian Government defines regulation as ‘any ‘rule’ endorsed by government where there is an expectation of compliance, for example, primary legislation (Acts), subordinate legislation (legislative or non-legislative instruments), treaties and quasi-regulation.’ (Australian Government, 2007, p. XIII). The alternative market and social-based approaches discussed in this research, while potentially endorsed by government, do not contain a requirement for compliance and are therefore discussed as separate approaches.

Following the discussion on the international context, housing energy performance policy in the Australian context will be detailed including both regulatory and alternative approaches. Critiques of current regulatory approaches are also reviewed in advance of detailed analysis of policy content in chapter 7.

The role that evidence, and particularly CBA, has played in informing current housing energy policy development internationally and in Australia is reviewed. In particular, the ‘affordability’ debate will be examined. The chapter concludes by discussing a number of issues in the Australian context of housing energy performance policy innovation.

3.1 Policy responses to environmental issues

The push for greater energy efficiency through regulatory, market mechanism and social-based approaches began in earnest in the early 1970s after the 1973/1974 oil shock crisis (Páez, 2010; Venn, 2002). The initial oil shock crisis in 1973/1974 was a result of Arab oil producers implementing an oil embargo for countries which were friendly to Israel during a military conflict.
Chapter 3: The development of housing energy performance policy

occurring in the region. As a result, oil supplies were cut to many countries, including the USA and UK, which led to limited oil supplies, rapid increases to the costs of remaining oil and, eventually, an economic recession around the world (Venn, 2002).

The way in which energy consumption in housing is addressed, and wider environmental policies in general, have also been shaped by a number of key events, programs and policy developments in the decades that followed the 1970s oil crisis. As stated in chapter 2, it is important to understand this past policy development in order to clearly understand the current and possible future policy context. While this thesis cannot address these past developments in detail, a brief overview of selected key developments is presented chronologically, to illustrate the change in energy policy debate from the 1970s:

- Seminal research published by the Club of Rome, titled *Limits to Growth* highlighted resource limitations, with particular reference to issues associated with an expanding population (Meadows et al., 1972).
- The foundation of key international agencies such as the International Energy Agency reflect growing international consensus of the need to address sustainability concerns (Wallace, Pollack, & Young, 2010).
- Introduction of cost abatement curves showed energy efficiency improvements as some of the least cost options to address greenhouse gas emissions (Ekins & Kesicki, 2011; Meier & Rosenfeld, 1982).
- From the 1990s, climate change and other environmental issues such as acid rain began to emerge as concerns in mainstream policy debate (IPCC, 1990).
- The Kyoto Protocol was developed to address greenhouse gas emissions reduction through an internationally coordinated response (United Nations, 2009).
- Cost reduction and technical development of sustainability products lead to products such as renewable energy technologies becoming more mainstream (Hearps & McConnell, 2011).
- The development and application of energy efficiency ratings and standards for appliances and minimum heating and cooling standards for new housing improves levels of energy efficiency (Greene & Pears, 2003).
- Implementation of non-regulatory approaches such as education and rebates for sustainability technologies begins to address consumer behaviours (Greene & Pears, 2003).
- Continuing energy security and supply issues such as the Russian-Ukraine gas dispute highlights the vulnerability of existing energy approaches (Stern, 2006); and
- Development of carbon trading/tax schemes aiming to drive market-based solutions to reducing greenhouse gas emissions (European Commission, 2011a).
The process of policy development and consensus building, which these listed developments point to did not occur without significant challenges. Perhaps the best case in point is the response to climate change through the Kyoto Protocol. The Protocol was developed to ensure that a consistent and global approach to reducing greenhouse gas emissions was taken by every country (United Nations, 2009).

On the one hand, the Protocol has generated significant international and scientific discussion and has proposed a calculated response pathway to reducing greenhouse gas emissions, which includes a significant focus on a transition to a low carbon energy future (United Nations, 2009). However, policy makers are still facing significant challenges in developing and implementing climate change policies due to ongoing debate from the general public regarding the legitimacy of climate change and if it does exist, if the cause is anthropogenic (Lomborg, 2007; Paltridge, 2009).

Slow and fragmented participation has proven to be a significant challenge to the effectiveness of the Protocol (Garnaut, 2008; IPCC, 2007a; Stern, 2007). However, a number of countries are now taking significant steps to reduce their greenhouse gas emissions, including members of the EU who have committed to an overall 8% reduction of 1990 levels by 2012 and reductions of 20-30% by 2020 (Tolón-Becerra, Lastra-Bravo, & Bienvenido-Bárccena, 2010; United Nations, 2009). The current Australian Government has committed to reducing greenhouse gas emissions by between 5 and 15% of 2000 levels by 2020 depending on whether an international agreement is reached (DCCEE, 2011). For the first reporting phase of the Protocol, Australia was allowed to increase greenhouse gas emissions by 8% on 1990 levels by 2012 (United Nations, 2009), highlighting the challenge which Australia will face in achieving significant emissions cuts in the future.

Despite facing significant challenges, progress has been made towards the development of environmentally progressive policies over the past two decades (Geller et al., 2006). The above events and developments have helped to develop the sustainability of the housing sector which has seen significant growth since the early 1990s (Lovell, 2004). The next sections of this chapter will explore the development of housing energy performance policies internationally and in Australia. Current and future policies will be outlined with regards to ZEH where feasible.

### 3.2 Response to housing energy performance

The period after the oil shocks of the 1970s saw an increased focus on the development of energy efficiency as a policy strategy, firstly to protect against energy shortages and increased prices and, post-Kyoto Protocol, as a response to climate change concerns (Table 3) (IEA, 2010a).
Table 3: Drivers of government energy policy (IEA, 2010a, p. 10).

<table>
<thead>
<tr>
<th>Driver</th>
<th>Typical objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy security</td>
<td>• Reduce imported energy</td>
</tr>
<tr>
<td></td>
<td>• Reduce domestic demand to maximise exports</td>
</tr>
<tr>
<td></td>
<td>• Increase reliability</td>
</tr>
<tr>
<td></td>
<td>• Control energy demand growth</td>
</tr>
<tr>
<td>Economic development and</td>
<td>• Reduce energy intensity</td>
</tr>
<tr>
<td>competitiveness</td>
<td>• Improve industrial competitiveness</td>
</tr>
<tr>
<td></td>
<td>• Reduce production costs</td>
</tr>
<tr>
<td></td>
<td>• More affordable energy customer costs</td>
</tr>
<tr>
<td>Climate change</td>
<td>• Contribute to global mitigation and adaption efforts</td>
</tr>
<tr>
<td></td>
<td>• Meet international obligations under the United Nations Framework Convention on Climate Change</td>
</tr>
<tr>
<td></td>
<td>• Meet supra-national (e.g. EU) accession requirements or directives</td>
</tr>
<tr>
<td>Public health</td>
<td>• Reduce indoor and local pollution</td>
</tr>
</tbody>
</table>

Energy efficiency has been recognised as one of the least costly abatement options available for addressing greenhouse gas emissions both in Australia and internationally (Harvey, 2010; Higgins, et al, 2011; Páez, 2010). Further, housing energy performance has been identified as a ‘low-hanging fruit’ to achieve lower per capita energy consumption targets (Hoppe, Bressers, & Lulofs, 2011; Lovell, 2004; Parag & Darby, 2009; UNEP, 2007).

To date, policy responses to reducing environmental impacts from housing have focused on reducing the operational energy of dwellings (Míguez, et al, 2006). Policy responses to reduce the operational energy of dwellings have typically focused on targeting heating and cooling energy requirements through setting minimum energy performance regulations (Greene & Pears, 2003; Míguez, et al, 2006). These minimum energy performance regulations have been the primary driver of improved energy efficiency in dwellings in Australia and other advanced economies internationally, although there have been a variety of approaches applied which have achieved a range of success (Table 4) (ABCB, 2011a; Geels, 2012; Greene & Pears, 2003; Hamza & Greenwood, 2009; Horne & Hayles, 2008; IEA, 2010a; Lee & Yik, 2004; Míguez, et al, 2006; Pérez-Lombard et al, 2009).
Table 4: Types of energy efficiency policy approaches (IEA, 2010a, p. 11).

<table>
<thead>
<tr>
<th>Policy</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pricing mechanisms</td>
<td>• Variable tariffs where higher consumption levels invoke higher unit prices</td>
</tr>
<tr>
<td>Regulatory and control mechanisms</td>
<td>• Compulsory activities, such as energy audits and energy management</td>
</tr>
<tr>
<td></td>
<td>• Minimum energy performance standards</td>
</tr>
<tr>
<td></td>
<td>• Energy consumption reduction targets</td>
</tr>
<tr>
<td></td>
<td>• Energy efficiency investment obligations on private companies</td>
</tr>
<tr>
<td>Fiscal measures and tax incentives</td>
<td>• Grants, subsidies and tax incentives for energy efficiency investments</td>
</tr>
<tr>
<td></td>
<td>• Direction procurement of energy efficiency goods and services</td>
</tr>
<tr>
<td>Promotional and market transformation mechanisms</td>
<td>• Public information campaigns and promotions</td>
</tr>
<tr>
<td></td>
<td>• Inclusion of energy efficiency in school curricula</td>
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<tr>
<td></td>
<td>• Appliance labelling and building certification</td>
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<tr>
<td>Technology development</td>
<td>• Development and demonstration of energy efficiency technologies</td>
</tr>
<tr>
<td>Commercial development and capacity building</td>
<td>• Creation of energy service companies</td>
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<td>• Training programmes</td>
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<td></td>
<td>• Development of energy efficiency industry</td>
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<tr>
<td>Financial remediation</td>
<td>• Revolving funds for energy efficiency investments</td>
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<td>• Project preparation facilities</td>
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<td>• Contingent financing facilities</td>
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The first housing regulations were developed to address public safety, health and amenity in buildings both for the construction and occupancy phases of the dwelling (Beerepoot & Beerepoot, 2007; Imrie, 2004; Lee & Yik, 2004; May, 2003). In Australia, housing regulations not only deal with safety but also set elements for wider societal benefit through the regulation of building heights, setbacks, size, etc. (ABCB, 2012). As will be explored in the following sections, regulations have evolved over the past two decades to include the setting of minimum energy performance requirements.

3.3 International responses to housing energy performance

A review of international housing energy performance literature from advanced economies shows that there are an increasing number of countries embracing more stringent energy performance standards for new housing, particularly ZEH standards (DCLG, 2006a; Horne & Hayles, 2008; Miguez, et al, 2006; Osmani & O'Reilly, 2009; Zhu, et al, 2009). Typically, these standards are either prescriptive or performance-based. Prescriptive regulations involve a detailed requirement for each element (e.g. staples shall be not less than 1.98mm in diameter), whereas performance-based regulations provide more of an overall requirement (e.g. residential buildings shall be
equipped with heating facilities capable of maintaining an indoor air temperature of 22°C) (Kordjamshidi, 2011; May, 2003; Oleszkiewicz, 1994).

This section will briefly explore some of the policy approaches for a number of selected international jurisdictions.

### 3.3.1 New Zealand

Australia’s closest developed neighbour, New Zealand, has a national building code. This code was first developed in 1992 (Duncan, 2005) and has recently been revised based upon the Building Act 2004 (NZ Government, 2011a). It is a prescriptive code and sets mandatory minimum requirements similar to the Australian Building Code (explored in section 3.4). The NZ Building Code contains 32 subsections, of which energy efficiency is one. Minimum energy performance requirements for new housing are mandated in this energy efficiency section of the code (NZ Government, 2011b). A voluntary rating tool ‘Homestar’ was recently released to encourage housing energy performance which goes beyond minimum standards, similar to Australia’s star rating scheme (discussed in section 3.4) (Homestar, 2012). In this way, a market for ‘premium’ environmental housing will be developed. There is no articulation of ZEH policy in NZ as of January 2012.

### 3.3.2 North America

In North America, Canada and the USA have taken similar approaches to address energy performance in housing to date. In Canada, housing minimum performance standards are set under the Model Construction Codes. These codes, first developed in 1941, contain a number of codes including the 2010 National Building Code and the 1997 National Energy Code for Houses (NRCC, 2010). However these codes are not legal requirements until the various local jurisdictions adopt them. The code can be adjusted to suit local jurisdictions if required. Similar to NZ and Australia, the codes are prescriptive.

In Canada, there is no performance rating equivalent to the star ratings scheme in Australia. However, there is an alternative code which can be followed known as the R-2000 program (Natural Resources Canada, 2005). This program was developed in 1981 with the aim to improve energy efficiency of housing by providing a certification for energy performance greater than that prescribed by the minimum building code. The Canadian Government is supporting practical ZEH research such as the EQuilibrium Project although as of January 2012, it was unclear if or when a ZEH standard will be formalised through minimum building regulations (Natural Resources Canada, 2011).

The first energy efficiency and housing policy in the USA was implemented in 1975 with the Energy Policy and Conservation Act (Lee & Yik, 2004). This led to the development of housing energy performance policy over the following decades, which cumulated with the current national
building code known as the *International Residential Code* (ICC, 2012c). Similar to Canada, the International Residential Code is not a legal requirement until states or local governments chose to adopt it. The International Residential Code can be adjusted to suit local areas and many of the states are using old versions of the International Residential Code (2006 or 2009 version), rather than the latest version, 2012 (ICC, 2012a). The International Residential Code sets minimum standards, including for energy efficiency. There is no performance rating in the International Residential Code as there is with the star rating scheme in Australia.

Within the USA there is an alternative standard which targets improved sustainability (including energy efficiency) from housing: the *National Green Building Standard* (NAHB, 2008). As of late-2011, California was the only state in the USA to have set the National Green Building Standard as the minimum housing requirements (CBSC, 2010). The US Government has set a policy goal of building affordable new ZEH standard houses by 2020 (Halverson, Shui, & Evans, 2009). A pathway to achieve this is being developed through the Building America program (DOE, 2010).

### 3.3.3 Europe

Housing energy regulations were first developed in EU Member States as far back at 1965 (Gann, Wang, & Hawkins, 1998; Hamza & Greenwood, 2009; McManus, Gaterell, & Coates, 2010). Throughout the 1970s housing energy regulations became more prevalent across jurisdictions of present-day EU Member States (Pérez-Lombard, *et al*., 2009). Collectively, the EU has developed a number of policies which are related to housing and energy efficiency to guide Member States, including *Directive 2002/91/EC on the energy performance of buildings* (European Commission, 2002). The latest version of these policies sets out regulatory requirements for Member States to build ZEH by no later than 2020 (European Commission, 2010). This approach has originated primarily as a response to requirements for meeting greenhouse gas emission targets and energy security concerns (Hamza & Greenwood, 2009).

A number of Member States have already made significant progress towards improving the energy performance of new housing, including Ireland, Germany, the Netherlands and the UK (Banfill & Peacock, 2007; DCLG, 2006a; McManus, *et al*., 2010; Míguez, *et al*., 2006; Smith & Kern, 2007). The primary driver of improving energy efficiency performance of housing across Europe has been minimum performance regulations (Pérez-Lombard, *et al*., 2009).

A summary of past, current and future energy performance targets for selected EU Member States is presented in Table 5. The goals for 2015 and 2020 are those developed before the announcement in 2010 from the EU requiring ZEH by 2020. These future goals will be adjusted to meet the new targets, however the table shows that a number of EU countries had already set goals of ZEH or similar by 2020.

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<tr>
<td>Denmark</td>
<td>Developed in 1997, a rating system which targeted energy and water conservation in buildings. This achieved a 20% energy reduction in new housing.</td>
<td>A revision of energy performance has meant that since 2010 all new buildings consume 25% less energy compared to the 2006 base year.</td>
<td>By 2015, all new buildings will consume 50% less energy compared to the 2006 base year.</td>
<td>By 2020, all new buildings will consume 75% less energy compared to the 2006 base year.</td>
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<td>UK</td>
<td>Since 1995, new housing had to undertake a Standard Assessment Procedure. This assessment was based on the building code at the time and primarily focused on heating and cooling. The 2001 revision was the first to include a carbon index.</td>
<td>The Code for Sustainable Homes was developed in 2006 setting out a 6 level, 10 year pathway to move building standards to ZEH. From 2010, level 3 of the Code was mandated, equivalent to a 25% improvement on emissions compared to 2006 requirements. Level 4, or 44% improvement, was required for public funds/land.</td>
<td>From 2013, level 4 of the Code will be mandated, equivalent to a 44% improvement on emissions compared to 2006 requirements. Level 6 or a zero emission house (100% improvement) will be required for public funds/land.</td>
<td>From 2016, all new dwellings are required to be zero net emissions and by 2019 all buildings are required to be zero net emissions.</td>
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<td>France</td>
<td>Introduced in 2001, Decree 2000-1153 set minimum performance levels for all new dwellings.</td>
<td>The building standard RT2005 set a maximum level of energy consumption of 150 kWh/m².</td>
<td>From 2012, all new buildings are low energy buildings under the Effinergie standard achieving a 66% reduction in energy consumption over the previous standard.</td>
<td>By 2020, all new buildings are to be energy positive.</td>
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<td>The Netherlands</td>
<td>Had a voluntary energy performance standard for all new dwellings.</td>
<td>From 2010, new housing was to be 25% more energy efficient compared to previous code.</td>
<td>By 2015, new housing is to be 50% more energy efficient compared to previous code.</td>
<td>By 2020, all new buildings to be energy neutral.</td>
</tr>
<tr>
<td>Ireland</td>
<td>Had a voluntary Heat Energy Rating regulation based upon their 1992 building regulations.</td>
<td>By 2010, new buildings to be 60% more energy efficient than previous code.</td>
<td>By 2013, all new buildings to be net zero energy.</td>
<td>All new buildings to be net zero energy.</td>
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<tr>
<td>Germany</td>
<td>2001 new building standard (Energy Saving Decree) states that new buildings are to use 30% less energy than under previous Heat Conditioning Decree 1982.</td>
<td>A new code EnEV 2009 improved housing energy efficiency by approximately 30%.</td>
<td>A revision to the code to be developed: EnEV 2015. This performance will be equivalent to the Passivhaus standard.</td>
<td>By 2020, buildings to be operating without fossil fuel.</td>
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3.3.4 Alternative approaches

Further to the regulatory approaches predominantly explored above, examples of alternative approaches to address housing energy performance can be found in the international literature. For example, continuing consumer education regarding reducing energy consumption and improving energy efficiency remains a strong approach to address housing energy performance (Boardman, et al, 2005). Education campaigns have been conducted throughout the development of housing energy performance regulations to address consumer energy behaviour with some success (Henryson, Håkansson, & Pyrko, 2000; Pyrko & Darby, 2011; Saidel & Alves, 2003).

A review of information campaigns in Sweden by Henryson et al. (2000) found that information campaigns improved the impact of energy efficiency measures by up to 10%, although a number of energy efficiency information campaigns had no significant impact on final energy consumption. Furthermore Eyre, et al (2011) explore how addressing human behaviours (or lifestyle) could reduce final energy demand across all sectors in the UK by 30% by 2050, highlighting the importance of approaches such as education and targeting changes in behaviours.

In conjunction with the provision of more information through awareness raising campaigns, product labelling programs, such as Energy Star, have provided consumers with improved information to aid purchasing decisions (Lee & Yik, 2004). The Energy Star program was developed in the USA in 1992 to address the increased energy from appliances, particularly in dwellings, and it is widely regarded as one of the more successful government energy efficiency programs (DEWHA, 2011; Geller, et al, 2006). Systematic improvements to the program have seen minimum energy efficiency standards of appliances increase over recent years. In the USA the Energy Star program was reported to have saved 4.8 exajoules of primary energy and generated $47 billion in savings in 2006 (Sanchez et al, 2008). Further, from 2007–2015, improvements to appliance energy efficiency was projected to reduce carbon emissions by 3.3% in the USA due to the Energy Star program (Sanchez, et al, 2008).

A further approach that has been used with varying success has been the use of rebates for energy efficient technologies or building practices (Lee & Yik, 2004). For example the UK offered significant stamp duty reductions to encourage consumers to purchase new housing which exceeded minimum performance regulations from 2007–2012 in a bid to reward early adopters of the higher energy performance standards (Healey, 2007; Williams, 2008). The use of rebates for renewable energy technologies and other market and social based approaches will be discussed in more detail in the Australian context in section 3.4.1.

In addition, the development of voluntary energy rating tools, such as the Passivhaus standard which originated in Germany but is now spreading internationally, also provides an opportunity to improve the energy performance of housing (Jakob, 2006; Kern, 2012). Again, these voluntary
tools have had varying success. Despite the stated success of voluntary standards such as the Passivhaus Standard, there is still low uptake of these standards when compared to the volume of new buildings (Kern & Howlett, 2009).

While these non-regulatory approaches have had some documented success, the consensus from the literature is that these options work well in conjunction with minimum housing energy performance regulations (Binder, 2008; Gann, *et al.*, 1998; Lee & Yik, 2004). As minimum performance standards continue to increase in stringency, incentives are provided for developing innovation which exceeds minimum requirements.

### 3.4 Housing energy performance regulations in Australia

Housing performance and building standards are not addressed in the Australian constitution. This has meant that prior to the 1970s, individual states and territories dealt with housing regulations (ABCB, 2011b). Throughout the early part of the 20\textsuperscript{th} century, housing performance and standards were often left to local councils to address (ABCB, 2011b). It was not until after World War II that a number of states recognised the potential benefit in working with other states to establish more uniform technical building requirements.

It took until the 1960s for the states and territories to came together to establish the first attempt at a uniform approach to housing standards. The Interstate Standing Committee on Uniform Building Regulations was established to pool resources and to work towards a national building regulation code (ABCB, 2011b). The first version of the current Building Code of Australia, the Australian Model Uniform Building Code, was released in 1971 (Oleszkiewicz, 1994). However the Australian Model Uniform Building Code was based upon the Local Government Act of NSW and many states found that they were required to alter the code to fit the particular requirements of their own state, or had difficulty with the usability of the format (ABCB, 2011b).

Concerns with the Australian Model Uniform Building Code led to the establishment of a new body known as the Australian Uniform Building Regulations Co-ordinating Council in 1980 (ABCB, 2011a, 2011b). This council was given the task of developing a representative and usable national building code. By 1990 they had developed the first ‘usable’ national building code: Building Code of Australia 90 (ABCB, 2011b). This contained state-based variations where required. While not taken up immediately, all states and territories signed up to the building code by 1998 (ABCB, 2011b).

Prior to the release of Building Code of Australia 90, the Council of Australian Governments undertook a review into building regulations in Australia. The review found that there were significant cost issues associated with the current regulatory processes (ABCB, 2011a). Based on recommendations from the review, the Australian Uniform Building Regulations Co-ordinating
Council was expanded to become the Australian Building Codes Board in 1994. This change led to an overhaul of the Building Code of Australia 90 and resulting in a performance-based regulation: Building Code of Australia 96 (ABCB, 2011b). A performance-based approach was taken with this regulation, to allow for cost savings and provided scope for flexibility within the building industry. Prior to this, performance regulations were prescriptive, a method which was heavily criticised by some academics and, more widely, by the building industry (May, 2003).


Until 1991, housing regulations in Australia were concentrated on providing safety, health and amenity outcomes. The increasing pressure to address energy efficiency across all sectors lead to the 1991 inclusion of minimum insulation regulations in Victoria (Greene & Pears, 2003; Sustainability Victoria, 2002). The setting of minimum insulation requirements was a clear attempt to include improved energy efficiency and improved thermal comfort through housing regulations, particularly for a state with a high consumption of energy for heating and cooling such as Victoria. The inclusion of the insulation requirement was further enhanced in Victoria with the development of the Building Act 1993, which remains the basis for building regulations in Victoria (Building Commission, 2011).

Further to this, in 1993 a number of house energy rating tools, notably the Nationwide House Energy Rating Scheme and First Rate (initially called VicHERS), were released (ABCB, 2011b; Kordjamshidi, 2011). Commonwealth Scientific and Industrial Research Organisation (CSIRO), backed by the Glass, Mass and Insulation Council of Australia, had been developing an energy rating tool for housing as far back as the mid-1980s (Ballinger, 1988). The initial energy rating tools were developed as a way to encourage improved thermal performance and differentiate between standard and energy efficient houses. These energy rating tools use computer models to predict the energy performance of housing, looking primarily at heating and cooling energy requirements. Results are presented across a ‘star’ rating band. The current star band ranges from 1 star (least natural thermal performance) to 10 star (best natural thermal performance, requires virtually no mechanical heating and cooling) (Hearne Scientific, 2011).

Application of these rating tools began as a voluntary measure. Pre-1990, when developments for minimum housing insulation were first made, existing housing had an average performance standard of 1 star. This rose to an average of 2.2 stars after the introduction of minimum insulation standards (NatHERS, 2011). A minimum star rating requirement was not set until 1997, when the Australian Capital Territory introduced a requirement that all new housing be built to a 4 star
minimum energy performance standard (DEWHA, 2008a). Victoria was the next state to introduce mandatory minimum star rating performance (Dalton, Horne, & Wakefield, 2007). From 2004, Victoria set 5 star as the minimum performance standard for new housing (Building Commission, 2009). The 2004 standard included an extra requirement for either onsite solar hot water or a rainwater tank to be incorporated on all new residential buildings. Other states and territories followed over the next few years, although not all implemented a 5 star standard. Requirements between states and territories continued to differ, particularly over which rating tools were allowed to provide ratings assessment.

In 2006, a second generation of rating tools was released, which addressed a number of criticisms of first generation rating tools (Delsante, 2005). These criticisms included a questioning of rationale underlying assumptions of calculations such as occupancy times and the amounts of energy required for thermal conditioning in specific climate zones (Delsante, 2005; Kordjamshidi, 2011; Saman et al, 2008). While some of these issues have been addressed in the second generation rating tools, criticisms still surround the use of rating tools (Kordjamshidi, 2011). Currently, the AccuRate modelling software is the most commonly used (AGO, 2008).

In 2008, the Council of Australian Governments, by now a critical driver of housing energy performance standards, announced that the Building Code of Australia would introduce a nationwide 6 star standard (ABCB, 2012). By May 2011 all states and territories adhered to the 6 star minimum standards. This improvement to minimum housing energy performance occurred after the Council of Australian Governments signed a memorandum of understanding to develop a National Strategy for Energy Efficiency in 2009 (ABCB, 2009b; COAG, 2009a). This was informed in part by research and developments in housing energy performance internationally as well as a requirement to undertake a regulatory impact statement, which involved a CBA of policy development options (ABCB, 2009b; COAG, 2009b).

The regulatory impact statement was open to public responses and 43 submissions were registered (ABCB, 2009b, p. 283). While some of the policy elements were adjusted based upon the feedback received, the initial goal of implementing a national 6 star standard for residential new housing remained after the consultation. As discussed earlier, the main concerns from key actors resistant to the proposal was the cost of change and what this would mean to housing affordability (MBAV, 2008). These are the same concerns stated with the proposed introduction of 5 star (see section 3.6).

The current 6 star regulations in Australia do not currently meet ZEH requirements. The Australian government has recognised in a recent report that international best practice will be ZEH by the end of the decade (Australian Government, 2010c). The same report suggests that it might be time for Australia to start thinking about this concept, but it does not say how this will happen or when.
While some research exploring improvements to housing energy performance in Australia currently exists, significant knowledge gaps remain in the debate, as will be explored further in section 3.6 (BZE, 2010; Morrissey & Horne, 2011; Morrissey, et al, 2011; Newton & Tucker, 2009; Pitt & Sherry, 2010).

The development of housing performance policy in Australia has followed the policy cycle as outlined in chapter 2 (Dalton, et al, 2007). While year to year revisions of the building code have followed the incremental policy making model, there have been occasions, such as the introduction of 5 star and later 6 star standards, where the approach adopted has been the middle approach between incremental and rational policy making. A number of non-regulatory approaches targeting energy improvements in dwellings have also been developed over the past decade.

3.4.1 Market-based approaches

While the focus of this thesis is on minimum energy performance regulations, one significant policy development in Australia over the past decade has been the 2001 introduction of a Mandatory Renewable Energy Target (MRET, later to become RET) which set a goal of 20% of total Australian energy generation from renewable energy sources by 2020 (Sivaraman & Horne, 2011). The RET advocated a two-pronged approach, which planned to use large scale as well as small scale domestic renewable energy installations to meet the renewable energy generation target in a transition towards a low carbon energy future. Similar programs and targets have been set internationally (European Commission, 2009).

In 2000, a market-based solar photovoltaic (PV) rebate scheme was developed to encourage the uptake of domestic PV systems, linking to the wider MRET policy (Sivaraman & Horne, 2011). A review of this scheme by Macintosh and Wilkinson (2010) found that it generated a steady but low demand for domestic solar photovoltaic installations. The scheme was revised a number of times over the decade, including at the change of federal government in 2007. The scheme saw a rapid take up of solar photovoltaic systems after 2007 (Figure 6) and consequently, quickly became oversubscribed and was terminated in 2009 (Macintosh & Wilkinson, 2011). The rebate scheme was relaunched again under different guidelines later in 2009 and has seen continued high uptake of photovoltaics (Clean Energy Council, 2010).
While the rebate scheme has helped to develop an increase in solar photovoltaic installations, the environmental outcomes were of particular importance for the Australian government. The review from Macintosh and Wilkinson (2010) found that the scheme will reduce emissions by 0.09 MtCO₂-e/yr over the life of the rebated PV systems, equivalent to 0.015% of Australia’s 2008 emissions. In total, the installations equalled around 0.2% of installed total energy capacity in Australia or around 1.8% for total household energy consumption (Macintosh & Wilkinson, 2010).

Based upon the economics to achieve these outcomes and other factors, including that the technology had to be imported rather than made in Australia, the report concluded that it was not the most cost effective way to have spent money to reduce greenhouse gas emissions. However, the report fails to take into account the fact that the PV industry in Australia prior to the rebate was limited (APVA, 2010; Zahedi, 2010). A decade later, the community-wide proliferation of PV installations means that a local industry can be viably developed. In addition, added PV installations have had the social benefit of enabling consumers to take more responsibility for their household energy consumption (Bergman & Eyre, 2011; Parker, 2008), a point which was overlooked in the report. The use of rebates to facilitate the uptake of renewable energy technologies has also been applied in other countries, for example in the UK (Bergman & Eyre, 2011).
Other government rebate programs in Australia have also been tried, including the home insulation program and the green loans scheme. Both programs experienced significant implementation issues and were forced to terminate early (Combet, 2010; Hawke, 2010). In the case of the home insulation program the vision was clear – provide rebates of up to $1,600 to homeowners who insulate their roof space. The aim was to install roof insulation in 2.2 million existing homes across three years, to reduce heating and cooling energy use in these homes by up to 40% (Hawke, 2010).

A review of the market-based program by Hawke (2010) found that the initiative was shut down within a year of its inception due to a number of implementation concerns, mainly safety issues to do with the insulation and the rise of insulation installers and retailers with limited training and experience. The deaths of several contractors, and over 100 house fires linked to the roof insulation program, led to the discontinuation of the program (Dollery & Hovey, 2010). In total, over 1 million houses had received the insulation rebate, at a total cost to the government of $1 billion dollars (Hawke, 2010). The government announced that it would assess at least 150,000 houses fitted under the scheme for insulation concerns, with implications that the total cost of the program would double (Hawke, 2010). While the program was widely viewed as a failure, it did manage to facilitate insulation fitting in 1 million homes, representing a saving of up to 20% of the total household energy consumption for occupants of these dwellings (Dollery & Hovey, 2010; Hawke, 2010). Wider benefits included the generation of more than 10,000 jobs and a higher profile and stimulus for the insulation industry in Australia (Hawke, 2010). This program in particular highlights the importance of developing a well-considered policy and allocating sufficient resources to ensure that it is undertaken as planned, as discussed in chapter 2.

In addition to these approaches, a number of educational and community social-based programs were undertaken across the past two decades. For example the ‘black balloons’ campaign was directed at households to educate them about energy conservation and greenhouse gas emissions. While specific energy saving outcomes from this program are ongoing, initial reviews stated that 61% of Victorians were aware of the program and that of these, 57% had made some energy efficiency/savings changes at home as a result of their experience with the program (DPI, 2011). The review was hesitant to suggest that it had been successful, saying that it worked well in conjunction with other approaches and that more work was still required to achieve energy saving targets (DPI, 2011).

Mandatory disclosure is another approach which aims to inform consumers. This approach provides energy performance information to consumers at the point of sale or rental for individual dwellings. Mandatory disclosure has been implemented in the UK and is a requirement in new EU legislation for all Member States as well as in the Australian Capital Territory in Australia (AGO, 2008; Boardman, et al, 2005; European Commission, 2010). Mandatory disclosure has been on the
government’s agenda in Australia for a nation-wide requirement for a number of years (COAG, 2009b), although it remains unclear as to if and when this will occur.

The construction of dwellings that go beyond minimum standard housing regulations is another approach which has helped to reduce cost and technical concerns and improve information for consumers. For example, CSIRO in conjunction with Henley Homes, have built an affordable ZEH on the urban fringe of Melbourne under the project title ‘AusZEH’ (CSIRO, 2010). While the AusZEH project achieves ZEH standards from a technical point of view, it can justifiably be criticised for not considering wider principles of sustainable housing (as presented in chapter 1) such as reducing house size, location close to accessible public transport and more extensive incorporation of energy reducing design principles.

Despite these shortcomings, the AusZEH project and other similar one-off housing projects have showcased the application of new technologies and building approaches and have provided critical, case-study evidence on the costs of ZEH, while also serving to change the market dynamics involved with such development (Natural Resources Canada, 2011; Peabody, 2009; Zhu, et al., 2009).

While non-regulatory approaches such as the AusZEH demonstration home have been important in the context of the overall policy debate, research has shown that typically, non-regulatory attempts to address housing energy efficiency on their own have limited impact (Binder, 2008). Regulatory and non-regulatory approaches do not have to be mutually exclusive and can work together for successful outcomes as stated already in this chapter (Meacham et al, 2005). In an international review of building energy codes and voluntary approaches, Lee and Yik (2004) found that there were strengths and weaknesses in the application of both approaches. However, the research found that, ultimately, jurisdictions were heading towards a middle road between these two approaches. While a number of benefits and critiques of non-regulatory approaches have been discussed in this section, the following section will discuss the regulatory approach in more detail, building upon the discussion from chapter 2 regarding the development of policy.

### 3.5 Critiques and benefits of mandatory standards of energy efficiency

A critical argument against the use of regulation to address housing energy performance is that it cannot guarantee a successful outcome (May, 2003). An example of this being the ‘leaky home syndrome’ in NZ, where up to 90,000 homes were built with inadequate weather sealing during the late 1990s and early 2000s, which resulted in houses which developed mould, leading to occupant health issues (Duncan, 2005; Hunn, Bond, & Kernohan, 2002; May, 2003; Shi, 2003). This was in part an outcome of a poorly constructed policy which failed to properly take into account the
practicalities and implementation resources required to achieve the desired outcomes, as discussed as part of the policy development cycle presented in chapter 2 (Meacham, et al, 2005).

Further to this, regulations typically add a requirement for additional resources within the building industry and from consumers. Regulations can add time, cost, paperwork, training and confusion to the building process (Droege, 2006; May, 2003; Oleszkiewicz, 1994). This was particularly evident in the earlier prescriptive building regulations applied in the Australian context, but has been partially addressed in new more flexible performance-based building regulations (ABCB, 2011a, 2011b; Oleszkiewicz, 1994).

Significantly, this chapter has presented housing energy performance as a market failure. It must be noted that there are those in the building industry who argue that the market will deal with the issue of housing energy performance, and that (further) regulations are not required, drawing upon the neo-classical economics debates presented in chapter 2 (Crabtree & Hes, 2009; Meacham, et al, 2005). They believe that consumers will demand improved housing performance if they are given the opportunity to consider the costs and benefits, or that industry innovation will create consumer demand.

This has not been found to occur in reality (Williams, 2008). The lack of energy efficiency and renewable energy uptake to date would indicate that the free market approach has failed and that a regulatory approach is required (Choguill, 2007; Clinch & Healy, 2000b; Lee & Yik, 2004; Oikonomou, et al, 2009). The Building Commission (2005a) acknowledges this, saying that consumers expect improving performance standards and expect the government to control this rather than allowing it to be a voluntary decision.

Research by Binder (2008) and Crabtree and Hes (2009) supports this by finding significant tensions between the Australian building industry, consumers and regulators on who exactly should be responsible for improving housing energy performance. The research found that the various participants blame each other for preventing further developments of housing performance regulations. Similar tensions have been also found in other countries (Lutzenhiser, 1994; Parag & Darby, 2009).

Many authors argue that if it is left to a market approach, improvements to energy consumption are unlikely to occur fast enough to limit climate change impacts (Beerepoot & Beerepoot, 2007; Boardman, et al, 2005; Scheer, 1993; Vringer, Aalbers, & Blok, 2007; Watson et al, 2008; Williams, 2008). These authors argue that the required changes must come through government regulations to ensure an adequate and timely response in the face of challenges posed by climate change.
Further, the use of regulation and instruments such as energy rating tools are seen as a way to ensure consistency and reduced risks, uncertainties and confusion over requirements (Lee & Yik, 2004; Meacham, 2010). Regulations also protect against slipping standards, particularly important for safety standards – the reason building regulations were originally developed.

Another contested topic in the literature is whether regulations constrain or encourage innovation (Gann, et al, 1998). The support for regulation as a driver of innovation is countered by those who argue that this can only be achieved if there is flexibility in the regulations (Ang, Groosman, & Scholten, 2005; Duncan, 2005; Gann, et al, 1998). This argument is particularly relevant to the discussion on the need for a broader scope in many current housing regulations to achieve true sustainability (Kordjamshidi, 2011; Lowe & Oreszczyn, 2008; Monahan & Powell, 2011).

Research has found there are diminishing benefits forthcoming from moving to higher star ratings using current materials and building practices (CIE, 2010; Morrissey & Horne, 2011; Pitt & Sherry, 2010). A widening of the scope of house ratings to include aspects such as renewable energy technology could be more cost effective than an incremental improvement of thermal performance (Güneralp & Seto, 2012; Newton & Tucker, 2009; Peterkin, 2009). Innovation requirements will be discussed further in chapter 4.

3.6 The costs and benefits of improving housing energy performance

Housing energy performance regulations, in Australia and internationally, have been informed by evidence of predicted impacts, particularly through regulatory impact statements and CBA, as alluded to throughout this chapter (ABCB, 2009b; Allen Consulting Group, 2002; COAG, 2009b; DCLG, 2008d). The requirement for policy development to be informed by strong evidence has been in part driven by continued resistance from the building industry to improving housing energy performance, as well as a need to ensure improved policy outcomes as discussed in chapter 2. The building industry’s primarily concern is affordability. As Pickvance (2009, pp. 337-338) states:

‘The house-building industry in general is against anything that adds to costs, or which, in its view, hampers the sale of houses. Its primary concern is thus with the additional cost of sustainability features, which it sees as imposing costs but without corresponding benefits since consumers do not value them. The industry’s view is that new house prices cannot deviate from existing house prices and that in the short-term, builders (and, in the longer-term, landowners) will bear the cost of energy-saving improvements’.

Therefore the development of housing policy both internationally and in Australia has evolved to include significant attempts to engage with building science in the form of ‘evidence’ and in
particular highlight the benefits of improving energy efficiency. For example, in the UK, the Code for Sustainable Homes was developed along a similar method to that used in Australia for the Building Code of Australia. Over a period of time, a number of CBA and impact statements were developed and revised based upon responses from the building industry and the general public (DCLG, 2006b, 2008a, 2008c, 2008d). Initial concerns regarding the affordability of improved housing energy performance standards raised by the building industry were addressed by the analysis (Osmani & O'Reilly, 2009).

The analysis found that ZEH standards would add up to 41% to the build costs for a detached house (DCLG, 2008a). However it was predicted that additional capital costs would drop by at least one third as industry innovation developed economic efficiencies in technologies, materials and building practices (DCLG, 2008a). Other forms of housing were less expensive to improve to a ZEH standard. The costs of flats, for example, were predicted to rise by an extra 24%. Benefits found included reduced utility bills, improved occupant comfort, improved occupant health, increased employment, industry innovation and reduced greenhouse gas emissions across the life of the house (Boardman, et al, 2005; DCLG, 2006a, 2007b, 2008a). The analysis presented evidence for a step change across 10 years to minimise impacts to the building industry and consumers.

Similarly, the EU now mandates empirical evidence to inform housing energy performance policy across Member States, specifying that Member States apply CBA to inform housing performance policy development across the next decade. Produced analysis will be reviewed by EU regulators to ensure that Member States do not fall short of goals to build ZEH by 2020 (European Commission, 2010).

In Australia, the implementation of 5 star minimum performance regulations in Victoria was informed by CBA (Allen Consulting Group, 2002). The analysis compared a BAU approach to 4 star and 5 star regulation alternatives. The most feasible outcome for households was identified as the 5 star minimum performance standard. Similarly, the development of 6 star minimum performance regulations nationally was informed by CBA. The 6 star analysis found there were significant benefits to the household, the environment and society when moving from 5 star to 6 star (ABCB, 2009b; Constructive Concepts & Tony Isaacs Consulting, 2009). As was found in the UK, benefits included reduced energy bills, improved occupant comfort and reduced greenhouse gas emissions (ABCB, 2009b).

Despite this, regulatory improvement to 5 star and more recently to 6 star in Australia was not achieved without significant resistance and criticism from the building industry (ABCB, 2009b; Dalton, et al, 2007). The building industry in Australia claimed that additional costs to meet higher performance standards outweighed the benefits of improved energy efficiency. They argued that improvements to housing performance policy impacts on ‘affordability’ for consumers. The Master
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Builders Association of Victoria claimed that the initial move to a 5 star performance standard added $2,000–$8,000 to the cost of a house and that a move from 5 star to 6 star would add a further $5,000–$10,000 per house (MBAV, 2008).

Similarly, a report by the Centre for International Economics on behalf of the Housing Industry Association argued that any increase on mandatory 5 star thermal performance for new housing would have limited economic benefits and in fact:

‘will be financially detrimental to most new home owners and economically detrimental to the community. It will manifest itself in higher house prices and lower disposable incomes of Australians and it will not result in efficient reductions in greenhouse gases’ (CIE, 2010, p. 8).

However, research has shown that the costs of implementing 5 star were significantly less than predicted. The Building Commission (2005b) found that the introduction of the 5 star standard for the average sized home (250m²) cost $3,500 (including water improvement elements, $1,500 for energy improvements only) which equated to an increase in total building costs of 1.5%; significantly less than the figures predicted by the building industry. In addition, ongoing economic savings of approximately $300 per annum were realised on the average electricity bill in 2005 (Building Commission, 2005b).

Similarly, the regulatory improvement from 5 star to 6 star has been shown to cost significantly less than predicted by the Housing Industry Association and Master Builders Association (DLGP, 2010). The move from 5 star to 6 star was calculated to cost on average $2,300, although in 10% of houses modelled, the cost could be $1000 cheaper to build than 5 star with more efficient reconfiguration of windows (Constructive Concepts & Tony Isaacs Consulting, 2009). On average, this equates to an increase in costs of around 1.5% on capital building costs, compared to the 3–6% claimed by the building industry (ABCB, 2009b). Wider social benefits were also presented, similar to those found in the UK. Further, the housing industry in Australia has been predicted to continue to grow into the future, even with a requirement to reduce greenhouse gas emissions by up to a third (CIE, 2007).

