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ORIGINAL ARTICLE

Residential energy efficiency standards in Australia: where to next?

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Abstract Increasing the energy and carbon efficiency of homes has been at the forefront of international climate change mitigation policy. In Australia, recent policy action led to the introduction of minimum energy efficiency standards for new homes within the Building Code of Australia in 2003, with subsequent stringency increases in 2006 and 2010. Although not yet reflecting international best regulatory practice, these standards represent substantial progress in addressing the energy and carbon emission impact of new homes, yet there are a number of energy policy challenges that highlight the need for further change. This paper documents the history of house energy standards in Australia and examines the post-occupancy evidence of that policy outcome. The paper examines international and domestic issues pointing to a possible future direction for Australian house energy regulation, highlighting the key drivers for change. In particular, we investigate the concepts of net zero carbon and net zero energy homes which have recently been adopted internationally, examining the technical and economic evidence that would support such a policy position in Australia.

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Introduction

Two key policy issues have driven the desire to improve building energy efficiency in Australia: energy security and environmental sustainability. During the 1970s, the oil crises prompted discussions about mandating thermal insulation in new dwellings as a mechanism to reduce Australia's dependency on imported energy resources (Williamson 2000), and since the 1980s, consecutive Australian Governments have recognised the need to address anthropogenic climate change and have highlighted building energy efficiency as a valid mitigation strategy (Australian Greenhouse Office 1998; Council of Australian Governments 1992; Department of Climate Change and Energy Efficiency 2010; Department of Resources Energy and Tourism 2012).

In the context of national and global issues, Australia has taken action to improve building energy efficiency through a policy mix of minimum energy performance standards for buildings and associated appliances and sporadic incentives for energy-efficient and renewable energy technologies. However, the established building energy performance standards fall below that set by similar developed economies (Horne et al. 2005) and well below the future standards proposed by many OECD members (Department of Climate Change and Energy Efficiency 2010). Whilst European nations, the

UK and some US States propose to increase standards towards a net zero energy or net zero carbon performance level, Australia has entered a building energy policy hiatus. The question remains whether a policy approach similar to other developed nations would be reasonable—should Australia reset policy to embrace a net zero carbon performance regulatory target for new homes.

This paper is structured to: (a) explore the history of Australian house energy efficiency regulation and the primary policy drivers, (b) analyse the evidence of the effectiveness of recent policy actions and (c) and examine the evidence for the need to rethink the Australian government policy position. Through exploring the national experience of house energy regulation and examining current international policy responses and the recent related domestic research, this paper provides a possible pointer to the future of Australia's house energy regulatory policy.

Background

Policy context

Global climate change has been the dominant landscape driver of domestic energy efficiency policy since the 1980s, although the form of Australia's response has varied across political cycles. The mitigation policy evolution has progressed from an initial programme of scientific research and the development of energy policy incorporating greenhouse gas emission considerations to the adoption of various national greenhouse response strategies (Council of Australian Governments 1992; Howard 1997; Australian Greenhouse Office 1998; Department of Prime Minister and Cabinet 2004; Department of Climate Change 2008; Department of Climate Change and Energy Efficiency 2010; Hawke 1989; Keating 1993).

International pressures to take action to address anthropogenic greenhouse gas emissions have been recognised in domestic politics. Under former Prime Minister Keating, Australia signed the United Nations Framework Convention on Climate Change agreeing to reduce and stabilise emissions to no higher than 1990 levels by 2000. Prime Minister Howard softened that stance by arguing that Australia's population growth rate exceeded that of other OECD countries, and the energy intensive export sector was critical to the economy. Early in the Rudd Prime Ministerial term, Australia ratified the Kyoto agreement and sought to re-establish Australia as a climate change policy leader, whilst the current Prime Minister Abbott has scaled back Australia's commitment for action.

Through this period, the emphasis for mitigation has moved from no regret (Bulkeley 2001) actions (e.g. energy efficiency) to higher cost actions (e.g. renewable energy subsidies) and to major economic reform (e.g. emissions trading) and back away from mandatory approaches towards voluntary industry action. Consecutive governments have recognised the growing body of scientific evidence for climate change, but conflicting interests have led to contrasting policy approaches. Overall, policy has been shaped by the dominant neo-liberalism paradigm, typical of an advanced capitalist nation, where the government's role is to steer the economy by developing the legal and institutional framework within which the market operates (M. Berry and Nelson 2007). As such, the government does not directly control national emissions, but sets targets, encourages action by others, enacts laws, supports the creation of institutions and provides incentives that facilitate change.

