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Involving occupants in net-zero-energy solar housing retrofits: An Australian sub-tropical case study

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A R T I C L E I N F O

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A B S T R A C T

Australia has a poor record of enforcement and compliance with national energy efficiency building regulations introduced in 2003 and moderately enhanced several times since. A significant challenge facing the nation and owners/occupiers of poor performing houses is how to retrofit the existing building stock to meet thermal comfort, lifestyle, energy efficiency and climate mitigation expectations and standards now and into the future.

The purpose of this study was to test a strategy for providing a range of information to the home owner to assist in their renovation decisions to achieve a net zero energy home in sub-tropical Australia and to evaluate the impact of their decisions in terms of net energy balance. A decision-making equation, rather than an economic-rationalist cost equation, was used to evaluate household actions.

The results show that a combination of a citizen science approach, simulation tools and experimental data assisted occupants in achieving a 50% improvement in building thermal efficiency, an annual average daily consumption of 20.1 kWh and solar generation of 19.6 kWh.

The cost of these actions was well under the average retrofit budget in Australia and resulted in the house achieving near net zero energy (NZE) balance for all household services on an annual basis and NZE balance for nine months of the year. Analysis of the motivations and actions of the home owner point to implications for building assessment tools, eco-feedback technologies, policy, and theories of household decision making.

1. Introduction

Net zero energy (NZE) buildings could be considered the goal for the world's building stock to address multiple issues such as global warming, resource management, energy security and resilience. Whilst there is continued discussion on exact definitions of net zero energy buildings, common definitions essentially reflect accounting variations in what is being measured (energy, electricity, carbon emissions or dollars), what energy services are included in the demand (e.g. combinations of space heating and cooling, water heating, lighting, all stationary energy sources) and types and boundaries of energy supply and connection (e.g. primary or end use energy; renewable energy source, location and nature of grid connection). All definitions assume significant energy efficiency (of the building and appliances) as a first step (Carlisle et al., 2008; Marszal et al., 2011; Pless and Torcellini, 2010). In broad terms a net zero energy dwelling produces as much energy as it consumes on an annual basis. For a subtropical climate, however, it has been argued that a well-balanced household energy system could be net zero energy on a seasonal and monthly basis and include all stationary household energy services (i.e. space heating and cooling, water heating, lighting and all plug loads). To achieve this, however, requires consideration of the system boundaries and balancing of the whole energy system: the thermal performance of the building envelope, the selection and operation of appliances, the output of the onsite renewable energy, and the behaviour of the occupants (Miller and Buys, 2012a, 2012b).

Although this is achievable (though not common) for newly constructed dwellings in subtropical Australia, it remains a challenge for existing dwellings. Home ownership in Australia is quite high, with 67% of dwellings owner-occupied (Australian Bureau of Statistics, 2013). In terms of energy performance, almost 80% of Australia's 9.1 million dwellings were constructed before the introduction of energy efficiency regulations in 2003. Seventy-six percent of these are detached houses (Australian Bureau of Statistics, 2003). Even for houses constructed since the introduction and periodic enhancement of energy efficiency standards (2003, 2006, 2010), the level of energy efficiency is questionable both in terms of regulatory aspirations and actual outcomes (Berry and Marker, 2015). The National Energy Efficiency Building Project, funded by joint state and territory governments, found that checking and enforcement of the energy efficiency requirements is

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very limited, that compliance is likely to be patchy, and that home owners know little about the likely and actual energy performance of their home (Harrington, 2014).

There is also little evidence of energy efficiency featuring in renovation activities, outside of periodic government rebate programs. General (i.e. not energy efficiency specific) house renovation (retrofit) activity in Australia has increased almost 150% since 2010. Approved renovations (those requiring planning approvals) accounted for AUD $600 m in August 2014 alone. Ten percent of Australian property owners undertook renovations at a cost greater than AUD$10,000 in the period 2012–2014, with an average renovation spend of AUD$48,000. The motivations for renovation included increased comfort, modernization and increasing the value of their property (RP Data Data and Research, 2014). These rejuvenation and modernization activities can include modifying house size, floor plans and/or key functional rooms (e.g. kitchens and bathrooms) to meet contemporary lifestyle preferences. Other activities included in the broad definition of 'renovations' include repair and reconstruction work as a response to natural disasters and general home maintenance work (a large volume of low value work) (Housing Industry of Australia Economics Group, 2014). Whilst major renovations trigger a requirement to meet current energy efficiency building regulations (low standards in comparison with world's best practice), the core goals of occupant-driven renovations appear to be focused on spatial, functional and aesthetic considerations.

In addition to this 'love affair' with home renovations, Australian's have also embraced rooftop photovoltaics, as evidenced by the 1.6 million small-scale (1.5–5 kW) rooftop PV systems, the world's highest proportion of households with rooftop PVs (16.5%). The distribution of PV uptake is nationwide, although it is stronger in some states than others (Fig. 1). Factors contributing to high levels of solar uptake are believed to be policy (e.g. rebates and feed-in-tariffs), a large proportion of owner-occupied detached houses with available roof area, high solar radiation levels and high residential electricity prices (Bruce and MacGill, 2016). This high PV penetration rate, however, does not mean that Australia has many NZE homes, as there appears to be little understanding of the importance of building thermal efficiency and energy consumption in relation to PV output, i.e. the overall energy balance at a household level.