The overestimation of costs and underestimation of benefits are not limited to the housing industry. The International Chemical Secretariat published a report of the costs and benefits of actual outcomes from regulations compared to predictions from resistant industry groups across a range of industry sectors (ICS, 2004). It found that in the majority of cases, resistant industry groups overestimated costs of change, sometimes by several billions of dollars. Benefits are often underestimated as well, particularly wider benefits which can be hard to predict. The report also
states that regulators often overestimate costs and underestimate innovation and cost-reduction potential within industry.

The use of CBA to inform housing performance regulations in Australia has been limited to a consideration of effects of star ratings increases only. Recent research by Pitt and Sherry (2010), Newton and Tucker (2009) and Morrissey et al. (2011) has considered the costs and benefits of higher minimum star rating regulations in Australia. Outcomes from these analyses suggest it is economically, socially and environmentally desirable to build higher star rating housing as new additions to the housing stock. Based on current building technology, practices and knowledge, an 8 star minimum standard has been suggested as optimal (Morrissey, et al, 2011; Pitt & Sherry, 2010).

While some progress is being made in Australia in the analysis of the cost-benefit implications of higher star ratings, there is limited evidence of research addressing the cost-benefit equation of housing with star ratings of higher than 8 star. Further, there is a lack of research exploring particular costs and benefits of improved thermal performance in combination with requirements for renewable energy technologies (Newton & Tucker, 2009). Apart from the notable initiative to promote solar hot water systems, to date, renewable energy requirements have been left out of the housing regulation debate in Australia.

3.7 Chapter summary

Governments, both internationally and in Australia, have recognised that building regulation plays an important function in achieving improvements in housing sustainability to the level required to address climate change or energy security concerns (Shorrock, Henderson, & Utley, 2005; Williams, 2008). Accordingly, minimum housing performance regulations have been implemented in many developed countries and these regulations are recognised to have been the most effective instrument for increasing the environmental performance of new housing stock (Gann, et al, 1998; Gellera et al, 2004; Williams, 2008).

Minimum housing performance policy in Australia has been found to be less stringent than policies in jurisdictions with comparable climates in Europe and the USA (Horne & Hayles, 2008). Countries such as the USA and across the EU are enacting policy and regulatory plans aimed at achieving widespread construction of ZEH standard homes during this decade. Policy innovation in these countries, and the current regulatory approach in Australia, has been informed by evidence, including that utilising CBA (ABCB, 2009b; DCLG, 2008d).

Historically, there has been a lack of research in Australia to reliably inform a discussion on the costs and benefits of higher minimum housing energy performance regulations and of renewable energy components. In order to test sub question 1 (what are the through-life costs and benefits of
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ZEH performance standards for owner-occupied new home buyers?) and sub question 2 (what implications arise from through-life costs and benefits of ZEH, both in practical and policy dimensions?), subsequent chapters will include methods, testing and results of extended CBA to housing in Australia, specifically in the Victoria context. The approach will include the examination of combinations of improved thermal performance and renewable energy technology options, and will explore the cost-benefit implications of these.

A transition to ZEH regulation, however, will require more than the generation of favourable cost-benefit data. In particular it will require policy and process innovation. The next chapter explores the concepts of policy innovation and theoretical frameworks which may be applied to the case of housing performance policy in order to transition to ZEH, should the costs and benefit determine it is a suitable building standard for the Australian context.
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Jurisdictions such as the EU and USA have recognised that in order to improve housing energy performance beyond traditional approaches, radical innovation of policy is required. However as discussed in chapter 3, this approach, in particular the requirement for ZEH standards, remains in the background of policy discussion in Australia.

This chapter explores a possible new framing to address the practical requirements for innovation of policy in order to progress beyond the current BAU approach to housing energy performance in Australia. To begin with, a brief summary of current environmental policy development through an ecological modernisation context, including limitations of this approach, will be presented. In building upon the strengths and addressing a number of the weaknesses of ecological modernisation, socio-technical transitions (STT) theory is presented as a more comprehensive framework for environmental policy development; one which advocates drawing upon technical, social and environmental elements to achieve a low carbon future. This chapter then examines the strengths, weaknesses and applicability of STT theory as a potential framework to assist in a transition to ZEH in Australia.

4.1 Environmental policy development and ecological modernisation: a brief summary

This section briefly summarises ecological modernisation for the purpose of highlighting the theoretical underpinnings of current environmental policy development. For a more detailed discussion regarding ecological modernisation, refer to Buttel (2000), Mol and Sonnenfeld (2000), Mol, Sonnenfeld, and Spaargaren (2009), Toke (2011) and York and Rosa (2003).

Since the 1980s, there has been a focus on linking technology innovation to environmental issues within policy approaches through an ecological modernisation approach. Current environmental policy development around the world is typically informed by the principles of ecological modernisation (Mol, et al, 2009). Within this context, the approach applied typically to address the energy performance of new housing, the setting of minimum standards, fits within an ecological modernisation approach (Smith & Kern, 2007).

Developed as a response to improving sustainability outcomes at the expense of economic growth, ecological modernisation theory states that innovation in technology, going further into ‘modernisation’, can continue to improve economic growth (capitalism through competition) while improving environmental outcomes (Mol, 1995; Mol & Sonnenfeld, 2000; Mol, et al, 2009). By doing so, external environmental costs are internalised. This provides a market and therefore
innovation to address environmental problems without having to address wider neo-classical economic structures, achieving a ‘win-win’ situation (Buttel, 2000; Curran, 2009). Putting a price on carbon and allowing the market to find cost efficient solutions is one example of this approach.

While there has been some success with this technology innovation approach, ecological modernisation has received significant criticisms regarding its ability to effect long-term environmental protection (Buttel, 2000; Fisher & Freudenburg, 2001; Leonard & Barry, 2010; Toke, 2011; York & Rosa, 2003). In particular, it has been criticised for failing to break the deep structural constraints, such as networks and consumer practices, which created the economic and environmental problems to begin with (Leonard & Barry, 2010).

The focus on technology providing the solution, a limited supply-side focus, continued market failures and the lack of social and demand-side considerations are among a number of further concerns with ecological modernisation (Fisher & Freudenburg, 2001; Leonard & Barry, 2010; York & Rosa, 2003). In highlighting this issue by failing to adequately address social elements, incremental energy efficiency technology improvements are often being outstripped by the rapid overall increase in energy consumption through the increased proliferation and use of appliances, referred to as the rebound effect (Kemp & van Lente, 2011; Tainter, 2011; van den Bergh, Truffer, & Kallis, 2011).

4.2 A socio-technical transitions approach

Although technological innovation and the approach of ecological modernisation remain important for environmental outcomes, recent shifts in response to addressing issues such as climate change, and the requirement for a transition to a low carbon future, have meant that wider innovation approaches are being argued for (Holtz, Brugnach, & Pahl-Wostl, 2008; Newton, 2008; Smith, Voß, & Grin, 2010; van den Bergh, et al, 2011).

STT theory builds upon a requirement for technology innovation from an ecological modernisation framing, but also advocates drawing upon social considerations, environmental outcomes and governance as well as generating deep structural change in order to achieve a transition to a low carbon future (Bergman, Whitmarsh, & Köhler, 2008; Geels, 2002; Smith, 2006). A transition is a passage from one state, stage, subject or place to another. In the context of this research, a transition is the move from the current housing energy performance standards to ZEH standards. This transition to a sustainable, low carbon future has been described as a:

‘dauntingly complex issue, both politically and theoretically. It includes exploration and stimulation of new ways of production and consumption, new types of regulation and, probably, new types of institutions to coordinate the various efforts’ (van Lente, et al, 2011, p. 36).
A detailed review of STT theory and its application in practice, including strengths, critiques, complexity and its applicability to zero emission housing is presented across the rest of this chapter.

4.3 Socio-technical transitions theory

As identified in chapter 1, STT is defined as ‘major technological transformations in the way societal functions such as transportation, communication, housing and feeding, are fulfilled’ (Geels, 2002, p. 1257). The requirement for deep structural changes to wider social elements, including to regulations, networks, markets, infrastructure, consumer practices and cultural meaning, as well as to technical elements, distinguishes STT from technical focused transitions approaches such as ecological modernisation (Geels, 2002; Grin, Rotmans, & Schot, 2011). Figure 7 presents an example of the various social and technical elements which make up a socio-technical configuration for factory production.

STT theory developed in the late 1990s in response to a shift in political decision making processes from short-term to longer-term policy development. Short-termism is attributed to current political electoral cycles which fail to provide incentives for politicians to develop policies beyond the next election campaign (Hendriks, 2009; Majone, 1996; Meadowcroft, 2011). Authors such as Kemp,
Rotmans, and Loorbach (2007) and Smith and Kern (2009) argue that a policy shift to longer-term thinking is critical for environmental sustainability.

The Dutch Government has embraced long-term transitions policy and principles, through the adoption of a transitions management framework (transitions management is discussed in section 4.5). STT theory is identified as a core practice for the Netherland’s Fourth National Environmental Policy Plan released in 2001, and is considered one of the most significant transitions policies in practice at present (Kemp, Loorbach, & Rotmans, 2007; Verbong & Geels, 2010). Other countries which have embraced transitions research and/or policy development include the UK, Austria, Belgium, Finland, USA, Mexico and Spain (Domènech & Sauri, 2010; Páez, 2010; Smith, et al, 2010). To date there has been limited application of STT, in either research or policy development contexts, in Australia (Brown & Keath, 2008; Moloney, Horne, & Fien, 2010; Newton, 2012).

While there are an increasing number of current STT case studies, the majority of empirical analyses which have informed the development of STT theory are based upon historical case studies, including:

- sailing ship to steam ship (Geels, 2002),
- coal to gas energy (Correljé & Verbong, 2004),
- cesspools to sewer systems (Geels, 2006b),
- modernisation of Dutch agriculture (Grin, 2010), and
- industrialised to sustainable agriculture in Switzerland (Belz, 2004).

STT theory draws upon aspects of innovation, history, ecology, biology, complex systems, sociology, political & governance studies and psychology (Geels, 2005; Rip & Kemp, 1998; Schot & Geels, 2007; Scrase & Smith, 2009; van den Bergh, et al, 2011). Critical to the development of STT theory are the concepts of technical regimes proposed by Nelson and Winter (1982) and the idea of technological paradigms and technological trajectories, as discussed by Dosi (1982). These concepts were developed further by Rip and Kemp (1998) who explored STT and the concept of evolutionary niches and the importance of protected spaces. A protected space is an area where market pressures to succeed does not apply, for example, areas facilitated by government funding or altered regulations in particular circumstances.

The fundamental structure that underpins STT theory, the multi-level perspective, was developed in the mid to late 1990s (Geels, 2002; Kemp, 1994; Rip & Kemp, 1998; Schot, Hoogma, & Elzen, 1994). The multi-level perspective identifies three critical levels which combine as a nested hierarchy to create a socio-technical system.
The three levels are (Figure 8):

- micro (niche),
- meso (regime), and
- macro (landscape).

*Niches* are protected spaces which are significantly different alternatives to the existing technological regime, where rules, behaviours, practices and wider social elements can develop without typical market, competition and innovation pressures (Elzen, Geels, & Green, 2004; Schot, 1998). Issues such as cost, prohibitive regulations or requirements for deep social change frequently act to prevent niches from challenging current regimes (Geels, 2011; Kemp & van Lente, 2011).

*A regime* is defined as the articulation of the paradigm sum of current practices, beliefs, methods, technologies, behaviours, routines and rules for societal functions (Rip & Kemp, 1998). It is these which form a deep structure which the niche aims to challenge to create a new regime. Regimes are characteristically difficult to change by niche pressure due to their locked-in and stable nature (Grin, Rotmans, & Schot, 2010).

*Landscapes* represent the overarching level, created by a combination of complex elements such as wars, economic development, climate change, oil prices, political persuasions as well as wider cultural and normative values (Geels, 2002). These elements are outside the direct influence of individuals, making this the most difficult of all three levels to change (Grin, *et al*, 2010). When change at the landscape level does occur, it typically occurs more slowly than across the other
levels. However some events such as a war or a financial crisis can change the landscape more quickly (Loorbach & Rotmans, 2006).

Understanding how these levels are formed, maintained and change has been a focus for STT research. Relationships, behaviours, norms, networks and social expectations of key actors and society in general have been identified as important for unlocking these processes (Frantzeskaki & de Haan, 2009; Smith, et al., 2010). In addition, significant focus has been placed on understanding the social groups (users, researchers, producers, suppliers, financiers, public authorities and societal groups) who produce and evolve socio-technical systems, as explored in Figure 9 (Geels, 2005).

![Figure 9: Social groups who produce and reproduce sociotechnical systems (Geels, 2005, p. 683).](image)

Equally as important to STT, but typically missing from other innovation approaches, such as ecological modernisation, is the consideration of social elements (Grin, et al., 2010; Moloney, et al., 2010). This includes a focus on consumer demand and functionality within the transitions framework. Addressing these social elements in practice has been challenging (Kemp & van Lente, 2011).

As a relatively new field of theory and investigation, STT is continuing to develop and evolve, with empirical and practical analysis continually emerging. What is clear is that STT presents a
promising framework to achieve the deep structural change required for a transition to a sustainable, low carbon future. The following section will explore the STT process.

4.4 Socio-technical transition process

The STT process has received significant focus within the transitions literature. Based upon the multi-level perspective framework, four broad phases have been identified. These phases are (Rotmans, Kemp, & Van Asselt, 2001):

- **Pre-development** – There is limited visible change at the systems level, however substantial experimentation and development in the niche level occurs in an attempt to find a challenger/s to the current regime. Pressure for change starts to build on the current regime;
- **Take off** – When enough pressure is exerted on the existing regime, the niche challenger is able to begin to destabilise it and increase its own diffusion;
- **Acceleration** – At a certain point the existing regime will be destabilised enough for the niche challenger to make significant structural changes (socio-cultural, economic, ecological and institutional) more rapidly and with less resistance; and
- **Stabilisation** – Once the speed of change decreases and deep structural changes have occurred, a new socio-technical regime is achieved.

Due to the complexities surrounding the development and introduction of niche challengers (including new or improved technologies, regulations, institutions, social design, practices and networks) to achieve deep structural change, the transitions process typically takes one or more human generations (Alkemade, Hekkert, & Negro, 2011; Grin, et al, 2011). These complexities and the time required to complete a transition means that there is rarely a single driver of a transition and causality is often difficult to determine (circular causality) (Geels, 2005; Vasileiadou & Safarzynska, 2010). While there is rarely a singular cause of a transition, a one-off event such as a war or global financial crisis can help to accelerate the transitions process (Loorbach & Rotmans, 2006).

The first part of the STT process is the development of a niche alternative which is capable of challenging the existing regime. The discussion in chapter 3 regarding PV rebates in Australia is an example of this niche development in a protected space. The provision of rebates allowed the PV industry to establish a foothold in Australia, on the basis of facilitating increasing consumer demand. Even with niche protection, the chance of a niche breaking through is often dependent on a ‘window of opportunity’ or involvement from significant actors from the current regime (Smith, et al, 2010).
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Once a niche is developed, it must destabilise the existing regime before the new regime can take shape. Destabilisation occurs when significant pressure is placed upon the existing regime (Figure 10). Initially, the multi-level perspective articulated a predominantly niche focus for pressure generation to the current regime (Geels, 2002). However this was criticised for its failure to allow for landscape or internal and external regime pressures (Berkhout, Smith, & Stirling, 2004). The multi-level perspective was later revised to include these wider pressure generation approaches (Geels, 2005; Verbong & Geels, 2010).

![Figure 10: A dynamic multi-level perspective on technical transitions (Geels, 2012, p. 4).](image.png)

It is difficult to predict when, where or how these pressures will emerge (de Haan & Rotmans, 2011; Frantzeskaki & de Haan, 2009). Identified pressures include (Berkhout, et al, 2004; Grin, et al, 2010; Smith, Stirling, & Berkhout, 2005):

- new or altered policy, regulation or taxation,
- subsidies for niche actors, technologies or consumers,
- new technologies or improved efficiencies in existing technologies (performance and/or economics),
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• public health issues,
• landscape changes such as fluctuation in petrol prices, climate change, war, and
• societal pressure groups, outside specialists, entrepreneurs and firms.

Once a niche alternative has developed sufficiently to exert enough pressure to break through and challenge the current regime, there are a number of pathways through which the transition can then evolve. STT can follow a singular pathway or have elements of multiple pathways (Grin, et al, 2011; Verbong & Geels, 2010). While analysis of case-study pathways has helped to develop STT theory, there is still a requirement for further research into pathway mechanisms and characteristics.

Five transitions paths have been identified in the literature (Geels & Schot, 2007; Genus & Coles, 2007):

• Transformation – Socio-technical regimes that change without recourse to one dominant technology.
• Technical substitutions – A radical technology replaces an existing technology creating a new socio-technical regime.
• De-alignment and re-alignment – Existing regimes begin to develop problems, competition between new technologies to solve these issues results in the emergence of a winner.
• Opening up new domain – Successful socio-technical system building provides new social function.
• Reconfiguration – System changes in many technologies and organisation changes.

Within each of these pathways, there is likely to be a level of conflict and power struggle between niche and existing regime actors throughout the take-off and acceleration phases of the transition (Geels, 2006b). Significant sunk investments such as time and money, pre-existing infrastructure and the resources required to learn and develop a market means that a challenge to the current regime is unlikely to be willingly accepted by the current regime actors (Hommels, Peters, & Bijker, 2007). The contestation will typically last until either the niche or existing regime can assert or reclaim dominance.

Current regimes generally have the ability to adapt to some degree in the face of pressures (Geels, 2006b; Smith, et al, 2005). If pressures continue without breaking through the current regime for the ‘take off’ phase, the current regime can, through a series of small adaptations, hold off a transition (de Haan & Rotmans, 2011; Geels, 2006b). If this occurs, the process is not classified as an STT, as it fails to address the requirements for deep structural change.
If a niche can break through and assert dominance over the existing regime, it will eventually reach a point where deep structural changes have occurred and the speed of change begins to slow down. At this point the challenger has become integrated into what has become a new regime. The process is continuous, so the new regime may face challenges from new niches in the future.

4.5 Transitions management framework

The transitions management approach is a process of governance which seeks to manage an STT towards a pre-defined goal or vision (Loorbach, 2007, 2010). It is not management in the traditional sense, more a process of ‘steering’ or facilitating (Loorbach & Rotmans, 2006). In this regard, transitions management involves the setting of goals, visions and pathways, and then adjusting, adapting, influencing, guiding and reflecting to allow for a transition to develop (Alkemade, et al, 2011; Grin, et al, 2010). The development of centralised energy systems, the transitions from piston engine to jetliners and the Dutch Fourth National Environmental Policy Plan are examples of an applied transitions management approach (Kemp, Loorbach, et al, 2007; Tukker et al, 2008). Transitions management is the approach taken most notably by the Dutch Government but other jurisdictions including the EU, UK and USA have begun to embrace transitions management policy framings.

Transitions management is based upon the transition process described in the previous section (4.4) and the broader multi-level perspective as described in section 4.3. There is not one set method for application of a transitions management framework (Tukker, et al, 2008). Historical case studies have shown that each case is different and responds to different stimuli. The literature suggests that a number of key aspects are common across historical and current STT case studies, and presents evidence that can be applied to differentiate transitions management from an evolutionary STT framework.

Key elements of transitions management include (Kemp & Rotmans, 2009; Rotmans & Loorbach, 2008; Tukker, et al, 2008):

- Long-term thinking, including the setting of visions and goals, which informs short-term policy development.
- Multiple domains, actors and levels, including links to wider national and international policy development such as Kyoto protocol.
- The establishment of a transitions arena for technology and social innovation, program development and ongoing learning.
- Policy oriented towards system innovation besides system improvement (deep structural changes).
- Reflexive governance (periodic reviews and assessment) throughout the process to ensure that the transition is ‘on track’ and to avoid a lock-in of technologies and practices; and
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- Identification and engagement of societal actors.

While each transition is different, a ten step framework was developed based upon an early transitions management case study which articulates a broad transitions management approach (Figure 11) (Dirven, Rotmans, & Verkaik, 2002). These ten steps present a useful guide for understanding the processes and complexities involved in undertaking a facilitated transition.

A number of these critical elements presented in Figure 11 will now be explored in more detail. These elements can be broadly classified as:

- visions and goals,
- scenarios and pathways, and
- reflexive governance.

4.5.1 Visions and goals

Critical to transitions management is the development of visions and goals (Kemp & Rotmans, 2009; Rotmans, et al, 2001; Späth & Rohracher, 2010). Visions and goals provide a focus, structure
and end point for the transition (Eames et al., 2006). Further, when clear visions and goals exist, technology innovation actors are provided with confidence that the research and development of ‘future’ technologies will be supported through policy, financial and wider social changes, creating a protected space (Eames, et al., 2006). The setting of longer-term visions also allows societal actors time to prepare for the transition, enabling a minimisation of costs and other disruptions relating to planned changes (Park, 2011).

The development of a set of visions and goals can occur through consultation between policy makers, key participants from the current regime and niche actors, or can be determined by policy makers alone (Berkhout, et al., 2004). The process for arriving at a consensus for visions and goals is often contested, particularly by the existing regime (Eames, et al., 2006). Complicating this process is the fact that some actors fall into the category of both current regime and niche level participants, and so may try to keep their options open by not committing to either level. Contention can lead to a watering down of visions and goals. It is also assumed that visions and goals which are agreed upon by key actors will be accepted by the wider public (Hendriks, 2009). Again, this can be a point of contention.

Visions and goals should not be seen as a concrete blueprint but something which contains some flexibility to allow for multiple sustainable outcomes and pathways to achieve them. This flexibility within visions and goals is required to adjust to future developments, such as new technologies, behaviour change and cost efficiency improvements (Grin, et al., 2010; Tukker, et al., 2008). If flexibility is not allowed for, visions and goals can become outdated, potentially even guiding a transition into a path of ‘lock-in’ for a regime that is no better off than the one it was replacing. However, too much flexibility can be as bad as not enough, as goals and visions can be constantly changing, hampering the progress of transitions. This is a significant challenge with the balancing act required by the transitions approach and if not undertaken with care, a new or altered regime may be worse than the previous regime.

To mitigate these issues, the development of visions and goal should draw upon information and learnings from not only within the current STT system but also from wider contexts (de Haan & Rotmans, 2011; Foxon et al., 2009; Geels, 2004; Holtz, et al., 2008; Kivimaa & Mickwitz, 2011). For example, the current energy transition underway in the Netherlands has drawn upon wider national and international visions and goals including the Kyoto Protocol and renewable energy targets (Kemp & Rotmans, 2009).

This energy transition first began as part of a wider introduction of transitions management into environmental policy development in the Netherlands in 2000. Longer-term goals to make ‘electricity supply more sustainable’ and to become ‘the most sustainable gas country in Europe’ were developed to be achieved by the year 2050 (Kemp, Rotmans, et al., 2007, p. 322). In addition,
a number of possible pathways to achieve these goals were developed in consultation with policy
makers, private and public actors (Kemp, Rotmans, et al, 2007). Specific goals to be achieved in
pursuit of a longer-term goal included improving energy efficiency by 2.0% per year and achieving
30% renewable energy generation by 2030 (Kemp, Rotmans, et al, 2007). In order to do this a
number of transition arenas were developed where niche actors have been able to develop
technologies and approaches to achieving a sustainable energy future.

While the adoption of transitions management promised to achieve deep structural changes,
outcomes by 2007 indicate that there are a number of concerns with this process including; that the
process has not been the open and reflexive process it initially claimed it would be; goals and
pathways have been developed from people within the existing regime which means that it is not
without bias and influence; and that society has not really been involved in the transitions
management process as much as the theory suggests should be. Further critiques of STT and
transitions management are presented in section 4.6.

4.5.2 Scenarios and pathways

The development of visions and goals are an important aspect of STT but they say little about the
approach required to realise them (Grin, et al, 2010; Hodson & Marvin, 2010). One method to fill
the gap between visions, goals and actions with regards to policy is the development of scenarios or
pathways, as was undertaken in the energy transition in the Netherlands which is briefly described
above. Hughes and Strachan (2010, p. 6056) describe scenarios as:

‘the use of the imagination to consider possible alternative future situations as
they may evolve from the present, with a view to informing and improving
decisions that must be made while the future remains uncertain or undecided’.

There are two main scenario methods: forecasting or back casting (Vergragt & Quist, 2011).
Forecasting refers to the development of possible pathways from the current point in time and
working forward in an evolutionary framework. Scenarios of this type can be developed towards a
vision or goal, through natural evolution or through specific inputs such as financial or regulatory
aspects (Quist, 2007). This differs from back casting, which works backwards from the desirable
future (vision) to work out what steps are required to reach that vision. As well as being used to
guide towards desired outcomes, it is possible to use forecasting and back casting to develop
scenarios to avoid undesirable futures (Vergragt & Quist, 2011). While forecasting is used in some
transitions case studies, the majority of transitions management approaches, particularly in the
Netherlands, use the back casting approach (Quist, 2007; Rotmans, et al, 2001).

Quist and Vergragt (2006) provide a number of key steps for creating and analysing scenarios.
They are:
1. strategic problem orientation,
2. develop future vision,
3. undertake back casting/forecasting analysis,
4. elaborate future alternative and define follow-up agenda, and
5. embed results and agenda and stimulate follow-up.

The significant role of scenarios and pathways is similar to that of visions and goals; it provides confidence to consumers and industries that there is a structured way forward (Eames, et al, 2006). In particular it makes milestones where certain changes will be made explicit. The incremental improvement of energy efficiency regulations every two years is an example. The importance here is that sufficient warning is given to all stakeholders involved in the wider transition process about what is to come, reducing both costs and disruptions from planned changes (Park, 2011). Without the use of scenarios, visions and goals remain a theoretical concept with little grounding in practicality.

A key element for developing a pathway within a transitions management approach is that there is equity amongst regime and niche actors. However, if the right balance is not achieved, the outcome is little more than the existing regime developing a pathway forward which best suits them and plays only lip service to longer-term sustainability and deep structural change requirements. How can it be expected that the regime which has contributed to the problem which needs addressing, can also be tasked with developing solutions which may or may not be in their best interests? Achieving this balance is proving to be more challenging than initially thought amongst transitions researchers.

4.5.3 Reflexive governance

Reflexive governance is the process of periodic formal or information monitoring and assessment of how a transition is progressing, ensuring that the transition remains headed in the right direction (Hansen, Sondergard, & Staerdahl, 2010). This process allows for assessment of visions, goals and pathways particularly in light of new or improved technologies or information, including changes to consumer preferences, which may have developed since the transition began (Kemp & Rotmans, 2009; Schot & Geels, 2007; Williams, 2008). Further, it also allows for an understanding of how changes are occurring and how societal actors and policy development are both impacted on and impacting on these changes (Foxon, et al, 2009).

If required, adjustments can be made to the transitions management process to ensure that the transition heads towards the ‘right’ outcome.
Chapter 4: Policy innovation and a transition to ZEH

Figure 12 presents this process visually. Firstly, long term goals have been set at the beginning of the transition and a pathway to achieve these developed (right of figure). Periodic reassessment of goals allows the pathway to achieving these goals to be assessed and altered if required, particularly if the end goal has changed. This can help to reduce the risks of implementation of an undesirable transition or ‘lock-in’ by technologies (Vasileiadou & Safarzynska, 2010; Williams, 2008). As Kemp, Loorbach, et al (2007, p. 88) state:

‘the best strategy is to take small steps in what is generally perceived to be ‘the right (sustainable) direction,’ to try different solutions and to alter course when needed.’

Figure 12: Current policy versus transition management (Kemp & Rotmans, 2004).

Transitions can still occur without addressing all of the above elements. However, the understanding and the inclusion of these key aspects can help to develop levers to help facilitate and improve the likelihood of a successful transition (Kemp & Rotmans, 2009; Moloney, et al, 2010).

4.6 Criticisms of socio-technical transitions and transitions management

A number of criticisms of STT and transitions management are presented within the literature. A key point of debate is whether or not STT processes can in fact be ‘managed’ or can only occur through an evolutionary process (Rotmans, et al, 2001; Shove & Walker, 2007). Opponents of the transitions management approach argue that due to the complexity involved, it is not possible to manage a transition (Shove & Walker, 2007; van den Bergh & Kemp, 2008; Vasileiadou & Safarzynska, 2010). Shove and Walker (2007, p. 1) ask:

‘…is it really possible to intervene and deliberately shift technologies, practices and social arrangements – not to mention their systemic interaction and
interdependencies – on to an altogether different, altogether more sustainable track?’.

They continue by arguing that:

‘the outcomes of actions are unknowable, the system unsteerable and the effects of deliberate intervention inherently unpredictable and, ironically, it is this that sustains concepts of agency and management’ (Shove & Walker, 2007, p. 8).

Voß, Smith, and Grin (2009, p. 289) add that:

‘it is impossible to predict precisely what will become of even the most neatly designed policy artefact out in the ‘field’.

Supporters of transitions management agree to some extent with these critiques but argue that it is more a process of ‘steering’ or facilitating rather than traditional management (Loorbach & Rotmans, 2006). This ‘management’ debate remains ongoing, particularly as outcomes of current transitions management approaches have not yet matched researchers’ aspirations (Kemp, Rotmans, et al, 2007; Scrase & Smith, 2009; Smith & Kern, 2009). In particular the openness and reflexive governance elements advocated by transitions management have not eventuated as predicted (Kemp, Rotmans, et al, 2007). Furthermore, the actors involved in the development of goals, visions and pathways are not including niche actors into the decision making process with as much representation as is stated within the transitions management theory.

It is still unclear if transitions management will be successful as a policy approach, and it may be another decade or two before this can be known (Grin, et al, 2010). For now transitions management is an ongoing ‘experiment’ as a potential means of forwarding wider societal and technological change (Kemp & van Lente, 2011; Meadowcroft, 2009).

In addition to the above critique, it is argued by some STT researchers that there remains too much of a focus on technology, policy and corporate actors and not enough attention paid to the demand side (consumers), particularly with respect to behaviours and levers for changes in practice (Grin, et al, 2011; Kemp & van Lente, 2011). For example, in addressing environmental impacts from housing, the focus to date has been on technical and material solutions, primarily to improve the energy efficiency of heating and cooling technologies and of other in-built household appliances (e.g. lighting) (Greene & Pears, 2003; Lee & Yik, 2004; Míguez, et al, 2006).

As part of the social considerations of transitions, there should be a focus on addressing wider requirements for housing to begin with (e.g. how the house is used, the meaning of home, addressing occupant health) as well as a consideration of other issues such as house size and occupant practices (Bergman, et al, 2007; Smith, 2006). If demand for energy within a house can
be reduced to begin with, then reducing remaining consumption of energy within the house may not be as significant a challenge to address (Kemp & van Lente, 2011; Vergragt, 2006). Recent research has begun to include more of these social elements into STT approaches, for example de Haan and Rotmans (2011) and Moloney, et al (2010).

Another criticism of STT is that it is the current regime which led to significant pressures/issues and a requirement for change, yet it is within this same context that the problem will be defined and possible solutions are to be determined. This is argued by Shove and Walker (2010, p. 472) who state:

‘regimes constitute the selection environments in which niche innovations fail or flourish, and which emphasise processes of alignment and path dependence’.

The problematic nature of this paradigm is particularly evident in current case studies where there is a difficulty in obtaining consensus for visions, goals and scenarios when the current regime actors are included in the transitions management process (Berkhout, et al, 2004; Shove & Walker, 2007; Smith, et al, 2005). Exactly who should be involved in developing the visions and scenarios of a new regime and how it differs to the existing BAU approach is not clear, with current case studies seeming to lack involvement from new regime actors, instead being dominated by current regime actors (Avelino, 2009; Smith & Kern, 2009). This has led to conflicts of interest and compromised transitions approaches (Avelino, 2009).

In addition, significant criticisms regarding mechanics and practicalities of the multi-level perspective have been discussed in the literature (Genus & Coles, 2007; Shove & Walker, 2007). In particular seven key criticisms have been raised (Geels, 2011):

- lack of agency,
- operationalization of regimes,
- bias towards bottom-up change models,
- epistemology and explanatory style,
- methodology,
- socio-technical landscape as residual category, and
- flat ontologies versus hierarchical levels.

These issues have been addressed in revisions of the application of the multi-level perspective in transitions research in recent years (Geels, 2006a; Verbong & Geels, 2010). For example, the early descriptions of the multi-level perspective were criticised for being niche focused (Genus & Coles, 2007). However, more recent revisions of the multi-level perspective framework have recognised the importance of landscape and regime influences to the transitions process (Berkhout, et al, 2004; Geels, 2011). While a number of the criticisms have been addressed within the literature, it remains
to be seen if responses will improve practical transitions outcomes and satisfy critics of STT theory and the multi-level perspective.

Furthermore, STT has been developed after being applied to a number of historical case studies. It seems that in reality, the nuances of applying STT to current transitions is providing more challenging than first thought. This may indicate that the historical case studies have been unable to capture the full complexity of transitions and that it may only be through ongoing real applications that the finer points of the theory can evolve. With such a reliance on transitions approach providing the answer to developing a sustainable future, a number of early adopters of a transitions approach (particularly in the Netherlands) may find that outcomes are not quite what they had planned for.

While there are criticisms of STT theory and implementation, STT is still evolving as more research and case studies are undertaken. When used with caution, the general principles of STT provide a basis for deep structural change leading to a more sustainable and socially considered future.

4.7 Socio-technical transitions and ZEH

Technical solutions, such as improved insulation levels, have traditionally been the focus of improving housing sustainability, while social aspects have been given limited consideration, as discussed in chapter 3 (Li & Shen, 2002; Pickvance, 2009; Smith, 2007). In recent years, a deeper understanding has developed leading to recognition that in order to achieve significant reductions in greenhouse gas emissions from the housing sector, more comprehensive approaches which consider more than a technology solution will be required (Svenfelt, Engström, & Svane, 2011). For example, the importance of occupant practices, appliance use and meanings of housing have received increasing attention within housing sustainability literature (Guy, 2011; Keirstead, 2007; Moloney, et al, 2010; Pilkington, Roach, & Perkins, 2011; Pyrko & Darby, 2011).

It is argued that a more comprehensive approach requires a complete paradigm shift which draws upon both the technical and social elements within a housing system in order to achieve a transition to a low carbon housing future (Bergman, et al, 2007). Such a paradigm shift is advocated by STT theory (Kemp & van Lente, 2011; Smith, 2007).

An STT approach to sustainable housing, including energy performance, has begun to emerge in the literature and in recent policy development. Predominantly, STT housing research has been undertaken in the UK and Sweden (Smith, 2007; Svenfelt, et al, 2011). However, policy development which moves beyond technological solutions alone is beginning to be more widely implemented, for example across the EU and USA (Kemp & Rotmans, 2009).
The research by Smith (2006; 2007) is an example of STT theory and its application to sustainable housing. Smith explored the development of sustainable housing niches and defined the current regime through an STT framework. The research makes an important contribution towards developing an understanding about the situation of niche actors and concerning the identification of current pressures between the existing regime and niche actors. Smith identifies a number of critical societal issues in the research, such as the need for engagement with householders to promote involvement within the new paradigm. Table 6 compares the differences between sustainable housing niches and the existing regime against an STT framework as found by Smith (2007).

Table 6: Contrasting socio-technical practices in niche and regime (Smith, 2007, pp. 433-434).

<table>
<thead>
<tr>
<th>Socio-technical dimension</th>
<th>Mainstream house building</th>
<th>Sustainable housing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Guiding principles</td>
<td>Profit and loss; high external inputs.</td>
<td>Ecology; autonomous housing; minimize ecological footprint within cost constraints.</td>
</tr>
<tr>
<td>2. Technologies</td>
<td>Tried and tested; grid services; routine; bulk purchasing; listed suppliers.</td>
<td>Small-scale; off-grid services; natural/reclaimed materials; green supplies.</td>
</tr>
<tr>
<td>3. Industrial structure</td>
<td>Speculative; volume building; subcontracted labour; construction costs; profit from contracted price; one fault on many dwellings – large liabilities; larger estates.</td>
<td>Bespoke building; specialist builders; lifecycle costs; premium for sustainable features; learn from correcting faults; single dwellings or small groups.</td>
</tr>
<tr>
<td>4. User relations and markets</td>
<td>Passive and conservative consumers.</td>
<td>Active commitment to a green lifestyle; high-user involvement or self-build.</td>
</tr>
<tr>
<td>5. Policy and regulations</td>
<td>Land use planning and building regulations are followed; lobby to control the pace of environmental standards.</td>
<td>Land use planning and building regulations can be a constraint; lobby to accelerate the pace of environmental standards.</td>
</tr>
<tr>
<td>6. Knowledge</td>
<td>Knowledge relevant to existing competencies and business practice; standard designs of developers choosing.</td>
<td>Knowledge relevant to reducing the ecological footprint of homes; site-specifics count, e.g. solar orientation, waste water treatment and recycling.</td>
</tr>
<tr>
<td>7. Culture</td>
<td>Markets and regulations.</td>
<td>Sustainable housing.</td>
</tr>
</tbody>
</table>

Bergman et al. (2008; 2007) adds to the work of Smith (2007) by assessing a transition to sustainable housing in the UK through the development of a number of potential policy development pathways to 2050. Bergman et al. (2008; 2007) found that significant pressure must be placed on the existing regime not only by niche actors but also by landscape elements (climate change for example), if deep structural changes are to be achieved. Further, significant support
must be given to niche actors to allow them to develop and challenge the existing regime (protected space). If this does not occur, it is predicted that the existing regime will adapt and hold off the requirement for deep structural changes. Bergman et al. find that a pathway to sustainable, low-carbon housing which achieves deep structural change is possible, although it will require radical changes to current housing and energy performance regulations.

Further to this, Bergman and Eyre (2011) explore the role that small-scale renewable energy generation (microgeneration) could play in a transition to a low carbon future in the UK. In particular they identify that it is not just a shift in energy generation technologies; it also has the potential to facilitate deep structural changes to the social side of energy consumption. For example, people generating their own energy would go from being energy consumers to ‘energy citizens’, who both consume and produce energy, giving them new responsibilities and levels of awareness, impacting on energy behaviours. This would be a significant departure from the existing energy regime and has a role to play in a transition to ZEH, which requires the inclusion of microgeneration technologies.

A different approach was taken by Tambach et al. (2010), who assessed existing housing and energy policies in the Netherlands for houses in the current housing stock against an STT framework. They concluded that a number of critical elements were missing from the current range of policies if a transition to a more sustainable, low-carbon housing and energy future was to occur. These included a lack of a long-term policy agenda (and in turn short and medium-term goals and visions), a lack of up-skilling industry in preparation for changes and a requirement for financial reconfiguration (for example rebates and low interest home loans – niche protection). This lack of wider social support, training, development and financial constraints has been identified in other housing energy transition research as limiting the capacity for a paradigm shift in the building sector (Williams, 2008).

In wider housing energy performance policy development, the UK is attempting a transition to ZEH, as introduced in chapter 3 (DCLG, 2008a). The Code for Sustainable Homes represents a significant departure from previous housing energy performance requirements as it aims to include wider social elements, which are critical for deep structural change (DCLG, 2007a, 2007b). While there is ongoing debate in the UK regarding the approach, timeline and technical requirements of the Code for Sustainable Homes (Osmani & O'Reilly, 2009), other jurisdictions such as the EU and USA have recognised the need to target a transition to zero emission new housing by 2020. This will not be without challenges as the energy sector has been identified as one of the more difficult aspects to address in a transition to sustainable housing, particularly due to the deeply embedded view across the socio-technical system that cheap energy is a basic right (Kemp & van Lente, 2011).
Further, it has been recognised that existing housing regimes are extremely resistant to sustainability changes (Crabtree & Hes, 2009). Importantly, vested interests may fight to ensure that changes are not implemented if they are deemed to have negative impacts (Bergman, et al., 2007). This period of development by niche actors and resistance by the existing regime has been identified as part of the transition process. By providing adequate government support for niche actors, there will come a point where the niche becomes dominant and the resistance from the existing regime reduces, allowing a transition to sustainable housing to evolve (Geels, 2002).

In summary, the concepts of STT and transitions management fit into the requirements for a paradigm shift in housing as shown with the international application of this approach. Such a shift would address deep structural changes which have so far limited a transition to sustainable, low-carbon housing. Despite the potential for STT theory to radically change the future of housing, as yet there has been no application of STT to housing sustainability in Australia. Recent housing energy performance developments in Australia do not in themselves constitute a transition, as they do not address the deeper structural issues at hand.

4.8 Chapter summary

This chapter has explored approaches for innovation of policy that sets out ambitions to go beyond the current BAU approach to dealing with housing sustainability issues. Increasingly, researchers are recognising that in order to achieve deep structural changes, technology innovation alone is not sufficient; there is a requirement for the consideration of societal elements in a more comprehensive innovation of policy approach. An STT transitions management approach has been presented as a framework that can achieve deep structural technological, social and environmental changes particularly for innovation of current policy measures to assist in a transition to a low carbon future.

Currently there has been no application of STT theory to housing energy performance in Australia. There is however increasing application of STT within housing research internationally, which this thesis draws upon, as will be discussed in chapter 5. Applying an STT framework to the existing housing regime in Australia would help to address a number of knowledge and policy gaps in the Australian context and facilitate a long-term transition to ZEH.
Chapter 5: Research design

This chapter presents the scope, approach and methods for data collection and analysis, drawing upon the information developed and gaps identified in chapters 2–4. In an attempt to address these gaps, a number of research questions were proposed (section 5.1). To answer these questions, two phases of data collection were required: through-life cost and benefit modelling (phase 1) and a comparative criteria-based policy document analysis (phase 2).

Briefly, phase 1 involved modelling 80 current detached house plans in thermal energy modelling software to generate a BAU scenario. From this starting point, a number of ZEH scenarios of improved building envelope thermal performance with the inclusion of various renewable energy technologies were developed and analysed to determine additional capital costs, through-life economic and environmental benefits and optimal technology requirements for ZEH. This phase is described in detail in section 5.4, including assumptions applied in the CBA.

Phase 2 involved developing a set of broad criteria based upon STT theory, as explored in chapter 4. From these broad criteria, a number of specific questions were developed to systematically interrogate policy documents relating to minimum housing energy performance standards and, where relevant, ZEH policies from Australia and selected international case study jurisdictions. Through this examination, strengths and weaknesses of these policies based upon an STT framework were ascertained, and requirements for policy development in the Australian context identified. This analysis is discussed in detail in section 5.5.

The following section reiterates the research question for this research. Section 5.2 discusses the scope of this thesis. Following this, the chapter explores the requirement for a mixed-methods approach. The methods for phase 1 and phase 2 of the data collection are then presented in detail.

5.1 Research questions

Research design is heavily dependent upon the questions being asked by the researcher (Tashakkori & Creswell, 2007). Based upon the literature and gaps discussed in chapters 2–4, this research aims to investigate the practical requirements for a facilitated transition to ZEH in Australia, using Melbourne as a focus for the analysis. The evidence presented in the literature review suggests that the current regulatory approach to addressing housing energy performance in Australia is inadequate to facilitate such a transition to ZEH.
Chapter 5: Research design

The overall question proposed for this research is:

What is the cost-benefit feasibility of, and policy requirements for, a transition to ZEH in Australia?

From this question, three subsequent sub-questions were developed, which are presented in section 1.7 on page 12. A range of research methods was required across two phases of data collection to answer these research questions. The scope of the research and the aforementioned research methods are presented in the following sections.