Energy pricing has also played a large role in shaping the emissions profile of the Australian economy. Australian residential and industrial electricity prices were for many years lower than those in the UK, Spain, France, Ireland, Germany, Italy and most of the European Union (Wells and Donaldson 2005). The Australian energy pricing regime, lower than the full environmental and social costs of supplying that energy, had resulted in higher than socially optimal energy use by end users (Productivity Commission 2005). The result was considerable energy wastage through poor building thermal efficiency, inefficient transport options and industrial processes and the higher than socially optimal use of inefficient appliances and equipment (PriceWaterhouseCoopers 2008; Department of Climate Change and Energy Efficiency 2010). More recently, electricity and gas prices have moved towards world average prices due to increases by the regulated monopoly transmission and distribution utilities, resulting in a growing financial burden to users of inefficient buildings and equipment. Although electricity price increases are expected to moderate in the immediate future (Australian Energy Market Commission 2013a), the development of infrastructure on the east coast of Australia facilitating the international trade of

liquefied natural gas is likely to put upward pressure on domestic gas prices (Australian Energy Market Commission 2013b).

Big picture landscape issues such as global climate change, energy security and energy economics have provided the context for taking action to improve the energy efficiency of the Australian economy, with the political cycle dictating the policy approach applied.

Residential building energy policy response

Throughout the development of Australian climate change mitigation policy, the residential sector has been highlighted as an important and integral part of the strategy to reduce Australia's greenhouse gas emissions (Department of Climate Change and Energy Efficiency 2010; Council of Australian Governments 1992, 2009; Greene and Wilkenfeld 1990; Howard 1997; Australian Greenhouse Office 1998; Australian Minerals and Energy Council 1990; Senate Standing Committee on Industry Science and Technology 1991).

The Australian building sector constructs approximately 140,000 new dwellings per year, subject to the prevailing economic conditions (Australian Bureau of Statistics 2010). Notwithstanding any overall change in national household energy efficiency due to various energy policy measures, the addition of each building below the performance of net zero carbon or net zero energy increases the need for electricity generation capacity and associated energy supply infrastructure and adds to national and global greenhouse gas emissions. For the purpose of this paper, the concepts of net zero energy and net zero carbon homes are fundamentally similar, with the primary difference being the carbon impact of on-site energy generation. Details of the definition of net zero energy and net zero carbon homes for regulatory purpose have been published (Berry et al. 2014a).

Aimed to address recognised market failures, the residential building energy policy debate has focused on options such as voluntary and mandatory codes and standards and the provision of information and market incentives to drive a more efficient use of energy (Productivity Commission 2005). From a regulatory perspective, the options have included mandating minimum energy performance standards through local or state government planning instruments or building regulations and mandating the disclosure of energy performance information at point of sale or lease (Productivity Commission 2004).

National mandatory building energy efficiency standards are relatively new in Australia having commenced in 2003, but the policy path has a much longer history. Through the 1970s and 1980s, building energy conservation was researched and promoted by governments, but as a voluntary action (Williamson 2000). Australia's commitment to the resolutions of the 1988 Toronto Conference *The Changing Atmosphere: Implications for Global Security* led to the publishing of reports from the Australian and New Zealand Environment Council *Towards a National Greenhouse Strategy for Australia* and the Australian Minerals and Energy Council *Energy and the Greenhouse Effect*, committing the Governments of Australia to the establishment of energy efficiency standards for residential and commercial buildings (Australian and New Zealand Environment Council 1990; Australian Minerals and Energy Council 1990). One of the technical reports commissioned by the Australian and New Zealand Environment Council pointed out that Australia was the only OECD country without building energy regulations at that time (Greene et al. 1990). A concurrent examination of building regulatory systems and processes by the Building Regulation Review Taskforce, established by the Australian Government in 1989, led to a funding commitment in 1990 to create model codes for energy-efficient residential and non-residential buildings with a completion goal of December 1993 and the development of a Nationwide House Energy Rating Scheme (NatHERS) to help promote climate appropriate design (Building Regulation Review Taskforce 1991a, b).

