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Transitioning to Net Zero Energy Homes—Learnings from the CRC's High-Performance Housing Living Laboratories

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Introduction

The Paris Agreement (UNFCCC 2015) contains a pledge to hold global temperatures to a maximum rise of 1.5 °C above pre-industrial levels. As buildings are the largest user of energy globally (International Energy Agency 2012) and responsible for a significant share of anthropogenic greenhouse gas (GHG) emissions, reducing energy consumption in our homes represent a key action to address global climate change (IPCC 2014). The Australian building sector constructs approximately

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200,000 new dwellings per year, subject to the prevailing economic conditions (HIA 2018). Notwithstanding any significant change in national household energy efficiency policy, the addition of each dwelling below a net zero energy standard increases the need for electricity generation capacity and associated energy supply infrastructure, and adds to national and global GHG emissions.

Internationally, governments have employed a variety of policy mechanisms to reduce household energy use, including energy retailer obligation programs, the provision of financial incentives to encourage the take-up of energy efficiency products or services, energy performance disclosure schemes for both appliances and buildings, and the setting of minimum house energy standards through building or planning codes. Overall, regulatory instruments such as building standards are more effective at reducing household energy use than information, retrofit or voluntary instruments (Koeppel & Ürge-Vorsatz 2007).

Australia has similarly employed a range of policy instruments, establishing the Nationwide House Energy Rating Scheme (NatHERS) in the mid-1990s to encourage thermally improved housing, regulating minimum energy standards in the Building Code of Australia (part of the National Construction Code) in the 2000s, and providing various incentives for householders to install energy efficient and renewable energy products such as insulation, solar hot water systems and solar photovoltaic (PV). At a regional level, some jurisdictions have introduced energy retailer obligations and mandatory energy performance disclosure schemes.

Most recently, driven by the need to meet international obligations to address global climate change, many nations and regions are looking to mandate net zero energy or nearly net zero energy homes (NZEH) as a policy solution. For example, in Europe the EU Directive on the Energy Performance of Buildings (European Commission 2010) specifies that by the end of 2020 all new buildings shall be 'nearly zero energy buildings'. In the USA, the California Long-term Energy Efficiency Strategic Plan sets out the goal to have all new homes achieve a zero net energy standard by 2020 (CPUC 2011).

In Australia, while there is a degree of government reluctance to meet international best practice in building energy regulation (Moore, Horne

& Morrissey 2014), industry is driving the change towards net zero energy buildings by documenting a trajectory to a net zero-carbon built environment (ASBEC 2018; Bannister et al. 2018). This does not mean that Australia is barren of housing innovation, as there are many excellent examples of innovation demonstrating net zero energy or nearly NZEH in a variety of climates and across building typologies. The following case studies explore some of the key learnings from the CRC for Low Carbon Living's high-performance housing 'Living Laboratories'.

Case Studies

Pushing Beyond the Norms: Lochiel Park Green Village—Adelaide, South Australia

The Lochiel Park Green Village in South Australia represented the first genuine attempt by government policy in Australia to create a suburb of (nearly) NZEH in a near zero-carbon estate. The suburban infill development includes 103 homes of various sizes, all utilising solar thermal and PV systems. The energy used and generated at each house is being monitored and analysed as a 'Living Laboratory' to extend our understanding of what happens when households bring their energy habits and expectations to high-performance homes. Appliance and equipment audits, surveys and householder interviews extend our knowledge of this intersection between technology-rich high-performance buildings and the energy service expectations of contemporary digital-age lifestyles.

Lochiel Park homes are built to a relatively high environmental standard, published in the project-specific Urban Design Guidelines (Land Management Corporation 2009). Table 8.1 lists some of the key design and fit-out requirements. These Guidelines established a new set of rules, calling for practices outside existing institutional and professional norms, requiring the application of technologies and systems uncommon to the mainstream building industry at the time, involving the consideration of new performance indicators bringing new concepts

Table 8.1 Mandatory and guidance standards for Lochiel Park homes

Energy service	Minimum requirement or typical fitout
Thermal comfort	7.5 NatHERS stars thermal comfort (i.e. <58 MJ/m^2 per annum)
	Ceiling fans in all bedrooms and living spaces
	Cooling: evaporative coolers or ducted reverse cycle or split system reverse cycle
	Heating: reverse cycle air conditioners, small gas room heaters or underfloor heating
	Space conditioning system capacity limited to 4 kVA (input)
	Fixed or seasonal shade devices on all North, East and West glazing
	Insulation levels: Roof/Ceiling = R4 plus foil, Walls = R2.5 plus foil
	Thermal mass: concrete slab on ground for lower level
	Double glazing and spectrally selective filters (e.g. low-e coating)
Water heating	Solar thermal with natural gas boost or air source heat pump
	Water efficient shower heads and tap fittings
Lighting	Compact fluorescent lights (CFLs) or light emitting diodes (LEDs)
Plug loads	High energy star rated (energy efficient) appliances
Feedback	In-home energy feedback display in main living zone
Renewable energy	Minimum 1.0 kW photovoltaic system for each 100 m^2 of habitable floor area

to building design and construction practices. These requirements also meant that households were exposed to different technologies and styles of house design compared to that commonly available in South Australia (Berry, Davidson & Saman 2013).