5.2 Scope of the study

The scope of this research is limited to new detached housing in Melbourne, Australia. Decisions made about new housing now can have consequences for 100 years or more (de Wilde & Coley, 2012; Golubchikov & Deda, 2012; Vale & Vale, 2000). In addition, it has been calculated that the greenhouse gas emissions from new residential stock in Victoria are set to be responsible for 70% of total Australian residential greenhouse gas emissions despite only being responsible for 32% of total Australian residential stock (Clune et al., 2012). As such, new housing presents an opportunity to integrate housing energy performance standards which can be incorporated from the construction stage, so as to avoid costly renovations in the future (Kellett, 2011). This focus on new housing complements the ongoing research in Australia and internationally addressing the energy performance of existing housing stock (Boardman et al., 2005; Pullen, 2010).

In phase 1, the through-life cost and benefit phase of data collection, energy efficiency improvements to the building envelope were explored through readily available material additions being applied within the energy simulation software AccuRate. Wider design changes, innovation in design (room layouts, size, window placement, etc.) and new materials were not considered in this analysis. While such approaches are valid, this particular research aimed to demonstrate costs and benefits in relation to the current housing stock and for currently available technologies, materials and construction practices, reflective of 2009/2010. It is not the aim of this thesis to critique the suitability of house designs to more effectively and efficiently achieve ZEH standards. By excluding design and material innovation, conservative ‘worst case’ outcomes are provided.

A significant part of the issue of increasing energy consumption from the residential sector is due to increasing house size as stated in chapter 1. Some researchers argue that house size must significantly reduce if a sustainable low carbon housing future is to be achieved (Clune et al., 2012; Vale & Vale, 2009). They state that reducing house size not only improve sustainability through reduce resources but that additional capital costs to improve the sustainability of the dwelling can be reduced or offset through smaller house size. In particular, Clune et al. (2012) found that
increases in house size in Victoria between 2003 – 2009 decreased the effectiveness of moving from 5 star to 6 star by 38%.

While reducing house size will be an important strategy to achieving a sustainable, low carbon housing future, house size is not focused on in this research. It is assumed that for all house models developed, the house size remains constant from the average calculated across the house plans applied in this research (section 5.4.). In doing so, this thesis provides a ‘worst-case’ outcome if current housing designs, size and use of housing remains the same.

Furthermore, the model does not apply wider climatic changes, such as air temperature increases or changes to severe weather events, within the modelling. This is due in part to the uncertainty surrounding some of these climatic changes. For example there are predictions that average air temperatures in Australia could increase by 1°C – 7°C by 2100 compared to 1990 temperatures (Garnaut, 2008). Therefore climatic conditions were assumed to be consistent with assumptions applied within the energy rating software used in this research, AccuRate.

However, the impact of future climatic conditions has been investigated in the Australian context. Wang, et al (2010) analysed heating and cooling energy requirements of typical residential houses in five different climate zones from around Australia. They found that depending on the climate, the heating and cooling energy requirement of (the then current minimum standard) 5 star houses would experience significant increases or decreases in energy requirements. A change in heating and cooling energy requirements of -26% to 101% by 2050 was found across the climate zones. Furthermore this change grows to -48% to 350% by 2100. The analysis found that improving the star ratings of houses may result in less absolute change in energy requirements in a changing climatic future. Wang, et al (2010) argue the importance of future housing standards, design and policy of considering the requirement for future climatic changes. Such consideration is outside the scope of this research (as outlined above), however the focus on improving the building envelope in this thesis may assist in reducing the impact of future climate changes on heating and cooling energy requirements.

The ZEH scenarios modelled in this research require renewable energy technologies. This research focused on grid-connected renewable energy systems rather than off grid autonomous systems. Focussing on grid-connected renewable energy systems ensures that greater economic efficiencies for households can be achieved, as additional resources such as battery storage banks are not required. There are also a number of additional user requirements to maintain battery banks compared to a grid-connected system, as well as additional space requirements to physically fit the battery bank.
Phase 2 focused on policy documents that relate directly to the setting of minimum housing energy performance regulations for new housing in a number of international and comparable case study jurisdictions. These were selected as examples of diverse and progressive regulatory settings for housing energy efficiency in order to provide significant research outcomes. Wider policies, such as those for greenhouse gas emissions mitigation, were not included in the analysis unless they directly influenced minimum housing energy performance regulations.

5.3 Approach

Coherent research design is critical for relevant and reliable research outcomes (Wadsworth, 2011). Figure 13 presents a general schematic of the typical research cycle. The cycle begins by identifying problems and developing a set of questions for inquiry (Guthrie, 2010). The exploration and definition of the problem/s is critical for determining the following research steps (Bryman, 2008). Following this, data are collected and analysed, leading to the development of outcomes or future directions to address the problem (a case for action). The previous chapters of this thesis have addressed the first three steps in the research cycle by presenting and discussing a number of problems. These problems have been related to a number of clearly defined knowledge gaps. In response, a number of research questions have been developed to generate data to inform knowledge development, in order to address these specific gaps.

![Figure 13: The research cycle, based upon Guthrie (2010).](image)

It is important that throughout the research cycle, the process is reliable, replicable and valid (Bryman, 2008; Hesse-Biber, 2010). Appropriate method selection and implementation as well as
assumptions and limitations of the research are important in validating outcomes from the research so that they can lead, where possible, to practical outcomes (Bergman, 2011).

5.3.1 Mixed methods approach

This research applies a mixed methods approach. Mixed methods have become increasingly popular as a research tool, particularly in the social research field (Creswell & Clark, 2007; Hesse-Biber, 2010). Mixed methods investigation draws upon both quantitative and qualitative research methods to answer one or more related research questions (Hesse-Biber, 2010; Johnson, Onwuegbuzie, & Turner, 2007).

Exponents of the mixed methods approach argue that the approach provides a more robust research methodology and reduces limitations (such as researcher bias) which can arise when researchers use more traditional, disciplinarily-specific and singular method research (i.e. quantitative or qualitative) (Creswell, 2009; Tashakkori & Creswell, 2007).

Five key reasons for using a mixed methods approach have been presented by Greene, Caracelli and Graham (1989):

- Triangulation – the use of more than one method to interrogate the same question, enhancing outcomes.
- Complementarity – allowing for deeper understanding of the research problem or clarifying results.
- Development – whereby the results from one method inform results from other method-led research stages.
- Initiation – unclear results may result in further study requirements; and
- Expansion – provides the ability for a wider range and depth to research.

In addition, the integration of mixed methods in the discussion of the research question is also an important benefit. As Bryman (2007, p. 21) states:

‘mixed methods research is not necessarily just an exercise in testing findings against each other. Instead, it is about forging an overall or negotiated account of the findings that brings together both components of the conversation or debate. The challenge is to find ways of fashioning such accounts when we do not have established templates or even rules of thumb for doing so’.

However, if the research question is better addressed by one method only, a mixed methods approach can present significant problems (Hesse-Biber, 2010). Issues or limitations relating to the use of mixed methods include (Bergman, 2008; Creswell & Clark, 2007; Hesse-Biber, 2010; Johnson, et al, 2007):
• the integration of individual methods, both in the data collection and write up stages,
• weighting given to qualitative and quantitative elements,
• more skills and resources are required to undertake mixed methods research compared to single method research,
• sample size – generalisations are difficult to make when applying multiple methods over a small sample size compared to applying a single method to a larger sample size, and
• the production of sometimes contradictory findings as a result of mixed methods. It can be unclear how to deal with this in the research process.

The range of knowledge gaps identified by this research suggests that a mixed methods approach is appropriate for development of this thesis. This is not only based upon the questions posed, but on the requirement for practical, policy-ready decision making outcomes. Further, the three research sub questions deal with inter-related but different elements requiring different methods to address them; one is an economic and technology modelling question (sub question 1), one is a policy mechanism question (sub question 3) and one is a combination of both (sub question 2).

The research for this thesis design draws upon the triangulation multilevel mixed methods model, as described by Creswell and Clark (2007) (Figure 14). This approach uses both quantitative and qualitative methods to address various levels within the system which defines the research area. The results from each level are then merged for overall interpretation. A benefit of this approach is that each level can be researched using individual appropriate methods, and then findings can be brought together to strengthen overall results and to determine practical outcomes (Creswell & Clark, 2007).
This research draws upon several specific methods including literature review (chapters 2–4), CBA (phase 1) and comparative criteria-based policy document analysis (phase 2) which form the different ‘levels’. These approaches combine to answer the research question and research sub questions posed and serve to develop comprehensive discussion and outcomes (chapters 8 and 9). The next sections of this chapter outline the wider methodological approaches and specific methods undertaken for the two data collection phases.

5.4 Phase 1 – Through-life modelling

Phase 1 addresses sub research questions 1 and 2. The method applied is a through-life CBA. The CBA draws upon the current Australian Building Codes Board and the Council of Australian Governments practice of modelling the costs and benefits of proposed improvements to housing energy performance standards as well as previous sustainable housing work from Australia (Constructive Concepts & Tony Isaacs Consulting, 2009; Newton & Tucker, 2009) and internationally (Boardman, et al, 2005; DCLG, 2008a). This is primarily a quantitative approach which develops a model for providing measurements (i.e. energy savings), however at times wider discussion will draw upon qualitative data to enhance outcomes.

For this study, 117 scenarios were developed across the following four categories:

1. **BAU** – existing new housing standards (6 star) for comparison to improved energy scenarios (BAU assumes gas cooking, heating, and water heating with electric cooling and appliances).
2. Building envelope thermal improvements – modelled to assess the most economic building envelope thermal improvements in terms of star ratings. This is in line with the approach to first reduce energy consumption and improve energy efficiency before addressing energy generation.

3. ZEH standard – developed based upon the results from the building envelope thermal CBA. Various renewable energy technology options were added to the more economical building envelope star rating improvements to achieve ZEH outcomes; and

4. Intermediate energy performance standards between BAU and most economical ZEH scenarios – these were scenarios of improved building thermal envelope and small amounts of renewable energy technology (not enough to make them ZEH).

Each scenario required various inputs for the modelling (Figure 15). These elements and the development of the scenarios, including assumptions used, will be discussed in detail in the following sections.

![Model inputs and outputs from through-life cost-benefit model. Based upon ZEH modelling framework from the UK (DCLG, 2008d, p. 28).](image.png)

**5.4.1 Building envelope improvements**

This section describes the process involved for the first requirement of the through-life modelling: building envelope improvements. The section begins by providing an overview of assumptions made about dwelling characteristics and location. Following this, the process of sample selection, base case modelling, building envelope upgrades and finally the costing process applied is presented. This was required before any of the scenarios could be developed and analysed. The
Chapter 5: Research design

CBA for the scenarios will be explored in section 5.4.2. The method for the building envelope improvements, as presented below, has been published in a peer-reviewed journal paper resulting from the research from this thesis (Morrissey, et al, 2011). This paper focuses on a narrow part of the overall research from this thesis and does not discuss or present outcomes relating to ZEH.

5.4.1.1 Dwelling characteristics and climate

The majority of Australians live in detached dwellings. At the time this research began in 2009, the percentage of all households living in detached houses was 78% (ABS, 2010a). In Victoria, the most common construction type is a brick veneer outer wall construction, built on a concrete slab on ground floor assembly. This construction type accounted for 65.8% of all dwellings constructed in 2008 (ABS, 2008b). For the purposes of this study, analysis was therefore focused on detached dwellings of brick veneer wall construction. For wider environmental and energy benefit calculations, the number of new dwellings assumed to be built per year was kept at the 2010 level (37,692 detached houses) for Victoria (ABS, 2011b).

Within the current minimum housing energy performance regulations (star ratings), location (climate) has a significant impact on the design and materials required to meet minimum standards. Climate zone 60 was selected as the focus of this study from the modelling software AccuRate. This climate zone falls within the urban growth region of Melbourne, which represents areas of housing development that contain typical houses selected for the analysis. It has been predicted that the urban growth region of Melbourne will accommodate 47% of all new dwellings in Melbourne from 2008–2030 (DPCD, 2008).

5.4.1.2 Dwelling sample selection and detailed characteristics

A sample of typical detached residential dwellings of various sizes was analysed for this research. The sample was selected to be representative of new residential housing in Victoria in 2009/2010. Defining characteristics of the houses used in modelling are provided in Table 7. A range of house types and sizes were included in the analysis. These dwellings ranged in size from 121.8–451.7 square metres (m²) with a mean value of 249.6 m². The mean is consistent with ABS data, which found that the average floor area for new housing in Victoria in 2008/2009 was 252.8 m² (ABS, 2011b). The average net conditioned floor area was calculated from the AccuRate modelling software to be 126.5m². The net conditioned floor area was calculated based upon which zones (as they are called in the modelling software) are assumed to have heating and cooling. It is not a measurement of the total indoor area minus the garage. The zones which were assumed to have heating and cooling requirements were bedrooms, living and kitchen areas. The zones which were assumed not to have any heating and cooling requirements included the garage, storage spaces, wet areas (bathrooms and laundries) and hallways. These zones made up around half of the floor area in the housing models.
### Table 7: Characteristics from 80 modelled detached house plans used in the analysis.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean</th>
<th>Minimum</th>
<th>Max</th>
<th>95% confidence intervals</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Bedrooms (#)</td>
<td>3.6</td>
<td>2.0</td>
<td>5.0</td>
<td>3.4</td>
<td>3.7</td>
</tr>
<tr>
<td>Floor size (m²)</td>
<td>249.6</td>
<td>121.8</td>
<td>451.7</td>
<td>233.3</td>
<td>266.0</td>
</tr>
<tr>
<td>Net conditioned floor area (m²)</td>
<td>126.5</td>
<td>55.0</td>
<td>241.1</td>
<td>118.3</td>
<td>134.7</td>
</tr>
<tr>
<td>Cost 6 star ($)</td>
<td>179,086</td>
<td>120,750</td>
<td>276,050</td>
<td>170,433</td>
<td>187,738</td>
</tr>
</tbody>
</table>

Note: A 95% confidence interval refers to the range of values in which the population parameter of interest will fall 95% of the time. It is used to indicate the reliability of the data. Standard deviation (SD) is a measure of the spread of data within a wider data set from its mean. The more spread apart the data, the higher the deviation. It provides a measure of confidence in the data for making generalisations about the wider population.

The average number of bedrooms found in this research (3.6) was slightly higher than the ABS average (3.1) (ABS, 2011a). This is not unexpected, as this project focused on detached housing, which typically involves relatively large dwelling sizes with more bedrooms. The ABS sample includes all housing types including small dwellings such as flats and units. The mean building envelope construction cost for this sample was calculated to be $179,086 ($717.40/ m²). A build cost range of $120,750–$276,050 was found across the 6 star house designs analysed. The mean building envelope construction cost for 6 star performance forms the basis for cost calculations throughout the rest of the chapter.

House plans were sourced from builders, developers, the internet and other public sources. In order to ensure house plans were not ‘one off’ designs, only sources with multiple house plans were selected. Based on this approach, a sample of 100 plans was selected for initial analysis. Figure 16 provides a schematic example of two plans from this initial sample.
A balance between research resource constraints and an acceptable margin of error for the sample size had to be considered. A margin of error is a measurement of the accuracy of the results; the lower the margin of error, the more accurate the results. The 100 house plans were modelled in AccuRate, software approved by the Nationwide House Energy Rating Scheme. They then underwent an initial analysis of key characteristics (floor area, wall to floor ratio, external wall area and total area of glazing) to ensure a representative sample of housing was selected. The analysis determined an acceptable margin of error and therefore sample size. Through this approach, it was determined that a margin of error of 7% for single storey houses and 15% for double storey houses would be accepted, given resource constraints (Figure 17).

The primary resource constraint being the availability of house plans from bulk-builders. A smaller sample of double storey house plans was obtained by the time when the modelling analysis was required to begin. As such, the margin of error is larger for the double storey house plans. Despite several attempts, no further double storey house plans were forthcoming from the building industry in Victoria. However, when compared to previous ZEH research, the total number of house plans included for analysis is significantly greater.

Samples of 62 single-storey plans and 18 double-storey plans were then randomly selected from the initial sample selection for analysis.
5.5.1.3 Base case modelling

Each house plan was initially modelled ‘as is’ using the AccuRate software to achieve minimum energy performance standards. At the time of analysis in 2009, the minimum energy performance standard was 5 star. The minimum regulatory requirements at the time of submission of this thesis (2012) had subsequently changed to 6 star. As will be explained later, adjustments were made to the methodology to account for this change in standards. Each house plan was modelled to meet the ‘deemed to satisfy’ criteria as set out in the Building Code of Australia (ABCB, 2009a).

AccuRate allows the calculation of heating and energy load requirements for the modelled house based upon climate, orientation, materials and inbuilt assumptions regarding occupant behaviour. The software has been validated through BESTEST (Delsante, 2004). It should be noted that concerns regarding the use of the software have been raised, particularly the assumptions used for occupant behaviour for heating and cooling energy loads (Saman, et al, 2008). However, as occupant behaviour falls outside the scope of this research, it was decided to use the default occupant behaviour settings in the software. These default assumptions are described in Table 8 and are based on the Protocol for House Energy Rating Software published by the Australian Building Codes Board (ABCB, 2009a).
Table 8: AccuRate default setting and implicit study assumptions (ABCB, 2009a).

<table>
<thead>
<tr>
<th>Thermal zone</th>
<th>AccuRate default settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living spaces (including kitchens and other spaces typically used during the waking hours)</td>
<td>Default settings for sensible and latent heat loads take account of appliances and cooking, lighting and people, with suitable adjustments for the house size and the area of each space. Heating and cooling available from 0700 to 2400. Heating thermostat setting of 20(°C)</td>
</tr>
<tr>
<td>Living spaces (that do not include a kitchen)</td>
<td>Default settings for sensible and latent heat loads; take account of lighting and people, with suitable adjustments for the house size and the area of each space.</td>
</tr>
<tr>
<td>Sleeping spaces (including bedrooms, bathrooms and dressing rooms, or other spaces closely associated with bedrooms)</td>
<td>Heating and cooling being available from 1600 to 0900. Heating thermostat setting of 18(°C) from 0700 to 0900 and from 1600 to 2400, and a heating thermostat of 15(°C) from 2400 to 0700.</td>
</tr>
<tr>
<td>All conditioned zones</td>
<td>Cooling default settings, For climate zone 60, cooling thermostat settings are set at 24(°C) for air conditioned spaces. The cooling initiation is based on the Effective Temperature method of calculating thermal comfort and includes the effect of air movement in that space.</td>
</tr>
</tbody>
</table>

As discussed in chapter 1, a number of important design and material principles contribute towards the energy performance of a dwelling. These have been identified in the literature and by the wider building industry. One such contributor is orientation. By orienting a dwelling to maximise the winter sun and minimise summer sun impacts, the requirement for mechanical heating and cooling is reduced compared to an equivalent non-oriented dwelling. The house plans in this research were modelled to optimal orientation. This allowed for a reduction in material requirements and, in turn, reduced building costs to achieve set building standards.

To ensure consistency across the analysis, assumptions were made about material choice based upon typical building characteristics in 2009/2010 for new housing in Melbourne. Table 9 provides details on design parameters assumed for the initial 5 star house modelling.

Table 9: Design parameters applied.

<table>
<thead>
<tr>
<th>Element</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>External wall</td>
<td>Brick veneer (single sided reflective foil on outside of frame)</td>
</tr>
<tr>
<td>Windows</td>
<td>Aluminium standard single glazed clear glass (U=7.32, SHGC = 0.77)</td>
</tr>
<tr>
<td>Floor</td>
<td>Concrete slab 100mm, carpet/bare</td>
</tr>
<tr>
<td>Ceiling</td>
<td>Plasterboard 13mm / glass fibre batt R2.5</td>
</tr>
<tr>
<td>Internal wall</td>
<td>Plasterboard on studs</td>
</tr>
<tr>
<td>Roof</td>
<td>Metal deck</td>
</tr>
</tbody>
</table>

Each house plan was accompanied by estimated costs for the initial 5 star house. This cost was taken as the starting point for the cost of the dwelling. Additional costs incurred through performance improvements and adjustments to a 6 star baseline performance scenario were added to these initial costs.
5.5.1.4 Building envelope systematic upgrades

A systematic approach to material additions was developed, with a clear hierarchy of additions defined. Reference was made to materials and building literature, in particular to publications by the Insulation Council of Australia and New Zealand (ICANZ, 2008) and Wilrath (1997) as well as to the Building Code of Australia (ABCB, 2009a). Performance scenarios were developed by systematically upgrading ceiling insulation, infiltration control, shading, external wall insulation, window glazing and internal wall insulation. The process of upgrading various elements was selected based on a compromise between practical price considerations and the ability to positively influence thermal performance for each star level. Table 10 presents these systematic upgrades. Not every upgrade had to be applied to reach each improved star rating performance, and in some cases, some house models required elements from the next star rating level to achieve the stated thermal performance standard.

Table 10: Systematic material upgrades typical for each star rating performance.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>6 star</strong></td>
<td>R2.5</td>
<td>Windows &amp; doors</td>
<td>Roller shutters</td>
<td>R1.0</td>
<td>Standard Single glazing</td>
<td>Plasterboard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>weatherstripped</td>
<td></td>
<td></td>
<td></td>
<td>R2.0 to garage</td>
</tr>
<tr>
<td><strong>7 star</strong></td>
<td>R3.0</td>
<td>Windows &amp; doors</td>
<td>Roller shutters</td>
<td>R2.5</td>
<td>Standard double glazing</td>
<td>Plasterboard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>weatherstripped</td>
<td></td>
<td></td>
<td></td>
<td>R2.5 to utilities and garage</td>
</tr>
<tr>
<td><strong>8 star</strong></td>
<td>R6.0</td>
<td>Windows &amp; doors</td>
<td>Roller shutters</td>
<td>R3.0</td>
<td>Standard double glazing</td>
<td>R2.5 all rooms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>weatherstripped</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>9 star</strong></td>
<td>R8.0</td>
<td>Windows &amp; doors</td>
<td>Roller shutters</td>
<td>R3.0</td>
<td>Improved double glazing</td>
<td>R2.5 all rooms</td>
</tr>
<tr>
<td></td>
<td>Floor insulation</td>
<td>R2.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>weatherstripped</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>10 star</strong></td>
<td>R8.0</td>
<td>Windows &amp; doors</td>
<td>Roller shutters</td>
<td>R4.0 extruded</td>
<td>Supertoned double glazing</td>
<td>R2.5 all rooms</td>
</tr>
<tr>
<td></td>
<td>Floor insulation</td>
<td>R4.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Material additions were recorded at each stage of material intervention, for each house plan at each star rating increment from 5 star to 10 star. These data, recorded in square metre quantities were entered into SPSS (a statistics computer program) to allow for cost calculation, as discussed in the next section.

5.5.1.5 Material upgrade costing

Costs were obtained through a triangulation approach. Firstly, *Rawlinsons Australian Construction Handbook* (Rawlinsons, 2009) was consulted, and costs in $/m² for material additions were obtained. Because Rawlinsons’ data are reflective of prices at the individual building level and are not reflective of rates in the volume build industry, these data were then further manipulated. The list of materials was reviewed by an independent building estimator who provided build and material costs for many of the materials based upon 2009/2010 bulk buying costs. While the building estimator costs were typically lower than those provided in Rawlinsons, a number of elements, such as roller shutters and glazing, were not priced by the building estimator and so Rawlinsons data was used in these cases. Finally, an industry expert was consulted to review the final costs and to highlight discrepancies and suggest adjustments to final cost figures. Due to RMIT ethics guidelines, the identities of both the independent building estimator and building industry expert can not be named. The final costs applied in this modelling have been presented in several peer reviewed journal and conference papers (Morrissey & Horne, 2011; Morrissey, et al, 2011).

Costs obtained through this triangulation method were then extrapolated to provide the total cost for each of the house plans at each performance scenario, using the template presented in Table 11. Recorded data were then analysed to provide the cost difference to upgrade the base case 5 star scenario to each improved thermal performance scenario modelled.

### Table 11: Template to calculate cost of upgrade elements.

<table>
<thead>
<tr>
<th>Quantity m²</th>
<th>External wall insulation</th>
<th>Ceiling insulation</th>
<th>Glazing</th>
<th>Weather stripping</th>
<th>Roller shutters</th>
<th>Internal wall insulation</th>
<th>Floor insulation</th>
<th>External wall construction</th>
<th>Internal wall construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average cost ($)/m²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL COST ($)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

90
Upgrade costs per house for each star rating increase were then averaged to provide a star rating upgrade cost. These data were used in the through-life costing as described in the next section. Due to the change in minimum regulations from 5 star to 6 star occurring mid project, data were adjusted in subsequent analysis to reflect a base case scenario of 6 star. Five star modelling outputs were removed from the analysis at this point.

5.4.2 Through-life costing

This section describes the approach taken to determine the through-life costs and benefits of zero operation emission (and intermediate) housing scenarios for an owner-occupied dwelling. This approach builds upon the house modelling and costing work presented in the previous section. The following sections explore the building envelope thermal upgrade, ZEH and intermediate scenarios developed for the analysis, including the assumptions used within the modelling.

5.4.2.1 Building envelope thermal scenarios

The first part of the through-life costing involved assessing the costs and benefits of building envelope thermal upgrades, from 6 star (BAU) to 10 star in one star increments. This approach was required to assess the feasibility of reducing heating and cooling energy requirements, and therefore total household energy consumption, based upon current materials and costs. This approach fits with the discussion from chapter 1 and the wider literature, whereby the aim of ZEH is to first reduce total energy consumption and improve energy efficiency where possible and then offset remaining energy consumption with renewable energy generation in a cost efficient manner (AGO, 2010a; Vale & Vale, 2000). This approach helps to reduce renewable energy technology requirements and in turn required resources. In Australia and internationally, significant research has been undertaken to determine the most cost efficient ways to reduce carbon, as presented in Figure 18. There are a number of approaches which are ‘cost negative’ to society, such as building insulation.
Household energy consumption was calculated for each of the star rating scenarios for an electric house and an electric (cooling and appliances)/gas (heating, cooking and hot water) house (detailed in section 5.4.3.1); from herein, electric/gas refers to electric cooling and appliances in addition to gas heating, cooking and hot water, unless otherwise specified.

Annual dwelling energy consumption was then applied to current and projected energy prices (detailed in section 5.4.3.4) to determine operational energy costs of the various star rating scenarios across time. The additional capital cost for the building envelope scenarios, as calculated in the previous section, was applied to the modelling to assess the through-life costs and benefits of improved building envelope thermal performance across the life of the house (40+ years; life of house applied in the modelling is discussed in section 5.4.3.6). The results provided an optimal cost-benefit star rating performance which new detached housing should be built to in Victoria. This then was applied as the minimum star rating applied in the ZEH scenarios.

5.4.2.2 ZEH scenarios

After the minimum building envelope thermal performance was determined, ZEH scenarios were developed. A number of additional elements were required to develop the improved building
envelope scenarios into ZEH scenarios. Specifically, renewable energy technologies, and associated costs, to offset remaining energy consumption were required for the ZEH analysis to achieve annual net zero energy emissions. Additional elements for analysis included various combinations of renewable energy technologies, rebates, feed-in tariffs and energy provision (gas/electricity). The aim was to select elements and develop scenarios which were typical of existing approaches to energy provision and ZEH. For example the majority of energy provision in housing in Victoria is either from electricity or gas (DEWHA, 2008b). These elements and their inclusion in this analysis are discussed in detail in section 5.4.3.

Table 12 shows the framework for the ZEH modelling options following this approach. As a result, 81 ZEH scenarios were developed.

<table>
<thead>
<tr>
<th>Energy provision</th>
<th>Sub options 1</th>
<th>Sub options 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All electric</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onsite PV</td>
<td>Hot water from solar hot water (SHW)</td>
<td></td>
</tr>
<tr>
<td>Near site RE farm</td>
<td>Hot water from SHW</td>
<td></td>
</tr>
<tr>
<td>Green energy</td>
<td>Hot water from SHW</td>
<td></td>
</tr>
<tr>
<td>Onsite PV without rebates or feed in tariffs</td>
<td>Hot water from SHW</td>
<td></td>
</tr>
<tr>
<td><strong>Gas/electric</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onsite PV</td>
<td>Gas hot water – gas carbon offset</td>
<td>Hot water from SHW (electric and gas boosted)</td>
</tr>
<tr>
<td>Near site RE farm</td>
<td>Gas hot water – gas carbon offset</td>
<td>Hot water from SHW (electric and gas boosted)</td>
</tr>
<tr>
<td>Green energy</td>
<td>Gas hot water – gas carbon offset</td>
<td>Hot water from SHW (electric and gas boosted)</td>
</tr>
<tr>
<td>Onsite PV without rebates or feed in tariffs</td>
<td>Gas hot water – gas carbon offset</td>
<td>Hot water from SHW (electric and gas boosted)</td>
</tr>
</tbody>
</table>

In addition to the 81 ZEH scenarios, 16 intermediate performance scenarios were developed. These scenarios were developed to analyse incremental improvements from the current BAU approach (6 star) and the economically optimal (lowest through-life accumulated costs after 60 years) ZEH scenario. The intermediate scenarios involved building envelope thermal improvements with small amounts of renewable energy technologies (1.0kW or 2.5kW onsite PV, with and without SHW) (Table 13). These scenarios did not contain sufficient renewable energy technologies to cover annual energy requirements. As such, remaining energy consumption was assumed to be purchased normally through the grid.
Chapter 5: Research design

Table 13: Framework for intermediate scenarios.

<table>
<thead>
<tr>
<th>Energy provision</th>
<th>Star rating</th>
<th>Onsite PV size (kW)</th>
<th>Hot water system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric/gas</td>
<td>7</td>
<td>1.0</td>
<td>SHW (gas boost)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gas hot water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.5</td>
<td>SHW (gas boost)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gas hot water</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.0</td>
<td>SHW (gas boost)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gas hot water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.5</td>
<td>SHW (gas boost)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gas hot water</td>
</tr>
</tbody>
</table>

The purpose of these scenarios was to explore the costs and benefits of possible step-change policy approaches on a transition to ZEH regulations. This draws upon the policy approach undertaken by the UK government, which developed a number of intermediate steps in their transition to ZEH regulations.

5.4.2.3 Model development

Microsoft Excel 2010 was used to develop a database for the through-life cost-benefit analysis. The database was designed with variables (e.g. building envelope upgrades, renewable energy technologies) listed vertically under each scenario and the through-life costs and benefits of the variables (e.g. capital costs, technology replacement costs, feed in tariffs) listed horizontally for each scenario (Figure 19). This approach draws upon methods described by Campbell and Brown (2003).

At year one, costs included the base case construction and capital upgrade costs for higher thermal performance of the housing building envelope. For building envelope upgrade only scenarios additional costs include yearly energy costs and hot water replacement costs. The ZEH scenarios, included capital and replacement costs for various renewable energy technologies and in scenarios where gas was used, offsets were applied (refer to section 5.4.3.2 for more detail). Depending on the scenario, annual cost inputs (after initial costs) may not have occurred for a number of years until the point where technology replacement is required.
<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>8 star per year electricity cost LOW</td>
<td>1404</td>
<td>1460</td>
<td>1519</td>
<td>1580</td>
<td>1627</td>
<td>1692</td>
<td>1760</td>
<td>1830</td>
<td>1903</td>
<td>1978</td>
<td>2056</td>
<td>2137</td>
<td>2217</td>
<td>2261</td>
</tr>
<tr>
<td>55</td>
<td>8 star per year electricity cost HIGH</td>
<td>1404</td>
<td>1590</td>
<td>1787</td>
<td>1994</td>
<td>2164</td>
<td>2278</td>
<td>2363</td>
<td>2469</td>
<td>2560</td>
<td>2656</td>
<td>2773</td>
<td>2876</td>
<td>2982</td>
<td>2982</td>
</tr>
<tr>
<td>56</td>
<td>8 star upfront cost</td>
<td>8154</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>8 star solar pv costs</td>
<td>18489</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>8 star inverter costs (included with system replacement)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>59</td>
<td>8 star solar hot water costs</td>
<td>4404</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>8 star other costs (feed in tariff)</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>61</td>
<td>2 - 8 star BAU accumulation costs LOW</td>
<td>13962</td>
<td>15422</td>
<td>16941</td>
<td>18521</td>
<td>20148</td>
<td>21840</td>
<td>23600</td>
<td>25430</td>
<td>27333</td>
<td>29310</td>
<td>31367</td>
<td>33504</td>
<td>35765</td>
<td>35765</td>
</tr>
<tr>
<td>62</td>
<td>2 - 8 star BAU accumulation costs HIGH</td>
<td>13962</td>
<td>15552</td>
<td>17339</td>
<td>19333</td>
<td>21497</td>
<td>23776</td>
<td>26139</td>
<td>28607</td>
<td>31168</td>
<td>33823</td>
<td>36596</td>
<td>39472</td>
<td>42454</td>
<td>42454</td>
</tr>
<tr>
<td>63</td>
<td>2 - 8 star ZEH (onsite solar PV) yearly cost</td>
<td>31046</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
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<td>-1</td>
</tr>
<tr>
<td>64</td>
<td>2 - 8 star ZEH (onsite solar PV) accumulation cost</td>
<td>31046</td>
<td>31045</td>
<td>31044</td>
<td>31043</td>
<td>31042</td>
<td>31041</td>
<td>31041</td>
<td>31041</td>
<td>31041</td>
<td>31041</td>
<td>31041</td>
<td>31041</td>
<td>35341</td>
<td>35341</td>
</tr>
<tr>
<td>65</td>
<td>2 - 8 star ZEH (onsite solar PV) accumulation cost</td>
<td>31046</td>
<td>31045</td>
<td>31044</td>
<td>31043</td>
<td>31042</td>
<td>31041</td>
<td>31041</td>
<td>31041</td>
<td>31041</td>
<td>31041</td>
<td>31041</td>
<td>31041</td>
<td>35341</td>
<td>35341</td>
</tr>
<tr>
<td>67</td>
<td>9 star per year electricity cost LOW</td>
<td>1337</td>
<td>1391</td>
<td>1447</td>
<td>1505</td>
<td>1550</td>
<td>1612</td>
<td>1676</td>
<td>1743</td>
<td>1812</td>
<td>1884</td>
<td>1958</td>
<td>2038</td>
<td>2134</td>
<td>2134</td>
</tr>
<tr>
<td>68</td>
<td>9 star per year electricity cost HIGH</td>
<td>1337</td>
<td>1515</td>
<td>1702</td>
<td>1899</td>
<td>2061</td>
<td>2170</td>
<td>2251</td>
<td>2351</td>
<td>2439</td>
<td>2529</td>
<td>2641</td>
<td>2739</td>
<td>2840</td>
<td>2840</td>
</tr>
<tr>
<td>69</td>
<td>9 star upfront cost</td>
<td>25367</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>9 star solar pv costs</td>
<td>17545</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>71</td>
<td>9 star inverter costs (included with system replacement)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>9 star solar hot water costs</td>
<td>4404</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>9 star other costs (feed in tariff)</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
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<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
</tr>
<tr>
<td>74</td>
<td>2 - 9 star BAU accumulation costs LOW</td>
<td>31108</td>
<td>32499</td>
<td>33946</td>
<td>35451</td>
<td>37000</td>
<td>38612</td>
<td>40288</td>
<td>42031</td>
<td>43843</td>
<td>45727</td>
<td>47686</td>
<td>49721</td>
<td>51875</td>
<td>51875</td>
</tr>
<tr>
<td>75</td>
<td>2 - 9 star BAU accumulation costs HIGH</td>
<td>31108</td>
<td>32623</td>
<td>34325</td>
<td>36224</td>
<td>38286</td>
<td>40455</td>
<td>42706</td>
<td>45058</td>
<td>47456</td>
<td>50026</td>
<td>52667</td>
<td>55406</td>
<td>58246</td>
<td>58246</td>
</tr>
<tr>
<td>76</td>
<td>2 - 9 star ZEH (onsite solar PV) yearly cost</td>
<td>47314</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
</tr>
<tr>
<td>77</td>
<td>2 - 9 star ZEH (onsite solar PV) accumulation cost</td>
<td>47314</td>
<td>47311</td>
<td>47309</td>
<td>47306</td>
<td>47304</td>
<td>47301</td>
<td>47301</td>
<td>47301</td>
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<td>47301</td>
<td>51601</td>
<td>51601</td>
<td>51601</td>
<td>51601</td>
</tr>
</tbody>
</table>

Figure 19: ZEH modelling data base screen shot.
The database provided a number of outcomes. These included:

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulated costs</td>
<td>Total costs across the set time-horizon and include all capital costs, any maintenance or replacement costs and yearly energy costs/savings.</td>
</tr>
<tr>
<td>Optimal technical balance</td>
<td>Establishes the balance between improving the building envelope (which primarily addresses heating and cooling energy) and the use of renewable energy technologies (to backfill remaining energy) based upon economic outcomes.</td>
</tr>
<tr>
<td>Energy savings compared to BAU</td>
<td>Calculates the difference between average energy consumption per household and that of a ZEH from the improved building envelope.</td>
</tr>
<tr>
<td>Net Present Value (NPV)</td>
<td>A calculation of cash flow over time (including inputs and outputs).</td>
</tr>
<tr>
<td>Environmental benefits</td>
<td>Calculates the reduction in CO$_2$e from a ZEH compared to a BAU approach.</td>
</tr>
<tr>
<td>Impact to household cash flows</td>
<td>Uses the additional capital cost to achieve a ZEH and the ongoing economic savings to analyse the impact to the household, primarily in terms of mortgage requirements.</td>
</tr>
</tbody>
</table>

### 5.4.3 Data assumptions

This section begins by detailing the process of calculating household energy consumption, followed by ZEH technical requirements, current and future energy prices of renewable energy technologies and energy markets, discount and inflation rates, timeframes, resale value, environmental benefits and electricity grid assumptions.

#### 5.4.3.1 Household energy consumption

Household energy consumption is linked to a number of different factors, including the age of house, construction type, size and layout of the house, number of heated/cooled rooms, number of occupants, occupation habits, energy provision and climate zone (DEWHA, 2008b; Newton, 2011; Newton & Meyer, 2012; Vale & Vale, 2009; Vringer, et al, 2007). The variability of these factors means that it is difficult to identify an average household energy consumption figure.

The Australian Government has data for total energy consumption by appliance and energy source, along with penetration rates for each technology type for the residential sector by state in Australia, (DEWHA, 2008b). These data were extrapolated to generate ‘average’ energy consumption for cooking, hot water and appliance energy consumption for both gas (where appropriate) and electric energy provision. The energy requirement for heating and cooling was derived directly from the AccuRate software across the 80 modelled houses.

Two main energy provision scenarios were applied in the modelling to the various scenarios, based on typical energy provision for new housing in Melbourne (DEWHA, 2008b). The first scenario was an electric/gas house and the second was a full electric house (with solar hot water electric boost due to phasing out of electric hot water systems currently occurring in Australia.
The average energy consumption for these scenarios will now be detailed.

For energy scenario one, the AccuRate modelling calculated an average heating (gas) energy requirement of 21,538 MJ/year and a cooling (electric) requirement of 186 kWh/year (6 star). Extrapolation from the Energy use in the Australian Residential Sector 1986–2020 Department of Environment, Water, Heritage and Arts (DEWHA) (2008b) report resulted in energy consumptions of 14,020 MJ/year for water heating (gas) and 3,260 MJ/year for cooking (gas). Electricity consumption for appliances and equipment use was calculated to be 4,310 kWh/year. This resulted in a total for gas of 38,818 MJ/year and 4,496 kWh/year of electricity for an electric/gas house scenario (Table 15).

The second energy scenario was calculated from the AccuRate modelling to have an average heating and cooling electricity consumption of 1,210 kWh/year (6 star). Based upon the DEWHA (2008b) data, energy consumption was calculated to be 3010 kWh/year for hot water, 500 kWh/year for cooking and 4310 kWh/year for appliance and equipment use. This gave a total of 9030 kWh/year (6 star) (Table 15).

Table 15: Average household energy consumption for new 6 star Melbourne homes.

<table>
<thead>
<tr>
<th>House energy scenario</th>
<th>Electricity (kWh/yr)</th>
<th>Gas (MJ/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas/electric</td>
<td>4,496</td>
<td>38,818</td>
</tr>
<tr>
<td>Full electric</td>
<td>9,030</td>
<td>0</td>
</tr>
</tbody>
</table>

When converted from MJ to kWh, the gas component of the gas/electric scenario equates to 10,782 kWh. This compares to 4,720 kWh of the full electric house for the same elements. This difference is due to the different gas efficiencies applied within the modelling. Details of the efficiencies of gas appliances included in the modelling can be found in the DEWHA (2008b) Energy use in the Australian residential sector 1986 – 2020 report.

Due to the lack of information regarding future household energy consumption projections, it was assumed that household energy consumption (including occupant behaviour and energy use practices) would remain constant throughout the through-life cycle modelled. Similarly, it was assumed that appliance use and appliance energy efficiency would remain consistent throughout the modelling. For example, it is projected that appliance numbers per house will continue to grow but that this trend will be offset in part by gains in energy efficiency (Pears, 2007).

5.4.3.2 ZEH technical requirements

Based upon the above household energy consumption data, ZEH renewable energy technology requirements were determined. Initial renewable energy requirements were calculated for an onsite PV system and then adjusted for other combinations of renewable energy technology. Based upon a
1kW PV system producing an average of 4kWh of electricity per day in Melbourne (Moore & Hamilton, 2008), total renewable energy requirements were calculated (Table 16 and Table 17). PV system sizes ranged from 3.0–6.2kWs and were larger for the full electric house scenarios. Improved star rating performance typically reduced size requirements for PV. Note that the renewable energy system’s size requirements were calculated to offset electricity consumption only; gas consumption was offset with the purchasing of carbon offsets, as explored later in the chapter.

Table 16: Energy consumption breakdown and PV system size requirement (for offsetting electricity only) for gas/electric house.

<table>
<thead>
<tr>
<th></th>
<th>6 star</th>
<th>7 star</th>
<th>8 star</th>
<th>9 star</th>
<th>10 star</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electricity (kWh/yr)</td>
<td>Gas (MJ/yr)</td>
<td>Electricity (kWh/yr)</td>
<td>Gas (MJ/yr)</td>
<td>Electricity (kWh/yr)</td>
</tr>
<tr>
<td>Heating</td>
<td>0</td>
<td>21,539</td>
<td>0</td>
<td>15,608</td>
<td>0</td>
</tr>
<tr>
<td>Water heating</td>
<td>0</td>
<td>14,020</td>
<td>0</td>
<td>14,020</td>
<td>0</td>
</tr>
<tr>
<td>Cooking</td>
<td>0</td>
<td>3,260</td>
<td>0</td>
<td>3,260</td>
<td>0</td>
</tr>
<tr>
<td>Cooling</td>
<td>186</td>
<td>0</td>
<td>135</td>
<td>0</td>
<td>86</td>
</tr>
<tr>
<td>Other</td>
<td>4,310</td>
<td>0</td>
<td>4,310</td>
<td>0</td>
<td>4,310</td>
</tr>
<tr>
<td>Total PV systems</td>
<td>4,496</td>
<td>38,819</td>
<td>4,445</td>
<td>32,888</td>
<td>4,396</td>
</tr>
<tr>
<td>size required</td>
<td>3.1</td>
<td>-</td>
<td>3.1</td>
<td>-</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Table 17: Energy requirement breakdown for full electric house.