The 1992 National Greenhouse Response Strategy reiterated the need for building energy efficiency regulation and called for the development of the Nationwide House Energy Rating Scheme to be expedited by 1994, but by 1995, little progress had been achieved in establishing nationally consistent voluntary codes and introducing a consistent rating scheme, and the progress report on implementing the strategy again called for action (Council of Australian Governments 1992; Intergovernmental Committee on Ecologically Sustainable Development 1995). Although national cooperation was failing to progress the agenda, several State and Territory governments—ACT, NSW and Victoria—were progressing with local building or planning codes.

Regulation for the insulation of new dwellings had been recommended by a Victorian parliamentary committee as early as 1978, but was not adopted as government policy until the mid-1980s. In 1986, the Victorian Department of Industry Technology and Resources recommended that insulation be installed in ceilings and external walls of new homes, and following an agreement between the Minister for Planning and Environment and the Minister for Industry Technology and Resources to incorporate insulation requirements into the local building codes, regulations came into operation in Victoria through the Building Control Act in 1991 (Australian Greenhouse Office 2000).

Following the lead from Victoria, mandatory wall insulation for new dwellings was introduced in the Australian Capital Territory (ACT) in 1992. In late 1995, the ACTHERS rating system, a variant of the Nationwide House Energy Rating Scheme (NatHERS), was introduced as a supplementary compliance requirement, and the ACT Government established a building fabric minimum energy performance requirement of 4 ACTHERS/NatHERS Stars in May 1996 (Williamson 2000).

In New South Wales, the Sustainable Energy Development Authority (SEDA) launched a mandatory minimum NatHERS 3.5 Stars standard within the 'Energy Smart Homes' policy in 1997, which was delivered through local council planning schemes. The standard was demonstrated in a large-scale rollout for the 2000 Olympic Games village 'Newington', which incorporated the Energy Smart Homes standard plus the integration of solar thermal hot water and solar photovoltaic technologies (Spooner et al. 2000).

The lack of support for regulatory change in northern and southern Australia was driven by differing concerns. The Tasmanian government was concerned about housing affordability and the additional costs of meeting energy standards, whilst Queensland considered that 'southern' solutions based on higher levels of insulation were not appropriate for hot humid climates.

Building regulation is within the Australian Constitution responsibility of State jurisdictions, and the role of the Commonwealth had been limited to encouraging national coordination and consistency through Ministerial Council processes. This had also been complicated by the sometimes separate and uncoordinated action of two policy areas, those bureaucracies responsible for energy policy and those responsible for building regulation. An example of this can be seen in the development of the voluntary Building Energy Code of Australia (BECA) in the mid-1990s, which was developed by Energy Ministers through the Australian and New Zealand Minerals and Energy Council rather than Building Regulatory Ministers, who were pre-occupied with the development of the Building Code of Australia first released in 1996. BECA failed to gain traction and the programme was closed in 1996, with the clear lesson that the regulation of building energy efficiency must be applied through the existing building regulatory framework (Berry et al. 2001).

With the implementation of various State Government building energy standards, national consistency was a major issue to industry, particularly for the building products supply industry and larger construction firms who operated across state boundaries. Gradually, various sections of the industry voiced support for national consistency, although not all industry representative organisations (e.g. Housing Industry Association) were supportive of mandatory minimum energy efficiency standards.

In 1997, Prime Minister Howard committed to introducing mandatory minimum energy standards in the new Building Code of Australia in his climate change address *Safeguarding the Future* (Howard 1997). The subsequent 1998 National Greenhouse Strategy echoed the Prime Minister's commitment with agreement by all levels of government to building energy regulation (Australian Greenhouse Office 1998).

With the newly formed Australian Greenhouse Office as the lead policy agency, research was commissioned to scope the addition of energy efficiency in the Building Code of Australia (Australian Greenhouse Office 1999) and analysis into the impact of the Victorian insulation regulations (Australian Greenhouse Office 2000). By 2000, the building and construction industry, represented by the Australian Building Energy Council, supported national minimum energy standards, and all Ministers responsible for building regulation agreed and funded the development of energy efficiency regulations by the Australian Building Codes Board (Berry et al. 2001). In parallel, the Australian Greenhouse Office, in the role of NatHERS National Administrator, worked with CSIRO to upgrade the Nationwide House Energy Rating Scheme and the associated building energy simulation software for regulatory use in all Australian climates (Delsante 2003).