Lochiel Park homes are detached or semi-detached two-storey buildings, ranging in size and style from 1 bedroom 'studio' apartments to 4 bedroom detached houses; the most common form being 3 bedroom detached houses. The average habitable floor area for Lochiel Park is 203.3 m^2, similar to the 199.3 m^2 South Australian average for new homes at that time (Australian Bureau of Statistics 2010).

Passive design strategies are implicit within the Urban Design Guidelines, with mandated North facing living spaces, thermal mass requirements, and relatively high levels of insulation; implicit in the minimum house energy rating requirement. The NatHERS 7.5 Star rating (<58 MJ/m^2 per annum) minimum standard for thermal comfort and energy efficiency represents a significant increase above the stock average which approximates NatHERS 2.5 Stars (<270 MJ/m^2 per annum) (Australian Greenhouse Office 2000), and the building regulatory standard of NatHERS 5 Stars (<125 MJ/m^2 per annum) applied at the time when most of these homes were approved for construction. Further detail on the NatHERS energy rating scheme is available from www.nathers.gov.au.

The monitored results reveal a strong outcome. Lochiel Park households use significantly less energy annually than typical similar age homes, the average for the South Australian building stock, and the national average (Berry et al. 2014a, 2014b). This is due to a more thermally efficient building fabric, the application of passive solar design, higher lighting and appliance efficiency, and the use of solar technologies. Figure 8.1 shows that the average energy use per floor area for Lochiel Park homes is less than half that of comparable houses, and when the local generation of electricity is included (self-supplied), the delivered energy (grid demand) is less than a third. Although not reaching the net zero energy standard on average, this represents a significant

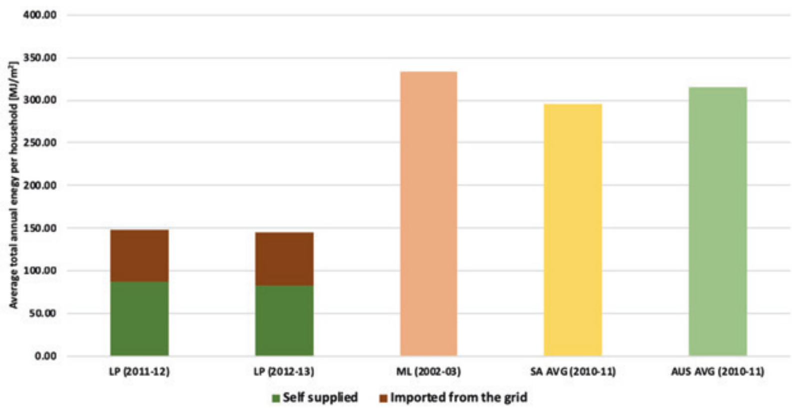

Fig. 8.1 Comparison of Lochiel Park (LP) homes against a sample of Mawson Lakes (ML) homes, and both State (SA) and National (AUS) averages (*Source* Berry et al. 2014a)

improvement in performance against typical homes in the same climate. A small number of homes within the estate regularly achieve a net zero energy operational outcome.

The economics also tell an important story. Analysis from Lochiel Park homes has found that the value proposition of net zero energy housing is overwhelmingly positive to owner-occupier households with a conservative NPV of $24,935 if the home was built in Year 1 of a policy change to net zero energy housing, and with larger net benefits received for homes constructed in subsequent years (Berry & Davidson 2016a). Many of the impacts are externalities not typically incorporated in policy analysis or the business case, yet are real and valued experiences to householders. The benefits far outweigh the costs associated with creating a low energy use, thermally comfortable home environment for low carbon living, powered by renewable energy.

From a public policy perspective the economics are equally strong. The value proposition of regulating all new homes in South Australia to the net zero energy standard would be overwhelmingly positive with a conservative NPV of $1.31 billion for a 10-year policy action, and a benefit/cost ratio of 2.42 (Berry & Davidson 2016b). The results would be similar in other States and Territories, and stronger in regions of more extreme climate where more energy is used for heating or cooling. The research also demonstrates that low carbon living will provide many benefits to the local economy including a net increase in employment, downward pressure on energy prices, increased economic activity within a more efficient economy better able to respond to global energy price increases, energy network infrastructure savings, improved human health and well-being, carbon emission reductions, and benefits from increased social capital. The benefits far outweigh the costs associated with creating net zero energy housing.