<table>
<thead>
<tr>
<th></th>
<th>6 star (kWh/yr)</th>
<th>7 star (kWh/yr)</th>
<th>8 star (kWh/yr)</th>
<th>9 star (kWh/yr)</th>
<th>10 star (kWh/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating and cooling</td>
<td>1,210</td>
<td>877</td>
<td>561</td>
<td>263</td>
<td>18</td>
</tr>
<tr>
<td>Water heating</td>
<td>3,010</td>
<td>3,010</td>
<td>3,010</td>
<td>3,010</td>
<td>3,010</td>
</tr>
<tr>
<td>Other</td>
<td>4,810</td>
<td>4,810</td>
<td>4,810</td>
<td>4,810</td>
<td>4,810</td>
</tr>
<tr>
<td>Total</td>
<td>9,030</td>
<td>8,697</td>
<td>8,381</td>
<td>8,083</td>
<td>7,838</td>
</tr>
<tr>
<td>PV systems size required</td>
<td>6.2</td>
<td>6</td>
<td>5.8</td>
<td>5.6</td>
<td>5.4</td>
</tr>
</tbody>
</table>

The following section will explore in detail the various renewable energy technology options that were applied in the ZEH scenarios.

5.4.3.3 Current and future costs of renewable energy technologies

While a number of renewable energy technologies are potentially available for use in buildings, only a limited number are currently both practical and cost effective enough to be integrated into a
domestic setting (IEA, 2008a; Sivaraman & Horne, 2011). For example, hydro energy generation requires a far larger body of water than is practical in a domestic setting.

This research draws upon the approach underpinning the UK ZEH policy development, where renewable energy technologies should be located onsite whenever practical. From the literature, PV and SHW have been identified as the most common of all renewable energy technologies currently installed at a dwelling level within the Australian context (ABS, 2010b). However it is also documented in the literature that cost efficiencies can be achieved for larger scale renewable energy technologies located offsite (Hearps & McConnell, 2011). To account for this, one renewable energy scenario (near site) did allow for other renewable energy generation technologies as discussed below.

For this research four main renewable energy technology options were modelled:

1. Onsite PV,
2. Onsite PV without rebates or a feed in tariff (PV without R/FIT),
3. Near site renewable energy (RE), and
4. Green power

All these options were modelled with and without SHW provision.

**Onsite PV and SHW**

The technology used onsite included:

- PV panels,
- SHW system unit and panels, and
- an inverter.

The costs for onsite PV systems, inverters and SHW, as well as base case gas hot water systems were determined by obtaining costs from a number of Melbourne retailers and local buyers guide reviews. These costs were averaged across different brands and sizes to generate a standardised cost/kW (Table 18). An operation and maintenance cost for all PV, inverters, SHW and gas hot water systems of 1% of capital costs/year was added at time of purchase as discussed within the literature (IEA, 2010b; Lazou & Papatsoris, 2000).
Chapter 5: Research design

Table 18: Costs of onsite renewable energy options and traditional hot water technology including maintenance costs.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Size</th>
<th>Cost ($)</th>
<th>Warranty</th>
<th>Assumed replacement frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV – grid connected (GC)*</td>
<td>Various</td>
<td>5,140/kW</td>
<td>25–30 years</td>
<td>30 years ***</td>
</tr>
<tr>
<td>Inverter GC – small**</td>
<td>0–2 kW</td>
<td>2,200/unit</td>
<td>2–10 years</td>
<td>10 years</td>
</tr>
<tr>
<td>Inverter GC – medium**</td>
<td>2.01kW–4kW</td>
<td>3,165/unit</td>
<td>2–10 years</td>
<td>10 years</td>
</tr>
<tr>
<td>Inverter GC – large**</td>
<td>4.01+kw</td>
<td>3,855/unit</td>
<td>2–10 years</td>
<td>10 years</td>
</tr>
<tr>
<td>SHW – gas boost**</td>
<td>300L</td>
<td>6,852/system</td>
<td>5–12 years</td>
<td>15 years</td>
</tr>
<tr>
<td>SHW – electric boost**</td>
<td>300 L</td>
<td>5,504/system</td>
<td>5–12 years</td>
<td>15 years</td>
</tr>
<tr>
<td>Gas hot water</td>
<td>Continuous flow</td>
<td>1,129/system</td>
<td>5–8 years</td>
<td>10 years</td>
</tr>
</tbody>
</table>

*Includes cost of inverter and installation.
** Includes cost of installation.
*** While the capital cost of the PV system includes an inverter, the life of the inverter is only 10 years and as such is replaced in the model every 10 years with one of the inverters listed from the table.

There is no certainty within the literature about the future evolution of renewable energy technologies in terms of both energy generation (efficiency and capacity) and new innovations (Parida, Iniyan, & Goic, 2011). Therefore when technologies were replaced at end of life throughout the modelling, it was assumed that their energy generation performance remains as it did in 2011. However, improvements to existing technology and new technology innovation will likely result in changes to technology requirements in future years. By assuming these changes do not occur, the modelling in effect presents a ‘worst case’ scenario.

The only assumption made to replacement technologies was that a learning curve of 18% cost reduction for each doubling of production would be applied, as used by International Energy Authority modelling (IEA, 2007, 2010b). This was calculated applying historical and current data regarding the supply and installation of PV systems as presented by the International Energy Agency (2007, 2010b). Predicted growth of PV globally was obtained from the International Energy Agency who predicted that total installed PV capacity would increase at about 13% per year between 2008-2035 (IEA, 2010b). This growth rate was assumed to continue throughout the modelling time-horizon due to the lack of any growth predictions beyond this time. This provided the basis for providing information on when the doubling of production of PV would occur.

In addition, it was assumed that there were no efficiency losses over time of installed renewable energy technologies. In reality, warranties for PV systems typically guarantee that over the 25–30 year lifespan of the system, efficiency losses will be no more than 10–20%. However, to ensure consistency between technologies applied within the modelling, the energy generation performance was kept consistent throughout the life of the technology. This is a limitation of this research.

For traditional gas hot water systems, no learning factor was applied. This was based upon saturation of gas hot water systems in Victoria being over 50% (69%) (DEWHA, 2008b) meaning...
that cost efficiencies for innovation decreased, as discussed in the innovation diffusion literature (Rogers, 2003).

At the time of this study, government rebates for renewable energy technologies were available. Table 19 shows the rebates that different size PV systems received in Victoria in October 2011, based upon $28 per credit. Credits have been set based upon PV system size as a measuring tool for the government rebate. The larger the system size, the more credits are available and, in turn, the greater the total rebate. These rebates are not guaranteed into the future, so have only been applied in modelling to the initial purchase of the renewable energy technologies. A feed-in tariff of 25c/kWh for excess energy exported back to the electricity grid was available in Victoria for new renewable energy systems from mid-2011. This was guaranteed for a period of 5 years and has been applied where appropriate. In addition, a rebate of $1,100 was applied to SHW systems. Rebates for SHW systems varied slightly depending on brand and performance and so an average rebate was assumed.

**Table 19: Cost reduction from rebates for different size PV systems for Melbourne in 2011.**

<table>
<thead>
<tr>
<th>PV system size (kW)</th>
<th>No. of renewable energy credits</th>
<th>Total rebate ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53</td>
<td>1,484</td>
</tr>
<tr>
<td>1.5</td>
<td>79</td>
<td>2,212</td>
</tr>
<tr>
<td>2</td>
<td>88</td>
<td>2,464</td>
</tr>
<tr>
<td>2.5</td>
<td>97</td>
<td>2,716</td>
</tr>
<tr>
<td>3</td>
<td>106</td>
<td>2,968</td>
</tr>
<tr>
<td>3.5</td>
<td>115</td>
<td>3,220</td>
</tr>
<tr>
<td>4</td>
<td>124</td>
<td>3,472</td>
</tr>
<tr>
<td>4.5</td>
<td>133</td>
<td>3,724</td>
</tr>
<tr>
<td>5</td>
<td>142</td>
<td>3,976</td>
</tr>
<tr>
<td>5.5</td>
<td>151</td>
<td>4,228</td>
</tr>
<tr>
<td>6</td>
<td>160</td>
<td>4,480</td>
</tr>
</tbody>
</table>

The onsite renewable energy scenarios assumed that there was sufficient roof space (including garage) to fit the renewable energy technologies. According to the *Your Home Technical Manual* (AGO, 2010b), a 1kW PV system requires 9m² of roof space. Based upon the largest PV size used in this modelling (a 6.2kW system), the required roof space area would be 56m² which is significantly less than the total roof space available within the house plans modelled (based upon floor space). It was further assumed that PV and SHW panels were mounted for maximum efficiency, facing north, and were not impeded by shading (Kellett, 2011). This builds upon the requirement to orientate the house to maximise the thermal performance from the sun.
Near site renewable energy

Near site RE refers to renewable energy that is generated away from the site where it is consumed. Renewable energy of this type is based upon the buying power and ownership of a community rather than an individual household. This allows for improved economic efficiencies to be gained and can minimise technology required per dwelling through sharing of resources. Community owned RE is not a new concept and has already been implemented successfully in some communities, most notably in Denmark and Germany through community wind farms (NCCNSW, 2010). In Australia, the Hepburn Wind project in Victoria provides a local example of community renewable energy (Hicks & Ison, 2011).

Unlike onsite PV options, this near site RE approach allows for a household’s exact energy requirement to be purchased. For this modelling, the RE is assumed to be purchased as an upfront block when the house is built. It was assumed that there was a 30 year life span before technology was required to be replaced, consistent with International Energy Agency modelling (Jay & Morad, 2005).

Costs of near site renewable energy generation were calculated from costs for wind farms and solar farms built since 2005 within Australia. In total, 13 off-site RE farms were selected for inclusion in analysis. Costs were obtained from DEWHA (Commonwealth of Australia, 2009) and from Solar Systems (Solar Systems, 2006). The average electricity generation cost, including a 2.8% operation and maintenance premium/kW (Markusson, Kern, & Watson, 2011), was $4,255/kW across the 13 RE farms; this was assumed to be the cost/kW for the base year (2011). This figure assumes that the cost of infrastructure and any land rental/purchase is covered in the capital costs reported within the DEWHA data. The higher operation and maintenance cost over onsite PV and SHW are due to higher costs associated with wind farm maintenance compared to PV. The International Energy Agency also found a learning rate of 13.03% for near site PV, which was applied for future cost predictions (IEA, 2010b).

Green energy

In this research, green energy refers to both green electricity and green gas. It is the provision of renewable energy through traditional means, by purchasing through current energy retailers. This renewable energy typically attracts a premium energy cost on top of normal energy costs. The purchase of green energy, while being able to achieve a ZEH standard, does not fit within the definition of ZEH as applied in this research, nor does it meet the requirement for deep structural change as called for by STT theory. Therefore, ZEH scenarios with green energy are presented after the main analysis in chapter 6 to provide a comparison to the other ZEH scenarios only.

For this analysis, it was assumed that only 100% green electricity would be used. This means that the energy retailer had to generate or purchase 100% of energy generated from renewable sources
to cover the energy use from the dwelling. Data on costs of green electricity for Victoria were obtained from five local Melbourne energy retailers (AGL, 2011; Energy Australia, 2010; Origin Energy, 2011; Red Energy, 2011; TRUenergy, 2011). An average cost premium of 5.944c/kWh was found.

For the scenarios which used gas and electricity, the consumption of green gas was required. Green gas is where gas methane is obtained from biomass, such as landfill waste, and converted into gas energy. There is limited green gas generation in Australia at present (Commonwealth of Australia, 2009). It was therefore assumed that to achieve green gas, the household would purchase carbon offsets. There is significant debate regarding the use of carbon offsets in pursuit of a sustainable low carbon future (Lovell, Bulkeley, & Liverman, 2009), however this option has been included here to assess the viability of gas energy provision in ZEH in the future.

Using data supplied by the company Carbon Friendly, based on the Carbon Offset Watch Report (TEC, ISF, & CHOICE, 2010), the price of 1 tonne of carbon on the 10th October 2011 was $24.20. This translates to a cost of $0.242/kg of carbon offset. One MJ of natural gas equates to 0.05kg of carbon emission (Australian Government, 2009). Therefore, one MJ of natural gas carbon offset costs $0.00121 (equivalent to $0.0044/kWh).

The costs across time for both green electricity and green gas were incorporated into the through-life modelling in comparing onsite/near site RE technologies.

5.4.3.4 Current and future costs of electricity and gas

The current cost of residential electricity and gas in Melbourne was averaged from data obtained from local energy retailers. Average energy costs for mid-2011 were (regardless of time or amount used and including the Goods and Services Tax):

- 22.37 cents/kWh - electricity
- 1.61 cents/MJ - gas

Utility connection fees were not included in the modelling. These fees currently apply regardless of the amount of gas or electricity consumed and are therefore assumed as constant across all scenarios.

Future energy price predictions were derived to the year 2050 from Garnaut (2008) and from Hatfield-Dodds and Denniss (2008). High and low energy cost scenarios were calculated. An extensive literature review search failed to find any significant information about cost predictions for gas or electricity prices beyond 2050. Based upon the projections made by Garnaut and Hatfield-Dodds and Denniss, cost predictions were extrapolated out to 2070 (60 years). For the low cost scenario for both gas and electricity it was assumed that there was no cost increase other than
that of inflation for the period 2050–2070. For the high cost scenario for both gas and electricity the average of the yearly cost increase until 2050 for each utility was applied to the post 2050 energy costs. Inflation was also added to these costs.

5.4.3.5 Discount rates, inflation, Net Present Value (NPV) and mortgage parameters

The discount rate is the rate applied to calculate the worth of future cash values in present values (Australian Government, 2007). Selecting the appropriate discount rate is an issue that is heavily contested, and the selection of a particular discount rate can significantly alter outcomes (Gollier & Weitzman, 2010; Le Dars & Loaec, 2007). The Australian Office of Best Practice recommends using a discount rate of 7% (Australian Government, 2007). However some researchers discuss that for long life modelling, such as in the case of housing, a lower discount rate should be applied (Garnaut, 2008; Stern, 2007). The UK government uses a declining discount rate of 3.5% for the first 30 years, falling to 3.0% from 31–60 years, for example (HM Treasury, 2003; Stern, 2007).

Three discount scenarios were considered, as outlined in Table 20. Scenario one was developed in line with the real discount rate advocated by Garnaut (2008), scenario two was applied in line with the real discount rates used in the UK (HM Treasury, 2003; Stern, 2007), with scenario 3 undertaken in line with the Australian Government (Australian Government, 2007) real discount rate requirements. A declining discount rate as used by the UK Government was applied for analysis between 31-60 years (HM Treasury, 2003).

Table 20: Discount rates applied.

<table>
<thead>
<tr>
<th>Discount rate scenario</th>
<th>Time scale (years)</th>
<th>Real discount rate (%)</th>
<th>Inflation rate (%)</th>
<th>Nominal discount rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0–30</td>
<td>1.65</td>
<td>3</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>30–60</td>
<td>1.15</td>
<td>3</td>
<td>4.18</td>
</tr>
<tr>
<td>2</td>
<td>0–30</td>
<td>3.5</td>
<td>3</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>30–60</td>
<td>3</td>
<td>3</td>
<td>6.09</td>
</tr>
<tr>
<td>3</td>
<td>0–30</td>
<td>7</td>
<td>3</td>
<td>10.21</td>
</tr>
<tr>
<td></td>
<td>30–60</td>
<td>6.5</td>
<td>3</td>
<td>9.69</td>
</tr>
</tbody>
</table>

A rate of inflation of 3.0% was applied throughout the modelling. This was calculated based upon an average taken from Reserve Bank of Australia data from January 2001–December 2010 (10 years) (RBA, 2011b). In the results, a sensitivity analysis is presented to analyse the impacts of lower (2.0%) and higher (4.0%) inflation rates. Unless otherwise specified, any results presented across time have had an inflation rate applied.

In order to assist with policy feasibility outcomes, an NPV calculator was developed in Microsoft Excel 2010. Analysis was undertaken for all three discount rate scenarios. Results were calculated
in 5 year increments across a 60 year time-horizon to assist with understanding policy feasibility of the various house modelling scenarios.

An exploration into the impact to household cash flows from ZEH standards was also undertaken, specifically by analysing the impact to home loans. For this analysis, a 25-year home loan was used. In addition two interest rates were applied based upon data from the Reserve Bank of Australia (RBA, 2011a). The first (5.16%) was the average interest rate over 10 years from 2001–2010. The second (7.25%) was the average interest rate over 25 years from 1986–2010. To assist with the home loan cost and repayment calculations, an online mortgage calculator was used (Your Mortgage, 2011).

5.4.3.6 Timeframes

Frequently, housing studies report their analysis across a period of 40–50 years (CIE, 2009; DCLG, 2008d; Gustavsson & Joelsson, 2010). A house lifespan of 40 years is applied by the Australian Building Codes Board, who undertake assessments for future housing energy performance policy development in Australia (ABCB, 2009b). However in reality dwellings can last significantly longer than this. An Australian Bureau of Statistics report found that in 1999, over 20% of occupied housing in Melbourne was over 50 years old (ABS, 1999). It is outside the scope of this research to address what the life of a dwelling should be.

For through-life modelling, it was deemed important to address longer time-horizons for a number of reasons. While a household might only be resident in a particular house for a short time span of perhaps a few years, the benefits of thermal efficiency and RE technologies accrue across the potential extent of the life of the house itself. A 60 year upper time-horizon was selected as it allowed for two complete life cycles of renewable energy technology (PV) installation. In addition, analyses at 40 years (Australian Building Codes Board house life time span used in modelling), 20 years (half of the Australian Building Codes Board assumed house life) and 10 years (average ‘hold period’ for detached housing in Melbourne in 2011) were applied (ABCB, 2009b; RP Data, 2012).

5.4.3.7 Resale value

Research has shown that improved housing energy performance adds to the resale value of a house. A report by DEWHA (2008a) titled Energy efficiency rating and house price in the ACT, found that for every one star improvement to a house in the Australian Capital Territory, Australia, an added economic resale value of almost $9,000 was achieved. Another significant resale value study is from the USA: Nevin and Watson (1998) found that for every dollar saved in energy bills an added value of $20 resale value is added to the house. Nevin and Watson’s study found lower
economic benefits for energy efficiency improvements than those found in the DEWHA study and as such was taken as the resale value applied in this modelling.

While the increased resale of sustainability features was included in the modelling, an assumption about land value increases was not included. In comparing a more sustainable house with a standard house in the same area, land value should be similar if the property size and dimensions are similar, therefore the difference in resale value is calculated to come from the addition of sustainability elements. As such land value was assumed to be constant across all the modelled scenarios.

The above resale value studies did not explore the resale value of onsite PV/SHW or near site RE connection. There is limited information in the literature regarding added resale value of renewable energy technologies. The most significant study in the field was undertaken in California, where 72,000 houses were analysed (Hoen et al., 2011). The report, commissioned by the U.S. Department of Energy, found that there was an added resale value of up to $17,000 for a 3.1kW PV system less than 1 year old. The authors acknowledge that this added value decreased across time (by up to one third after 5 years). Specific data across time as required for this thesis were not provided in the report, so a method for resale value calculation for renewable energy technologies was developed.

Applying a standard depreciation approach has been identified within renewable energy technology literature as an appropriate method to apply to calculate future worth of renewable energy technologies (Hearps & McConnell, 2011). Two standard depreciation methods were applied in this research. First, for onsite PV and SHW a declining-balance depreciation method was used (Jackson, Liu, & Cecchini, 2009). This left a salvage value at the end of life which was similar to figures reported by Lazou and Papatsoris (2000) in their study. This method assumes a decrease in value that is more rapid closer to the start of the asset’s life span. The second method applied was straight-line depreciation for near site RE (Fisher & Freudenburg, 2001). Near site RE used this method as both costs and energy units remaining decreased at the same rate across time.

5.4.3.8 Environmental benefits

Environmental benefits were calculated based upon average energy consumption for the various scenarios. Benefits were compared to the 6 star BAU scenarios. Data taken from life cycle analysis software (Australasian Unit Process Life Cycle Inventory) was used to calculate avoided greenhouse gas emission equivalent (CO₂-e) (ESAA, 2010). For one MJ of gas this equated to 0.0583 kgs/CO₂-e and for one kWh of electricity this equated to 1.34 kgs/CO₂-e for the Victorian context. A comparison to overall Australian CO₂-e was made based upon figures provided by the Australian Government (Commonwealth of Australia, 2010). Australia produced a CO₂-e of 576,200,000 t for the year 2008.
5.4.3.9 Electricity grid assumption

There are a number of issues regarding the integration of renewable energy technologies on a larger scale into existing electricity grids (Mol & Sonnenfeld, 2000). However, for this research it is assumed that these issues are not barriers for preventing a transition to ZEH in Australia, in line with recent research from Beyond Zero Emissions (BZE, 2010). Further investigation of these issues is outside of the scope of this research.

5.4.4 Comparison to other research

In chapter 8 this research highlights links to wider ZEH CBA research emerging from Australia and internationally. There are differences between these studies including methods and numbers and types of housing modelled/built, as presented in Table 21. These studies have been significant in enhancing the ZEH debate. However, while there is emerging research in the Australian context, ZEH remains in the background of policy development. In particular, the research undertaken in this thesis aimed to build a case-book of evidence which provides significant depth, in particular by the inclusion of significantly more house plans studied in order to help overcome the perceived limitation of empirical evidence regarding ZEH costs and benefits. As discussed earlier, the inclusion of 80 house plans has reduced the margin of error within the cost upgrade modelling, providing increased confidence in the outcomes.

Table 21: Comparison of calculation method and numbers of housing modelled/built in other ZEH research compared to this thesis.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>Australia</td>
<td>Australia</td>
<td>Australia</td>
<td>Australia</td>
<td>Australia</td>
<td>Canada</td>
<td>USA</td>
<td>UK</td>
</tr>
<tr>
<td>Name</td>
<td>NA</td>
<td>Cape Patterson EcoVillage</td>
<td>AusZEH</td>
<td>Jade 909</td>
<td>Hybrid buildings</td>
<td>Zero net house Alberta</td>
<td>ZEH Las Vegas</td>
<td>Code for Sustainable Homes</td>
</tr>
<tr>
<td># of houses in study</td>
<td>80</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>~12 (4 building types modelled at 3 performance standards)</td>
<td>1</td>
<td>2</td>
<td>16+ (4 building types by 4 building areas)</td>
</tr>
<tr>
<td>Built or modelled</td>
<td>modelled</td>
<td>modelled</td>
<td>built</td>
<td>built</td>
<td>modelled</td>
<td>modelled</td>
<td>built</td>
<td>modelled and built</td>
</tr>
</tbody>
</table>

Note - Further details regarding housing characteristics used in the research presented in this table can be found within the relevant references.

The above sections have detailed the methods applied for the cost-benefit analysis generated for this research. The results of the above methods are presented in chapter 6 and discussed in chapter 8.
5.5 Phase 2 – STT analysis

An understanding of the through-life costs and benefits of ZEH provides an important case-book of evidence through which to inform policy changes. However, in order to best facilitate practical policy outcomes, a comparative criteria-based policy document analysis was carried out to address the third research sub question. This phase of research involved a systematic review of relevant housing energy performance policies across three case study jurisdictions. Set criteria were developed and applied to analysed policies, based upon a socio-technical ZEH framework. A comparative matrix, which contained a number of specific questions to systematically interrogate the policy document, was developed to facilitate clear comparisons of trends and gaps between policy approaches across jurisdictions. The matrix was then populated with data through a comparative document analysis of the selected case policies.

A comparative case study methodology was applied, analysing and comparing multiple relevant cases. This process involves studying two or more case studies using identical methods (Bryman, 2008). In this way, the contextual circumstances and conditions of the case studies can be analysed and understood (Yin, 2009; Zartman, 2005). Due to the limited number of relevant cases, a comparative approach is best suited to this research context. Analysing multiple cases adds improved rigour and increases the likelihood that generalisations can be made from the findings (Zartman, 2005). Further, Bryman (2008, p. 61) states:

‘the key to comparative design is its ability to allow the distinguishing characteristics of two or more cases to act as a springboard for theoretical reflections about contrasting findings’.

Case study analysis asks why, how, what and so what with the aim of unlocking critical elements that make up specific cases (Burnett, 2009). Due to the depth of analysis required for case study research, the focus is more often on fewer case studies, incorporating a richer analysis than typical quantitative research (Guthrie, 2010). Because of this, it is difficult to always develop generalisations from case study research. Other limitations include dealing with researcher bias, assumptions and boundary issues on the case studies (Burnett, 2009).

Within case study analysis, a range of methods can be applied for data collection. In this research, the method of document analysis is applied. Document analysis is a process of identifying and evaluating policy making decisions (O’Leary, 2005). Like case studies, document analysis can be either a qualitative or quantitative analysis technique (Creswell, 2009; Creswell & Clark, 2007). For example counting the number of times an idea or particular phrase appears in a document would be classified as a quantitative approach. Exploring deeper trends, themes and connections is a qualitative approach. This research draws upon both of these approaches.
The focus of the document analysis in this research is upon policy documents, in line with the requirement for a regulatory approach to address housing energy performance. Policy analysis provides an understanding of how a problem is viewed, how it is being dealt with and how it is likely to be dealt with in the future, in the policy arena (Althaus, et al., 2007; Thomas, 2007). This builds on the premise that good policies are developed through better information from research and empirical evidence, as discussed in chapter 2. Policy analysis includes analysing not only current policy for areas of improvement but also policies and strategies that may be in place elsewhere, or past policies and strategies (Bryman, 2008).

There is not one agreed method for undertaking a comparative policy document analysis. Broadly methods involve collating data and information through ‘objective and impartial’ means (Althaus, et al., 2007). By systematically analysing a policy or group of policies, rigorous outcomes are more likely. This is particularly important in the case of radical transitions from current approaches, such as that to ZEH, where systematically derived evidence is crucial to inform the policy debate. The main limitations of policy document analysis include time pressures, temporal inconsistencies, contesting evidence, the over use or under use of evidence, and the requirement of the research to remain impartial and objective throughout the analysis (Althaus, et al., 2007). Policy document analysis ultimately provides data and advice for decision makers, but does not make the decision itself.

The criteria used for comparative policy analysis are developed from further insights gained in chapter 4, from the discussion on the application of STT theory. There has been a limited application of STT in a sustainable housing context to date, as explored in chapter 4 (Bergman, et al., 2007; Smith, 2007; Tambach, et al., 2010). An STT approach has not been applied in the Australian housing context. In addition there has been limited focus within the STT field on assessing existing policy against an STT framework, as will be applied in this research (Beerepoot & Beerepoot, 2007; Kern, 2012; Kern & Howlett, 2009; Tambach, et al., 2010).

5.5.1 Case study selection

Chapter 3 explored housing energy performance requirements in Australia and internationally, with reference to ZEH standards. This wider context helped to inform the selection of case study jurisdictions for the comparative policy document analysis undertaken in this research. Three case study jurisdictions were selected. Each involved a state and federal level governance focus. This enabled appropriate comparison across different levels of government.

In addition to the discussion regarding energy performance policy development in chapter 3, a number of selection criteria were applied to assist with case study selection. Firstly, selected international case studies were required to have either implemented or be in the process of developing ZEH policy. Case studies were also selected that faced broadly similar problems in
relation to fossil fuel energy consumption and greenhouse gas emission concerns to those in the Australian context (Garnaut, 2008; Stern, 2007). The response to these issues from the selected case study jurisdictions has previously been similar to that of the Australian context; that being the setting of minimum energy efficiency standards for new dwellings. Furthermore, as climate zones can impact on energy and building requirements for addressing heating and cooling energy, it was important to draw upon policies that were developed in jurisdictions with similar climate zones (Horne & Hayles, 2008).

Therefore based upon the above criteria and the discussion from chapter 3, the following three state jurisdictions were identified as good candidates for the case study analysis:

- **California** – The State of California has been identified as having similar climate zones to Victoria (Horne & Hayles, 2008). In addition, California has a long history of energy efficiency innovation, which includes addressing residential energy consumption through the setting of minimum energy performance standards, similar to that in the Australian context (CPUC, 2008; Pears, 2007). Furthermore, since 2008 California has begun implementing policy leading to ZEH standards. These elements make California a relevant and practical candidate for analysis.

- **UK** – The UK has had a ZEH policy in place since 2008, providing a practical case study and learnings for Australian policy development. In addition, prior to the development of ZEH standards, standards in the UK were primarily focused on addressing heating and cooling energy requirements, as is currently the case in Australia. In addition, the UK and California have been identified by the Australian Government as exemplars of international best practice for energy performance standards (SOGEE, 2010).

- **Victoria** – In 2010, Victoria had the largest number of new residential building approvals of any state in Australia (ABS, 2011b). In addition it has been identified that new detached housing in Victoria will be responsible for up to 70% of new residential greenhouse gas emissions in Australia, despite only accounting for 32% of new Australian building stock (Clune, et al, 2012). This means that any development of ZEH standards in Australia will likely result in the greatest costs and benefits being achieved in the Victorian housing market, as such it presents a significant case study opportunity.

In supplementing these state case study jurisdictions, the federal, or equivalent, level of governance in each case was also selected for analysis. This resulted in the USA, EU and Australia being included in the analysis. The EU and UK, while not technically a federal/state partnership as with USA/California and Australia/Victoria, have been included as such in this analysis to make comparisons of the different governance levels easier.
5.5.2 Policy instruments selection

Current housing performance policy documents (instruments) as of 1st January 2012 were selected from each case study area (Table 22). Policies were selected based upon their relevance to housing energy performance. Key literature helped identify relevant policy documents (Halverson, et al., 2009; Shui, Evans, & Somasundaram, 2009; SOGEE, 2010; Williams, 2008).

Table 22: Case study jurisdictions and current housing energy performance policies selected for analysis.

<table>
<thead>
<tr>
<th>Case study</th>
<th>Federal level entity</th>
<th>Policy document</th>
<th>State level entity</th>
<th>Policy document</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>United States of America</td>
<td>2012 International Residential Code</td>
<td>California</td>
<td>CALGreen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>International Energy Conservation Code 2012</td>
<td></td>
<td>California long-term energy efficiency strategy strategic plan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>National Green Building Standard ICC 700–2008</td>
<td></td>
<td>Assembly Bill 212 Zero net energy buildings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Building Energy Code initiative – Building America</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Action Plan for Energy Efficiency: Realising the Potential</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Report of the Prime Minister's Task Group on Energy Efficiency</td>
<td></td>
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</tr>
</tbody>
</table>

Four key policy documents and position statements were reviewed at the federal level in the USA with three at the state level. These were explored in section 3.3.2 in chapter 3. Figure 20 presents the links between these policy documents.
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In the EU context, three policy documents were analysed at the European level, with two at the state (UK) level (discussed further in section 3.3.3 in chapter 3). Figure 21 shows the links between these policy documents.

Similar to the policy documents from the USA and EU, the relevant policy documents in the Australian context were identified in section 3.4 in chapter 3. Three policy documents at the federal level and one at the state level were analysed, as described in Figure 22.
5.5.3 Criteria development

The framework for analysis was based upon both social and technical elements required for achieving a transition to ZEH. As explored in the previous chapters, particularly chapter 4, a number of elements are required to create a ZEH regime. Drawing in particular upon the work of Geels (2002), Smith (2006), Bergman, et al (2007) and Tambach et al. (2010) as well as on wider STT research, Figure 23 identifies elements which make up the ZEH STT regime. From these, 17 primary criteria were developed across two key elements: socio-technical transitions theory principles and, within this, technical requirements for zero emission housing.
As discussed in chapter 4, and presented in Figure 23, a number of key elements have been identified for facilitating socio-technical transitions. These key elements inform the criteria developed for the analysis. These criteria include:

- long-term policy and vision setting,
- scenarios (pathways),
- international best practice,
- link to wider policy goals,
- reflexive governance,
- social elements,
- research and development,
- financial sector,
- institutional structure/reform, and
- behaviour.

Further, there are number of performance requirements identified by ZEH standards which fit within the wider requirements of STT theory. These performance requirements were also applied as criteria and included:

- energy efficiency of building envelope,
- reduction of overall emissions,
Chapter 5: Research design

- energy generation/infrastructure,
- house as part of larger system,
- smart technology integration,
- through-life costs and benefits, and
- appliances.

Within the 17 criteria areas, 66 specific questions were developed to interrogate compliance with the criteria. The full list of the questions is provided in the appendix. The questions were developed to ascertain level of compliance (or not) with the different broad criteria. In some cases multiple questions were asked to gain more detail. For example to determine if energy generation was considered, and to what level, the following questions were developed and asked:

- Is energy generation included as part of the house performance assessment?
- Is there a requirement for renewable energy technologies?
  - Onsite?
  - Offsite?
  - SHW?
  - PV?
  - Other renewable energy technologies?
- Does the policy address the impact that increased micro-generation may have on current or future electricity infrastructure?

In this way detailed responses could be determined and gaps and trends identified.

5.5.4 Assessment

A matrix for the analysis was developed in Microsoft Excel 2010. Criteria questions were placed vertically and specific policy documents horizontally (see chapter 7 and the appendix). The matrix was populated with data obtained by coding the policy documents against the framework criteria. Inspected document analysis was conducted for each criterion. This ensured a systematic approach was applied across all of the policy documents in all of the case study areas.

Outcomes of the analysis provide evidence on trends and gaps in the policy documents in order to assess critical gaps in the Australian policy context. The outcomes of this analysis are not intended to be generalised for all housing energy performance policy development. Rather, the aim was to identify learnings from those case study areas studied for relevance to the Australian context.

5.6 Chapter summary

This chapter has explored the scope of the research and methods applied to address identified questions from the literature review chapters. In particular, it was identified that the use of
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qualitative or quantitative approaches on their own would not be sufficient to address these questions. Therefore a mixed methods approach was applied. A two phase triangulation multilevel mixed methods model was developed to answer two separate but related sub questions and the overall research question.

In phase 1, a cost-benefit through-life analysis was conducted to assess ZEH technical options. This was conducted to provide an evidence base for informing policy development. Phase 2 builds upon this by conducting a comparative, criteria-based policy document analysis between the EU, USA and Australia to unlock critical policy document elements required for a facilitated transition to ZEH standards in Australia. A mixed methods approach is designed to produce robust outcomes that are relevant for future housing energy policy development in Australia. The following chapters present the results and implications of the research.
Chapter 6: Zero emission housing scenarios cost-benefit analysis

This chapter presents the results from phase 1 of the mixed methods approach discussed in chapter 5. The chapter is primarily concerned with sub question 1 and sub question 2:

- What are the through-life costs and benefits of ZEH performance standards for owner-occupied new home buyers? and
- What implications arise from through-life costs and benefits of ZEH, both in practical and policy dimensions?

The focus of the results is primarily on ZEH, however a number of intermediate scenarios are also presented, to accommodate the incremental policy development approaches favoured by Australian decision makers.

Section 6.1 of this chapter explores various housing energy performance scenarios developed for this research. The scenarios investigate the financial and ecological implications of changes to future housing performance across a number of key economic and environmental parameters.

Analysis is presented in four main parts:

1. Building envelope upgrade costs and the implications of various energy efficiency standards are analysed (sub question 1) (sections 6.3 and 6.4),
2. Outcomes from this analysis inform the minimum building envelope performance standard applied in developed ZEH scenarios and intermediate scenario analysis (sub question 1, sub question 2 and sub question 3) (sections 6.5–6.10),
3. The NPV of optimal economic scenarios are presented across three different discount rates (sub question 2) (section 6.11), and
4. An environmental analysis is presented as well as a sensitivity analysis of inflation rates (sub question 2) for a number of key and significant scenarios (sections 6.12 and 6.13).

Unless otherwise stated, all costs presented throughout this chapter are in 2011 Australian Dollars (A$).

6.1 Results

A total of 117 different energy performance scenarios were modelled across a 60 year time-horizon. These scenarios fit within four distinct categories, as discussed in chapter 5:
• **BAU** (step one: section 6.2) – 2 scenarios: 6 star electric/gas (gas hot water) for low and high energy price projections. These scenarios, while not examples of ZEH, were developed and analysed to form a base case for comparative purposes.

• **Building envelope thermal upgrades** (step 2: section 6.3 and 6.4) – 18 scenarios: Building envelope thermal upgrades were applied to achieve higher thermal star ratings. These scenarios, while not ZEH, were developed and analysed to ascertain the optimal minimum building envelope thermal performance with which to achieve ZEH.

• **ZEH** (step 3: sections 6.5, 6.6 and 6.7) – 81 scenarios: Combinations of improved building envelope thermal performance, with a number of different renewable energy technologies. This is the main category of scenarios, and the one with the most important results for this study.

• **Intermediate** (step 4: section 6.8) – 16 scenarios: Various combinations of building envelope improvements and renewable energy technology, but not sufficient to achieve zero net emissions. While not ZEH, these scenarios were developed and analysed to explore possible incremental policy developments for a transition towards ZEH standards.

Scenarios were developed in these category groupings in a step-wise manner, applying results from the preceding category. The results from the BAU scenarios were drawn upon to create the building envelope improvement only scenarios and so on, as demonstrated in Figure 24. As such, categories will be referred to as steps from here on in.
6.2 Building envelope energy efficiency through-life costs and benefits: BAU scenario (step 1)

The accumulated through-life capital and operation costs (herein referred to as accumulated costs unless specified) after 60 years for the BAU scenario (6 star building envelope, gas heating, cooking, hot water, electric all other) against a low and high energy price scenario are presented in Figure 25. As expected, the high energy price scenario results in higher accumulated costs across time compared to the low energy price scenario. The gap between the low and high energy price scenario also increases across time. At a 40 year time-horizon, the low energy price BAU scenario accumulated costs of $157,192 are 26.07% less than the high energy price BAU scenario accumulated costs of $212,618. After a 60 year time-horizon, this difference increased to 37.4%: $354,603 for the low energy price scenario compared to $566,900 for a high energy price scenario.
6.3 Building envelope upgrade costs (for steps 2–4)

The additional capital costs required to upgrade the 6 star base case scenario to higher standards of performance (7, 8, 9 and 10 star) are presented in Table 23. The results show that the mean upgrade cost increased as star rating increased; 7 star mean $3,012, SD $1,585, 95% CI $2,659–3,364, 8 star mean $8,154, SD $4,861, 95% CI $7,072–9,236 and 9 star mean $25,366, SD $7,539, 95% CI $23,328–27,405. This was not unexpected, as the higher star ratings required increased material requirements as well as more cost intensive interventions, as discussed in chapter 5.

Table 23: Upgrade costs from 6 star base scenario for 7, 8, 9 and 10 star building envelopes.

<table>
<thead>
<tr>
<th>Star rating</th>
<th>Sample size</th>
<th>Mean capital upgrade cost from 6 star ($)</th>
<th>Minimum ($)</th>
<th>Maximum ($)</th>
<th>95% confidence intervals (CI) ($)</th>
<th>SD ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 star</td>
<td>80</td>
<td>3,012</td>
<td>376</td>
<td>6,983</td>
<td>2,658.73–3,364.40</td>
<td>1,585.49</td>
</tr>
<tr>
<td>8 star</td>
<td>80</td>
<td>8,154</td>
<td>2,712</td>
<td>23,097</td>
<td>7,071.89–9,235.62</td>
<td>4,861.46</td>
</tr>
<tr>
<td>9 star</td>
<td>54</td>
<td>25,366</td>
<td>10,510</td>
<td>38,959</td>
<td>23,328.55–27,404.61</td>
<td>7,538.83</td>
</tr>
<tr>
<td>10 star</td>
<td>NA</td>
<td>50,733</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

All initial house models were adjusted to achieve 7 and 8 star performance standards through material additions. At the 9 star performance standard, it was only possible to adjust 54 house models (67.5%) to reach the desired performance standard through application of practical material upgrades. None of the analysed house designs achieved a 10 star rating. This is not an indication that a 10 star standard is impossible to achieve, more that with current house designs, material-only
upgrades are not enough to achieve this standard (discussed further in chapter 8). A capital cost for a 10 star house scenario was nevertheless required for the analysis. A proxy figure was calculated by doubling the capital cost to achieve the 9 star standard.

6.4 Building envelope energy efficiency through-life costs and benefits: thermal upgrades (step 2)

Figure 26 presents the through-life accumulated costs for 7, 8, 9 and 10 star building envelope upgrade scenarios compared to 6 star BAU low and high energy price scenarios. Both gas/electric and all electric energy provision are modelled within the scenarios. A difference in accumulated costs is again seen in analysis between low and high energy price scenarios.

![Figure 26: Accumulated costs for building envelope upgrade scenarios from 7–10 star and 6 star BAU across gas/electric and electric house energy options across time. Each data line represents one house scenario.](image)

When these building envelope scenarios are presented across different time-horizons, various cost effective outcomes are realised (Table 24). After 10 years, the 6 star BAU low energy price scenario has the least accumulated costs. By 20 years the most cost effective scenario is a 7 star (electric/gas) building envelope which is 0.31% ($158) more economical than the 6 star BAU low energy price scenario. For time-horizons beyond this 20 year mark, the cost gap between the 6 star BAU low energy price scenario and the most economical building envelope scenarios continues to increase. The most economical scenario at 40 years was found to be an 8 star (electric/gas) house. This scenario is 6.93% ($10,888) more cost effective than the 6 star BAU low energy price scenario. At a 60 year time-horizon the most economical scenario is the 9 star (electric/gas) house,
which is 10.81% ($38,339) more economical than the 6 star BAU low energy price scenario. The results in Table 24 demonstrate that the higher star rating scenarios become more cost effective the longer the time-horizon of analysis (and by extension, the assumed life of the house in question).

Table 24: Top 5 building envelope scenarios in terms of least accumulated through-life costs at 10, 20, 40 and 60 time-horizons, compared to the 6 star BAU low energy price scenarios.

<table>
<thead>
<tr>
<th>10 year time-horizon</th>
<th>20 year time-horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rating</strong></td>
<td><strong>Energy supply</strong></td>
</tr>
<tr>
<td>1</td>
<td>6 star BAU – low</td>
</tr>
<tr>
<td>2</td>
<td>7 star</td>
</tr>
<tr>
<td>3</td>
<td>6 star</td>
</tr>
<tr>
<td>4</td>
<td>6 star BAU – high</td>
</tr>
<tr>
<td>5</td>
<td>7 star</td>
</tr>
<tr>
<td>BAU low</td>
<td>6 star</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>40 year time-horizon</th>
<th>60 year time-horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rating</strong></td>
<td><strong>Energy supply</strong></td>
</tr>
<tr>
<td>1</td>
<td>8 star</td>
</tr>
<tr>
<td>2</td>
<td>7 star</td>
</tr>
<tr>
<td>3</td>
<td>8 star</td>
</tr>
<tr>
<td>4</td>
<td>7 star</td>
</tr>
<tr>
<td>5</td>
<td>9 star</td>
</tr>
<tr>
<td>BAU low</td>
<td>6 star</td>
</tr>
</tbody>
</table>

If housing is designed for a longer lifespan than 60 years, 9 star rated housing becomes most economical compared to all other building envelope upgrade scenarios. Applying the rationale that the lifespan of a house is 40 years (which is the assumption used by the Australian Building Codes Board in their regulatory impact statements, which inform the development of the Building Code of Australia), the minimum housing standard that detached housing should be built to in Melbourne is 8 star. Therefore, the base housing standard used in the ZEH modelling is 8 star as a minimum, in the next stage of analysis.

### 6.5 Zero emission house scenarios additional capital costs (step 3a)

A total of 81 ZEH models were developed, building upon the results of step 2 of the analysis. Table 25 presents the additional capital costs for the various ZEH elements for 48 of the ZEH scenarios.
The remaining 33 ZEH scenarios are the green power and gas scenarios compared to a high energy price scenario. The initial additional costs for these scenarios are the same as for the low energy price scenarios and so have been filtered from the table.
Table 25: Additional capital costs for ZEH elements and total additional capital costs for 48 base ZEH scenarios.