While research is being undertaken to develop strategies for identifying and prioritizing cost effective energy-related retrofit activities at national or regional scales (Leinartas and Stephens, 2015; Dernie and Gaspari, 2015; Chantrelle et al., 2011; Kelly, 2009; Suarex and Fernandez-Aguera, 2015; Natarajan and Levermmore, 2007) there remains a need to develop practical strategies that enable solar NZE goals to be implemented through incorporation into the aspirations and actions of owners undertaking their own renovations in detached housing. The objective of this research was to test a strategy for providing a range of information to the home owner to assist in their renovation decisions to achieve a net zero energy home in sub-tropical Australia and to evaluate occupants' decisions and the impact of their decisions in terms of net energy balance.

2. Methodology

This research study uses simulation and experimental data as part of a strategy to inform occupant-lead renovation to achieve net zero energy status through the use of rooftop solar. The study uses an *Adaptive Citizen Science Model* (Cooper et al., 2007; Roetman and Daniels, 2011), an iterative approach that requires researchers and participants to contribute to project design and implementation, and to the bilateral exchange of information. Michelsen and Madlener's *integrated theoretical framework for assessing homeowners' decisions* (Michelsen and Madlener, 2010) is used to evaluate the occupants' actions and decisions. This decision making framework moves beyond the traditional cost-benefit decision making process (a cost equation assuming economic rationalism) by acknowledging that there are multitude contextual barriers that may prevent what could be considered 'rational' decisions. Michelsen and Madlener explain that their framework blends components of economic rationalism, behavioural economics, the theory of planned behaviour and the perceived characteristics of innovations. Applied to energy efficiency retrofit decisions, this framework could be presented mathematically as:

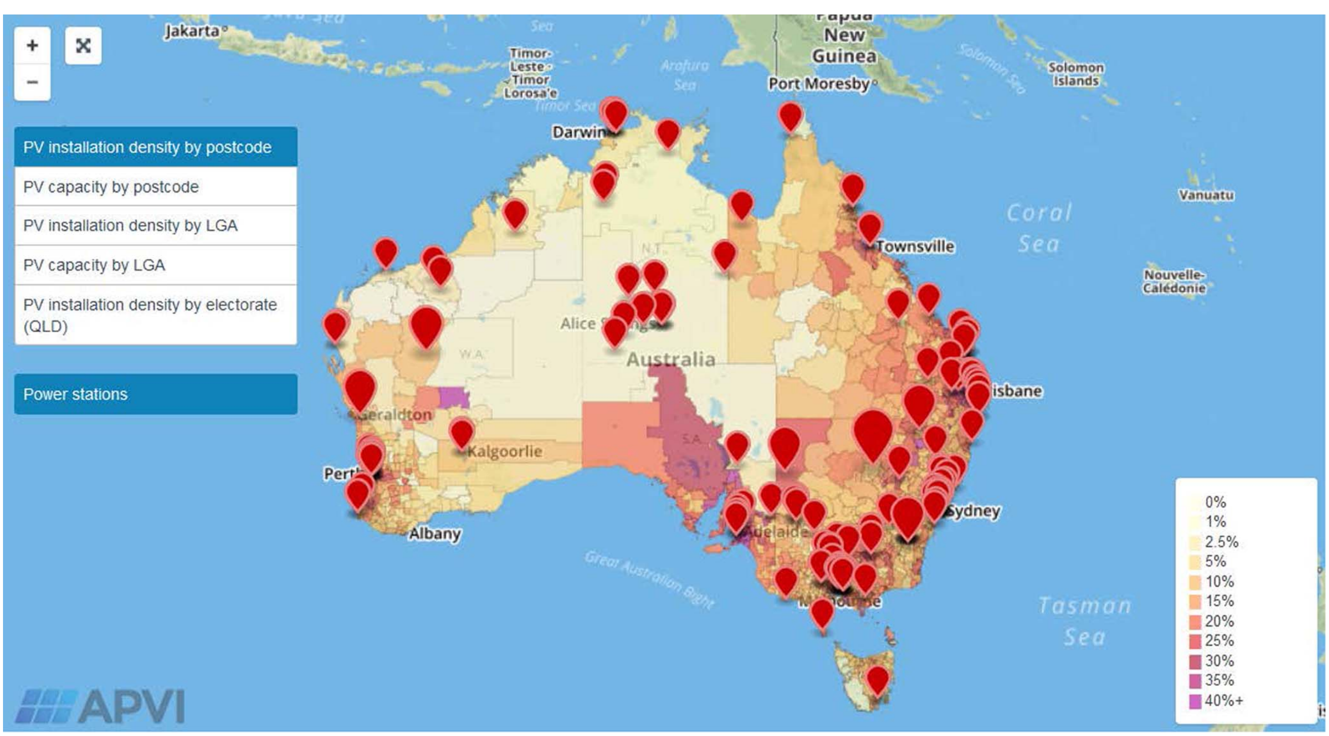

Fig. 1. Australia's PV installation density.http://APVI.org.au
Source: .