Exciting the Market and Testing Innovation: Josh's House—Perth, Western Australia

Josh's House is a three bedroom, two bathroom detached dwelling located in the Fremantle suburb of Hilton, Western Australia. Built in 2013, the home achieved a 10 Star NatHERS rating (i.e. <4 MJ/m^2 per annum) using volume building industry construction methods, materials and trades, demonstrating that high-performance houses can be delivered for little or no extra cost in Perth's climate (NCC climate zone 5; NatHERS climate zone 52).

The house design is based on well-established solar passive design principles (Byrne et al. 2019b) to ensure maximum thermal comfort year-round, with no air conditioning or artificial heating requirement. Key climate responsive features include east-west orientation of the building envelope with maximum glazing to the north for winter solar gain (shaded in summer) and minimal glazing to the east and west to minimise summer heat entry. Effective use of thermal mass inside the home including 'slab on ground' construction, reverse brick veneer perimeter walls (east and west) and brick internal walls help to stabilise internal temperatures. Careful consideration was given to internal room layout and window apertures to ensure good cross ventilation for summer night time heat purging. The thermal shell incorporates climate zone appropriate insulation values to roof and walls to minimise uncontrolled heat loss/gain, low-E glazing, and pelmeted curtains on the windows to reduce heat loss in winter.

The result is a highly thermally efficient home providing high levels of comfort throughout the year (Josh Byrne & Associates 2014). Energy and water efficient fixtures and appliances, combined with onsite power generation, rainwater harvesting, and greywater recycling all contribute to the environmental performance of the home (Eon & Byrne 2017).

What makes this case study unique is that in addition to operating as a family home for two adults and two young children, it has also functioned as a 'living laboratory' (Morrison, Eon & Pickles 2017) for applied research on high-performance housing, as well as providing opportunities for industry and community engagement. Detailed performance monitoring has been undertaken over five years via a carefully planned network of sensors and meters (Eon & Byrne 2017) enabling close scrutiny of the home's thermal performance and household energy and water consumption. This period of data collection spans three distinct stages that relate to changes in the home's energy supply infrastructure and major fixed appliances that were made in response to the availability of innovative technologies and emerging consumer trends. These are described in Table 8.2. The energy use (by load), the energy source and the subsequent calculated GHG emissions for each stage from operational data across these respective stages is presented in Fig. 8.2.

The energy source for the original house design included both grid connect electricity and reticulated natural gas to service the gas cooktop and instantaneous gas booster for the solar-thermal hot water system. The PV system was sized for the home to operate as a NZEH, that is, it was designed to meet or exceed net household operational energy requirements over the period of a year, including offsetting natural gas usage. At the time of designing the home (in 2012), this was considered a pragmatic and cost-effective approach in keeping with the volume market demonstration intent of the project.

The Stage 1 PV system configuration didn't include battery storage. Annual energy demand for the household during this period was 3148 kWh, compared with the local area average of 6570 kWh (Josh Byrne & Associates 2014). Energy demand was met with 35%

Table 8.2 Energy system and major fixed appliance upgrades at Josh's House 2013–2018

Stage	Cooktop	Hot water	PV system	Battery storage	Other
Stage 1: 2013–2014 Original design	Gas	Solar thermal with gas booster	3 kW PV 2.5 kW inverter (grid connected)	None	NA
Stage 2: 2015–2017 Inclusion of battery	Gas	Solar thermal with gas booster	3 kW PV 2.5 kW inverter (grid connected)	8 kWh lithium chemistry based battery	NA
Stage 3: 2018+ Solar-electric upgrade (gas disconnected)	Induction	Heat pump	6.4 kW PV 5 kW inverter (grid connected)	10 kWh lithium chemistry based battery (upgraded)	Electric vehicle introduced and charge point installed