<table>
<thead>
<tr>
<th>Star rating</th>
<th>Energy supply</th>
<th>Hot water supply</th>
<th>Additional upfront costs ($)</th>
<th>Total additional upfront costs for ZEH ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Building envelope upgrade</td>
<td>Onsite PV without rebates</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hot water without rebate</td>
<td>Hot water with rebate</td>
</tr>
<tr>
<td>8 Electric</td>
<td>Electric</td>
<td>SHW - electric boost</td>
<td>8,154</td>
<td>5,504</td>
</tr>
<tr>
<td></td>
<td>Electric</td>
<td>SHW - gas boost</td>
<td></td>
<td>6,852</td>
</tr>
<tr>
<td></td>
<td>Electric</td>
<td>SHW - electric boost</td>
<td></td>
<td>5,504</td>
</tr>
<tr>
<td></td>
<td>Electric</td>
<td>Gas HW</td>
<td></td>
<td>1,129</td>
</tr>
<tr>
<td>9 Electric</td>
<td>Electric</td>
<td>SHW - electric boost</td>
<td>25,367</td>
<td>5,504</td>
</tr>
<tr>
<td></td>
<td>Electric</td>
<td>SHW - gas boost</td>
<td></td>
<td>6,852</td>
</tr>
<tr>
<td></td>
<td>Electric</td>
<td>SHW - electric boost</td>
<td></td>
<td>5,504</td>
</tr>
<tr>
<td></td>
<td>Electric</td>
<td>Gas HW</td>
<td></td>
<td>1,129</td>
</tr>
<tr>
<td>10 Electric</td>
<td>Electric</td>
<td>SHW - electric boost</td>
<td>50,733</td>
<td>5,504</td>
</tr>
<tr>
<td></td>
<td>Electric</td>
<td>SHW - gas boost</td>
<td></td>
<td>6,852</td>
</tr>
<tr>
<td></td>
<td>Electric</td>
<td>SHW - electric boost</td>
<td></td>
<td>5,504</td>
</tr>
<tr>
<td></td>
<td>Electric</td>
<td>Gas HW</td>
<td></td>
<td>1,129</td>
</tr>
</tbody>
</table>
The total cost for ZEH scenarios was made up of two components: the building envelope upgrade cost and the cost of the renewable energy technologies. Table 25 shows that capital costs for the various renewable energy technologies range from $0 (green power) to $22,101 (PV for 8 star full electric house). When renewable energy technologies are combined with building envelope upgrade to achieve ZEH scenarios, the capital costs ranged from $9,283 (8 star, electric/gas, gas HW, green power) to $76,796 (10 star, electric, SHW, onsite PV without rebates).

The inclusion of economic rebates for PV and SHW systems made onsite renewable energy technology ZEH scenarios 4.41%–13.18% cheaper than the aforementioned prices at the time of purchase. The ZEH scenarios with least additional capital costs were the 8 star ZEH scenarios, followed by 9 star ZEH scenarios and finally 10 star ZEH scenarios.

As the building envelope performance improved (the house increased in star ratings), the size requirement for renewable energy technologies decreased. This impacted on the cost ratios between these two cost components. For example, the building envelope upgrade capital costs made up 22.80% of an 8 star (electric/gas, SHW gas boost) ZEH scenario and 78.74% of a 10 star (electric/gas, gas HW) ZEH scenario.

6.6 Zero emission house scenarios through-life costs and benefits (step 3b)

The additional capital costs for the various ZEH scenarios presented in the previous section were analysed for their through-life costs and benefits. Figure 27 presents accumulated costs for all 81 ZEH scenarios across a 60 year time-horizon. Three discrete groupings of accumulated costs emerge after approximately 35 years. The highest accumulated cost group at 60 years represents the green power high energy price scenario. The middle accumulated cost group at 60 years represents the green power low energy price scenario. The lowest accumulated cost group at 60 years represents all remaining ZEH scenarios.
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Figure 27: Accumulated through-life costs for all 81 ZEH scenarios across time. Each data line represents one ZEH performance scenario across time.

Figure 28 presents the accumulated costs across time for onsite and near site renewable energy ZEH scenarios (herein ZEH scenarios unless otherwise specified) with comparison to the 6 star BAU low and high energy price scenarios. Both 6 star BAU scenarios have significantly greater accumulated costs across the 60 year time-horizon when compared to the ZEH scenarios. It takes 14 years before the first ZEH scenario (8 star electric, SHW, near site RE) and 34 years before the last ZEH scenario (10 star electric/gas, gas HW, onsite PV with no R/FIT) become more cost efficient compared to the 6 star BAU low energy price scenario. For the 6 star BAU high energy price scenario, this falls to 11 years (8 star electric/gas, gas HW, near site RE) and 25 years (10 star electric/gas (high gas price scenario), gas SHW, onsite PV with no R/FIT).
At both 40 and 60 year time-horizons, the 63 ZEH scenarios presented in Figure 28 had lower accumulated costs compared to both the 6 star BAU low and high energy price scenarios. At a 20 year time-horizon, 20 ZEH scenarios had lower accumulated costs compared to the 6 star BAU low energy price scenario and 37 ZEH scenarios had lower accumulated costs than the 6 star BAU high energy price scenario. Of the 20 scenarios with lower accumulated costs, all were 8 star building envelope standards. There was an almost equal mix of full electric and electric/gas energy provision amongst them. In addition, half had SHW, and the rest traditional gas hot water systems. A third were near site renewable energy scenarios, however all of the near site renewable energy scenarios were the 4 most economical scenarios.

The accumulated costs after 10, 20, 40 and 60 years of the top 5 performing scenarios in terms of least accumulated cost at each time-horizon are presented in Table 26. After 10 years, the accumulated costs show that the 6 star BAU low and high energy price scenarios are most economical. However after this time, ZEH scenarios become more economical. There was a shift in the top 5 scenarios from 8 star ZEH scenarios after 20 years to a mix of 8 and 9 star scenarios after 60 years. The bias towards the 8 star scenarios after 20 years is not unexpected as these scenarios had the lowest capital costs, meaning that they would typically be expected to see shorter pay back...
periods. Over longer time-horizons, the greater energy savings achieved with higher star ratings, along with the associated reduced renewable energy generation requirements, provide greater economic efficiencies.

Table 26: Accumulated costs of top 5 ZEH scenarios at 10, 20, 40 and 60 year time-horizons with comparison to 6 star BAU low and high scenarios.

<table>
<thead>
<tr>
<th>10 year time-horizon</th>
<th>20 year time-horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rating</strong></td>
<td><strong>Energy supply</strong></td>
</tr>
<tr>
<td>1</td>
<td>6 star BAU - low</td>
</tr>
<tr>
<td>2</td>
<td>6 star BAU high</td>
</tr>
<tr>
<td>3</td>
<td>8 star</td>
</tr>
<tr>
<td>4</td>
<td>8 star</td>
</tr>
<tr>
<td>5</td>
<td>8 star</td>
</tr>
<tr>
<td><strong>BAU low</strong></td>
<td>6 star</td>
</tr>
<tr>
<td><strong>BAU high</strong></td>
<td>6 star</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>40 year time-horizon</th>
<th>60 year time-horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rating</strong></td>
<td><strong>Energy supply</strong></td>
</tr>
<tr>
<td>1</td>
<td>8 star</td>
</tr>
<tr>
<td>2</td>
<td>8 star</td>
</tr>
<tr>
<td>3</td>
<td>8 star</td>
</tr>
<tr>
<td>4</td>
<td>9 star</td>
</tr>
<tr>
<td>5</td>
<td>8 star</td>
</tr>
<tr>
<td><strong>BAU low</strong></td>
<td>6 star</td>
</tr>
<tr>
<td><strong>BAU high</strong></td>
<td>6 star</td>
</tr>
</tbody>
</table>
Based upon the top 5 ZEH scenarios at each time period, the most cost effective mode of energy generation shifted from an electric/gas house after 20 years to a full electric house after 40 years. This was not unexpected as the costs in the model to provide gas energy as well as associated gas carbon offsets continued to increase across time, whereas the cost of electric renewable offsetting remained relatively static.

At each time period (except for 10 years), one ZEH scenario was consistently the most economical: 8 star, electric, SHW, near site RE. This ZEH scenario demonstrated a cost reduction of 28.26% ($14,480) after 20 years compared to the 6 star BAU low energy price scenario, as well as 62.15% ($97,698) after 40 years and 81.63% ($289,461) after 60 years compared to the same baseline. When compared to 6 star BAU high energy price scenario, cost reductions of 40.87% ($25,402) after 20 years, 72.02% ($153,124) after 40 years and 88.51% ($501,758) after 60 years were achieved.

All top 5 scenarios at each time period included SHW, except after 10 years where the ZEH scenarios included gas hot water systems. The scenarios included a mix of onsite and near site renewable energy options. Economically, near site ZEH scenarios were more cost efficient. After 20 years the near site ZEH scenarios were 10.21% ($4,178) more economical compared to onsite PV ZEH scenarios. After 40 years this increased to 16.94% ($12,130) and after 60 years it rose to 22.90% ($19,349).

Figure 29 compares the most economical building envelope upgrade only scenario after 40+ years (8 star) with the most economical onsite and near site ZEH scenarios after 40+ years (8 star, electric, SHW, near site/onsite PV) in terms of accumulated costs and benefits across time. Over a 60 year time-horizon, the 8 star near site ZEH scenario is 79.59% (low energy price scenario) and 87.26% (high energy price scenario) more economical than the 8 star building envelope only scenario. It shows cost reductions of $253,965 using the low energy price scenario and $446,381 using the high energy price scenario. It takes 10 years (high energy price scenario) and 13 years (low energy price scenario) before the ZEH scenarios are more cost effective than 8 star building envelope (low and high energy price scenario) scenarios. This result shows that ZEH scenarios are more cost effective over time when compared to thermal efficiency options that address the building envelope in isolation.
Results show that for a house life of 40+ years, ZEH is cost effective when compared to BAU and building envelope upgrade only approaches. The most economical ZEH scenario was found to be 8 star (electric) with SHW and near site renewable energy. This was followed by the 8 star (electric) with SHW and onsite PV scenario. As demonstrated below, both ZEH scenarios require additional capital investment costs, however they both also achieve significant savings across 60 years.

8 star near site:

Additional capital costs of $30,842 or 7.85% extra of house and land total cost. Economic savings across 60 years of 81.63% at a low energy price scenario and 88.51% at a high energy price scenario.

8 star onsite:

Additional capital costs of $31,047 or 7.89% extra of house and land total cost. Economic savings across 60 years of 76.17% at a low energy price scenario and 85.10% at a high energy price scenario.

6.7 Other scenario options

An alternative approach to providing renewable energy generation is through the provision of green power. Green power does not fit within the definition of ZEH and wider requirement for deep
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structural changes as called for by STT theory, as discussed in chapter 5 but has been included here for comparative purposes. This section presents the analysis from the ZEH green power scenarios.

Figure 27 demonstrated that green energy ZEH had significantly higher accumulated costs for both a high and low energy price scenario future compared to ZEH with onsite or near site RE technologies. This difference in costs over time was not unexpected: green energy is a premium cost on top of traditional energy prices, so it typically costs more on an annual basis than other ZEH scenarios, which are not faced with such premiums. An increase of between approximately $150,000 and $400,000 of additional accumulated costs across the 60 year time-horizon was found for the green energy scenarios compared to other ZEH scenarios. Compared to the other ZEH scenarios, green power ZEH scenarios resulted in higher accumulated costs after 4 years.

After 10, 20 and 40 year time-horizons, not one ZEH green power scenario was more cost effective than the BAU 6 star low energy price scenario (Table 27). However the top 5 green power scenarios were more economical across 60 years when compared to the 6 star BAU scenarios (low and high energy price scenarios). This is likely due to the increasing cost of energy between 40 and 60 years. Compared to the 6 star BAU low energy price scenario, an accumulated cost reduction of 5.74% ($20,449) is observed for the most economical green power scenario after 60 years (9 star electric/gas, gas hot water). Further, accumulated energy costs across a 60 year time-horizon for ZEH green power scenarios reduce as building envelope thermal performance increases. Due to these results, and the failure of green energy to fit within an STT framework, ZEH green power results were filtered from the remaining analysis and are not discussed further in this research.
Table 27: Top 5 accumulated cost ZEH green power scenarios at 10, 20, 40 and 60 years with comparison to 6 star BAU low and high scenarios.

<table>
<thead>
<tr>
<th>10 year time-horizon</th>
<th>20 year time-horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rating</strong></td>
<td><strong>Energy supply</strong></td>
</tr>
<tr>
<td>1</td>
<td>6 star BAU - low</td>
</tr>
<tr>
<td>2</td>
<td>6 star BAU - high</td>
</tr>
<tr>
<td>3</td>
<td>8 star</td>
</tr>
<tr>
<td>4</td>
<td>8 star</td>
</tr>
<tr>
<td>5</td>
<td>8 star</td>
</tr>
<tr>
<td><strong>BAU low</strong></td>
<td>6 star</td>
</tr>
<tr>
<td><strong>BAU high</strong></td>
<td>6 star</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>40 year time-horizon</th>
<th>60 year time-horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rating</strong></td>
<td><strong>Energy supply</strong></td>
</tr>
<tr>
<td>1</td>
<td>6 star BAU - low</td>
</tr>
<tr>
<td>2</td>
<td>8 star</td>
</tr>
<tr>
<td>3</td>
<td>9 star</td>
</tr>
<tr>
<td>4</td>
<td>8 star</td>
</tr>
<tr>
<td>5</td>
<td>8 star</td>
</tr>
<tr>
<td><strong>BAU low</strong></td>
<td>6 star</td>
</tr>
<tr>
<td><strong>BAU high</strong></td>
<td>6 star</td>
</tr>
</tbody>
</table>
6.8 Intermediate scenarios (step 4)

While the focus of this research is on ZEH, the analysis in this section focuses on the costs and benefits of likely step changes between the current BAU approach and ZEH requirements. This analysis is conducted in order to inform future policy development, which is typically incremental and stepwise in the Australian context. Sixteen intermediate scenarios were modelled with varying building envelope improvements and limited renewable energy technologies (onsite PV and SHW). Table 28 presents the disparate elements considered as well as total additional capital costs required for the various intermediate scenarios. These additional capital costs ranged from $7,796 (7 star, 1.0 kW PV, gas HW) to $24,039 (8 star, 2.5 kW PV, SHW gas boost). The eight scenarios presented in Table 28 were analysed against a low and high energy price scenario (16 scenarios in total).

Table 28: Description and additional capital costs for intermediate scenarios.

<table>
<thead>
<tr>
<th>Star rating</th>
<th>Size of PV (kW)</th>
<th>SHW included?</th>
<th>Cost for building envelope upgrade ($)</th>
<th>Cost for PV ($)</th>
<th>Cost for HW ($)</th>
<th>Total additional capital cost for intermediate scenario ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 star</td>
<td>1</td>
<td>No</td>
<td>3,011</td>
<td>3,656</td>
<td>1,129</td>
<td>7,796</td>
</tr>
<tr>
<td>7 star</td>
<td>2.5</td>
<td>No</td>
<td>3,011</td>
<td>10,133</td>
<td>1,129</td>
<td>14,273</td>
</tr>
<tr>
<td>7 star</td>
<td>1</td>
<td>Yes</td>
<td>3,011</td>
<td>3,656</td>
<td>5,752</td>
<td>12,419</td>
</tr>
<tr>
<td>8 star</td>
<td>2.5</td>
<td>Yes</td>
<td>3,011</td>
<td>10,133</td>
<td>5,752</td>
<td>18,896</td>
</tr>
<tr>
<td>8 star</td>
<td>1</td>
<td>No</td>
<td>8,154</td>
<td>3,656</td>
<td>1,129</td>
<td>12,939</td>
</tr>
<tr>
<td>8 star</td>
<td>2.5</td>
<td>No</td>
<td>8,154</td>
<td>10,133</td>
<td>1,129</td>
<td>19,416</td>
</tr>
<tr>
<td>8 star</td>
<td>1</td>
<td>Yes</td>
<td>8,154</td>
<td>3,656</td>
<td>5,752</td>
<td>17,562</td>
</tr>
<tr>
<td>8 star</td>
<td>2.5</td>
<td>Yes</td>
<td>8,154</td>
<td>10,133</td>
<td>5,752</td>
<td>24,039</td>
</tr>
</tbody>
</table>

The majority of intermediate scenarios (75%) were more economical across a 60 year time-horizon than the baseline 6 star BAU low energy price scenario (Figure 30). All intermediate scenarios were more economical across 60 years when compared to the 6 star BAU high energy price scenario. The first intermediate scenario to become more economical in terms of accumulated costs compared to the 6 star BAU low energy price scenario occurs after a 7 year time-horizon (7 star, electric/gas, 1kW PV onsite) with the longest payback period taking 25 years (8 star, electric/gas, 1kW PV onsite, SHW). Compared to the 6 star BAU high energy price scenario, it takes 12 years for the first intermediate scenario (7 star, 2.5kW PV onsite) to become more economical and 22 years for the least cost effective intermediate scenario (8 star, 1kW PV onsite, SHW) to achieve this.
After 10, 20 and 40 years, the most economical intermediate scenario compared to the 6 star BAU low energy price scenario is the 7 star with 1kW PV scenario. The 7 star with 1kW PV scenario was found to be 16.3% ($3,360 accumulated costs saved) more economical after 10 years, 32.24% ($16,516 accumulated costs saved) more economical after 20 years and 40.61% ($63,840 accumulated costs saved) more economical after 40 years compared to 6 star BAU low energy price scenario (Table 29). In comparison to 6 star BAU high energy price scenario, the 7 star with 1kW scenario was found to be 29.30% ($7,152 accumulated costs saved) more economical after 10 years, 44.71% ($28,080 accumulated costs saved) more economical after 20 years and 56.09% ($119,265 accumulated costs saved) more economical after 40 years.

After a 60 year time-horizon, the 8 star, 2.5kW PV, SHW scenario was most economical. Compared to low and high energy price baseline scenarios (6 star BAU), the 8 star, 2.5kW PV, SHW scenario demonstrated an accumulated cost reduction of 50.15% ($177,817 accumulated costs saved) and 68.82% ($390,113 accumulated costs saved) at low and high energy price scenarios respectively.

Figure 30: Accumulated costs across time for 16 intermediate scenarios with comparison to 6 star BAU low and high energy price scenarios. Note these intermediate scenarios are not ZEH.
Table 29: Top 5 intermediate (not ZEH) scenarios in terms of accumulated costs at 10, 20, 40 and 60 years with comparison to 6 star BAU low and high scenarios.

<table>
<thead>
<tr>
<th>10 year time-horizon</th>
<th>20 year time-horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rating</strong></td>
<td><strong>Energy supply</strong></td>
</tr>
<tr>
<td>1</td>
<td>7 star</td>
</tr>
<tr>
<td>2</td>
<td>6 star BAU low</td>
</tr>
<tr>
<td>3</td>
<td>7 star</td>
</tr>
<tr>
<td>4</td>
<td>7 star</td>
</tr>
<tr>
<td>5</td>
<td>6 star BAU high</td>
</tr>
<tr>
<td>BAU low</td>
<td>6 star</td>
</tr>
<tr>
<td>BAU high</td>
<td>6 star</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>40 year time-horizon</th>
<th>60 year time-horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rating</strong></td>
<td><strong>Energy supply</strong></td>
</tr>
<tr>
<td>1</td>
<td>7 star</td>
</tr>
<tr>
<td>2</td>
<td>8 star</td>
</tr>
<tr>
<td>3</td>
<td>7 star</td>
</tr>
<tr>
<td>4</td>
<td>8 star</td>
</tr>
<tr>
<td>5</td>
<td>7 star</td>
</tr>
<tr>
<td>BAU low</td>
<td>6 star</td>
</tr>
<tr>
<td>BAU high</td>
<td>6 star</td>
</tr>
</tbody>
</table>

6.9 Comparisons

The results presented in this chapter so far have led to the identification of a number of cost effective scenarios across various time-horizons (10, 20, 40 and 60 years). These scenarios are presented in Figure 31 for comparison, together with the 6 star BAU low and high energy price baseline scenarios. The graph shows that across time, the benefits of higher star ratings and additional renewable energy technology (intermediate scenarios) noticeably accumulate and can significantly reduce operational energy costs for owner-occupied households. In addition to major accumulated cost reductions, ZEH scenarios also provide significant periods of time where no
annual costs are incurred. This is in comparison to the BAU, building envelope upgrades or intermediate scenarios where annual energy costs continue to increase.

Figure 31: Comparison of accumulated costs for most economical ZEH scenario, intermediate scenarios, building envelope thermal upgrade and 6 star BAU (low and high energy price scenarios) across 60 years.

The most economical (accumulated cost) ZEH scenario after 40 years (8 star, electric, SHW, near site RE) becomes cost effective compared to 6 star BAU after 12 years (high energy price scenario) or 14 years (low energy price scenario). In addition, it becomes the most economical scenario of all 117 scenarios after 21 years, when it becomes more economical than the 7 star (1kW PV) intermediate scenario.

Table 30 presents the capital and accumulated costs (10, 20, 40 and 60 years) for the most economical ZEH scenario, intermediate scenarios, building envelope thermal upgrade and 6 star BAU low and high energy price scenarios. The cost reductions compared to 6 star BAU have been previously presented in the appropriate sections in this results chapter. The comparison table shows that compared to 6 star BAU low and high energy price scenarios, most scenarios are more cost effective across time, negating the higher capital costs to achieve the improved energy performance standard. The exceptions to this are 8 star building envelope low and high energy price scenarios at 20 years and all scenarios at 10 years except 7 star intermediate.
Table 30: Comparison of accumulated costs for most economical ZEH, intermediate scenarios and building envelope thermal upgrade scenarios, together with 6 star BAU (low and high energy price scenarios) after 10, 20, 40 and 60 years.

<table>
<thead>
<tr>
<th>Star rating</th>
<th>Energy price future</th>
<th>Energy supply</th>
<th>Size of renewables (kW)</th>
<th>HW type</th>
<th>Additional upfront costs ($)</th>
<th>Accumulated costs ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10 years</td>
<td>20 years</td>
</tr>
<tr>
<td>7 star intermediate</td>
<td>low</td>
<td>Electric</td>
<td>1</td>
<td>Gas</td>
<td>7,796</td>
<td>17,261</td>
</tr>
<tr>
<td>8 star intermediate</td>
<td>low</td>
<td>Electric</td>
<td>2.5</td>
<td>SHW gas boost</td>
<td>24,039</td>
<td>30,176</td>
</tr>
<tr>
<td>8 star ZEH (near site RE)</td>
<td>NA</td>
<td>Electric</td>
<td>4.3</td>
<td>SHW electric boost</td>
<td>30,842</td>
<td>30,842</td>
</tr>
<tr>
<td>8 star ZEH (onsite PV)</td>
<td>NA</td>
<td>Electric</td>
<td>4.3</td>
<td>SHW electric boost</td>
<td>31,047</td>
<td>31,047</td>
</tr>
<tr>
<td>8 star building envelope only</td>
<td>low</td>
<td>Electric</td>
<td>0</td>
<td>Gas</td>
<td>9,283</td>
<td>26,281</td>
</tr>
<tr>
<td>8 star building envelope only</td>
<td>high</td>
<td>Electric</td>
<td>0</td>
<td>Gas</td>
<td>9,283</td>
<td>29,835</td>
</tr>
<tr>
<td>6 star BAU</td>
<td>low</td>
<td>Electric</td>
<td>0</td>
<td>Gas</td>
<td>0</td>
<td>20,621</td>
</tr>
<tr>
<td>6 star BAU</td>
<td>high</td>
<td>Electric</td>
<td>0</td>
<td>Gas</td>
<td>0</td>
<td>24,413</td>
</tr>
</tbody>
</table>

The results show that across time, building envelope only upgrades are less cost effective when compared to scenarios which include renewable energy technologies for all time-horizons after 10 years. In comparison, the 8 star ZEH (electric, SHW, near site RE) is 30.94% ($16,463 accumulated costs saved) at a low energy price scenario and 42.51% ($27,169 accumulated costs saved) at a high energy price scenario, more economical after 20 years than the 8 star building envelope only upgrades. After 40 years this increases to between 59.38% ($86,811 accumulated costs saved) at a low energy price scenario and 69.75% ($137,230 accumulated costs saved) at a high energy price scenario, more economical after 20 years than the 8 star building envelope only upgrades. After 60 years this cost reduction from 8 star ZEH near site RE increases to 79.58% ($253,965 accumulated costs saved) at a low energy price scenario and 87.26% ($446,381 accumulated costs saved) at a high energy price scenario. At 10 years the building envelope only upgrade is between 3.26% ($1,007 accumulated costs saved) and 14.78% ($4,561 accumulated costs saved) more economical compared to scenarios that include renewable energy technologies.

After 20 years the 7 star intermediate scenario is 5.54% ($2,036 accumulated costs saved) more economical compared to the 8 star ZEH near site. However after 40 years, the 8 star ZEH near site scenario is 36.27% ($33,858 accumulated costs saved) more economical compared to the 7 star intermediate scenario. After 60 years this cost reduction from 8 star ZEH near site RE increases to 65.99% ($126,424) over the 7 star intermediate scenario. It should be noted that at a 10 year time-horizon, both the intermediate scenarios are more economical than the ZEH scenarios.
Finally there are a number of energy efficiency improvement options available that will achieve significant cost and energy efficiency reductions for the household compared to the 6 star BAU low and high energy price scenarios. Improving the building envelope thermal performance to 8 star improves cost efficiencies over 60 years by 10.01% ($35,496 accumulated costs saved) for a low energy price scenario or 9.76% ($55,377 accumulated costs saved) for a high energy price scenario. The inclusion of renewable energy technologies results in substantial cost reductions for the household compared to 6 star BAU low and high energy price scenarios. The 8 star (2.25kW PV, SHW) intermediate scenario demonstrated cost reductions of 50.14% ($177,817 accumulated costs saved) and 68.81% ($390,113 accumulated costs saved) compared to 6 star BAU low and high energy price scenarios. However the ZEH scenarios are most economical (beyond 20 years compared to intermediate scenarios and 14 years compared to 6 star BAU low energy price scenario) with cost reductions of 81.63% ($289,461 accumulated costs saved) and 88.51% ($501,758 accumulated costs saved) for near site ZEH scenarios and 76.17% ($270,112) and 85.09% ($482,409) for onsite ZEH scenarios compared to 6 star BAU low and high energy price scenarios.

In terms of accumulated through-life costs, the results show that with current (2011) technologies and costs, it is economically beneficial for new detached housing in Melbourne to be built to an 8 star ZEH standard. The following section will explore what impact the additional capital costs has to household budgets, to further assess the feasibility of achieving this standard of housing energy performance.

**6.10 Household economic impacts of ZEH**

The most economic ZEH across 40+ years (8 star, full electric, near site RE with SHW) would add almost $31,000 to the required home loan in this scenario. This cost is made up of $8,154 for the building envelope thermal upgrades, $4,404 for an electric boosted solar hot water system and $18,284 for near site RE requirements – totalling $30,842 which is rounded up to $31,000 for the analysis in this section.

An additional of $31,000 equates to a 7.8% increase to the mortgage borrowing amount. This is offset by energy efficiency savings of 49.31% ($35,765) across 25 years of the home loan. Table 31 presents the breakdown of house and land costs, required mortgage borrowing amount and energy efficiency savings which would result from this housing scenario.
Table 31: Cost breakdown for 8 star ZEH scenario compared to 6 star BAU for home loan requirements.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Additional capital cost ($</th>
<th>Total building cost ($)</th>
<th>Land cost ($)</th>
<th>Total capital cost ($)</th>
<th>Borrowed (90%) ($)</th>
<th>Accumulated through-life energy costs (25 years) ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 star ZEH (near site RE with SHW)</td>
<td>30,842</td>
<td>209,928</td>
<td>214,000</td>
<td>423,928</td>
<td>382,000</td>
<td>36,750</td>
</tr>
<tr>
<td>6 star BAU low</td>
<td>0</td>
<td>179,086</td>
<td>214,000</td>
<td>393,086</td>
<td>354,000</td>
<td>72,526</td>
</tr>
</tbody>
</table>

The additional costs to achieve a ZEH, if added to the capital cost of the mortgage, would add an additional $166/month ($1,992/year) at an interest rate of 5.16% or $202/month ($2,424/year) at an interest rate of 7.25% (Table 32). This would result in an additional $21,894 paid in interest at 5.16% or $32,714 paid in additional interest at a rate of 7.25% across the life of the home loan.

Table 32: Comparison of impact to mortgage repayments from an 8 star ZEH scenario and 6 star BAU.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Interest rate (fixed) (%)</th>
<th>Monthly repayments ($)</th>
<th>Interest paid over 25 years ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 star BAU</td>
<td>5.16</td>
<td>2,103</td>
<td>276,772</td>
</tr>
<tr>
<td>6 star BAU</td>
<td>7.25</td>
<td>2,559</td>
<td>413,618</td>
</tr>
<tr>
<td>8 star ZEH (near site RE with SHW)</td>
<td>5.16</td>
<td>2,269</td>
<td>298,666</td>
</tr>
<tr>
<td>8 star ZEH (near site RE with SHW)</td>
<td>7.25</td>
<td>2,761</td>
<td>446,332</td>
</tr>
</tbody>
</table>

In comparison to the 6 star BAU scenarios, the 8 star ZEH (near site RE with SHW) scenario is predicted to achieve accumulated savings of $35,765 (6 star BAU low energy price scenario) and $53,509 (6 star BAU high energy price scenario) across 25 years. This equates to an average monthly saving of $119.22/month for the low energy price scenario and $178.36/month for the high energy price scenario. If these savings are paid back into the home loan as extra repayments it significantly alters the mortgage outcomes.

As is presented in Table 33, by reinvesting the energy efficiency savings into the home loan, savings of up to $55,691 in interest repayments are possible compared to not reinvesting the energy efficiency savings. Compared to 6 star BAU, mortgage savings of up to $22,977 are possible under a low scenario energy price scenario. This also results in paying off the mortgage between 29 (low interest rate, low energy price scenario) and 44 (high interest rate, high energy price scenario) months sooner.
Table 33: Comparison of mortgage repayments when energy efficiency economic savings are reinvested into the home loan for 8 star onsite/near site ZEH scenarios compared to low and high BAU scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Low or high energy price scenario</th>
<th>Interest rate (fixed) (%)</th>
<th>Monthly repayments ($)</th>
<th>Additional monthly payments from energy efficiency savings ($)</th>
<th>Interest paid over 25 years ($)</th>
<th>Paid off sooner (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 star ZEH (near site with SHW)</td>
<td>low</td>
<td>5.16</td>
<td>2,269</td>
<td>119.22</td>
<td>265,951</td>
<td>29</td>
</tr>
<tr>
<td>8 star ZEH (near site with SHW)</td>
<td>low</td>
<td>7.25</td>
<td>2,761</td>
<td>119.22</td>
<td>390,641</td>
<td>31</td>
</tr>
<tr>
<td>8 star ZEH (near site with SHW)</td>
<td>high</td>
<td>5.16</td>
<td>2,269</td>
<td>178.36</td>
<td>252,410</td>
<td>40</td>
</tr>
<tr>
<td>8 star ZEH (near site with SHW)</td>
<td>high</td>
<td>7.25</td>
<td>2,761</td>
<td>178.36</td>
<td>368,444</td>
<td>44</td>
</tr>
</tbody>
</table>

In summary, given the stated assumptions, the optimal ZEH scenario would add almost $166/month at an interest rate of 5.16% or $202/month at an interest rate of 7.25%. However, energy savings of $120–$180/month (low–high energy price scenarios) are realised across the 25 years, reducing the difference in additional payments by 60–110%. In addition, if these energy savings were to be reinvested into the mortgage as additional repayments, there is the potential to take 3.7 years off the home loan and to save up to $55,691 in interest payments (over a 21.3 year period).

6.11 Net Present Value

The most economical ZEH (onsite and near site), intermediate and building envelope scenarios across time were analysed for net present value of the initial investment required, compared to BAU scenarios, at 5 year intervals in order to further assess feasibility and future policy development. Analysis was undertaken for both low and high energy price scenarios and compared to 6 star BAU low and high energy price scenarios. Three discount rate scenarios were applied as discussed in chapter 5. The discount rate scenarios are as follows (Table 34):

Table 34: Discount rate scenarios applied for NPV calculations.

<table>
<thead>
<tr>
<th>Discount scenario</th>
<th>Real discount rate (%)</th>
<th>Inflation rate (%)</th>
<th>Nominal discount rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-30 years</td>
<td>31-60 years</td>
<td>0-30 years</td>
</tr>
<tr>
<td>1</td>
<td>1.65</td>
<td>1.15</td>
<td>3.00</td>
</tr>
<tr>
<td>2</td>
<td>3.50</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>3</td>
<td>7.00</td>
<td>6.50</td>
<td>3.00</td>
</tr>
</tbody>
</table>

The NPV for capital costs and through-life operational costs (compared to 6 star BAU low and high energy price scenarios) for the three discount rate scenarios are presented in Table 35, Table 36 and Table 37. At the lowest discount rate (discount rate scenario 1, Table 35), all building performance
scenarios demonstrated a positive NPV at a 45 year time-horizon. The highest NPV after 40 and 60 years is demonstrated by the 8 star ZEH near site scenario (high and low energy price scenarios). The ZEH scenarios achieved a positive NPV by 20 years for a high energy price scenario and by 25 years for a low energy price scenario.

Table 35: Net present values for the most economical ZEH, intermediate scenarios and building envelope improvements across 5 year increments for discount rate scenario 1. Shaded results indicate a positive NPV.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Energy price future</th>
<th>NPV ($) across time</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 star building envelope only</td>
<td>kw</td>
<td>-7,124</td>
</tr>
<tr>
<td>8 star intermediate</td>
<td>kw</td>
<td>-2,827</td>
</tr>
<tr>
<td>8 star intermediate</td>
<td>kw</td>
<td>-17,396</td>
</tr>
<tr>
<td>8 star ZEH onsite</td>
<td>kw</td>
<td>-21,865</td>
</tr>
<tr>
<td>8 star ZEH near site</td>
<td>kw</td>
<td>-21,665</td>
</tr>
<tr>
<td>7 star intermediate</td>
<td>kw</td>
<td>-4,608</td>
</tr>
<tr>
<td>8 star intermediate</td>
<td>high</td>
<td>-16,675</td>
</tr>
<tr>
<td>8 star building envelope only</td>
<td>high</td>
<td>-7,060</td>
</tr>
<tr>
<td>8 star ZEH onsite</td>
<td>high</td>
<td>-20,872</td>
</tr>
<tr>
<td>8 star ZEH near site</td>
<td>high</td>
<td>-20,671</td>
</tr>
</tbody>
</table>

Table 36: Net present values for the most economical ZEH, intermediate scenarios and building envelope improvements across 5 year increments for discount rate scenario 2. Shaded results indicate a positive NPV.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Energy price future</th>
<th>NPV ($) across time</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 stars building envelope only</td>
<td>kw</td>
<td>-7,160</td>
</tr>
<tr>
<td>7 stars intermediate</td>
<td>kw</td>
<td>-2,978</td>
</tr>
<tr>
<td>8 stars intermediate</td>
<td>kw</td>
<td>-17,588</td>
</tr>
<tr>
<td>8 stars ZEH onsite</td>
<td>kw</td>
<td>-22,145</td>
</tr>
<tr>
<td>8 stars ZEH near site</td>
<td>kw</td>
<td>-21,945</td>
</tr>
<tr>
<td>7 stars intermediate</td>
<td>high</td>
<td>-4,683</td>
</tr>
<tr>
<td>8 stars intermediate</td>
<td>high</td>
<td>-16,984</td>
</tr>
<tr>
<td>8 stars building envelope only</td>
<td>high</td>
<td>-7,099</td>
</tr>
<tr>
<td>8 stars ZEH onsite</td>
<td>high</td>
<td>-21,202</td>
</tr>
<tr>
<td>8 stars ZEH near site</td>
<td>high</td>
<td>-21,002</td>
</tr>
</tbody>
</table>
Table 37: Net present values for the most economical ZEH, intermediate scenarios and building envelope improvements across 5 year increments for discount rate scenario 3. Shaded results indicate a positive NPV.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Energy price future</th>
<th>NPV ($) across time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 yrs</td>
<td>10 yrs</td>
</tr>
<tr>
<td>8 stars building envelope only</td>
<td>low</td>
<td>-7,221</td>
</tr>
<tr>
<td>7 stars intermediate</td>
<td>low</td>
<td>-3,238</td>
</tr>
<tr>
<td>8 stars building envelope only</td>
<td>low</td>
<td>-17,917</td>
</tr>
<tr>
<td>8 stars ZEH onsite</td>
<td>low</td>
<td>-22,626</td>
</tr>
<tr>
<td>8 stars ZEH near site</td>
<td>low</td>
<td>-22,425</td>
</tr>
<tr>
<td>8 stars intermediate</td>
<td>high</td>
<td>-17,295</td>
</tr>
<tr>
<td>8 stars building envelope only</td>
<td>high</td>
<td>-7,166</td>
</tr>
<tr>
<td>8 stars ZEH onsite</td>
<td>high</td>
<td>-21,769</td>
</tr>
<tr>
<td>8 stars ZEH near site</td>
<td>high</td>
<td>-21,568</td>
</tr>
</tbody>
</table>

At discount rate scenario 2 (Table 36), all building performance scenarios achieved a positive NPV by 60 years except the 8 star building envelope upgrade, low energy scenario. The highest NPV after 60 years is achieved by the 8 star ZEH near site scenario (low and high energy price scenarios). After 40 years, the 8 star ZEH (near site) again achieved the highest NPV for the high energy price scenarios. However at a low energy price scenario, the 7 star intermediate scenario has the highest NPV (followed by 8 star ZEH near site and onsite scenarios). The ZEH scenarios achieved a positive NPV by 25 (onsite) and 20 (near site) years (high energy price scenario) and 30 (onsite) and 25 (near site) years (low energy price scenario). Not unexpectedly, outputs are lower and positive NPVs take longer to achieve compared to discount rate scenario 1. The amount of total positive outputs decreases by 23.1% for discount scenario 2 compared to discount scenario 1 (Table 35).

Table 37 presents the NPV outputs for discount rate scenario 3. Again, as the discount rate increases, the NPV output decreases. The amount of positive NPV outputs decreased by 75.6% compared to discount scenario 1 (Table 35) and by 68.3% compared to discount rate scenario 2 (Table 36). At the higher discount rate, only the 7 star intermediate scenario achieved a positive NPV for a low energy price scenario by 15 years. For a high energy price scenario, the 8 star ZEH scenarios achieved a positive NPV by 40 years (near site) and 50 years (onsite). The 7 star intermediate scenario achieves a positive NVP by 60 years.

The above results do not include the added resale benefit from improved energy efficiency and environmental performance. Taking this into account, the same three discount rate scenarios are
applied to the same building scenarios, this time with added resale value included (Table 38, Table 39 and Table 40).

Table 38 shows that in comparison to the same scenario without resale value (Table 35), NPVs are typically higher when resale value is taken into account. In addition, there is an increase of 26.9% of total positive outputs. All building scenarios achieved a positive NPV by 25 years, which was 20 years sooner than the NPV analysis without resale value. The 7 star intermediate scenario achieved a positive NPV by 5 years for both low and high energy price scenarios. The ZEH near site scenario achieved a positive NPV by 10 years (high energy scenario) and 15 years (low energy scenario). This outcome was achieved 5 years sooner than the same scenario without added resale value. Similar to discount rate scenario 1 (Table 35), the ZEH near site scenario achieved the highest NPV at 60 years and at 40 years for both a low and high energy price scenario.