This policy imperative manifested as minimum energy efficiency standards introduced into the Building Code of Australia approximating 4 NatHERS stars in 2003, 5 stars in 2006 and 6 stars in 2010 (Australian Building Codes Board 2002, 2006, 2009) or in New South Wales a 'BASIX' standard using a planning approval instrument (see www.basix.nsw.gov.au). The 2010 BCA changes also included performance requirements for water heating and fixed indoor lighting. The BCA now forms part of the newly established National Construction Code of Australia.

The role of the Commonwealth and State Governments varied throughout that period of BCA energy efficiency adoption. The Commonwealth championed the initial 2003 standard with the support of State jurisdictions, but the move to 5 stars in 2006 was led by the Victorian and ACT Governments rather than the Commonwealth, who although funding much of the evidence used to support the case for an increase in stringency, had a policy backflip (Macdonald 2005) but was unable to veto the change. The Commonwealth Government's reticence for increased stringency was echoed in Productive Commission analysis of energy efficiency policies which raised questions about the evidence used to support building energy regulation (Productivity Commission 2005). The roles reverted for the 2010 BCA change, with the Commonwealth leading the process with the support of State jurisdictions.

With renewed interest by the Commonwealth in building energy regulatory reform, by 2012, COAG processes had developed the concept of regular 5 yearly building energy code stringency reviews and the potential to communicate longer term stringency goals within the draft National Building Energy Standard-Setting, Assessment and Rating Framework (Department of Climate Change and Energy Efficiency 2012b). No national agreement was achieved for the Framework and the programme ground to a halt in 2012/13.

Complementing mandatory energy standards for new homes is the requirement for disclosing the modelled energy efficiency performance of existing homes on sale or lease. This policy measure was introduced in the ACT in 1999, and in 2004, the Australian Government committed to the concept of mandatory energy efficiency disclosure, a commitment supported by all State and Territory jurisdictions through the Ministerial Council on Energy. The commitment was reiterated in the 2009 National Strategy on Energy Efficiency, which stated the measure would commence in 2011 (Council of Australian Governments 2009), and was included within the National Building Energy Standard-Setting, Assessment and Rating Framework in 2012 (Department of Climate Change and Energy Efficiency 2012b). Following the development of the regulation impact statement for the proposed measure (Allen Consulting Group 2011) and the lack of agreement on a nationally consistent approach, the policy fell out of favour with State and Territory jurisdictions and Commonwealth funding for the initiative ended.

Evidence of measure effectiveness

Although Australian house energy regulatory policy has had a chequered history and difficult gestation, the resultant measures have been in place for sufficient time to determine their effectiveness. During the period of initial reform, various experts and policy organisations questioned the modelling evidence used to support building energy regulation, particularly the use of NatHERS as a tool for assessing performance (Productivity Commission 2005; Williamson et al. 2006). Recent analysis has found that: (a) building energy efficiency regulatory standards has delivered measurable household energy use reductions and associated economic benefits for new homes (Australian Energy Market Commission 2013b; Saddler 2013; Ambrose et al. 2013) and (b) mandatory energy performance disclosure for existing homes has provided home buyers with a mechanism to value homes (Department of the Environment Water Heritage and the Arts 2008).

Studies from different perspectives, ranging from top down analysis of energy use in Australia to the examination of regional energy use and to the examination of individual household energy use have consistently found that the energy standards in the Building Code of Australia have decreased average household energy use for new homes. For example, Saddler (2013) related recent total national electricity use reductions to a suite of energy efficiency measures including building code change. The Australian Energy Market Commission (2013b) noted that distributor SP Ausnet had identified significant reductions in daily energy use for households in eastern Melbourne due to progressive changes to house energy efficiency standards, with improvements to both average daily and peak electricity demand of around 20 %. Ambrose et al. (2013) monitored energy

use in a sample of detached houses built in the last 10 years in Brisbane, Adelaide and Melbourne and found that 5 star houses used significantly less energy to maintain thermally comfortable conditions, particularly in winter where saving ranged from 20 to 50 %.

The research conducted by Ambrose et al. (2013) also found that houses built to the 5 star standard were not only cheaper to heat but were also less expensive to build than lower rated houses. Whilst this finding may appear to be counter-intuitive, the design response to the higher energy standard may have encouraged simpler floor plans with lower cost construction.