Table 38: Net present values for the most economical ZEH, intermediate scenarios and building envelope improvements across 5 year increments including added resale value for discount rate scenario 1. Shaded results indicate a positive NPV.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Energy price future</th>
<th>NPV ($) across time</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 stars building/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>envelope only</td>
<td>low</td>
<td>-3,060 -2,245 -1,387 -632 99 744 2,051 2,891 3,562 4,195 4,794 5,359</td>
</tr>
<tr>
<td>7 stars intermediate</td>
<td>low</td>
<td>2,254 5,009 6,714 10,142 12,685 15,859 19,399 22,794 25,754 28,991 31,812 34,713</td>
</tr>
<tr>
<td>8 stars intermediate</td>
<td>low</td>
<td>-3,646 -3,254 -2,139 -560 2,138 5,253 8,826 12,166 15,893 19,043 22,732 26,029</td>
</tr>
<tr>
<td>8 stars ZEH onsite</td>
<td>low</td>
<td>-2,348 -1,953 -415 2,992 7,555 12,321 17,455 22,752 28,111 33,147 38,534 43,440</td>
</tr>
<tr>
<td>8 stars ZEH near site</td>
<td>low</td>
<td>-2,385 -808 3,360 6,215 11,845 16,826 22,960 28,602 34,606 39,478 45,195 50,168</td>
</tr>
<tr>
<td>7 stars intermediate</td>
<td>high</td>
<td>690 1,506 1,355 3,127 4,065 5,813 7,996 10,141 12,064 14,475 16,667 19,118</td>
</tr>
<tr>
<td>8 stars ZEH near site</td>
<td>high</td>
<td>-2,502 -671 1,876 5,149 9,505 14,463 20,624 26,789 33,741 40,417 47,901 55,214</td>
</tr>
<tr>
<td>8 stars building/</td>
<td>high</td>
<td>-2,574 -1,596 -505 642 1,647 2,672 4,607 5,940 7,236 8,499 9,743 10,966</td>
</tr>
<tr>
<td>envelope only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 stars ZEH onsite</td>
<td>high</td>
<td>-2,945 -492 3,482 9,204 16,432 23,694 31,891 40,689 50,330 60,086 70,616 81,028</td>
</tr>
<tr>
<td>8 stars ZEH near site</td>
<td>high</td>
<td>-2,982 -652 7,257 12,426 20,722 28,199 37,397 46,539 56,825 66,417 77,276 87,756</td>
</tr>
</tbody>
</table>
Chapter 6: Zero emission housing scenarios cost-benefit analysis

Table 39: Net present values for the most economical ZEH, intermediate scenarios and building envelope improvements across 5 year increments including added resale value for discount rate scenario 2. Shaded results indicate a positive NPV.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Energy price future</th>
<th>5 yrs</th>
<th>10 yrs</th>
<th>15 yrs</th>
<th>20 yrs</th>
<th>25 yrs</th>
<th>30 yrs</th>
<th>35 yrs</th>
<th>40 yrs</th>
<th>45 yrs</th>
<th>50 yrs</th>
<th>55 yrs</th>
<th>60 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 stars building envelope only</td>
<td>low</td>
<td>-3,378</td>
<td>-2,979</td>
<td>-2,568</td>
<td>-2,261</td>
<td>-1,987</td>
<td>-1,779</td>
<td>-1,234</td>
<td>-0.813</td>
<td>-0.673</td>
<td>-0.552</td>
<td>-0.448</td>
<td></td>
</tr>
<tr>
<td>7 stars intermediate</td>
<td>low</td>
<td>1,750</td>
<td>3,818</td>
<td>4,903</td>
<td>7,251</td>
<td>8,004</td>
<td>10,651</td>
<td>12,490</td>
<td>14,103</td>
<td>15,384</td>
<td>16,687</td>
<td>17,719</td>
<td>18,698</td>
</tr>
<tr>
<td>8 stars intermediate</td>
<td>low</td>
<td>-4,792</td>
<td>-5,391</td>
<td>-5,098</td>
<td>-4,446</td>
<td>-2,987</td>
<td>-1,301</td>
<td>0.358</td>
<td>1.785</td>
<td>3.326</td>
<td>4.492</td>
<td>5.795</td>
<td>6.859</td>
</tr>
<tr>
<td>8 stars ZEH onsite</td>
<td>low</td>
<td>-3,903</td>
<td>-4,964</td>
<td>-5,456</td>
<td>-6,262</td>
<td>45</td>
<td>2,722</td>
<td>5,168</td>
<td>7,520</td>
<td>9,765</td>
<td>11,701</td>
<td>13,638</td>
<td>15,257</td>
</tr>
<tr>
<td>8 stars ZEH near site</td>
<td>low</td>
<td>-4,003</td>
<td>-3,960</td>
<td>-1,409</td>
<td>65</td>
<td>3,484</td>
<td>6,300</td>
<td>9,329</td>
<td>11,854</td>
<td>14,399</td>
<td>16,258</td>
<td>18,329</td>
<td>19,974</td>
</tr>
<tr>
<td>7 stars intermediate</td>
<td>high</td>
<td>247</td>
<td>587</td>
<td>156</td>
<td>1,260</td>
<td>1,706</td>
<td>2,649</td>
<td>3,696</td>
<td>4,638</td>
<td>5,400</td>
<td>6,316</td>
<td>7,067</td>
<td>7,851</td>
</tr>
<tr>
<td>8 stars intermediate</td>
<td>high</td>
<td>-3,714</td>
<td>-3,079</td>
<td>-1,668</td>
<td>187</td>
<td>2,712</td>
<td>5,481</td>
<td>8,526</td>
<td>11,330</td>
<td>14,308</td>
<td>16,906</td>
<td>19,616</td>
<td>22,042</td>
</tr>
<tr>
<td>8 stars building envelope only</td>
<td>high</td>
<td>-2,924</td>
<td>-2,417</td>
<td>-1,856</td>
<td>-1,304</td>
<td>-0.895</td>
<td>-0.504</td>
<td>0.331</td>
<td>0.778</td>
<td>1.165</td>
<td>1.505</td>
<td>1.808</td>
<td>2.079</td>
</tr>
<tr>
<td>8 stars ZEH onsite</td>
<td>high</td>
<td>-4,520</td>
<td>-3,563</td>
<td>-1,992</td>
<td>2,586</td>
<td>7,076</td>
<td>11,298</td>
<td>15,463</td>
<td>19,621</td>
<td>23,885</td>
<td>27,850</td>
<td>31,806</td>
<td>35,398</td>
</tr>
<tr>
<td>8 stars ZEH near site</td>
<td>high</td>
<td>-4,540</td>
<td>-2,559</td>
<td>2,045</td>
<td>5,273</td>
<td>10,515</td>
<td>14,876</td>
<td>19,625</td>
<td>23,955</td>
<td>28,519</td>
<td>32,407</td>
<td>36,497</td>
<td>40,115</td>
</tr>
</tbody>
</table>

Table 40: Net present values for the most economical ZEH, intermediate scenarios and building envelope improvements across 5 year increments including added resale value for discount rate scenario 3. Shaded results indicate a positive NPV.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Energy price future</th>
<th>5 yrs</th>
<th>10 yrs</th>
<th>15 yrs</th>
<th>20 yrs</th>
<th>25 yrs</th>
<th>30 yrs</th>
<th>35 yrs</th>
<th>40 yrs</th>
<th>45 yrs</th>
<th>50 yrs</th>
<th>55 yrs</th>
<th>60 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 stars building envelope only</td>
<td>low</td>
<td>-3,911</td>
<td>-4,077</td>
<td>-4,161</td>
<td>-4,256</td>
<td>-4,323</td>
<td>-4,385</td>
<td>-4,313</td>
<td>-4,361</td>
<td>-4,383</td>
<td>-4,399</td>
<td>-4,411</td>
<td></td>
</tr>
<tr>
<td>7 stars intermediate</td>
<td>low</td>
<td>900</td>
<td>1,994</td>
<td>2,352</td>
<td>3,494</td>
<td>4,096</td>
<td>4,767</td>
<td>5,312</td>
<td>5,716</td>
<td>5,985</td>
<td>6,227</td>
<td>6,388</td>
<td>6,520</td>
</tr>
<tr>
<td>8 stars intermediate</td>
<td>low</td>
<td>-6,716</td>
<td>-8,631</td>
<td>-9,212</td>
<td>-9,303</td>
<td>-9,020</td>
<td>-8,512</td>
<td>-8,154</td>
<td>-7,892</td>
<td>-7,604</td>
<td>-7,430</td>
<td>-7,243</td>
<td>-7,114</td>
</tr>
<tr>
<td>8 stars ZEH onsite</td>
<td>low</td>
<td>-6,728</td>
<td>-9,532</td>
<td>-10,308</td>
<td>-9,848</td>
<td>-8,937</td>
<td>-8,046</td>
<td>-7,471</td>
<td>-6,980</td>
<td>-6,545</td>
<td>-6,223</td>
<td>-5,934</td>
<td>-5,726</td>
</tr>
<tr>
<td>8 stars ZEH near site</td>
<td>low</td>
<td>-6,721</td>
<td>-8,736</td>
<td>-8,062</td>
<td>-7,906</td>
<td>-6,603</td>
<td>-5,649</td>
<td>-4,859</td>
<td>-4,319</td>
<td>-3,810</td>
<td>-3,507</td>
<td>-3,192</td>
<td>-2,980</td>
</tr>
<tr>
<td>7 stars intermediate</td>
<td>high</td>
<td>-498</td>
<td>-804</td>
<td>-1,490</td>
<td>-1,080</td>
<td>-1,035</td>
<td>-754</td>
<td>-502</td>
<td>-312</td>
<td>-186</td>
<td>-39</td>
<td>60</td>
<td>153</td>
</tr>
<tr>
<td>8 stars intermediate</td>
<td>high</td>
<td>-5,751</td>
<td>-6,737</td>
<td>-6,614</td>
<td>-6,160</td>
<td>-5,318</td>
<td>-4,409</td>
<td>-3,612</td>
<td>-2,984</td>
<td>-2,372</td>
<td>-1,926</td>
<td>-1,514</td>
<td>-1,200</td>
</tr>
<tr>
<td>8 stars building envelope only</td>
<td>high</td>
<td>-3,512</td>
<td>-3,644</td>
<td>-3,675</td>
<td>-3,678</td>
<td>-3,725</td>
<td>-3,752</td>
<td>-3,618</td>
<td>-3,617</td>
<td>-3,622</td>
<td>-3,629</td>
<td>-3,635</td>
<td>-3,641</td>
</tr>
<tr>
<td>8 stars ZEH onsite</td>
<td>high</td>
<td>-7,168</td>
<td>-8,246</td>
<td>-7,527</td>
<td>-6,016</td>
<td>-4,201</td>
<td>-2,673</td>
<td>-1,502</td>
<td>-475</td>
<td>468</td>
<td>1,222</td>
<td>1,874</td>
<td>2,382</td>
</tr>
<tr>
<td>8 stars ZEH near site</td>
<td>high</td>
<td>-7,160</td>
<td>-7,450</td>
<td>-5,281</td>
<td>-4,074</td>
<td>-1,867</td>
<td>-277</td>
<td>1,111</td>
<td>2,186</td>
<td>3,204</td>
<td>3,938</td>
<td>4,616</td>
<td>5,128</td>
</tr>
</tbody>
</table>

Discount scenario 2 with added resale value (Table 39) shows decreased NPV outputs when compared to discount scenario 1 with added resale value (Table 38). However in comparison to discount scenario 2 without added resale value, an increase of 28.6% of positive outputs was achieved and outputs were higher. All building scenarios achieved a positive NPV by 35 years (except for 8 star building envelope upgrade low energy price scenario, which did not achieve a positive NPV). This was 10 years sooner compared to discount scenario 2 without added resale value. The 7 star intermediate scenario achieved a positive NPV by 5 years for both low and high
energy price scenarios. The ZEH near site scenario achieved a positive NPV by 15 years (high energy scenario) and 20 years (low energy price scenario) which was 5 years sooner compared to discount scenario 2 without added resale value. Again, the ZEH near site scenario achieved the highest NPV at 60 years and at 40 years for high energy price scenario. At 40 years for a low energy price scenario the 7 star intermediate scenario achieved the highest NPV followed by the 8 star ZEH near site scenario.

Similar to the results from the NPV without resale values, when the higher discount rate is applied, the value of the NPV decreases, as do the number of positive outputs. However outputs are still higher than the discount rate scenarios which did not include resale value. In comparison to discount rate scenario 1 and 2 with added resale value (Table 38 and Table 39), discount rate scenario 3 with added resale value (Table 40) had a decrease in positive outputs of 75.7% and 70.4%. However in comparison to discount rate scenario 3 without resale value (Table 37) there was an increase of positive outputs of 26.3%. At a low energy price scenario only the 7 star intermediate scenario achieved a positive NPV by 5 years. For a high energy price scenario the 7 star intermediate scenario achieved a positive NPV by 55 years, as did 8 star ZEH onsite (by 45 years) and 8 star ZEH near site (by 35 years). This is 5 years sooner than compared to equivalent scenarios without added resale value. For the high energy price scenario, the 8 star ZEH near site scenario achieved the highest NPV at 40 and 60 years.

The NPV results show that ZEH scenarios achieve a positive NPV across the Australian Government’s 40 year assumed life span for discount rate scenarios 1 and 2 (both with and without added resale value). The 8 star ZEH scenario achieved the highest NPV output after 60 years for discount rate scenarios 1 and 2 (both with and without resale value) as well as for discount rate scenario 3 for high energy price scenario (both with and without resale value). Adding resale value to the NPV analysis significantly increased the number of positive outputs, shortened the time taken to achieve positive outputs, and resulted in overall higher NPV totals.

6.12 Environmental benefits

The results so far have focused on the economic ramifications of improving the energy efficiency and environmental performance of new housing. However the economics of improving housing energy performance is only one element of the debate, as explored in chapter 1. The other critical element is the environmental impact from the way we construct and use housing. This section will present the environmental benefits of the various top-performing economic housing scenarios discussed in the previous sections. This analysis is based upon energy consumption through-life, and does not consider impacts from the building process, technologies or materials.
Chapter 6: Zero emission housing scenarios cost-benefit analysis

The environmental impacts per year for a typical 6 star BAU house and for the other top economic scenarios in terms of greenhouse gas emission equivalent (CO$_2$-e) are presented in Table 41. For a detached 6 star (BAU) house with both gas and electricity energy requirements, this results in a yearly CO$_2$-e of 8,288 kgs/dwelling. Improving the building envelope to 8 star would reduce CO$_2$-e by 807 kgs/dwelling (9.74%). For the 7 star intermediate scenario, a CO$_2$-e reduction of 1,939 kgs/dwelling (23.40%) is demonstrated compared to the 6 star BAU and a CO$_2$-e reduction of 5,839 kg/dwelling (70.45%) for the 8 star intermediate scenario is demonstrated. A 100% reduction in CO$_2$-e was achieved for the ZEH scenarios for operational energy emissions.

Table 41: Kilograms of CO$_2$-e for energy consumed for the various top energy performance scenarios compared to 6 star BAU.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Energy consumption (minus renewable energy amount)</th>
<th>Kg CO$_2$-e per total energy consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas (MJ)</td>
<td>Electricity (kWh)</td>
</tr>
<tr>
<td>6 star BAU</td>
<td>38,819</td>
<td>4,496</td>
</tr>
<tr>
<td>8 star building envelope only</td>
<td>27,269</td>
<td>4,396</td>
</tr>
<tr>
<td>7 star intermediate (1kW PV)</td>
<td>31,825</td>
<td>3,353</td>
</tr>
<tr>
<td>8 star intermediate (2.5kW PV, SHW)</td>
<td>16,392</td>
<td>1,114</td>
</tr>
<tr>
<td>8 star ZEH (4.3kW PV, SHW onsite or near site)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Across the life of the dwelling, a ZEH has the potential to avoid significant amounts of energy requirements and, in turn, associated CO$_2$-e emission. For a single detached ZEH (full electric) house this equates to displacing 4,496 kWh of electricity generation and avoiding 38,819 MJ of gas generation (Table 42). If all new detached housing was built to ZEH standards this would equate to displacing 169,463 MWh of electricity generation and avoiding 1.4 X $10^6$ GJ of natural gas consumption. Across a 40+ year life span of a house these savings are significant, especially if each proceeding year new housing stock also achieves a ZEH standard. This will be discussed in further detail in chapter 8.

Table 42: Avoided energy consumption across time for a single detached house and assumed all 2011 new detached housing in Victoria.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1 year</th>
<th>20 years</th>
<th>40 years</th>
<th>60 years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electricity (MWh)</td>
<td>Gas (GJ)</td>
<td>Electricity (MWh)</td>
<td>Gas (GJ)</td>
</tr>
<tr>
<td>1 detached house</td>
<td>4.5</td>
<td>38.8</td>
<td>90</td>
<td>776</td>
</tr>
<tr>
<td>37,692 detached houses</td>
<td>169,463</td>
<td>1,463,166</td>
<td>3,389,265</td>
<td>29,263,315</td>
</tr>
</tbody>
</table>

Table 43 presents avoided CO$_2$-e (t) for a single detached ZEH as well as the wider implications for new detached housing built across a year in Victoria. For a single detached house this equates to 8.3 t/yr avoided CO$_2$-e. Extrapolating for all detached housing assumed built in 2011 in Victoria,
this equates to 312,383 t/yr of avoided CO₂-e., equal to about 0.05% of Australia’s total CO₂-e from 2008 (Table 44) (Commonwealth of Australia, 2010).

Table 43: Avoided tonnes of CO₂-e across time for a single detached house and assumed all 2011 new detached housing in Victoria.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1 year</th>
<th>20 years</th>
<th>40 years</th>
<th>60 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 detached house (t)</td>
<td>8.3</td>
<td>166</td>
<td>332</td>
<td>497</td>
</tr>
<tr>
<td>37,692 detached houses (t)</td>
<td>312,383</td>
<td>6,247,666</td>
<td>12,495,332</td>
<td>18,742,998</td>
</tr>
</tbody>
</table>

Table 44: Percentage of total Australian CO₂-e from total ZEH detached housing in one year.

<table>
<thead>
<tr>
<th>Victoria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total CO₂-e Australia 2008 (t)</td>
</tr>
<tr>
<td>Total CO₂-e detached housing Victoria - 1 year (t)</td>
</tr>
<tr>
<td>% of total Australian CO₂-e</td>
</tr>
</tbody>
</table>

In summary, there are significant environmental savings to be achieved by building housing to higher energy standards. While improvements to building envelope standards and the integration of limited renewable energy technologies reduces environmental impacts, any standard less than ZEH continues to add to CO₂-e levels. If all new detached housing in 2011 was built to a ZEH standard this would equate to a 0.05% reduction of 2008 total CO₂-e in Australia.

6.13 Sensitivity analysis

A sensitivity analysis was undertaken to assess the impact of inflation rates on the results. Figure 32 shows the 6 star BAU low energy price scenario and the 8 star ZEH (near site) scenario across three inflation rates: the 3.0% used in the analysis throughout this chapter and 2.0% and 4.0% inflation rates. As expected, the higher inflation rate increases total costs across the life of the house. The impact to 6 star BAU increases after about 20 years and continues to increase until the end of the analysis period. There is comparatively less impact to the ZEH scenarios. These scenarios only begin to show differences after approximately 30 years. This has to do with the fact that the majority of costs for a ZEH occur upfront and again at 30 years, whereas the BAU approach includes yearly costs. The results demonstrate that inflation has limited impact as a variable for a low carbon future compared to a BAU future.
6.14 CBA results summary

A significant gap in the literature existed with regards to the costs and benefits of improved energy performance from new housing, specifically ZEH, in the Australian context, as discussed in chapters 1 and 3. In response to this, a series of questions were raised. This chapter specifically addressed (sub question 1) ‘what are the through-life costs and benefits of ZEH performance standards for owner-occupied new home buyers’ and (sub question 2) ‘what implications arise from through-life costs and benefits of ZEH, both in practical and policy dimensions’?

The results presented throughout this chapter demonstrate the economic and environmental benefits of improving the energy performance of new housing stock. Across the 40 year life of a house, the results show that it is economically beneficial to build to a ZEH standard. The additional capital costs (7.8% additional on house and land total) may add to living costs through additional mortgage repayments, however this can be offset through energy savings (up to 88.5% or $502,000 across 60 years compared to 6 star BAU), leading to the mortgage being paid off up to several years quicker and incurring less total interest repayments.

In addition, significant environmental benefits can be achieved through building new housing to a ZEH standard. If all new detached housing in Victoria is built to a ZEH standard, in one year this would equate to avoidance in CO₂-e of 0.05% of the Australian total (2008), which while a small amount, is still 0.05% which does not need to be addressed elsewhere in the residential or wider...
sectors. Furthermore the ongoing yearly benefits of avoided CO₂-e will continue to accumulate as more ZEH is added to the building stock. The results have demonstrated that ZEH is economically and environmentally feasible based upon current technologies and costs. The next chapter asks how future energy performance policies can be developed to transition to a ZEH future.
Chapter 7: Housing energy performance policy document analysis

This chapter presents results from the comparative policy document analysis conducted using an STT criteria framework, as described in chapter 5 (phase 2). The chapter primarily addresses sub question 3:

- What actions may facilitate a transition to ZEH through minimum housing energy performance regulation in the Australian context?

Section 7.1 presents a summary of the results of this analysis with full results presented in the appendix. These results are discussed with reference to each case study jurisdiction in sections 7.2–7.4, beginning with the USA and within this, the State of California. This is then followed by the EU and UK discussion, before finishing with the Australian and Victorian context. Where appropriate, comparisons between case study jurisdictions are made. Discussion of the implications of results presented in this chapter is continued in chapter 8.

7.1 Results

A total of 17 key policy documents were analysed across the three case study jurisdiction areas, as identified in chapter 5. Each policy document was analysed against 17 broad criteria categories, incorporating 66 specific questions. These questions address both social and technical aspects, as identified from the literature on socio-technical transitions theory discussed in chapters 4 and 5.

Responses to the criteria questions are coded into one of 6 categorical answers, as presented in Table 45.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>Yes: Mandatory requirement included in policy</td>
</tr>
<tr>
<td>R</td>
<td>Yes: Recommended requirement in policy, generally one of a number of options which needs to be addressed - Not a mandatory requirement</td>
</tr>
<tr>
<td>P</td>
<td>Yes: Partially addressed, but does not completely address the criteria question</td>
</tr>
<tr>
<td>N</td>
<td>Acknowledged within the policy but not included as a requirement</td>
</tr>
<tr>
<td>f</td>
<td>Discussed in the policy for future inclusion (mandatory)</td>
</tr>
<tr>
<td>-</td>
<td>Aspect is not mentioned in any way</td>
</tr>
</tbody>
</table>

Table 46 presents a summary of the coded results from the policy document analysis for each of the 17 broad criteria categories for each jurisdiction. An example of the detailed results is presented in Table 47. The completed coded results for each policy document and specific questions are presented in the appendix of this thesis.
Table 46: Summary of policy document analysis coded results.

<table>
<thead>
<tr>
<th>Social criteria</th>
<th>USA</th>
<th>California</th>
<th>EU</th>
<th>UK</th>
<th>Australia</th>
<th>Victoria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-term policy and vision setting</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Scenarios (pathways)</td>
<td>P</td>
<td>Y</td>
<td>P</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>International best practice</td>
<td>-</td>
<td>Y</td>
<td>P</td>
<td>-</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Link to wider policy goals</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Reflexive governance</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>(Wider) Social elements</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>Y</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Research and development</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Financial sector</td>
<td>-</td>
<td>P</td>
<td>Y</td>
<td>Y</td>
<td>P</td>
<td>-</td>
</tr>
<tr>
<td>Institutional structure/reform</td>
<td>-</td>
<td>-</td>
<td>P</td>
<td>Y</td>
<td>P</td>
<td>-</td>
</tr>
<tr>
<td>Behaviour</td>
<td>N</td>
<td>P</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>N</td>
</tr>
</tbody>
</table>

| Technical ZEH criteria                        |     |            |    |    |           |          |
| Energy efficiency of building envelope        | Y   | Y          | Y  | Y  | Y         | Y        |
| Reduction of overall emissions                | Y   | Y          | Y  | Y  | Y         | Y        |
| Energy generation/ infrastructure             | Pf  | R/Yf       | R/Yf| R/Yf| N         | N        |
| House as part of larger system                | P   | -          | -  | P  | Y         | -        |
| Smart technology                              | R   | R          | R  | R  | -         | -        |
| Through-life costs and benefits               | -   | Y          | P  | Y  | P         | P        |
| Appliances                                    | Y   | Y          | Y  | Y  | Y         | Y        |
Table 47: Example of the detailed policy document analysis. For the full analysis refer to the appendix.

<table>
<thead>
<tr>
<th>Social criteria: Long-term policy and vision setting</th>
<th>USA</th>
<th>California</th>
<th>EU</th>
<th>UK</th>
<th>Australia</th>
<th>Vic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is ZEH a policy goal/requirement?</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>P*</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Is there evidence of a medium-term (5–14 years) housing performance policy strategy?</td>
<td>-</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Technical criteria: Energy generation/infrastructure</td>
<td>Is energy generation included as part of the house performance assessment?</td>
<td>N</td>
<td>R</td>
<td>Y</td>
<td>R/Yf</td>
<td>-</td>
</tr>
<tr>
<td>Is there a requirement for renewable energy technologies?</td>
<td>N</td>
<td>R</td>
<td>Y</td>
<td>R/Yf</td>
<td>-</td>
<td>R/Yf</td>
</tr>
</tbody>
</table>

* These policies refer to ZEH but use a different definition than the one applied in this research.

The remainder of this chapter presents a discussion of the results for each of the case study jurisdictions. STT criteria incorporated into established policy documents to date, along with clear omissions and gaps in current policy documents, are addressed for each case jurisdiction. The use of direct quotation of statements from relevant policy documents is applied where appropriate to support the analysis. In addition, wider policy document description and context is provided for each case study jurisdiction, augmenting the literature presented in chapter 3.

### 7.2 United States of America/California

#### 7.2.1 United States of America

**Policy description and context**

The USA has a national minimum residential building code standard known as the International Residential Code, which is briefly discussed in chapter 3 (ICC, 2012c). The International Residential Code was first published in 2000 and since then has been revised a number of times
The current version is the 2012 International Residential Code, with the next revision expected in 2015 (ICC, 2012c).

Every state (with the exception of Wisconsin, as at 1st February 2012) has implemented some form of the International Residential Code (ICC, 2012a). States, and in some cases regions within states, are free to modify this code as they see fit. Some states and local government areas enforce older versions of the International Residential Code, as there is no requirement to revise state and local regulations when updated International Residential Code guidelines are released. No state had yet adopted the 2012 International Residential Code update, with the majority of states split between the previous 2009 International Residential Code (20 states) and the 2006 version (19 states) (ICC, 2012a). In addition, six states had a standard based upon the 2000 or 2003 version of the International Residential Code with the remaining states identified as having some form of International Residential Code at a local level but not specifying what year they were based upon (ICC, 2012a).

The International Residential Code prescribes minimum standards for residential dwellings through requirements for material use as well as for aspects such as heating and cooling needs (ICC, 2012c). The energy efficiency performance of the International Residential Code is set by the International Energy Conservation Code 2012 (ICC, 2012b). The International Energy Conservation Code sets the minimum performance standards primarily for space heating, cooling and water heating in relation to residential dwellings. Under the current code, the International Residential Code does not meet ZEH standards.

In addition to the International Residential Code, the USA has a National Green Building Standard which builds upon the requirements set in the International Residential Code (NAHB, 2008). The National Green Building Standard is currently a voluntary standard except in California where it is mandatory (discussed further in section 7.2.2). The National Green Building Standard is developed and overseen by the International Code Council who developed the International Residential Code. The National Green Building Standard aims to:

‘establish practices for the design and construction of green residential buildings, building sites, subdivisions, and renovation thereof. This Standard is intended to provide flexibility to permit the use of innovative approaches and techniques’ (NAHB, 2008, p. 1).

In terms of ZEH standards, the US Department of Energy has articulated a goal of all new housing being built to a ZEH standard by 2020. This goal will be implemented through the Building Energy Code initiative and specifically the Building America Program.
Chapter 7: Housing energy performance policy document analysis

**STT inclusions**

Across the selected policy documents, analysis identified a number of specific elements within the broader STT criteria which were addressed. These will be discussed below for relevant policy documents and include:

- medium-term goals,
- more comprehensive policy approach,
- a requirement for renewable energy technologies,
- links to wider policy,
- (limited) wider social element integration, and
- evolution of rating tools and performance checks.

There is a stated federal government goal of achieving ZEH standards by 2020 (medium-term policy) through the Building America program and with a focus on research, development and demonstration projects, which employ innovative solutions to achieve the new standard. The Building America program aims to achieve ZEH outcomes through improving energy efficiency of the house by up to 70% and then generating enough renewable energy to cover the remaining energy consumption. The Building America program includes a shift in focus from traditional heating and cooling energy efficiency measures to a whole of house energy approach, including renewable energy technologies.

The program goals provide further evidence of this wider scope and approach, including the following objectives (DOE, 2010):

- Integrate clean onsite power systems leading to Zero Energy Homes.
- Reduce average whole-house energy use by 40%–100%.
- Reduce construction time and waste.
- Improve indoor air quality and comfort.
- Implement innovative energy and material saving technologies.

The Building America program also includes links to wider greenhouse gas emission reduction targets, renewable energy targets and includes limited integration of wider social elements such as human health, living affordability, occupant comfort, and the reduction of demand for energy to begin with. For example, benefits to homeowners and the nation more broadly, have been identified, including (Barry, 1999):

- reduced utility costs leading to the improved affordability of homes,
- increased thermal comfort,
- improved indoor air quality,
higher resale values,
lower greenhouse gas emissions,
reduced health issues resulting from unhealthy or unsafe housing, and
job creation.

Of the current range of housing energy performance standards, the International Residential Code and National Green Building Standard both address a number of the STT criteria. The International Residential Code addresses a number of the technical requirements for improving energy efficiency, such as the setting of minimum insulation requirements for each climate zone as well as elements such as air leakage rates. These requirements have been updated and stringency increased in the 2012 version, which includes new mandatory requirements such as testing to ensure that certain energy performance criteria are met. As one example of these performance testing requirements, the following quote presents the mandatory requirement for blower door tests to ensure that air leakage rates are met:

‘N1102.4.1.2 (R402.4.1.2) Testing.

The building or dwelling unit shall be tested and verified as having an air leakage rate of not exceeding 5 air changes per hour in Zones 1 and 2, and 3 air changes per hour in Zones 3 through 8. Testing shall be conducted with a blower door at a pressure of 0.2 inches w.g. (50 Pascals). Where required by the building official, testing shall be conducted by an approved third party. A written report of the results of the test shall be signed by the party conducting the test and provided to the building official. Testing shall be performed at any time after creation of all penetrations of the building thermal envelope.’ (ICC, 2012c, p. 484).

The National Green Building Standard has been developed with explicitly stated links to greenhouse gas emission reduction targets and renewable energy targets. In this regard, this standard applies a wider consideration of energy use in buildings than previous standards. The National Green Building Standard aims to deliver housing performance beyond the minimum requirements and include within the rating system points aspects that are not included in the minimum International Residential Code. Some examples of this include the use of renewable energy technologies and improving indoor air quality.

Assessment within the National Green Building Standard provides four levels of rating; bronze, silver, gold and emerald (Table 48). It is possible to obtain the top rating, emerald, without the house being a ZEH as there is no requirement for renewable energy generation. An National Green Building Standard emerald rating is equivalent to a 60% energy saving over the 2006 International
Chapter 7: Housing energy performance policy document analysis


**Table 48: Threshold point ratings for green buildings (NAHB, 2008).**

<table>
<thead>
<tr>
<th>Green Building categories</th>
<th>Performance level points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bronze</td>
</tr>
<tr>
<td>Lot design, preparation, and development</td>
<td>39</td>
</tr>
<tr>
<td>Resource efficiency</td>
<td>45</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>30</td>
</tr>
<tr>
<td>Water efficiency</td>
<td>14</td>
</tr>
<tr>
<td>Indoor environmental quality</td>
<td>36</td>
</tr>
<tr>
<td>Operation, maintenance, and building owner education</td>
<td>8</td>
</tr>
<tr>
<td>Additional points from any category</td>
<td>50</td>
</tr>
<tr>
<td><strong>Total points</strong></td>
<td><strong>222</strong></td>
</tr>
</tbody>
</table>

Further to the above technical performance criteria, there are a number of social criteria addressed in the National Green Building Standard, similar to those included within the Building America program. For example, the following extract shows a reference to improving indoor air quality, which can improve occupant health:

‘901.6 Wall coverings. A minimum of 85 per cent of installed hard-surface flooring is in accordance with the emission concentration limits of CDPH 01350 (using the office scenario), as certified by a third-party program, such as the Resilient Floor Covering Institute’s FloorScore Indoor Air Certification Program or the GREENGUARD Environmental Institute’s Children and Schools Certification Program’ (NAHB, 2008, p. 72).

**STT gaps/limitations**

A number of specific gaps within the broader STT criteria are evident from the analysis. These will be discussed below and include:

- no pathway development,
- no long-term policy development,
- limited comprehensive energy approach in current standards,
- no current mandatory requirement for renewable energy technologies,
- limited inclusion of wider social elements, and
- limited financial innovation.
While the Building America program has a stated goal of a ZEH standard for new housing, this is not yet linked to the International Residential Code or the National Green Building Standard. Similarly, there is no pathway or scenario developed to date on how to achieve ZEH standards in practice. The International Residential Code and the National Green Building Standard do not state any future performance goals. Nor do any of the policy documents contain long-term goals beyond 2020 (medium-term).

Further, there is limited focus in the main performance governing document, the International Residential Code, of reducing greenhouse gas emissions beyond that of improving heating and cooling efficiencies. There is no requirement for aspects of renewable energy technology for example. While the National Green Building Standard does include a number of these wider technical criteria, they are voluntary standards.

Across all of the aforementioned policy documents, there is limited inclusion of wider social elements such as lifetime affordability, addressing fuel poverty, addressing consumer behaviour/education and the sociological meanings of home. In addition, there is limited focus on industry reform such as the requirement to re-train current actors in the building industry or the need to address the wider impacts of new regulation on the building sector within the policy documents analysed. Wider government policies are addressing the requirement for ‘green’ jobs and re-training of existing labour force (USDL, 2012), however to date there has been limited integration of this approach into the policy documents analysed in this research regarding improving housing energy performance requirements.

Furthermore, there is a lack of discussion about the financial elements of ZEH, such as initiatives to reduce the capital costs of construction, or efforts to work with the financial sector to create new sustainability-led approaches, within the policy documents analysed. In addition, there is a lack of cost-benefit information surrounding measures mandated by the International Residential Code, the National Green Building Standard and Building America performance standards.

**USA summary**

In summary, at the federal level, the USA has taken initial steps to a transition to ZEH standards by setting this as a long-term goal. However the goal remains detached from the housing energy performance standards. Two green building standards do exist but these remain voluntary and are also not linked to longer-term Building America program goals. Furthermore, a number of wider socio-technical criteria have not yet been addressed in the policy documents.
7.2.2 California

Policy descriptions and context

Since the 1st of January 2011, housing energy performance requirements for new housing in the State of California have been mandated through the CALGreen code, which replaced a standard based upon the International Residential Code 2009. Housing policy in California falls under ‘Title 24’ which contains several aspects of housing policy including energy efficiency and minimum standards – the International Residential Code (previously) and CALGreen/National Green Building Standard fall under Title 24.

CALGreen is based upon the National Green Building Standard and was the first state-wide adoption of a ‘green’ housing standard in the USA. Prior to the introduction of CALGreen, the California Green Building Standards Code (based upon the National Green Building Standard) was introduced in 2009 as a voluntary standard. Implementation of CALGreen as a minimum building standard for new housing was predicted to achieve a 15% improvement in energy efficiency compared to the previous standard (CBSC, 2010). However the standard also addressed wider issues such as planning and design, water efficiency and conservation, material conservation and resource efficiency and environmental quality.

A ‘green’ housing standard for California resulted from the passing of Assembly Bill 32 Global Warming Solutions Act of 2006. This Bill set out legal requirements to achieve a 25% reduction of 1990 levels of greenhouse gas emissions for the State of California by 2020. As an outcome, two key documents to address the reduction of energy consumption and greenhouse gas emissions in the residential sector in California were developed.

The first document is Assembly Bill 2112 Zero Net Energy Buildings. This legislation set forth the requirement to build all new housing to a zero net energy performance level by no later than 2020. To achieve this, a second document was developed: the California long-term energy efficiency strategy strategic plan (Strategic Plan). The following analysis focuses on the CALGreen standard, Assembly Bill 2112 and the Strategic Plan.

STT inclusions

Analysis of the above Californian policy documents has identified that a number of specific elements within the broader STT criteria were addressed. These will be discussed below for relevant policy documents and include:

- medium-term goals,
- comprehensive policy approach,
- a mandatory requirement for renewable energy technology (in future years),
pathway development,

links to wider policies,

limited integration of wider social elements, and

addressing wider financial elements.

There is a requirement within CALGreen for the energy efficiency of the building envelope to be assessed against predefined performance standards. This requirement goes beyond a heating and cooling focus and includes other energy consuming elements such as the setting of lighting energy efficiency. The improvement to the thermal performance of the building envelope remains the primary focus of CALGreen. The standard promotes the incorporation of passive solar techniques, in this regard. For example, building to optimal orientation will gain a dwelling additional credits towards achieving a higher rating:

‘Voluntary measure - A4.106.1 Building orientation. Orient buildings to optimize the use of solar energy with the long side of the house oriented within 30° of south.’ (CBSC, 2010, p. 56).

The inclusion of renewable energy and smart technologies is recommended within CALGreen. While currently voluntary, Assembly Bill 2112 and the Strategic Plan detail a requirement for these technologies to be part of the building standard by 2020 (Table 49) (CPUC 2011). This is a clear indication of a change in focus beyond the regulation of heating and cooling energy.
Table 49: Californian residential sector energy goals (CPUC, 2011, p. 11).

<table>
<thead>
<tr>
<th>Goal</th>
<th>Goal results</th>
</tr>
</thead>
<tbody>
<tr>
<td>New construction will reach “zero net energy” (ZNE) performance (including clean, onsite distributed generation) for all new single and multi-family homes by 2020.</td>
<td>By 2011, 50% of new homes will surpass 2005 Title 24 standards by 35%; 10% will surpass 2005 Title 24 standards by 55%.</td>
</tr>
<tr>
<td></td>
<td>By 2015, 90% will surpass 2005 Title 24 standards by 35%.</td>
</tr>
<tr>
<td></td>
<td>By 2020, all new homes are ZNE.</td>
</tr>
<tr>
<td>Home buyers, owners and renovators will implement a whole house approach to energy consumption that will guide their purchase and use of existing and new homes, home equipment (e.g., HVAC systems), household appliances, lighting, and “plug load” amenities.</td>
<td>Energy consumption in existing homes will be reduced by 20% by 2015 and 40% by 2020 through universal demand for highly efficient homes and products.</td>
</tr>
<tr>
<td>Plug loads will be managed by developing consumer electronics and appliances that use less energy and provide tools to enable customers to understand and manage their energy demand.</td>
<td>Plug loads will grow at a slower rate and then decline through technological innovation spurred by market transformation and customer demand for energy efficient products.</td>
</tr>
<tr>
<td>The residential lighting industry will undergo substantial transformation through the deployment of high-efficiency and high-performance lighting technologies, supported by state and national codes and standards.</td>
<td>Utilities will begin to phase traditional mass market CFL bulb promotions and giveaways out of program portfolios and shift focus toward new lighting technologies and other innovative programs that focus on lasting energy savings and improved consumer uptake.</td>
</tr>
</tbody>
</table>

Table 49 (from the Strategic Plan) provides evidence that a number of non-technical social STT criteria are included in the California state policy discourse. In particular it sets out a clear end-goal of zero net energy housing to be achieved by 2020. In the Californian policy, zero net energy housing is defined as a home that ‘will employ a combination of energy efficiency design features, efficient appliances, managed plug loads and clean on-site distributed generation to result in no net purchases of energy from the grid’ over a typical year (CPUC 2011 p.13).

The policy goal to achieve zero net energy housing is accompanied by a policy implementation pathway with targets to achieve the stated goal of ZEH by 2020. Reference is made to future implementation of a ‘whole house approach to energy consumption’ (CPUC, 2011, p. 11), providing further evidence of changes to the traditional focus on heating and cooling energy only.

There is a clear link to climate change emission reduction targets and renewable energy generation targets within the analysed policy documents. In particular, references are made to Assembly Bill 32, highlighted as a driver through which to achieve ZEH by 2020:

‘The Commission recognized that California’s very ambitious energy efficiency and greenhouse gas reduction goals require long-term strategic planning to eliminate persistent market barriers and effect lasting transformation in the market for energy efficiency across the economy. Accordingly, the Commission
committed to prepare and adopt a long-term strategic plan for California energy efficiency through 2020 and beyond’ (CPUC, 2008, p. 1).

The policy documents analysed also included some of the wider social elements from identified STT criteria. Occupant health (through improved indoor air quality) is mentioned, and there is a recognition that housing affordability remains an important consideration while legislating for sustainable outcomes, as described in the following quote:

‘Affordability is a key consideration in California, where the cost of housing is a serious, long-term issue. A key element of this Goal is to develop ZNE example homes across the spectrum of housing options, including multifamily affordable housing in urban infill areas with access to public transportation’ (CPUC, 2008, p. 16).

There is also recognition within the Strategic Plan that addressing costs associated with proposed changes would present an important focus area for government. In this regard, government rebates as well as market level levers are explicitly identified:

‘…the CPUC will establish a Finance Task Force for the commercial and residential sectors made up of members of the financial/investment industries; building and developer community; and, State, Federal and local governments to identify existing and additional needed tools, instruments, and information necessary to attract greater participation of capital markets in funding efficiency transactions. The Task Force will identify actors to develop innovative and effective financing tools especially suited for ZNE and ultra-low-energy buildings’ (CPUC, 2008, p. 16).

**STT gaps/limitations**

While a number of specific STT element inclusions were found, a number of specific gaps within the broader STT criteria are evident from the analysis of Californian policy. These will be discussed below and include:

- long-term policy development,
- long-term financial assistance plan,
- institutional reform, and
- limited wider social inclusions.

There is no evidence in the documents analysed of a long-term (15+ years) housing performance policy direction. There is also a lack of discussion on how the socio-technical system will be
stabilised (e.g. financial support withdrawn) as ZEH becomes the new socio-technical regime in future years.

In contrast to the clear pathway set out for technical performance requirements of new housing to 2020, there was a dearth of discussion on deeper institution structural changes or reform within the policy documents analysed. Plans to re-train current regime actors and research into what performance changes mean in terms of building industry practices and physical housing outcomes are absent. As at the federal level, there are wider state policies and programs which do address these elements (California Workforce Investment Board, 2012), however to date they are not integrated with their transition towards ZEH policy documents.

In addition, while a number of wider social elements are addressed in the policy documents, a number of significant social aspects are not. These include instruments to address fuel poverty, research into and consideration of householder. However, compared to the wider USA policy analysis, wider social elements were more prevalent.

**California summary**

The State of California has set a clear goal of achieving a ZEH standard for new housing by 2020. This is accompanied by a clearly stated policy implementation pathway with interim targets. To achieve this goal, a green building standard was implemented in 2011. This standard and wider policy documents address a number of social and technical criteria such as recommendations and future requirements for renewable energy technologies. However some significant socio-technical criteria remain outside of the focus of these policy documents, including the articulation of a longer-term policy vision (15+ years) and discussion of means to address institutional reforms. In comparison to federal policy development, the State of California has addressed more STT criteria and has fewer STT criteria omissions in their policy documents. In particular, the setting of a clear pathway with renewable energy recommendations (and future requirements) sets the policy documents in California apart from USA policy documents at the federal level.

**7.3 European Union/United Kingdom**

**7.3.1 European Union**

**Policy description and context**

In May 2010, the EU revised Directive 2002/91/EC on the energy performance of buildings and replaced it with Directive 2010/31/EU on the energy performance of buildings (recast) (Directive 2010) (European Commission, 2010). This is the main policy governing housing performance and standards across the EU. It differs from the International Residential Code in the USA in that it does not provide specific requirements for housing performance; rather it provides an overall guide
on improving the sustainability and energy performance of housing. The primary aim of this policy is to direct efforts to reduce ‘the large differences between Member States’ housing energy performance policies and continue to improve minimum standards (European Commission, 2010, p. 2). Due to issues with providing a single, uniform standard across 27 Member States, the Directive allows each state to set its own minimum performance standards based upon recommendations outlined.


**STT inclusions**

Analysis of the EU policy documents identified that a number of specific elements within the broader STT criteria have been addressed. These will be discussed below for relevant policy documents and include:

- medium-term goals,
- pathway development,
- comprehensive policy approach,
- requirement for financial assistance innovation,
- requirement for mandatory renewable energy technologies (future),
- wider energy efficiency of building envelope innovation,
- links to wider policies,
- wider social element integration, and
- industrial reform consideration.

Directive 2010 explicitly states as a goal that national plans ‘for increasing the number of nearly zero-energy buildings, must be included in housing performance policy, a target which the EU has mandated to achieve by 31st of December 2020 for all new dwellings. In the EU policy context case, (nearly) zero emission buildings are not clearly defined, however they are referred to as buildings with:

‘a very high energy performance…the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby’ (European Commission, 2010, p. 18).
Zero emission buildings had already been flagged as a goal in earlier policy documents. For example, the Action Plan called for a revision to the previous Directive 2002 to include a requirement for policy measures to encourage low carbon housing, approaching the performance standards of PassivHaus (Germany) by 2015 (European Commission, 2006, 2010).

As part of the ZEH goal, Directive 2010 states that interim targets for energy efficiency for 2015 must be set by Member States. To ensure that the ZEH goal is achieved, a number of reflexive governance criteria are addressed within Directive 2010. This includes a requirement for each Member State to submit regular cost-benefit analysis on the setting of their minimum standards:

‘It is the sole responsibility of Member States to set minimum requirements for the energy performance of buildings and building elements. Those requirements should be set with a view to achieving the cost-optimal balance between the investments involved and the energy costs saved throughout the lifecycle of the building, without prejudice to the right of Member States to set minimum requirements which are more energy efficient than cost-optimal energy efficiency levels. Provision should be made for the possibility for Member States to review regularly their minimum energy performance requirements for buildings in the light of technical progress’ (European Commission, 2010, p. 2).

This requirement is intended to provide a check, and to ensure that Member States remain ‘on track’ to meet the ZEH goal. In addition the checks prescribed by the Directive provide a mechanism through which to address financial elements as well as to integrate innovation on cost and technological elements into future policy revision and development.

Further finance criteria are addressed in Directive 2010 and the Action Plan. For example Directive 2010 requires Member States to report on current and proposed financial instruments to help achieve ZEH standards by 2020. It is a requirement to update this report at a period of no longer than every 3 years. Member States are also to set a range of penalties which will apply for failure to meet the Directives targets. In addition, the Action Plan calls for a revision of taxation approaches and seeks banking sector reform to assist progress towards a low carbon future. The following articulates the requirement for improving the cost-benefit equation associated with ZEH:

‘Financial incentives and market barriers

1. In view of the importance of providing appropriate financing and other instruments to catalyse the energy performance of buildings and the transition to nearly zero-energy buildings, Member States shall take appropriate steps to consider the most relevant such instruments in the light of national circumstances.
2. Member States shall draw up, by 30 June 2011, a list of existing and, if appropriate, proposed measures and instruments including those of a financial nature, other than those required by this Directive, which promote the objectives of this Directive.

Member States shall update this list every three years. Member States shall communicate these lists to the Commission, which they may do by including them in the Energy Efficiency Action Plans referred to in Article 14(2) of Directive 2006/32/EC.

3. The Commission shall examine the effectiveness of the listed existing and proposed measures referred to in paragraph 2 as well as of relevant Union instruments, in supporting the implementation of this Directive. On the basis of that examination, and taking due account of the principle of subsidiarity, the Commission may provide advice or recommendations as regards specific national schemes and coordination with Union and international financial institutions.’ (European Commission, 2010, p. 22).

In addition to setting of the ZEH goal, identifying pathways and addressing financial issues, a number of technical criteria are also met within the policy documents. As with the codes in the USA, a house rating is required and minimum heating and cooling energy requirements must be achieved. While not specifying exact technical or performance element requirements, Directive 2010 provides a list of areas suggested for inclusion in house performance minimum standards. This includes renewable energy technologies, which while currently a voluntary addition are set to become mandatory as the performance standards reach ZEH levels. This has been informed from Directive 2009 which calls for Member States to have included mandatory renewable energy requirements in their building standards by 2015:

‘By 31 December 2014, Member States shall, in their building regulations and codes or by other means with equivalent effect, where appropriate, require the use of minimum levels of energy from renewable sources in new buildings and in existing buildings that are subject to major renovation. Member States shall permit those minimum levels to be fulfilled, inter alia, through district heating and cooling produced using a significant proportion of renewable energy sources’ (European Commission, 2010, p. 22).

This is evidence that this document moves beyond a heating and cooling energy focus. Further recommendations include building to optimal orientation and the inclusion of smart technologies. To help develop these and future technologies, Directive 2010 and the Action Plan are supportive
Chapter 7: Housing energy performance policy document analysis

of increasing research and development to assist with the identification and development of innovative solutions.

Moreover, Directive 2010 is clearly linked into climate change emission reduction targets and renewable energy generation targets (European Commission, 2006, 2009). The importance of these targets and the impact of housing (especially the long-term impact), as well as other key energy issues, such as peak energy loads due to increased air conditioning use, are clearly discussed at the beginning of the Directive. The following is an extract from Directive 2010 and clearly sets out the importance of improving housing energy performance:

‘Buildings account for 40% of total energy consumption in the Union. The sector is expanding, which is bound to increase its energy consumption. Therefore, reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute important measures needed to reduce the Union’s energy dependency and greenhouse gas emissions. Together with an increased use of energy from renewable sources, measures taken to reduce energy consumption in the Union would allow the Union to comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change, and to honour both its long-term commitment to maintain the global temperature rise below 2°C, and its commitment to reduce, by 2020, overall greenhouse gas emissions by at least 20% below 1990 levels, and by 30% in the event of an international agreement being reached. Reduced energy consumption and an increased use of energy from renewable sources also have an important part to play in promoting security of energy supply, technological developments and in creating opportunities for employment and regional development, in particular in rural areas.

Management of energy demand is an important tool enabling the Union to influence the global energy market and hence the security of energy supply in the medium and long-term’ (European Commission, 2010, p. 22).

Further to this, the importance of moving to low carbon housing is clearly set out in the Action Plan:

‘The European Union is facing unprecedented energy challenges resulting from increased import dependency, concerns over supplies of fossil fuels worldwide and a clearly discernible climate change. In spite of this, Europe continues to waste at least 20% of its energy due to inefficiency. The EU can and must lead
the way in reducing energy inefficiency, using all available policy tools at all different levels of government and society’ (European Commission, 2006, p. 3).

The policy documents, in particular Directive 2010, also address a number of wider social elements including human health, living affordability, measures to address fuel poverty, a reduction in demand for energy and measures to developed deep understanding and education of householder practices. The Action Plan, for example, calls for an improvement in energy efficiency of 20% by 2020, a target which Directive 2010 draws upon. As part of this approach, the education of consumers is identified as a key strategy. Social elements of this nature are addressed to a level comparable to that in the California context and are more in-depth than those identified in the USA context.

Finally, a limited number of industry reform criteria have been addressed. In particular the requirement for industry re-training and inclusion in future policy development has been recognised:

‘Since local and regional authorities are critical for the successful implementation of this Directive, they should be consulted and involved, as and when appropriate in accordance with applicable national legislation, on planning issues, the development of programmes to provide information, training and awareness-raising, and on the implementation of this Directive at national or regional level. Such consultations may also serve to promote the provision of adequate guidance to local planners and building inspectors to carry out the necessary tasks. Furthermore, Member States should enable and encourage architects and planners to properly consider the optimal combination of improvements in energy efficiency, use of energy from renewable sources and use of district heating and cooling when planning, designing…’ (European Commission, 2010, p. 16).

**STT gaps/limitations**

Further to the above STT element inclusions, a number of omissions of specific elements within the broader socio-technical criteria are evident from the analysis. These will be discussed below and include:

- long-term policy development,
- limited pathway development (Member States),
- limited wider social inclusions, and
- limited institutional reforms.
No long-term (15+) year housing energy performance plan has been established, as is the case in the USA and California. The Action Plan was recently revised to establish an energy pathway to 2050, although this addresses wider energy efficiency improvements across various sectors (European Commission, 2011b).

In addition, while there is a firm end goal of ZEH, and a requirement for a 2015 interim goal to be set by Member States, there is no clear pathway developed by the EU. The outcome is dependent on individual Member States and their own responsibilities to meet their individual obligations. A number of reflexive governance requirements, such as the requirement to regularly submit financial reports, will help to keep check on the progress of this broader pathway and goal for the EU.

A number of wider social elements have been identified throughout the three policy documents, however a number of significant social elements have not been included. For example, redefining housing affordability represents significant omissions. Further, the issue of occupant behaviour receives limited attention within the policy documents analysed.

While some institutional reform criteria were addressed, significant gaps remain in this area, as was found in analysis of the USA and California. Criteria such as changes to building practices, future costs and risks are not explored. However as the policy documents, in particular Directive 2010, are broad goal setting policy frameworks, as opposed to directed and specific policy documents in their own right, it was not unexpected that such elements are not evident.

**European Union summary**

The EU has a clear goal of achieving ZEH standards across Member States by 2020. This is accompanied by a requirement for a more comprehensive energy approach, in particular the inclusion of renewable energy technologies by 2015. These goals and energy generation requirements are linked to wider climate change and renewable energy policies. The policy documents also address some wider social considerations such as housing affordability and, in particular, financial and reflexive governance criteria. However, as with the USA and Californian contexts, there is a lack of longer-term housing energy performance policy pathway planning. In addition, a number of wider social criteria and the issue of institutional reform have so far been omitted from the policy discourse.

**7.3.2 United Kingdom**

**Policy document description and context**

While the EU revised Directive 2010 to include the development of pathways to achieve ZEH by 2020, the UK has had a ZEH policy in place since 2006. The Code for Sustainable Homes (the Code) was launched as a voluntary code in December 2006 and became mandatory for all new
dwellings in May of 2008 (DCLG, 2006a, 2010). It built upon the previous green housing standard EcoHomes System (DCLG, 2006a). The Code was designed as a step process between existing housing performance requirements and ZEH standards. Currently, the Code is midway through a 10 year transition to ZEH. By 2016 all new housing will be required to reach a zero (net) emission standard. In the case of the UK policy, ZEH is defined as a house which generates net renewable energy (across a typical year) to cover energy from heating, hot water, fixed lighting and building services.

The Code was developed as part of wider EU and UK efforts to reduce greenhouse gas emissions, increase energy efficiency and increase the use of renewable energy. In addition to the Code, the UK Government has since released the UK Low Carbon Transition Plan (Transition Plan). This document develops a plan to move towards a low carbon society in a timely and efficient manner and covers all sectors, including housing.

**STT inclusions**

Analysis of the UK policy documents identified that a number of specific elements within the broader STT criteria have been addressed. These will be discussed below for relevant policy documents and include:

- medium-term goals,
- defined pathway,
- evidence based policy support,
- links to wider policies,
- reflexive governance requirements,
- financial assistance innovation,
- wider social element integration,
- comprehensive emissions approach,
- requirement for renewable energy and ‘smart’ technologies, and
- requirement for industry reforms.

The analysis found that UK policy documents analysed in this research address more of the STT criteria than all the other case study jurisdictions. Similar to the EU, USA and California, the UK has set a goal of ZEH. The UK has mandated that ZEH performance be achieved by 2016 as opposed to 2020. To meet this goal, a 10 year, step change pathway was developed. This pathway clearly identified when improvements to minimum performance standards were to be implemented. The pathway has been informed by cost-benefit analysis, including a consideration of wider environmental and social benefits.
In supporting this pathway and end goal, the Code includes clear references to the importance of ZEH standards. In particular, a clear link is made between wider greenhouse gas reduction targets and renewable energy generation targets and the requirement of achieving ZEH. Further the Transition Plan makes explicit the expected role each individual sector has in meeting these aforementioned targets. This linking of policy is similar to that observed in the case of higher EU level policies and in the case of California.

To ensure that the targets are met, a number of reflexive governance criteria are evident from the analysis. The Code is continually reviewed and updated to adjust for new technologies, practices, economic evidence, new learnings and knowledge. This, in addition to the defined pathway with set interim performance and policy targets, helps to ensure that the direction for a low carbon housing future remains appropriately flexible yet directed.

The Code also addresses a number of STT financial criteria. To assist with the introduction of the Code and to encourage innovation and building beyond minimum performance standards, a number of financial assistance elements have been offered. One such offering is the elimination or reduction (depending on property value) of stamp duty for houses achieving a performance standard of code level 6 (ZEH standard) between 2007 and 2012 (Healey, 2007). The provision of financial assistance for ZEH has arguably already achieved beneficial outcomes. A recent revision to the costs of achieving the different code performance levels found that significant cost reductions have been realised for building to higher energy performance standards, compared to when the Code was introduced.

The Code addresses wider criteria elements not addressed in the other case study jurisdictions. In addition it includes elements that consider the future functionality of housing, with consideration of for example, working from home. Furthermore, the Code addresses wider social issues such as occupant health, behaviour, housing affordability and fuel poverty:

‘Improved well-being: Homes built to Code standard will provide a more pleasant and healthy place to live, for example with more natural light, and adaptability for future needs.

Lower running costs: Homes built to Code standard will have lower running costs through greater energy and water efficiency than homes not built to the Code standard, so helping to reduce fuel poverty’ (DCLG, 2006a, p. 9).

From a technical perspective, while the Code sets improving heating and cooling energy efficiency requirements, a more comprehensive approach to reducing the environmental impact of new housing, including reducing energy consumption and improving energy efficiency, is evident. The inclusion of aspects such as low carbon and zero carbon technologies (such as renewable energy;
recommended currently but mandatory by 2016), the environmental impact of materials, lifetime homes and home user manuals is evidence of wider STT consideration in the policy (Table 50).

Table 50: Categories and issues addressed in the Code for Sustainable Homes (DCLG, 2010, p. 10). (M) Denotes issues with mandatory elements.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Issue</th>
</tr>
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<tbody>
<tr>
<td>Energy and CO₂ emissions</td>
<td>Dwelling emission rate (M)</td>
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<tr>
<td></td>
<td>Fabric energy efficiency (M)</td>
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<tr>
<td></td>
<td>Energy display devices</td>
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<tr>
<td></td>
<td>Drying space</td>
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<td></td>
<td>Energy labelled white goods</td>
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<td></td>
<td>External lighting</td>
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<td></td>
<td>Low and zero carbon technologies</td>
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<td></td>
<td>Cycle storage</td>
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<tr>
<td></td>
<td>Home office</td>
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<tr>
<td>Water</td>
<td>Indoor water use (M)</td>
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<tr>
<td></td>
<td>External water use</td>
</tr>
<tr>
<td>Materials</td>
<td>Environmental impact of materials (M)</td>
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<tr>
<td></td>
<td>Responsible sourcing of materials—basic building elements</td>
</tr>
<tr>
<td></td>
<td>Responsible sourcing of materials—finishing elements</td>
</tr>
<tr>
<td>Surface water run-off</td>
<td>Management of surface water run-off from developments (M)</td>
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<tr>
<td></td>
<td>Flood risk</td>
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<tr>
<td>Waste</td>
<td>Storage of non-recyclable waste and recyclable household waste (M)</td>
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<tr>
<td></td>
<td>Construction site waste management</td>
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<tr>
<td></td>
<td>Composting</td>
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<tr>
<td>Pollution</td>
<td>Global warming potential of insulates</td>
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<tr>
<td></td>
<td>NOₓ emissions</td>
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<tr>
<td>Health and well-being</td>
<td>Day lighting</td>
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<tr>
<td></td>
<td>Sound insulation</td>
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<tr>
<td></td>
<td>Private space</td>
</tr>
<tr>
<td></td>
<td>Lifetime Homes (M)</td>
</tr>
<tr>
<td>Management</td>
<td>Home user guide</td>
</tr>
<tr>
<td></td>
<td>Considerate Constructors Scheme</td>
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<tr>
<td></td>
<td>Construction site impacts</td>
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<tr>
<td></td>
<td>Security</td>
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<tr>
<td>Ecology</td>
<td>Ecological value of site</td>
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<tr>
<td></td>
<td>Ecological enhancement</td>
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<tr>
<td></td>
<td>Protection of ecological features</td>
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<tr>
<td></td>
<td>Change in ecological value of site</td>
</tr>
<tr>
<td></td>
<td>Building footprint</td>
</tr>
</tbody>
</table>

In addition to the above STT inclusions, the Code addresses in greater detail the requirement of industry reform. Through this it provides requirements for industry re-training and explores
elements such as the impact to building practices, risks to the building industry, adaptability of building industry networks and the role of markets in the transition.

**STT gaps/limitations**

Despite all the above STT inclusions, a limited number of socio-technical criteria omissions are evident from the broader analysis. These will be discussed below and include:

- longer-term policy development, and
- changing performance requirements.

Again, there is no longer-term housing energy performance plan beyond that of the 2016 goal, much like the EU, USA and Californian contexts. However, the broader Transition Plan does include a wider scope of low carbon future policy directions, similar to that at the Action Plan at the EU level.

The other main concern which emerges from the policy document analysis is that the definition of zero net emission homes has continued to change throughout the policy implementation process (McLeod, et al, 2012). To begin with, it was defined to cover all energy generation of the household. In the 2011 iteration, the definition now refers only to energy from heating, fixed lighting, hot water and building services (HM Treasury, 2011). Similarly, the requirement for renewable energy technologies to be situated onsite has been relaxed for certain circumstances. These changes may mean that the outcome of the policy is not ZEH as defined in this thesis. This is because the definition of ZEH applied in this thesis encompasses all energy consumed within the dwelling, not just the energy consumed from heating, fixed lighting, hot water and building services as with the revised definition in the UK.

**United Kingdom summary**

The UK addresses more of the STT criteria compared to the other jurisdictions analysed. In particular the policy documents in the UK address the area of pathway generation, include wider social elements, address industry reform and include recommendations and future requirements for renewable energy and smart technologies. However, as with the other jurisdictions, there is a lack of longer-term policy goals and pathways and, to date, the continual adjustment of definitions and end-goal performance outcomes has led to confusion and ultimately may mean that the 2016 housing standard is not realised as originally designed.
7.4 Australia and Victoria

Policy description and context

As discussed in chapter 3, in Australia the Building Code of Australia 2012 currently sets minimum housing energy performance requirements nationally (ABCB, 2010). The Building Code of Australia is revised annually, with the new revision implemented in May of each year. The Building Code of Australia is based on a star rating system where 10 star is the highest rating possible and 1 star the worst. Currently (August 2012), the minimum standard is 6 star. The state of Victoria implemented the 6 star minimum requirement from May 2011. This was an increase from the previous 5 star standard which had been in place since 2005. Victorian Building Code of Australia requirements are similar to those set nationally, however some climate specific adaptations are set through the Building Code of Australia, rather than a local adaptation such as in the USA. This means that the Australian and Victorian analysis will be presented together, with Victorian differences highlighted where appropriate.

In a wider context, the Report on the Prime Minister’s Task Group on Energy Efficiency and the National Strategy on Energy Efficiency (National Strategy) have both been influential in the introduction of the 6 star standard. As such they are also included in the policy document analysis.

It must be noted that the version of the National Strategy used in this analysis is the 2010 version. In May 2012 an updated version was released, however this was past the 1st of January 2012 date set for the inclusion or exclusion of policies as stated in chapter 5. This cut-off date was set to allow adequate time to analyse and discuss the documents. This is a limitation of this research.

As a summary, the 2012 version presented an updated direction for future policy development based upon consultation from the draft 2009 and 2012 reports (Australian Government, 2012). In essence, if the 2012 version is implemented by the Council of Australian Governments, the new National Strategy will include some pathway development with increasing standards scheduled for 2015 and 2020. There will also be an increased focus on wider energy considerations within the standards with the inclusion of energy from all fixed appliances and equipment to be included. However, there is still no goal set for achieving ZEH standards, although there is an allowance for renewable energy to be possibly included in the future where ‘appropriate’.

STT inclusions

Analysis of the Australian and Victorian policy documents identified that a number of specific elements within the broader STT criteria have been addressed. These will be discussed below for relevant policy documents and include:

- importance of ZEH,
• recognition of international best practice,
• limited evolution of existing standards,
• research and development focus,
• financial assistance innovation,
• reflexive governance,
• limited wider social elements, and
• limited renewable energy requirements.

While there is no ZEH standards goal in Australia, the importance of improving housing environmental performance has been recognised within the Task Group on Energy Efficiency and National Strategy. In particular, the Task Group on Energy Efficiency recognises that international best practice will be ZEH by 2020 and cites the UK and USA as examples of international best practice, not only in terms of current building standards but also in terms of policy directions to 2020:

‘Internationally, the potential for energy efficiency and emissions reductions from the buildings sector is well recognised. For example, a survey of 80 international studies found that there is a global potential to cost-effectively reduce around 29 per cent of the projected baseline emissions in the residential and commercial sectors by 2020.

In addition, many countries have begun to adopt long-term strategies to deliver highly energy-efficient buildings — including setting national goals and pathways towards zero-energy or zero-emissions buildings’ (Australian Government, 2010c, p. 151).

As a response to this, the Task Group on Energy Efficiency states in the report that recommendations for future policy development should ‘consider the development of a pathway towards zero-emissions buildings’ (Australian Government, 2010c).

To date, the Building Code of Australia has been primarily focused on improving heating and cooling energy efficiency as the chief approach to address environmental sustainability. However, the increase to a 6 star standard also saw a subtle shift in the standard. For example, there was a shift in the object of the Building Code of Australia from ‘… to reduce greenhouse gas emissions by efficiently using energy’ (ABCB, 2009a) to ‘… to reduce greenhouse gas emissions’ (ABCB, 2010). This is evidence that there is an overall shift towards reducing greenhouse gas emissions in a more comprehensive way beginning to emerge. A number of energy elements such as lighting energy efficiency are now receiving more attention in the current Building Code of Australia.
Current housing standards are developed with the input of cost-benefit empirical analysis (ABCB, 2009b). However, as discussed throughout this thesis, there is currently a lack of CBA evidence on ZEH and, across the domain of improved energy performance standards in general, in Australia.

The Building Code of Australia, Task Group on Energy Efficiency and National Strategy include a number of wider financial elements. These include the setting of government rebates for sustainability technology elements, as discussed in chapter 3. In addition to these rebates, wider banking sector reform has been attempted in the form of the Green Loans program.

A number of reflexive governance criteria have been identified in the analysis. In addition to the yearly revision of the Building Code of Australia, allowing for new technologies, building practices and learnings to be integrated, there is a recommendation from the National Strategy that more regular reviews are planned and undertaken to assess the performance outcomes at a more comprehensive level. For example the report states that:

‘Governments will set out a clear process and timetable for periodic review (for example, every three years starting in 2012) of energy efficiency standards so that over the life of this strategy energy efficiency requirements will be progressively increased. This will give industry greater confidence to innovate and develop affordable solutions to improve building energy efficiency. For example, six, seven and eight star buildings, or equivalent, will become the norm in Australia, not the exception’ (COAG, 2009b, p. 22).

A number of wider social STT criteria are also evident from the analysis. These include limited inclusions concerning housing and living affordability. Primarily, these social elements are provided as a caution against improving housing standards without evidence that negative impacts on social considerations are unlikely or if likely, can be mitigated appropriately. In comparison, in the EU and UK, wider social criteria are integrated as a way of strengthening the requirement for a transition to ZEH.

The analysis for the Victorian context differs from the Australian context in that there is a requirement for either the inclusion of a solar hot water system or a rain water tank within the minimum requirements. Otherwise the criteria addressed, or not addressed, are the same as the federal level.

**STT gaps/limitations**

A number of omissions of specific elements within the broader socio-technical criteria are evident from the Australian and Victorian policy documents analysis. These will be discussed below and include:
• no medium or long-term goals,
• no pathway development,
• limited renewable energy and ‘smart’ technology requirements,
• lack of wider policy links,
• limited wider social element integration, and
• limited industrial reform.

Despite the acknowledgment of the Task Group on Energy Efficiency and National Strategy of the need for improving energy performance from housing (including that decisions made now can have an impact for 100 years or more) and that international best practice will be ZEH by the end of the decade, there is no indication that ZEH or any other performance standard will be set as a medium or longer-term goal in the near future. The Task Group on Energy Efficiency states that a ZEH performance standard should be considered but does not commit to means or timescales for this. There is no firm commitment to any future performance standard beyond the annual review of the Building Code of Australia. This also means that there are no pathways developed to achieve longer-term goals, despite recognition that setting a long-term goal and pathway would be beneficial. The following is an extract from the Task Group on Energy Efficiency report regarding ZEH and possible pathway development:

‘A ‘pathway towards zero-emissions buildings’ could be developed to better link measures in the sector under a clear and coherent strategy. Bringing the threads together in a way that makes sense for industry and the community is likely to increase certainty and enhance outcomes. A pathway would also complement a national energy efficiency target by providing sector-specific context.

The policy goal for such a pathway could be to establish a vision and timeframe for delivery of new standards for net zero-emissions buildings, and to drive a transformation of our existing building stock. A comprehensive pathway would therefore cover both new and existing buildings, in both the residential and commercial sectors. It could also seek to better link actions across policy domains and across levels of government, such as improving synergies between energy efficiency in buildings and broader urban or infrastructure planning’ (Australian Government, 2010c, p. 148).

While a subtle shift has taken place in the Building Code of Australia 2010 and 2011 to address reducing overall greenhouse gas emissions, the lack of requirement of renewable energy and other smart technologies, and a continued focus primarily on reducing heating and cooling energy requirements, are limiting technical factors in a transition to ZEH in Australia.
In addition, unlike in the other case study jurisdictions, there are no clear links from the current Building Code of Australia to state or national level climate change emission reduction targets or renewable energy targets. While the Task Group on Energy Efficiency and National Strategy draw upon these wider environmental requirements, they still fail to link these into recommendations regarding housing energy performance standards.

Furthermore, while some wider social criteria are met, most are not. These include addressing fuel poverty, reducing demand for energy, understanding and education of householder practices and addressing financial sector innovation. These findings are similar to observations made in the USA analysis.

In addition, there has been limited focus on addressing institutional reforms such as industry retraining and the impacts and costs to the building industry of such a transition.

**Australia and Victoria summary**

Significant gaps in STT criteria are evident in the policy documents in comparison to the other case study jurisdictions. There is no ZEH or longer-term housing energy performance goal in the Australian context. Due to this, there is no pathway forward for the future direction of housing energy performance policy. From a technical perspective, there is a lack of consideration or requirement for renewable energy technologies compared to the other jurisdictions. In addition, there is limited consideration of wider social criteria and elements such as requirements for industry reform. In terms of STT criteria, the Australian and Victorian policy documents analysed addressed the least amount of STT criteria of all the studied jurisdictions.

**7.5 Overall policy analysis summary**

The analysis of the housing energy performance policy documents from the case study jurisdictions using a socio-technical ZEH framework found that there are a number of gaps and trends across the policy documents and case study jurisdictions analysed. Five key practical policy requirements missing in the current Australian ZEH policy context were identified:

- long-term goals,
- development of a pathway,
- links to wider government policy,
- financial instruments, and
- wider social considerations.

A number of these element gaps were also identified in the international case study jurisdictions. Chapter 8 will discuss these five elements in detail with reference back to the STT literature, together with their implications.
Chapter 8: Prospects for a facilitated socio-technical transition to ZEH

This chapter provides a discussion of key results presented in chapters 6 and 7. These are placed into a policy context, drawing upon the review of relevant literature from earlier chapters. Furthermore, the implications of research findings for future energy performance regulations in the new housing context in Australia are explored. The chapter is structured to address the three sub research questions (see page 12) in sections 8.1–8.3, before synthesising research findings to address the main research question. In addressing each question, the discussion links to the wider contextual setting of the research, particularly in sections 8.1 and 8.2, where the overlap of established insights for each question is highlighted.

8.1 Through-life costs and benefits of ZEH standards (sub question 1)

Evidence plays an important, but sometimes contentious, role in informing the development of policies in Australia, as discussed in chapters 2 and 3 (Althaus, et al, 2007). In this thesis it has been argued that a significant barrier to improving minimum energy performance standards in Australia has been the lack of reliable and transparent evidence regarding the costs and benefits of ZEH. This thesis, through research sub questions 1 and 2, aimed to address this evidence gap in the Australian context. A more comprehensive, valid and transparent casebook of evidence was established to inform future housing energy performance standards in Australia. This section explores the key results from the cost-benefit analysis, discussing the capital costs and through-life economic and environmental benefits.

8.1.1 Capital costs

The results in chapter 6 show that the most financially beneficial lifetime housing affordability outcome (lowest accumulated costs across time compared to BAU), and optimal technology balance, was achieved with an 8 star building envelope with 4.3 kW of PV and SHW. The additional capital cost to achieve this performance standard was $30,842 for offsite RE or $31,047 for onsite RE. This additional capital cost was made up of $8,154 to upgrade the building envelope from 6 star to 8 star and $22,688 (offsite)–$22,893 (onsite) for the renewable energy system, including SHW. For homeowners, analysis indicates an additional capital cost of 7.8% for new detached housing (including land) in Victoria. Against build cost only, this represents an additional capital cost of 17.2%.

While Australian ZEH cost-benefit analysis is limited, one recent report based upon the proposed Cape Paterson Ecovillage (Satzow, 2011) has reported on costs comparable to those found by this
research. Szatow (2011) found that the predicted cost to achieve a ZEH standard in the new housing development would be an additional $32,450 per housing unit. This equated to an additional capital cost (house and land) of 6.1% compared to the reference cases used for the modelling. While total additional costs reported in Szatow’s study are comparable to those figures found in analysis for this thesis, the percentage increase to expected house and land price is smaller, due to the higher house and land costs in the Cape Paterson development ($533,000 approximately) compared to those applied in this study ($393,086).

While the total costs are similar to those found in this thesis, the split in costs between the building envelope improvements and renewable energy technologies differs. The Cape Paterson analysis found that to achieve a 7.5 star house would cost $16,000, or almost double the cost found for the same upgrade in this research (Szatow, 2011). Furthermore, the renewable energy technology component is cheaper in the Cape Paterson analysis ($16,450) than results produced by this analysis. This difference can be attributed to the smaller system size requirement applied in the Cape Paterson modelling (3.4 kW compared to 4.3 kW for this research). The Cape Paterson analysis modelled two house designs only however, and this may have led to a higher cost outcome. This thesis modelled 80 house designs across 117 scenarios in an effort to reduce the margin of error of results and to increase the representativeness of findings.

Another Australian ZEH case study of note is the AusZEH project, run by the CSIRO. This provides observed cost data from an actual built ZEH. It is estimated that the AusZEH home (8 star with 6kW of PV onsite) cost an additional $40,000 to build, over a comparable design without ZEH features. This figure is comprised of $20,000 each for the building envelope upgrade and renewable energy technologies (Pitt & Sherry, 2010). This equates to an additional 10.2% onto the total cost of house and land, using the average house and land price data applied in this research. The cost for the renewable energy system reported for the AusZEH home is comparable to the cost identified by this thesis, although the system size is slightly larger in the AusZEH case study (6kW compared to 4.3kW). The higher costs reported over the figures found in this research arise from the building envelope component, which is double the price found in this research. It should be noted however that these costs are specific to one particular house design and, as discussed further in section 8.2.2, there can be significant cost differences between house designs of different size and configuration. In addressing this issue, this thesis attempted to reduce variances in costs by analysing a statistically significant number of houses in order to improve outcomes.

The ‘Jade 909’ is a market ready zero emission display house in Western Australia which opened in 2010. It is estimated that the additional build cost to achieve ZEH performance for this house is in the range of 2–5% more than the same design, built to a standard specification (Pitt & Sherry, 2010). This is lower than the values found in this research. For a build cost of $205,000–$225,000,
the house achieves a 9 star thermal envelope rating, includes renewable energy technology and is predicted to use 119% less operating energy than an average Australian house (Starc, 2010). Again costs from this example are based upon a single house.

In situating this research in the context of wider international debates, a number of relevant studies can be drawn upon. In Canada, a ZEH study found the additional capital costs required to achieve ZEH to be similar to those reported in this thesis when figures are adjusted for currency and market relativity, with an additional cost of C$31,824 (AUD$32,177 at a conversion rate of C$1 = AUD$0.989) and a total ZEH build cost of C$235,484 (AUD$238,103) to achieve a ZEH standard (Zabaneh, 2011). The additional costs add 15% to the typical house cost (without land) in Alberta, Canada, which fits within the wider 10%-20% cost range demonstrated elsewhere in Canada (Zabaneh, 2011). Percentage wise, the Canadian examples are similar to those found in this research.

In the USA, a single demonstration ZEH was developed for additional costs of US$55,331 (AUD$53,667 at a conversion rate of US$1 = AUD$1.031), compared to the same house design with a standard specification (Zhu, et al., 2009). This reported figure included energy efficient lighting and air conditioning technology, elements which fell outside of the scope of this thesis but which could be included in future modelling. No total build cost or percentage of total cost information was provided in the research by Zhu et al. (2009), however, another USA study estimated that it would cost no more than an additional 20% (without rebates) to achieve very low energy houses, which was within the ‘marketable realm’ (Tsai et al., 2011, p. 518).

In the UK, the cost predictions for achieving a ZEH standard for a detached house located on the urban fringe was predicted to cost £43,200 (AUD$64,142 at a conversion rate of £1 = AUD$0.673) when costs were calculated in 2008 (DCLG, 2011). This equated to an additional cost increase of 48.5% on the cost of a base scenario house (no land). The additional cost is more than double that found in this research and those mentioned for Australian and North America examples. The overall costs across various building types was estimated to be between a 13–16% price increase (house and land) to achieve ZEH standards (DCLG, 2007a; Pickvance, 2009).

8.1.2 Economic through-life benefits

A number of benefits of ZEH are evident across the life-span of the building. These benefits frequently have significant economic implications. In this analysis accumulated (capital and through-life operational costs) economic savings of 28.26% ($14,480) after 20 years, 62.15% ($97,698) after 40 years and 81.63% ($289,461) after 60 years for a low energy price scenario were achieved. For a high energy price scenario, accumulated economic savings of 40.87% ($25,402) after 20 years, 72.02% ($153,124) after 40 years and 88.51% ($501,758) after 60 years were
achieved. This includes all through-life maintenance and technology replacement costs where appropriate.

Analysis from the Cape Paterson Ecovillage report found that through-life economic benefits of ZEH were substantial. The report found that accumulated economic savings from energy, water and mortgage interest were predicted to result in reduced costs of over $300,000 over 40 years (including benefits from a hybrid car) (Szatow, 2011). The Cape Paterson Ecovillage report also contends that wider sustainability concerns such as water and transportation are important considerations for reducing through-life costs of housing choices as well as for moving to a low carbon housing and lifestyle future. As raised in chapter 1, while important, these elements were outside the scope of this research.

The Canadian ZEH study discussed previously, while only analysed for a 20 year time-horizon, calculated accumulated economic savings of $242,364 (Zabaneh, 2011). This result is significantly higher than the accumulated economic savings for a comparable 20 year time-horizon in Australia. The difference is due to energy price predictions in the Canadian analysis increasing at a substantially quicker rate (10X) than those used in this thesis. Despite this, the Canadian analysis shows that there are significant accumulated cost savings to be achieved across the lifespan of a ZEH. While other international case studies have been mentioned above, they have not clearly presented through-life economic benefits. However they have presented results in terms of payback periods.

The cost to achieve ZEH standards (8 star ZEH) for detached housing in Melbourne has a calculated payback period of 12 years at high energy price BAU scenario and 14 years at a low energy price BAU scenario. After this time, the accumulated savings as presented above would be available to the household as additional household cash flow. With an average hold time of 10 years for detached housing in Victoria (RP Data, 2012), many households may not own their homes long enough to achieve these cashflow benefits after payback is achieved. However as will be discussed in section 8.2.4, other benefits may be forthcoming to the household such as additional resale value, which can help reduce payback periods and ensure the household recovers some, if not all, of the additional capital costs.

The payback periods found in this research are shorter than those found by Newton and Tucker (2009), who found that payback periods for renewable energy technologies (not including building envelope upgrades) were commonly 20 years or more, although some elements demonstrated payback periods of as little as 7 years. The Canadian ZEH research found that the payback period for additional build costs was less than 9 years (Zabaneh, 2011). One USA ZEH study derived a payback period of 0.3 years to 26.4 years for most of the individual improvements required for the ZEH standard (Zhu, et al, 2009). Further USA research has indicated a payback period of less than...
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30 years for low carbon housing (Walker et al., 2009). All of these reported payback periods are less than the typical lifespan of a house: 40 years as used in Australian Building Codes Board modelling (ABCB, 2009b).

Accumulated economic savings and payback periods are significantly affected by a number of assumptions used in the modelling, including future energy prices, household energy consumption rates, cost of building upgrade elements and cost of renewable energy technology in each particular jurisdiction. This makes direct comparisons between studies and countries problematic. The capital costs and payback periods from this research nevertheless fit within the range presented from the various Australian and international ZEH research cases reviewed. Furthermore, this research goes beyond existing research in the Australian context in terms of the transparency, level of detail and rigour of costs estimates reported in each scenario modelled, across a much larger sample of house designs than has previously been considered.

The analysis has shown that there are significant economic savings potentially available to the household across longer time-horizons from ZEH related economies. These savings are greater than the capital costs discussed in section 8.1.1.

8.1.3 Environmental benefits

In addition to economic benefits, there are significant environmental benefits to be achieved from ZEH when compared to standard specification housing. The reduction in CO2-e per house predicted from the housing models applied by this research is similar to that found by Newton and Tucker (2009) in the Melbourne context. If all new detached housing in Victoria were to be built to a ZEH standard, CO2-e emissions savings would equate to 0.05% of the total greenhouse gas emissions (2008 level) of Australia. While this amount may seem trivial, it is still 0.05% less emissions which will need to be reduced elsewhere in the residential and wider sectors if greenhouse gas emission reduction rates of up to 80% by 2050 are to be achieved.

Furthermore, extrapolated to all new dwellings in Australia over a one year period, this would equate to a reduction of 0.25% of the total Australian greenhouse gas emissions; assuming all dwelling types and households use the same amount and type of energy (this is not the case but the assumption is used here to demonstrate possible potential of wider environmental benefits). Each year in which new ZEH stock is built would add to this avoided greenhouse gas emission amount. For example, after 10 years of successive new construction throughout Australia, all to a ZEH standard, equivalent CO2-e emissions savings of 2.5% of Australia’s greenhouse gas emissions from 2008 would be forthcoming, highlighting the increasing benefit over time (although this assumes wider emissions levels remain static). Due to the uncertainty over future greenhouse gas emission levels, the impacts on these from ZEH have not been presented. However the above
analysis does indicate that ZEH standards may contribute to wider policy objectives regarding reductions in greenhouse gas emission and achieving renewable energy targets.

It is important to note there are definitional differences in ZEH across jurisdictions (Riedy, et al, 2011). Most of the examples discussed in this chapter refer to net zero energy across a year from all energy consumption within the house. However in the UK, the government has recently refined their definition of ZEH so that it only covers space heating, water heating and lighting (HM Treasury, 2011; McLeod, et al, 2012). The new definition differs from the definition used for ZEH by this thesis. The economic and environmental benefits drawn upon from the UK context in this thesis are from modelling and reports undertaken prior to the definition change. The EU definition is for ‘nearly’ zero emission housing, meaning that it too differs from the definition as used in this analysis. Nonetheless, both jurisdictions are making significant progress towards low carbon housing and remain exemplars of international best practice.

8.2 Implications and feasibility of implementing ZEH standards in Australia (sub question 2)

This thesis and other emerging research (Newton & Tucker, 2009; Szatow, 2011) suggests that ZEH in Australia is an achievable and feasible energy performance standard, both in terms of through-life economics and environmental benefits, based upon the assumptions used in the modelling. However, it is also recognised that there are a number of practical and policy implications relating to the transition to ZEH standards, in particular with regard to addressing the additional capital cost component. A more detailed analysis of associated policy requirements is provided in section 8.3.

8.2.1 Household cash flow implications

A ZEH standard for a typical new house is projected to incur additional capital costs of approximately $31,000 to the average house and land package. This has a number of impacts on mortgage costs and the repayment of these, as presented in chapter 6. The analysis found that ZEH performance would add $200 a month to mortgage repayments (at an interest rate of 7.25%). However, if energy savings were invested back into the home loan, the householder could repay their debt up to 3.7 years sooner, and avoid $55,691 in additional interest accumulation.

Improved through-life mortgage outcomes were also found in the Cape Paterson Eco-village analysis, which found ZEH could save 2.5–5.5 years on a 25 year home mortgage if the economic benefits of energy and water savings were returned into the home loan (Szatow, 2011). While not specifying how much would be saved on the mortgage in this scenario, the overall accumulated savings of $300,000 included energy, water and mortgage savings. Similar outcomes, where overall
economic benefits outweigh additional mortgage impacts, have also been found internationally (DOE, 2009).

There is limited wider research focusing on the impact on the household in terms of mortgage debt repayments from improved housing energy performance standards. Most of the literature discussed throughout this thesis focuses on the capital costs or yearly energy savings associated with ZEH. The implications of the cost-benefit outcomes for the cash flow of households are an area in need of further research.

While there is only limited research that focuses on the impacts on household mortgage debt, a range of policy approaches have been applied designed to improved energy performance in new housing. As discussed in chapter 3, the low interest ‘Green Loans’, rebates, bulk buying programs and feed-in-tariffs for renewable energy technologies are examples of market mechanisms that have been applied to date in Australia (Combet, 2010; Hawke, 2010; Macintosh & Wilkinson, 2011). The results from the cost-benefit analysis indicate that any move to ZEH standards could usefully continue to include, and expand upon, the current range of financial assistance approaches available to help reduce additional capital costs while the building industry and consumers adjust to new expectations in terms of costs and performance. These financial instruments are discussed further in section 8.3.4.

8.2.2 Cost efficiency implications

As discussed in chapter 3, predictions of cost implications of energy efficiency provided by public bodies such as the Housing Industry Association and Master Builders Association are significantly over estimated (Building Commission, 2005b; Constructive Concepts & Tony Isaacs Consulting, 2009; DLGP, 2010). Furthermore the costs presented within relevant regulatory impact statements and associated literature fail to address economic efficiencies through phenomena such as ‘learning rates’ and ‘economics of scale’ from mandating ZEH requirements. In this regard, the assumptions contained in the modelling in this research are conservative yet support overwhelmingly that positive lifetime cost-benefits are forthcoming from ZEH.

In highlighting cost efficiencies, the average 8 star building envelope upgrade cost was $8,154. However, the least cost option amongst the 80 house designs to achieve 8 star was only $2,712; a 66.7% reduction. Cost efficiencies were found in house designs with improved passive design and improved house layouts. Similarly the purchase costs for the cheapest PV system used in the analysis was 25.3% lower than the average PV cost used, and the purchase cost for the cheapest SHW system was 34.4% lower than the average SHW price used. Combined this would result in a reduction in costs of 37.5% ($11,641) compared to the average price applied. Without any design changes or further economic benefits such as bulk buying, this ZEH scenario would achieve a
payback in less than 9 years against a 6 star BAU low energy price scenario. This reduces the payback period by 4 years compared to the average cost option.

The thermal modelling approach undertaken was limited to applying iterative materials changes, rather than taking a fundamental design change approach. Characteristics such as dwelling size, numbers and types of rooms, room locations, window size and placement were not altered in the thermal modelling conducted. A ‘for purpose’ ZEH designed house would likely achieve significantly greater cost efficiencies than the upgrade of an existing 5 star house design (Bambrook, Sproul, & Jacob, 2011). The UK cost-benefit modelling predicts that costs could be reduced by 20% or more as industry innovation identifies economic efficiencies in design, technologies, materials and building practices (DCLG, 2008d). In a review of build costs in 2011, the cost to achieve the same house type in the same location had dropped from £43,200 (AUD$64,142, 48.5% additional build cost) to £39,650 (AUD$58,873, 42.8% additional build cost) (DCLG, 2011). This is a cost reduction of 8.2% in four years. In the USA it is also expected that costs for sustainability features will decrease in price as these features become more prevalent and market competition in materials and technologies increases (Walker, et al, 2009).

In addition to this, this research assumed that occupant behaviour and appliance use and efficiency performances would remain constant. With continued improvement to appliance efficiency and education targeting occupant behaviour, further energy efficiencies and reduction in total energy demand can be achieved (Boardman, et al, 2005; Eyre, et al, 2011; Pears, 2007; Pyrko & Darby, 2011). Furthermore a reduction of house size can reduce the cost of new housing and ongoing operating costs (Clune, et al, 2012). This, in turn, would also help to reduce the costs of ZEH standards. These elements are outside the scope of this research, so were not explored in depth.

### 8.2.3 Net present value

From a policy perspective there are a number of implications from the cost-benefit analysis of ZEH standards in addition to those already discussed. NPV is often used in policy development as an indicator through which to weigh up the costs and benefits across time of a proposed change compared to a BAU approach. This research found that ZEH achieved positive NPV outcomes at discount scenarios 1 and 2 after 25 to 30 years. This was based upon capital costs and through-life energy savings. When resale value is added to the NPV analysis, the time taken to achieve a positive NPV for ZEH scenarios reduces by 5 to 10 years. Discount rate scenario 1 is the discount rate recommended by Garnaut (2008). Discount rate scenario 2 is the rate used by the UK Government (HM Treasury, 2003; Stern, 2007). At the discount rate scenario recommended by the Australian Government (Australian Government, 2007) and used by the current Australian Building Codes Board in analysis (discount rate scenario 3) positive NPV outcomes were only
achieved after 35 years (with resale value) and 40 years (without resale value) in a high energy price scenario.

A positive NPV was found in the Cape Paterson report, using a discount rate of 6% over a 40 year time-horizon (Szatow, 2011). Similarly, in the UK, which applied discount rate scenario 2, a positive NPV was achieved for their overall analysis, although some elements of the code requirements achieved negative NPVs (DCLG, 2008c). What these wider results show is that the modelling from this research produced comparable findings to other emerging ZEH research in Australian and international contexts, with much improved sample rates, transparency and therefore confidence in the results.