To investigate the effectiveness of mandatory disclosure regulations, the Australian Bureau of Statistics employed hedonic modelling to analyse the relationship between energy efficiency rating and sales price for a sample of 5000 houses sold in Canberra in 2005 and 2006. The study found a statistically significant relationship between the rating and the sale price with the housing market valuing higher star rating properties after the consideration of all other major factors (Department of the Environment Water Heritage and the Arts 2008).

Whilst the evidence available to date does not provide comprehensive analysis of the cost-effectiveness of each policy measure, the various studies provide a consistent picture that the measures have achieved measurable changes in household energy performance and market valuation outcomes.

International policy direction

The residential energy efficiency has featured prominently in greenhouse gas emission mitigation plans in many nations and regions (Laustsen 2008; Organisation for Economic Co-operation and Development 2011; International Energy Agency 2013). Whilst the potential for mitigation from the building sector is relatively large, strong barriers especially exist in this sector and hinder the market uptake of cost-effective technologies and practices (Intergovernmental Panel on Climate Change 2014). These barriers render some actions, such as building regulation, more effective than energy or carbon pricing instruments alone.

Residential building energy efficiency standards have been a regulatory tool of governments for many years; for example, the first UK standards for heat loss were introduced in 1965. Building energy standards were introduced or increased in many countries as a result of the oil crises of the 1970s: For example, in the USA, the Model Code for Energy Conservation was published in 1977 by the National Council of States on Building Codes and Standards in response to the first oil crisis (Halverson et al. 2002). Germany has implemented progressively more stringent residential building energy standards no less than seven times over a 35-year period reducing requirements from 300 kWh/m^2 to below 50 kWh/m^2 per annum (Schettler-Kohler 2009). These regulations have been complemented by policies for existing buildings, mandatory energy performance disclosure, and a raft of policies to increase the use of renewable energy systems including minimum contributions for new buildings (Schettler-Kohler 2009; Schimschar et al. 2011).

Typically, Australia has lagged changes to the UK, European or North American house energy standards by approximately 10 to 15 years, possibly due to its more moderate climates resulting in energy use as a lesser economic concern. An international comparison of house energy standards found that regulations in the UK and North America, for equivalent climates, averaged 6.8 NatHERS stars when Australian regulators were considering the move to 5 stars (Horne et al. 2005). By the time the Australian stringency level was raised to 6 stars in 2010, many developed nations had already increased their mandatory minimum energy performance standards for new homes (Department for Environment Food and Rural Affairs 2007; Schimschar et al. 2011). Since the 2010 Australian stringency increase, the global market for energy technologies such as photovoltaics (PV) and light-emitting diodes (LED) has matured, and the local market for higher performance building products such as double glazing has developed, substantially improving the cost-effectiveness of creating homes with an energy performance beyond current building energy standards.

Most recently, future building regulatory performance targets approximating operational net zero energy or net zero carbon have been announced in Europe, UK, South Korea and USA (Department of Communities and Local Government 2006; European Commission 2010; Kapsalaki and Leal 2011; Senior Officials Group on Energy Efficiency 2010). These building energy standards require high levels of energy efficiency to reduce the energy demanded for typical household energy services, with an equivalent amount of energy to the consumed, being produced on-site,

probably from renewable energy sources. Many countries have established mandatory or voluntary building energy codes that deliver highly energy-efficient and low-carbon emission homes (Buildings Performance Institute Europe 2011; Janda 2008). For example, the Buildings Performance Institute Europe (2011) provides a comprehensive list of European voluntary and mandatory building energy codes that seek to deliver low-energy, low-carbon emission or near zero energy building performance.

In 2006, the UK became the first national government to determine that residential building energy regulations be increased to net zero carbon (Department of Communities and Local Government 2007, 2006). The European Union followed by requiring that member states ensure that all newly constructed buildings be 'nearly net zero energy' by 2020, the energy needs to a significant extent be met from renewable sources (European Commission 2010; Schimschar et al. 2011), and a number of national governments within Europe have developed detailed roadmaps describing their path to nearly zero energy buildings (Jagemar et al. 2011). In the USA, the Department of Energy has announced a goal of cost-effective net zero energy buildings by 2025 and the incorporation of that performance in building codes (US Department of Energy 2010) Building energy standards in the USA is a State responsibility, and some jurisdictions such as California have legislated that all new residential construction is to be zero net energy by 2020 with all new commercial buildings achieving this goal by 2030.

International direction for building energy standards is firmly pointed towards net zero energy or net zero carbon performance levels (Berry et al. 2014a), a policy position being supported by the development of detailed roadmaps. Is this a sensible policy direction for Australia?

Evidence supporting future policy options in Australia

In Australia, while some policy discussions of the previous Australian Government referred to the potential for higher building energy standards (Department of Climate Change and Energy Efficiency 2010, 2012b), in the absence of longer term goals and transition pathways (Moore et al. 2014), it appears that the current Australian Government and the State Governments have lost their desire for building energy reform, with the Northern Territory and Queensland yet to fully adopt the 2010 BCA 6 star target. However, whilst the political appetite for change may have stalled, evidence is beginning to emerge demonstrating both the effectiveness of previous building energy code change (Australian Energy Market Commission 2013b; Saddler 2013; Ambrose et al. 2013) and the benefits of moving beyond current stringency (Beyond Zero Emissions 2013; Moore 2012).

In the background, recently escalating domestic electricity and gas prices (Saddler 2013; Australian Energy Market Commission 2013b), combined with the falling cost of installed rooftop photovoltaics (Business Spectator 2013; de La Tour et al. 2013), have created an economic environment more supportive of a move to net zero carbon homes. Peak energy demand, due to an increasing use of residential air-conditioning, is placing growing strain on electricity supply infrastructure and upward pressure on energy prices (Langham et al. 2010), and although this concern may have lessened in the short term by the rapid uptake of domestic photovoltaics plus improvements in building thermal characteristics and appliance energy efficiency, the match between air conditioner energy use and photovoltaic generation is less than perfect. In parallel, governments are seeking new policy actions that can deliver greenhouse gas emission abatement without damage to the domestic economy or export industries. Given these landscape pressures, it could be argued that the time is right for a new examination of the evidence.

A number of niche ultra-low carbon residential developments have been created across Australia by either government organisations or private developers (Miller et al. 2012; Berry et al. 2014b; Berry et al. 2013; AusZEH 2010). These niche developments demonstrate the Australian building sector has the capacity to design and build homes that are at or near net zero carbon in performance. A possible net zero carbon regulatory standard could be similar to the covenant applied at the Lochiel Park Green Village in South Australia, demonstrating that the building sector has the knowledge, tools and skills to design and construct homes that meet that performance level (S. Berry et al. 2014d). There is a clear policy implication that the creation of additional zero carbon niche developments will facilitate further innovation, learnings and skill development, reduce the costs associated with creating low carbon homes and

support change within the incumbent socio-technical regime.

These niche ultra-low-carbon estates have been accompanied by a flurry of research into both the technical and economic feasibility of net zero carbon homes in Australian climates and building typology (S. Berry et al. 2014b; Beyond Zero Emissions 2013; Moore 2014, 2012; Berry et al. 2014d). Beyond Zero Emissions (2013) produced a roadmap to move the Australian building stock to net zero carbon operational performance, Berry et al. (2014a, b) utilised monitored energy performance data from Lochiel Park to determine a recipe for creating net zero carbon homes in Australian climates and Moore (2012) suggested a pathway to net zero energy homes in Australia.

The analysis of economic impacts is a crucial step along the policy development pathway, and the evidence for the economic feasibility of regulating low-energy use and net zero carbon homes is rapidly taking shape (Berry 2014; Morrissey and Horne 2011; Moore 2014). For example, Berry (2014) has demonstrated that regulating at a net zero carbon standard is economically beneficial in warm temperate Australian climates, and Moore (2014) has demonstrated the economic benefits of a net zero energy houses in temperate Australian climates.

Other analysis has suggested that significant improvements in building energy standards upwards of 7 NatHERS stars could be achieved at little or no extra construction cost (Sustainability House 2012), whilst providing improved thermal comfort and lower ongoing energy costs. A study into the potential inclusion of energy generation into Australian building energy efficiency standards has also suggested that household scale photovoltaic systems would soon be cost-effective as the industry matured and product prices fell (Department of Climate Change and Energy Efficiency 2012a). This work was based on costs much higher than current and no subsidy other than net pricing, and when current PV prices are modelled with low electricity buy-back rates and 50 % on-site generation exported to the grid, the model used for that study shows that photovoltaics are now cost-effective. Similarly, there is rapid global transition in lighting efficiency, a step change in technology from incandescent and dichroic lamps to CFL and LED technology, with resultant improvements in energy efficiency per light output (Tsao et al. 2010). As global LED production increases and the Australian market adopts the new technology, the economics of energy-efficient lighting will further improve, facilitating an increase above the current standard.