8.2.4 Resale implications

A significant benefit and practical implication of ZEH for the household is the likely improved resale value which may be achieved for improved energy efficiency and renewable energy technologies. Increased resale value was included in the cost-benefit modelling undertaken in this research based upon documented evidence within the wider literature. To date, detailed additional resale value analysis is missing from ZEH research in the Australian context. The additional resale value for an 8 star ZEH with onsite renewable energy technologies ranged from $13,223 (after 30 years) to $37,640 (after 60 years). The resale value decreased as renewable energy technologies reduced in capacity/life expectancy but once technologies were replaced the resale value again appreciated. In addition, the resale value increased as the cost of energy increased in the future, based upon the assumptions used in the modelling.

If an owner-occupier household sold their house after 10 years (current occupancy duration for housing in Melbourne (RP Data, 2012)), an additional resale value of $18,439 could be expected (4.3% additional value on initial house and land cost). This would offset 59.5% of the initial capital costs. Furthermore, if sold after 10 years, the accumulated energy savings would be $29,310–$33,823. When combined with resale value and capital costs, it would leave the household with a net gain of $16,749 compared to a BAU scenario.

The analysis for resale value used in this research was based upon the more conservative data from the literature (Nevin & Watson, 1998). In comparison, research from the ACT in Australia found that an added resale value of up to 2.4% or $9,000 was achieved for each star equivalent increase in the Nationwide House Energy Rating Scheme (DEWHA, 2008a). The ACT research did not include data regarding the impact on house price of renewable energy technologies. However the report shows that greater resale values than those predicted using the more conservative figures applied in this thesis.
8.2.5 Policy implementation
As discussed in chapters 2 and 3, housing energy efficiency policy in Australia and internationally has typically followed an incremental development pathway. This research has presented the costs and benefits for a range of possible intermediate performance standards which could act as incremental policy development in a transition to ZEH standards. In particular two intermediate scenarios were found to be most cost effective, in terms of total accumulated costs, over the life of a house (7 star, 1kW PV and 8 star 2.5 kW PV and SHW). By introducing one or both of these standards prior to the introduction of ZEH standards, the burden of additional capital costs, could be spread across time and allow some of the market efficiencies discussed to develop. The importance of pathways in this context is further discussed in section 8.3.2.

8.3 Policy actions for a facilitated socio-technical transition to ZEH (sub question 3)
As discussed in chapter 4, new or altered policy and regulation has been described as a potential driver to generate deep structural changes in socio-technical regimes (Geels, 2005; Smith, et al, 2005). This section aims to identify those policy levers that might assist with a transition to ZEH in the Australian regulatory context. The application of STT criteria to policy documents from selected jurisdictions has shown that there are a number of gaps and omissions, as well as areas of strength in current housing energy performance policy. Drawing upon the STT literature discussed in chapter 4, and the analysis presented in chapter 7, five key elements have been identified as being limited or missing in the Australian policy context. These are discussed in turn below.

8.3.1 Long-term goals – ZEH
STT theory was developed as a response to addressing short-term policy development which was becoming more common, as discussed in chapter 4. The setting of long-term goals is critical for a transitions management approach to STT (Kemp & Rotmans, 2009). Goal setting in itself is identified in wider policy development literature as a requirement to develop ‘good’ policy, as discussed in chapter 2 (Colebatch, 2002). In the case of housing energy performance standards this is particularly important as housing is a relatively long life infrastructure. As such, there is a requirement for longer-term thinking regarding how housing is designed, developed and used.

Developing and continuing to implement long-term policies can prove to be challenging in a climate where governments are changed at regular intervals. This is especially the case in a country like Australia where the current Australian Government has introduced a range of policies to address climate change issues, and the opposition fails to acknowledge that climate change is an issue which requires action (or at least not until other countries also take action). However the development of the energy transition in the Netherlands has survived at least four changes to the government since it was introduced (Kemp, Rotmans, et al, 2007). This shows that bi-partisan
support can be developed for longer-term policy development and that if the right mechanisms are put in place, it can be difficult for changes in government to change these longer-term policies.

Policies regarding housing energy performance beyond 15 years appear to be generally absent in the international policy documents analysed. The lack of a long-term policy agenda has been identified within the housing STT literature as a barrier to a low carbon future (Tambach, et al, 2010). Furthermore, it has been argued in the wider environmental literature that long-term goals are an important part of the policy mix in moving to a low carbon future (Schmidt et al, 2012). ZEH as a policy goal is typically justified in the context of wider requirements for greenhouse gas emission reduction as a mitigation response to climate change, as well as by assessments of technology, costs and benefits.

The implementation of ZEH standards is stated as a medium-term (5–15 years) policy goal of the international case study jurisdictions. There is no ZEH goal in Australia at present, and current policy is largely limited to annual revision of the Building Code of Australia. This absence of a medium/long-term ZEH goal represents a significant barrier to achieving ZEH in Australia. Without a longer-term goal, there is no structure, direction or end point for the transition (Eames, et al, 2006). While ZEH in itself might not be the endpoint of the transition, it provides a signpost for the future direction of housing energy performance requirements and allows for the development of required structures and wider innovation to achieve a sustainable future; in this case with respect to low carbon housing (Eames, et al, 2006; Park, 2011; Tambach, et al, 2010). In this way, a longer-term goal can enable the minimisation of costs and other disruptions by preparing for change in a systematic and planned manner (as discussed further in section 8.3.2).

The need for a long-term goal has been recognised by the Australian Government as an important factor in moving towards a low carbon future (Australian Government, 2010b, 2010c). The same government reports recognise that ZEH standards will be international best practice by 2020. However, to date, there has been little development in the policy documents analysed for this research of advancing this recognition to more affirmative policy development.

Based on the STT criteria framework analysis and other experience and commentary, a longer-term goal of ZEH is an important element of a transition towards a low carbon future. This goal should not be rigid and is expected to evolve in line with principles of reflexive governance as the transition progresses (Grin, et al, 2010; Tukker, et al, 2008). The goal of ZEH must also contain within it an inherent requirement for the inclusion of renewable energy technologies as well as drawing upon wider social elements to achieve the paradigm shift required (Smith, 2006). In Australia this would be a significant departure from current policy.
Both the EU and USA have included renewable energy generation as part of their ZEH policy. Of the current housing performance policies analysed, only California and the UK have a requirement for renewable energy generation to be included, although this only becomes a mandatory requirement in future policy developments. The lack of mandatory renewable energy requirements is a limitation in USA and EU current policy approaches, however the inclusion of renewable energy requirements in future policy development is foreshadowed (DOE, 2010; European Commission, 2010). In the EU for example, it is a requirement that Member States include mandatory requirements for some renewable energy technologies to be included on all new dwellings from 2015.

Mandating the inclusion of renewable energy technology into minimum new housing energy performance standards in Australia would signal a radical policy shift away from addressing heating and cooling energy only. Increasingly, the literature in Australia is highlighting the need for renewable energy technologies to be included in improved housing energy performance standards (Newton & Tucker, 2011).

8.3.2 Develop a pathway

The development of pathways (or scenarios) has been identified in the ZEH STT literature as critical to the process of facilitated socio-technical regime change (Bergman, et al, 2007; Smith, 2006; Tambach, et al, 2010). However, the process of goal setting is removed and distinct from the process of goal realisation (Eames, et al, 2006; Grin, et al, 2010; Hodson & Marvin, 2010). Pathway development has also been identified within wider policy development literature (refer to chapter 2) as an important contributor to improving the likely chance for a successful policy outcome (Considine, 2005). Without the use of pathways (or scenarios), goals remain distant with little grounding in practicality.

In the EU, UK and California, pathways are in place to achieve longer-term policy goals i.e. ZEH. In order to ensure longer-term targets are met, the EU has clearly set requirements for interim targets and assessments to ensure that Member States achieve ZEH. For example, there is a requirement that by 2015 the minimum standards of individual Member States must include some element of renewable energy technology.

The UK government set a 10 year step-change policy pathway. This included improvements to minimum standards in 2010 with further improvements in 2013, before the introduction of ZEH standards in 2016. This pathway development has been based upon feasibility studies which analysed costs and benefits. It has been argued that basing pathway and goal development on a strong evidence base strengthens policy outcomes (Hudson & Lowe, 2004). Innovation has apparently led to a cost reduction to achieve ZEH, while the development of a pathway has allowed
for an open discussion regarding the way forward, helping to legitimise the process (Osmani & O'Reilly, 2009).

In California, a step change pathway began with the introduction of a voluntary green housing standard in 2008, and became mandatory in 2011. Further performance changes are planned in 2015 and the full introduction of ZEH standards in 2020. This policy pathway was developed based upon feasibility analysis. In contrast, at the federal level in the USA and in Australia, there does not appear to be any evidence to suggest pathway development towards ZEH at this stage.

Much like the setting of longer-term goals, the development of pathways is deemed important for encouraging innovation and reducing costs and disruptions from planned changes (Park, 2011). It is envisaged as providing a structure and focus for all actors involved and provides improved certainty for all stakeholders regarding the future (DCLG, 2006a; Eames, et al., 2006). It is argued that in the absence of pathways and goals, particularly from governments, innovation and community uptake is likely to rapidly decline (DCLG, 2007c). If we accept this argument, the lack of pathways (or goals) in Australia means that there is significant uncertainty surrounding future energy performance requirements. This affects all stakeholders in the housing system, building industry and consumers.

Transition management advocates also argue that as a transition progresses, changes to technologies, costs and actor responses mean that there is a requirement for regular reassessment of pathways, goals and wider approaches (Foxon, et al, 2009), as presented in Figure 12 (page 69). Evidence for such a reflexive governance approach was found in the EU, UK and Californian contexts in the case of this research. In each jurisdiction there has been a review of both the end goal and the pathway leading to updated information (e.g. technology innovation, occupant behaviour) to be included in policy and niche support mechanisms. Recent changes to the definition of ZEH in the UK context could be regarded as an example of such reflexive governance policy making as consideration of updated costs data and impact to the building industry and consumers was evaluated (HM Treasury, 2011; McLeod, et al, 2012). In this context reflexive governance may be seen to have softened the outcome regarding energy performance standards. These standards were introduced in a period of global economic instability (the global financial crisis) and these definitional changes may have been made to protect the building industry and consumers in the short term. However, reflexive governance has been limited as an approach in the Australian context to date.

8.3.3 Links to wider policy

In international case study jurisdictions, discernible links exist between ZEH policy and wider government policy approaches, in particular those relating to climate change and renewable energy generation policies. Policy makers in these jurisdictions have seemingly linked ambitions for
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greenhouse gas emissions reduction and renewable energy generation targets in combination with feasibility analysis, to inform and provide justification for mandating zero emissions for new housing stock (Pickvance, 2009).

In the UK, for example, it is predicted that the Code for Sustainable Homes will be responsible for generating (through renewable energy technologies) 1.4% of the UK’s total energy consumption by 2020 (DCLG, 2008d). This would contribute to the UK Government’s goal of achieving 15% of energy from renewable energy technologies by 2020 and 80% of greenhouse gas emission reduction by 2050 (DECC, 2011).

For Australia, the analysis in chapter 7 reveals little evidence of a link between minimum housing energy performance policy and federal government objectives such as greenhouse gas emissions reduction targets. This has been identified by other researchers in Australia (Newton & Tucker, 2011).

The lack of a link between future housing energy performance policy development in Australia and wider government policies may be a significant constraint for policy progress towards ZEH. This not only includes links to environmental policies but also to other policies such as health and social wellbeing (Pickvance, 2009). According to transition management advocates Bergman et al. (2008; 2007), apart from strengthening housing energy performance policy, strong links to other policies can put pressure on the existing regime via landscape pressures (as well as niche pressure) such as climate change and can help to legitimise the niche alternative. Incorporating strong links to wider policy is also reflective of the more comprehensive approach, which underpins transitions theory. Transitions include multiple domains, actors and levels, which are difficult to capture comprehensively in one policy (Kemp & Rotmans, 2009; Rotmans & Loorbach, 2008).

8.3.4 Financial instruments

Dealing with the capital costs of ZEH and delivering innovative financial instruments has, to date, been presented in the wider building industry as an important factor in improving energy performance requirements in dwellings (HIA, 2009; MBAV, 2008). The results presented in chapter 6 and discussed earlier in this chapter find that taking a through-life perspective of costs and benefits identifies significant economic, social and environmentally beneficial outcomes. In addition to developing innovative ways to address capital costs, a shift in policy thinking from a focus on capital to through-life costs and benefits is indicative of the type of deep structural change which is required for a transition to ZEH (Smith, 2006).

The EU, UK and Californian policy agendas include requirements to address capital costs. Specific examples from these three case study jurisdictions are presented in chapter 7, including reducing these capital costs through economic efficiencies in the material and building process and
introducing financial mechanisms such as low interest loans or tax breaks (reduced stamp duty for example). It is explicitly recognised here that the government must work with the financial sector to develop innovative economic levers to achieve such changes (CPUC, 2011; Lorraine, 2012; Tambach, et al, 2010).

Through such policy innovation, governments in the EU, UK and California are beginning to change current modes of thinking from one of capital costs to through-life costs and benefits. This process involves changes within the financial sector. As banks recognise the benefits of reduced living costs and improved resale values, which are characteristic features of low emission housing, they can account for the changed risks and benefits through new loan mechanisms. New financial instruments may be required to accurately reflect the lifetime consideration of costs and benefits in this way. This is part of the wider societal shift towards longer-term economic and sustainability thinking (Smith, 2006), and present a challenge to the existing regime as discussed in chapter 2.

Within the wider transitions literature, the requirement for financial innovation through rebates and low interest home loans has been discussed as an important requirement to assist a wider transition to a low carbon future (Smith, 2006; Williams, 2008). The importance of such a requirement is highlighted by Tambach et al. (2010, p. 994) who state that ‘new national, as well as local forms of financing energy efficient renovation projects in housing also deserve special attention in further research’. Furthermore, Smith (2006) identified the importance of financial innovation to help break the building supply networks of the existing regime.

In Australia there is a history of policy innovation in housing finance, but the scale of initiatives regarding ZEH lags behind the EU, UK and California. A range of rebates have been provided by the Australian government across the past decade for renewable energy technology as well as for some energy efficient materials (e.g. insulation). However, as discussed in chapter 3, these rebates have had an inconsistent history. Whilst issues surround the rebate programs, they have helped to deliver a market for renewable energy technologies which was virtually non-existent prior to the rebates schemes and, in turn, have improved overall cost efficiencies (Hawke, 2010; Macintosh & Wilkinson, 2011). In addition, the Australian Government has attempted in recent years to work with the banking sector to offer low/no interest loans to households who make sustainability improvements to their homes (e.g. Green Loans program) (Combet, 2010).

Innovative financial instruments are arguably important in enabling niche uptake of ZEH, and through this applying significant pressure on the existing regime (Geels, 2012; Lorraine, 2012; Smith, 2006). The lack of wider structural change relating to financial instruments has been recognised as a barrier to achieving improved energy performance from key actors within the Australian building industry. For example the Housing Industry Association (HIA, 2009, p. 25) states:
‘Home lenders do not take into account operating housing costs, such as energy efficiency savings, when assessing the capacity of borrowers to make repayments on home loans. The preference of home lenders to assess repayment capacity on the basis of current and not future income is suggestive of a market failure in the mortgage market. That home lenders are unwilling or reluctant to approve larger loans to cover the additional entry cost of energy efficient new dwellings is not addressed by mandating more stringent building regulations’.

It is reasonable to assume that a significant increase in innovative and attractive finance products to address capital cost issues for owner-occupiers would, over time, result in more lifetime thinking and practical knowledge of relating operating costs, housing energy performance and mortgage costs. This, in turn, would shift the way in which payback is viewed. This has been identified by the Australian Government, who recognise that consumers rarely entertain improving energy efficiency options if the payback period is seen to be more than a few years (Australian Government, 2010c). Furthermore, the requirement to move to lifetime thinking with regards to both costs and outcomes has been identified in the wider housing STT literature (Smith, 2006).

While Australia has made some progress with addressing wider financial structural concerns, there is still more to be done in order to achieve a transition. Addressing these elements can help to address the increased capital costs of ZEH standards as well as enhance the through-life benefits of such standards.

**8.3.5 Wider social elements**

To date, debates and policies aimed at improving the environmental performance of housing have been dominated by a technical focus, while rarely considering wider social aspects (Li & Shen, 2002; Pickvance, 2009; Smith, 2007). The transition scenarios to ZEH presented within the STT literature all include acknowledgement of wider social elements, such as improving occupant health and social well-being, reducing fuel poverty and understanding and responding to building industry dynamics (Bergman, *et al.*, 2007; Smith, 2006; Tambach, *et al.*, 2010). The limited consideration of social and industry dimensions of housing energy performance policies to date, has been regarded as limiting the capacity for a paradigm shift in the building sector (Tambach, *et al.*, 2010; Williams, 2008).

The UK case study provides the most integrated example of social and technical requirements within the policy documents analysed. These include links to, and performance indicators for, wider social elements such as improving occupant health, improving living affordability, reducing fuel poverty and developing the active participant household. Institutionally, there is a focus on developing an understanding of existing and future actors and networks in the building industry in order to identify risks and benefits of a transition to a low carbon housing future.
The analysis of the EU, USA and California case studies found that while similar householder social elements are beginning to be integrated into policies, there remains limited consideration of these to date. This difference between the UK and the EU, USA and California may be as a result of the UK having developed their policies earlier.

In Victoria and Australia, debate regarding broader housing provisions is dominated by considerations of “affordability”. However, this debate is still focused on the capital costs rather than on through-life costs and benefits (Morrissy & Horne, 2011). Beyond this, there is recognition from the Australian Government that any further improvement to energy performance standards require supplementary measures including programs of training and education for the building industry (Australian Government, 2010c; Pitt & Sherry, 2010).

Limited consideration of ‘non-technical’ factors in the Australian context has also been recognised by Newton and Tucker (2011, p. 46) who state ‘policy analysts need to engage with both technology and behaviour-based approaches to energy conservation’. The authors also discuss how addressing deeper social constructs of housing could lead to a reconfiguration of physical house design outcomes (demand for smaller, more appropriate size housing), as personal concern and responsibility for environmental impacts and outcomes improves. The idea of raising awareness of householder practice and their role in shaping energy demand is another related issue explored in the transitions literature (Vergragt, 2006).

Across all of the jurisdictions considered here, there remains limited evidence of the need to incorporate a systematic understanding of building industry networks and actors; the meaning of and connection to home; and culture and institutional socio-technical dynamics of housing systems into policy initiatives in the context of ZEH policy ambitions. This, despite research which finds significant social benefits for elements such as improvements to health, well-being and comfort (Clinch & Healy, 2000a), and building industry transition considerations (Osmani & O’Reilly, 2009).

8.4 Synthesis

Individually sections 8.1–8.3 above have addressed elements of the overall research question. Below, these discussions are summarised and integrated in order to address the overall research question (see page 12).

Improvements to housing energy performance minimum standards in Australia have typically revolved around the affordability versus sustainability debate as discussed in chapters 1 and 3. There is a lack of clear evidence regarding the through-life costs and benefits of improved energy performance standards, and policy development in the Australian context has been spasmodic. In order to inform this debate, this thesis has developed a casebook of evidence on the costs and
benefits of ZEH in Melbourne, Australia. The analysis has found significant economic, social and environmental benefits when taking a through-life approach to ZEH, and demonstrates that from a cost-benefit perspective, ZEH is currently feasible in Australia.

The results show that the most financially beneficial lifetime housing affordability outcome was achieved with an 8 star building envelope with 4.3 kW of PV and SHW. This ZEH scenario has a calculated additional capital cost of $30,842 (offsite RE) or $31,047 (onsite RE) compared to existing 6 star detached housing. For homeowners, analysis indicates that this equates to an additional capital cost of 7.8% for new detached housing (including land) in Victoria. Against build cost only, this represents an additional capital cost of 17.2%. However, the through-life economic benefits could be as much as $400,000 or more over 60 years. In addition, significant environmental savings can be achieved, assisting with wider greenhouse gas emission reduction requirements.

While a ZEH is technically and economically feasible, there are still significant additional capital costs involved for the household. The analysis showed that this additional capital cost can be negated by reinvesting energy cost savings back into home loans for owner-occupiers. An existing range of financial incentives such as rebates do exist in Australia and further financial innovations such as reduced stamp duty and low interest loans for ZEH could assist with ZEH uptake.

The evidence produced was found to be comparable to analysis undertaken internationally and other emerging Australian ZEH research which shows that Australian housing can be part of the emerging transition to low carbon housing. However, the analysis here is more transparent, includes a larger sample size and allows more detailed findings to be drawn regarding the elements of costs and benefits than previous research has done.

The second part to the overall research question asked ‘what are the policy levers that could help to facilitate a regulatory transition to ZEH in Australia?’ The analysis found that from an STT perspective, there are a number of significant gaps in the current Australian policy context, which need to be addressed. In particular five key elements of STT theory are missing or limited in the Australian context as discussed in section 8.3:

- long-term ZEH goal (which includes a mandatory requirement for renewable energy technologies),
- a pathway/s to achieve ZEH goal/s,
- links to wider policy development (e.g. climate change emission reduction targets),
- innovation of financial elements to address capital cost concerns, and
- detailed integration of wider social elements.
While it is too early to tell if the international jurisdictions studied will achieve deep structural change or merely incremental technology development, it is clear from the analysis that these five key criteria could usefully be addressed in future policy development in the Australian housing energy performance policy context. Indeed, such developments would inform the basis for ZEH policy and could facilitate a transition to a low carbon housing future. Central to this transition is likely to be a shift to a more comprehensive policy focus (whole of life) and the integration of social elements in housing policy approaches (socio-technical, institutional, systematic). Without such developments, a ZEH transition in Australia is less feasible, less likely and less practical.
Chapter 9: Conclusion

Current housing energy performance in Australia is unsustainable, given increases in total energy demand across the residential sector and the use of fossil fuels to provide the majority of this energy. The housing sector has been identified as having an important role in reducing greenhouse gas emissions.

Increased stringency in housing energy performance standards to a ZEH standard has become international best practice in recent years, including in the EU, UK, and California. Within the framing and associated constraints of ecological modernisation, ZEH policy interventions invariably set out to address both a reduction in total energy consumption, as well as the provision of on or near site renewable energy technologies to offset remaining energy use. While policies vary in their delivery, there is a general emphasis on the tools of reflexive governance to enable monitoring, steering and evaluation of progress towards ZEH. There are significant differences between ZEH policies and a focus on heating and cooling energy efficiencies only.

In Australia, where housing energy performance regulation is focussed on heating and cooling energy efficiencies, the housing market has failed to deliver a low emission housing stock. The main policy activity in the area of minimum housing energy performance standards in Australia has been the introduction of star ratings in 2003, and apart from incremental improvements to these standards there has been little policy innovation since (Newton & Tucker, 2011). Typically, arguments advanced against ZEH or other significantly improved energy performance centre upon capital costs and impacts on affordability (Morrissey, et al, 2011; Pitt & Sherry, 2010).

A lack of clear cost-benefit evidence and the practical implications of this for innovation of minimum housing energy performance policy has been identified as a barrier to a transition to ZEH in Australia as introduced in chapter 1 and discussed in chapters 2 and 3.

In responding to this knowledge gap, this thesis addresses the research question:

What is the cost-benefit feasibility of, and policy requirements for, a transition to ZEH in Australia?

Three sub questions were developed to guide the research response (see page 12). A mixed methods approach was applied across two main phases of analysis to address these research questions: a cost-benefit analysis (phase 1) and a policy document analysis using STT theory (phase 2). Following analysis of the results, this research provides a significant contribution to knowledge, through provision of specific and clear responses to the defined research questions. In addition to the empirical evidence generated, the research has added to the development of
environmental CBA methods and to the fledgling empirical field of socio-technical transitions theory and its application. Policy analysis of this type, incorporating STT theory and targeted cost-benefit analysis, has not been completed in the housing sphere previously. This research represents a world first in this regard, with outcomes highlighting the importance of both elements in a transition to a low carbon future.

While there have been small-scale investigations of CBA in energy efficient housing and ZEH, the research presented here provides the first rigorous, transparent and comprehensive study of its type. Outcomes of the research include a case-book of evidence on the capital and through-life costs and benefits of detached ZEH options for Melbourne, Victoria. A detailed analysis of the limitations of existing policy in the Australian context is also presented in respect to a facilitated transition to ZEH standards and the implications of this for decision-makers. Critical elements that are absent or given limited attention in Australian housing energy policy are highlighted with reference to international best practice and STT theory. A number of significant practical ramifications for future policy development of, and transition to, ZEH energy performance standards in Australia are thematically drawn from the research findings.

9.1 Significant findings and implications for advancing policy and practice

A number of significant findings are evident from the analysis. These are discussed below, synthesised here from the detailed presentation of individual findings provided in chapters 6–8.

9.1.1 Costs and benefits significantly favour ZEH (sub question 1)

Based on findings of the applied cost-benefit analysis (phase 1, chapters 6 and 8), together with insights from the wider literature, this research concludes that the economic and environmental benefits of ZEH significantly outweigh additional capital costs. The economic outcomes identified for the Australian context are broadly comparable to those reported for international jurisdictions in the process of a transition to ZEH.

By inference, a continuation of the current BAU policies would mean that sub-optimally performing new buildings would continue to be added to the housing stock, locking in housing stock and households to high operational costs and high energy demand across the long life-span of the housing stock.

9.1.2 From capital cost to lifetime affordability (sub question 2)

While a through-life approach finds that ZEH is economical, the time-profile of the costs relative to the benefits is a significant consideration. Achieving a ZEH standard requires additional capital. However the analysis in chapter 6 and discussion in chapter 8 identified that if energy savings from a ZEH are invested into home loans, the mortgage debt could be paid off several years sooner, and significant economic savings could be achieved in avoided interest repayments.
Chapter 9: Conclusion

Current discourse on housing affordability is focused on the front-end or capital costs. From ZEH and sustainable housing perspectives, ‘lifetime’ approaches are more useful to ascertain the actual life-cycle economic and environmental costs.

Within the case for ZEH, there is a further implication of the research, arising from the timeframes over which costs and benefits of ZEH occur. Since these extend beyond the average residency time of owner-occupied housing (average of 10 years in Melbourne), there is a strong public policy case for comprehensive and binding ZEH standards to ensure that future households access the social, economic and environmental benefits of ZEH through their housing careers.

9.1.3 Developing a more comprehensive policy approach (sub question 3)

While cost-benefit analysis is informative, it says little about how the mechanics of a transition to ZEH can be achieved through a policy approach. Building on the cost-benefit analysis, phase 2 focused on the practical policy requirements to facilitate a ZEH transition in Australia, and in doing so addresses sub question 3. The analysis found five key policy limitations of current housing energy performance policy in Australia based upon the STT framework, as presented and discussed in chapters 7 and 8. These five key limitations are:

- A lack of longer-term goals;
- No pathway to achieve longer-term goals;
- Limited links to wider government policies;
- Limited financial innovation; and
- A lack of wider social considerations.

Given current housing policy discourse in Australia, a policy shift in perspective and focus will be required if these identified policy limitations (STT elements) are to be included in housing energy performance regulation. Such a shift is occurring in the international case study jurisdictions analysed in this research. While the policy inclusion of limited STT elements does not guarantee a successful transition to a ZEH regime, the analysis presented here suggests that it would improve the chances of a successful outcome through targeting of a wider range of critical housing parameters.

9.2 Limitations of this research

All due care was taken with the research to ensure that a rigorous and valid approach was applied. Limitations of the research have been discussed in chapter 5, however a number of additional limitations are briefly summarised below:

1. The modelling is based upon specific building practices, materials, designs and climate zones relevant to the Melbourne context. Application of the cost-benefit analysis work outside these considerations needs, therefore, to be undertaken with due caution;
2. Numerous assumptions are made with regard to the cost-benefit calculations. These have been tested rigorously, but remain assumptions; and

3. STT theory is, as yet, formative and unproven and its application to the case study is therefore open to critique and interpretation.

Regarding point 1, the energy requirements, particularly for heating and cooling, differ between building types and across climate zones in Australia, impacting on the energy requirements for dwellings (Wang, et al, 2010). However, the evidence presented in this research indicates that there are significant benefits in ZEH standards and that the information provided will be of benefit to informing the debates regarding ZEH policy in Australia. The methodology developed and applied in this research is applicable to analysis of other building types, building tenure and climate zones in Australia.

Addressing point 2, a significant critique of the application of cost-benefit analysis is the determination and use of key assumptions. This research sought to test key assumptions and presented the impacts of these across a range of parameters in the analysis where appropriate. For example, a low and high energy price scenario was applied within the modelling to show the range of possible future costs and benefits. If these key assumptions alter in the future, the modelling may need to be updated to ensure that reliable cost and benefit outcomes are forthcoming.

Regarding point 3, as explored in chapter 4, STT theory is still evolving and its application to current transitions is, to date, limited. There is ongoing debate within the transitions literature with a number of critiques and attempts to address these presented within the chapter 4 discussion. This research has assumed that STT theory is applicable in a transition to ZEH in Australia. As further research is undertaken in the STT field, this position may alter. The application in this research has been undertaken with consideration of the limitations and critiques of STT theory.

9.3 Implications for policy development in Australia

This research is not designed to produce policy but instead to provide an evidence base upon which policy-makers can draw. A number of key implications emerge from the analysis for policy-makers concerned with the future development of minimum energy performance requirements in Australia. From these implications, propositions are made as follows, drawn directly from the key findings presented above:

- Set a longer-term (10+ years) housing energy performance agenda including the setting of medium-term and long-term goals, and a requirement for renewable energy technologies to be part of minimum standards.
- Develop a pathway to achieve specified goals. Drawing upon the international case study jurisdictions, effective pathways would likely be across 10 years with two or three key
minimum energy performance policy upgrade milestones set across that time. The results and discussion in chapters 6 and 8 highlight two intermediate performance standards (7 star building envelope with 1 kW PV and 8 star building with 2.5kW PV and SHW) that could be adopted in a transition to ZEH standards. Such an approach has the advantage of providing certainty to the building industry and consumers about the future direction of standards and can provide an incentive to innovate solutions to improve energy outcomes and find cost efficiencies.

- Link housing energy performance standards to wider government policies such as greenhouse gas emission reduction and renewable energy targets. This would provide confidence that there were significant benefits to implementing such a policy and that policy outcomes were part of a society-wide transition to a low carbon future.

- Address financial innovation to improve cost efficiencies to achieve ZEH standards. This would help the building industry and consumers to adapt to the requirements of ZEH standards and encourage innovation of technologies, materials and building practices. Examples of this innovation are evident in the case study jurisdictions; the reduction of stamp duty for achieving the ZEH standard from the UK is one example. In addition, a reframing of housing affordability is required by banking institutions, building industry actors and consumers from a capital cost focus to a through-life approach.

- Integrate wider social considerations into minimum housing energy performance standards to ensure a more comprehensive policy approach is developed. These elements include household level considerations (such as addressing fuel poverty and the meaning of home), but also broader building industry level considerations (for example the requirements to retrain workers and fostering of cultures of innovation in industry stakeholders).

### 9.4 Further research needs

This thesis has addressed a significant gap in knowledge regarding the costs, benefits and practical requirements for a facilitated regulatory transition to ZEH in the Australian context. While clear evidence and analysis is presented, the research raises questions where future research is required. These areas include:

- Extending the cost-benefit methodology developed in this research to include other dwelling types, including existing dwellings, and climates zones (including possible changes to future climates) around Australia;
- Extending the cost-benefit methodology to different scales (street, precinct, suburb, etc.) to establish a better understanding of the impact of scale;
- Analysis of new ZEH buildings, including an assessment of actual energy performance outcomes as well as wider social impacts.
- Analysis which investigates the impact of reducing house size in achieve ZEH standards;
Chapter 9: Conclusion

- Analysis of other technologies (and performances of applied technologies) for ZEH scenarios;
- Further research to understand the role of ZEH in risk reduction for households and the wider community;
- Extension of the application of the STT policy methodology developed for this thesis to existing housing;
- Mapping the STT actors from the existing regime and the current ZEH niche to develop a better understanding of how a wider STT transition to ZEH may occur, both in Australia and internationally; and
- Further research to understand cultural, consumption and social dimensions of home and how these may be accounted for in ZEH policy.
Appendix

This appendix presents the detailed results from the STT policy analysis presented in chapter 7. Responses to the criteria questions are coded into one of 6 categorical answers, as presented in Table 51.

Table 51: Categorical response code for the policy analysis matrix.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>Yes: Mandatory requirement included in policy</td>
</tr>
<tr>
<td>R</td>
<td>Yes: Recommended requirement in policy, generally one of a number of options which needs to be addressed - Not a mandatory requirement</td>
</tr>
<tr>
<td>P</td>
<td>Yes: Partially addressed, but does not completely address the criteria question</td>
</tr>
<tr>
<td>N</td>
<td>Acknowledged within the policy but not included as a requirement</td>
</tr>
<tr>
<td>f</td>
<td>Discussed in the policy for future inclusion (mandatory)</td>
</tr>
<tr>
<td>-</td>
<td>Aspect is not mentioned in any way</td>
</tr>
</tbody>
</table>

Table 52 presents the full detailed results from the policy document analysis.
### Table 52: Complete responses from the policy analysis.

<table>
<thead>
<tr>
<th>Social criteria</th>
<th>USA</th>
<th>California</th>
<th>EU</th>
<th>UK</th>
<th>Australia</th>
<th>Vic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Is ZEH a policy goal/requirement?</strong></td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>P*</td>
<td>P</td>
</tr>
<tr>
<td><strong>Is there evidence of a long-term (15-25+ years) housing performance policy strategy?</strong></td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td><strong>Is there evidence of a medium-term (5-14 years) housing performance policy strategy?</strong></td>
<td>N</td>
<td>-</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Is there evidence of a short-term (0-4 years) housing performance policy strategy?</strong></td>
<td>P</td>
<td>P</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Are wider functions of housing (such as working from home) addressed in the policy?</strong></td>
<td>N</td>
<td>-</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>P</td>
</tr>
<tr>
<td><strong>Is the importance of ZEH articulated?</strong></td>
<td>-</td>
<td>-</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Is there a mix of representation from current regime and future actors involved in policy development?</strong></td>
<td>-</td>
<td>-</td>
<td>Y</td>
<td>-</td>
<td>Y</td>
<td>P</td>
</tr>
<tr>
<td><strong>Is there recognition of the current regime?</strong></td>
<td>-</td>
<td>-</td>
<td>Y</td>
<td>P</td>
<td>P</td>
<td>-</td>
</tr>
<tr>
<td><strong>Is there self-recognition of any gaps in current policy/ regime?</strong></td>
<td>N</td>
<td>-</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Are backcasting/forecasting scenarios generated to achieve longer-term policy objectives?</strong></td>
<td>-</td>
<td>-</td>
<td>P</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Is a clear and defined movement from current (or previous) position to a new position (i.e. a transition to ZEH) outlined in the policy?</strong></td>
<td>-</td>
<td>-</td>
<td>P</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Is there recognition of what is current international best practice?</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>N</td>
<td>P</td>
<td>-</td>
</tr>
<tr>
<td><strong>Is there a consideration of how current policy compares to international best practice?</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>N</td>
<td>-</td>
<td>P</td>
</tr>
<tr>
<td><strong>Is there a requirement in the policy to achieve international best practice?</strong></td>
<td>-</td>
<td>-</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>P</td>
</tr>
</tbody>
</table>

---

**Scenarios (pathways)**

| Is there recognition of what is current international best practice? | -   | -          | -  | N  | P        | -   |
| Is there a consideration of how current policy compares to international best practice? | -   | -          | -  | N  | -        | P   |
| Is there a requirement in the policy to achieve international best practice? | -   | -          | Y  | N  | N        | P   |

---

**International best practice**
### Appendix

<table>
<thead>
<tr>
<th>Social criteria</th>
<th>USA</th>
<th>California</th>
<th>EU</th>
<th>UK</th>
<th>Australia</th>
<th>Vic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link to wider policy goals</td>
<td>-</td>
<td>Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y P P P P P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attachment of renewable energy generation policy?</td>
<td>-</td>
<td>P P P Y Y Y Y Y Y Y Y Y Y P P P P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wider social elements</td>
<td>-</td>
<td>Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reflected governance</td>
<td>-</td>
<td>Y Y Y Y Y Y Y Y Y Y Y Y Y Y P - - -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Does the policy clearly state who is governing the policy?</td>
<td>-</td>
<td>Y Y Y P Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Does it clearly state who is responsible for steering housing performance policy</td>
<td>-</td>
<td>Y Y Y Y Y Y Y Y Y Y Y Y Y Y P - N -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is the regulator neutral? (i.e. not self-regulated through current regime)</td>
<td>-</td>
<td>N N Y P Y Y Y Y Y Y Y Y P - Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is there a requirement for periodic review of the policy?</td>
<td>-</td>
<td>P Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research and development</td>
<td>-</td>
<td>Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y P - - -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are the following explored within the policy?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing affordability?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living affordability?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel poverty?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultural and symbolic meanings of housing?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reducing demand for energy?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Understanding and education of householder practices?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Does support (economic or other) provided for demonstration ZEH projects or</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>technology development?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If support is provided, is there also information on future expectations of the</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
<td></td>
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<td>support (including reduction)?</td>
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<tr>
<td>Is there dedicated research into how to achieve long-term policy (including if</td>
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<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>it is the right policy)?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>Financial sector</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>Is there any exploration of methods to help reduce increased capital costs</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>(if there are any) (i.e. green loans)?</td>
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<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>Is there any exploration of changes to approaches to lending money/valuing</td>
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<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>housing (banks)?</td>
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<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>Does the policy contain a market mechanism to decide the costs consumers</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>are willing to pay (for example through a CPRS)?</td>
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<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>Institutional structure/ reform</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>Is there understanding of the role markets can play in a transition to ZEH?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>Are future policy changes accompanied by a plan to (re)train and improve skills</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>of current regime?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>Is there exploration of possible changes to volume builder practices from</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>future policy change?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>Does future policy change include costs of change to the building industry?</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>Are the risks and benefits of future policy change to the building industry</td>
<td>-</td>
<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>included?</td>
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<td>- - Y Y Y Y Y Y Y Y Y Y Y Y Y Y P -</td>
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<tr>
<td>Are current building industry key relationships defined?</td>
<td>-</td>
<td>- P - - - - - - Y - - Y - Y P -</td>
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<tr>
<td>Are future building industry key relationships and actors predicted?</td>
<td>-</td>
<td>- P - - - - - - Y - - Y - Y P -</td>
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<tr>
<td>Is there an understanding of how change in industry has occurred before?</td>
<td>-</td>
<td>- P - - - - - - Y - - Y - Y P -</td>
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<tr>
<td>Behaviour</td>
<td>-</td>
<td>N Y P - P N Y R N Y N Y</td>
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<tr>
<td>Technical criteria</td>
<td>USA</td>
<td>California</td>
<td>EU</td>
<td>UK</td>
<td>Australia</td>
<td>Vic</td>
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<tr>
<td>Energy efficiency / infrastructure</td>
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<tr>
<td>Is the energy efficiency of the building envelope rated/scored/assessed?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>-</td>
<td>Y</td>
</tr>
<tr>
<td>Is there a requirement for heating and cooling minimum energy performance levels?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>-</td>
<td>Y</td>
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<tr>
<td>Is the environmental impact of individual building envelope materials assessed?</td>
<td></td>
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<tr>
<td>Is there a requirement to build to optimal orientation?</td>
<td>N</td>
<td>R</td>
<td>-</td>
<td>R</td>
<td>-</td>
<td>Y</td>
</tr>
<tr>
<td>Reduction of overall emissions</td>
<td></td>
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<tr>
<td>Is the aim of the policy to reduce overall dwelling emissions?</td>
<td>-</td>
<td>-</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Is there a focus on reducing emissions beyond the energy efficiency of the building envelope (heating and cooling)?</td>
<td>N</td>
<td>P</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Does the policy provide advice on how to achieve improved energy performance?</td>
<td>-</td>
<td>-</td>
<td>R</td>
<td>-</td>
<td>P</td>
<td>-</td>
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<tr>
<td>Energy generation / infrastructure</td>
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<tr>
<td>Is energy generation included as part of the house performance assessment?</td>
<td>N</td>
<td>-</td>
<td>R</td>
<td>Y</td>
<td>R/Yf</td>
<td>-</td>
</tr>
<tr>
<td>Is there a requirement for renewable energy technologies?</td>
<td>N</td>
<td>-</td>
<td>R</td>
<td>Y</td>
<td>R/Yf</td>
<td>-</td>
</tr>
<tr>
<td>Onsite?</td>
<td>-</td>
<td>-</td>
<td>R</td>
<td>-</td>
<td>R/Yf</td>
<td>-</td>
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<tr>
<td>Offsite?</td>
<td>-</td>
<td>-</td>
<td>N</td>
<td>-</td>
<td>-</td>
<td>R/Yf</td>
</tr>
<tr>
<td>SHW?</td>
<td>-</td>
<td>-</td>
<td>R</td>
<td>-</td>
<td>R/Yf</td>
<td>-</td>
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<tr>
<td>PV?</td>
<td>-</td>
<td>-</td>
<td>R</td>
<td>-</td>
<td>R/Yf</td>
<td>-</td>
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<tr>
<td>Other?</td>
<td>-</td>
<td>-</td>
<td>R</td>
<td>-</td>
<td>R</td>
<td>-</td>
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<tr>
<td>Does the policy address the impact that increased micro-generation may have on current or future electricity infrastructure?</td>
<td>N</td>
<td>-</td>
<td>N</td>
<td>-</td>
<td>-</td>
<td>Y</td>
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<tr>
<td>House as part of larger system</td>
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<tr>
<td>Is there any reference to housing having a wider impact in shaping (physical) suburbs or cities?</td>
<td>-</td>
<td>-</td>
<td>P</td>
<td>-</td>
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<tr>
<td>Smart technology</td>
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<tr>
<td>Is there a requirement for 'smart' technologies such as in home energy monitoring systems as part of minimum building requirements?</td>
<td>-</td>
<td>-</td>
<td>R</td>
<td>-</td>
<td>R</td>
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<tr>
<td>Through-life costs and benefits</td>
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<tr>
<td>Are the through-life economic costs and benefits presented?</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>P</td>
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<td>Y</td>
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<tr>
<td>Are the through-life environmental costs and benefits presented?</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Y</td>
<td>P</td>
<td>-</td>
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<tr>
<td>Are the through-life social costs and benefits presented (such as reducing fuel poverty)?</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>P</td>
<td>P</td>
<td>-</td>
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<tr>
<td>Appliances</td>
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<tr>
<td>Is there a requirement for certain energy efficiencies of appliances or limitations to appliance use in minimum building standards?</td>
<td>Y</td>
<td>-</td>
<td>Y</td>
<td>-</td>
<td>Y</td>
<td>Y</td>
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</tbody>
</table>

* These policies refer to ZEH but use a different definition than the one applied in this research.
References


References


References


References


CIE. (2007). Capitalising on the building sector’s potential to lessen the costs of a broad based GHG emissions cut. Canberra: Centre for International Economics.


References


References


References


References


ESAA. (2010). Victorian low-voltage electricity mix from Australasian Unit Process Life Cycle Inventory: Data from inventory developed from Energy Supply Association of Australia.


References


References


References


References


References


References


References


References


References


230


References


References


234


References


Williams, J. (2008). Green houses for the growth region. *Journal of Environmental Planning and Management, 51*(1), 107 - 140. doi: 10.1080/09640560701712283