In addition to the direct economic benefits of net zero carbon homes, the reduction of total energy loads and changes to daily and season load profiles, particularly from the application of photovoltaic systems, provide peak load benefits to the electricity network, resulting in lower energy infrastructure costs to both commercial and household users (Langham et al. 2010). Although the match between photovoltaic electricity generation and peak electricity demand is less than perfect (Watt et al. 2003), when combined with the reduction in air-conditioning demand, the overall impact of net zero carbon homes lowers typical new home energy infrastructure costs.

Beyond the economics of net zero carbon homes, data collected from niche ultra-low-carbon residential developments is also demonstrating that households greatly value the improved thermal comfort and lower energy costs of near net zero carbon homes and are reasonably comfortable operating the range of energy systems and technologies typically found in net zero carbon homes (Berry et al. 2014c).

From the growing volume of net zero energy and net zero carbon literature and from the monitored energy use and renewable energy generation data available from various ultra-low-carbon case study housing estates, the body of evidence is building that net zero carbon is a feasible building energy standard in Australia for new homes. The literature also shows that global technology change will continue to make it easier and cheaper to design and construct at that performance level, and there is clear evidence that supply chains adapt readily to building energy regulatory change, and product development learnings lead to increased performance at lower unit costs (Weiss et al. 2010; van Mierlo 2012; Papineau 2006).

The economic results generated by recent research demonstrates that the Australian community would benefit appreciably from adopting a net zero or near net zero carbon standard for new homes (Morrissey and Horne 2011; Moore 2014, 2012; Berry 2014). This result is further enhanced by the large and important co-benefits, particularly thermal comfort, human health and productivity benefits, available from a move to energy-efficient and low-carbon impact homes (Ürge-Vorsatz et al. 2009; Bi et al. 2011; Leech et al. 2004; International Energy Agency 2014). In the context of global climate change and concern in Australia over an increase in the

frequency of extreme conditions such as heatwaves, the thermal comfort impact of zero carbon homes may provide significant physical and mental health benefits (Bi et al. 2011; Saniotis and Bi 2009; Nitschke et al. 2007).

Conclusion

The need for governments to address the greenhouse gas emission impact of buildings and other policy drivers has led many to regulate the energy efficiency of homes. Some governments are moving to regulate housing energy performance at levels equivalent to, or near, net zero energy or net zero carbon.

The Australian experience of regulating the energy efficiency of homes has demonstrated an almost glacial speed of policy manifestation, even within a landscape of global and national pressure. Changing practices for an industry, the size and complexity of the housing sector have been a slow and difficult process, yet the creation of niche near net zero carbon housing developments has demonstrated that the Australian house design and construction industry have the tools, skills and products available to produce highly energy-efficient homes.

In Australia, the policy drivers of rapidly increasing energy prices and peak energy demand continue to place pressure on household economics even through building energy efficiency policy action that has engaged 'sleep mode' since the last regulatory change in 2010. Internationally, building energy regulatory change continues to improve the energy efficiency of residential buildings and incorporation of renewable energy technologies.

There is a growing body of evidence that net zero carbon and net zero energy homes are technically feasible in various Australian climates using commonly available building products and energy systems. There is also growing evidence that a net zero carbon standard would pass the economic tests used to assess the viability of new building energy regulations and would provide significant benefits to the Australian community.

While other policy mechanisms, including carbon taxes or emissions trading or renewable energy targets, price environmental externalities and therefore may address the carbon emission impact of the economy, these typically increase overall household costs. Improving the energy efficiency of residential buildings through performance-based regulation can provide significant direct and indirect economic benefits to both the building users and wider society and provide additional health and productivity co-benefits.

The missing link is the political will to improve the environmental, social and economic performance of Australian homes. History demonstrates that building energy policy change is slow and difficult and will be resisted by many and varied vested interests. In this light, although significant benefits are readily available from building energy regulatory reform, change towards a net zero carbon housing or a similar energy efficiency standard may need to wait for the political leadership and bureaucratic commitment to catch up with the technical and economic potential.

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