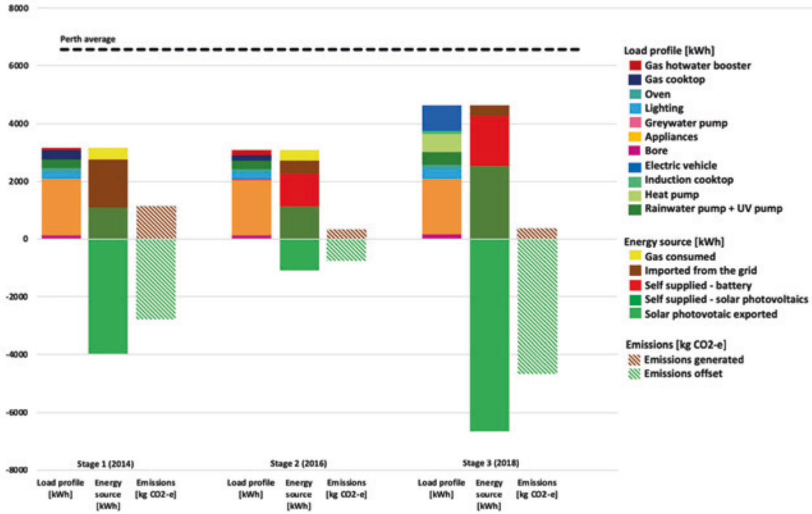

Fig. 8.2 Energy use by load, energy sources and related GHG emissions for Josh's House over three stages of energy system and fixed appliance configuration

self-supply from PV, 52% from grid and 12% from gas. Annual PV export was 3970 kWh, or 78% of total production. Total calculated annual GHG emissions from household operational energy use was 1157 kg of CO_2-e, which was offset by 140% or 2779 kg of CO_2-e by exported solar.

Stage 2 was marked by the introduction of a LiPO battery (BYD DESS 8kWh), representing the first residential grid-connected lithium chemistry-based battery on the South West Interconnected System (the regional electricity network). The objective was to increase the amount of self-supplied energy by storing surplus PV electricity produced during the day for use at night. All other energy infrastructure items and appliance remained the same. Self-supply (PV plus battery) represented 73% of demand (an increase of 38% from Stage 1). GHG emissions reduced by 71% to 332 kg of CO_2-e, and grid export reduced by 71% to 474 kWh as the result of the increased self-consumption enabled by the battery, plus losses due to the parasitic load of the specific battery product (Byrne, Taylor & Green 2017).

Stage 3 upgrades involved replacing the gas stove with an induction cooktop and substituting the gas boosted solar hot water system with an electric heat pump, negating the need for the reticulated gas service. One of the two household cars was replaced with an electric vehicle (EV) (Mitsubishi iMiev) and a domestic charging point was installed in the garage. The PV system was increased to 6.4 kW of PV with a 5 kW inverter, with sizing calculated to cover the anticipated load of the now 'all-electric home' plus cover the net energy requirements of two EV's (the current one and a second in the future). The battery was also upgraded to more contemporary model (LG Chem Resu 10) to eliminate the parasitic load issue. The heat pump hot water system was programmed to operate during the middle of the day and, when practical, the EV was charged during the day to utilise available PV electricity.

In Stage 3, household operational energy usage increased by 50% to 4628 kWh, including 19% (or 867 kWh) for EV charging. Self-supply was 92%, made up of 59% PV and 41% battery. Grid import was 367 kWh and export was 6647 kWh. The inclusion of a second EV (as intended in the system sizing) will reduce this figure. The retail cost for the Stage 3 upgrades was $31,000 (excluding EV). Annual household financial savings from reduced energy bills, fuel costs (realised from the use of the EV), plus feed-in tariff is around $3500, resulting in a payback period under nine years.

Mainstreaming Net Zero Energy Homes: Z-Range Display Home—Melbourne, Victoria

During 2017 and 2018, a national research project was run by the CRC for Low Carbon Living to better understand the cost barriers and market interest in NZEH. The project, 'Mainstreaming NZEH' involved recruiting major land developers and their nominated volume builders to build NZEH display homes in new developments in different locations around Australia, representing different climate zones and different markets. Partners were recruited in Townsville (Stockland and Finlay Homes), Canberra (Riverview Group and Rawson Homes), Melbourne (Parklea and SJD Homes) and Perth (Mirvac and Terrace).

The project approach began with a collaborative design review workshop involving each set of partners with the aim of methodically working through the required steps to make a builder's nominated display house design meet ZEH status. The workshops included the builder, building designer and cost estimator, along with developer representatives and members of the research team.

The pre-existing display house design presented by the builder was considered a BAU (or baseline) scenario and proposed energy improvements were allocated into three alternative scenarios according to their ease of implementation and cost-effectiveness, with costs provided by the builder. Principles of passive solar design (e.g. appropriate glazing, insulation, ventilation, thermal mass, shading, orientation) guided the first part of the conversation, which was followed by a discussion about energy efficient options for appliances and lighting, and finally the inclusion of PV and batteries.

Design modifications were modelled using CSIRO's AusZEH Design Tool (Ren et al. 2011) which combines a thermal energy simulation model, a projection of energy used for lighting, water heating and major household appliances, and house occupancy profiles. The software SAM (System Advisor Model), developed by the U.S. National Renewable Energy Laboratory (NREL), was employed to determine adequate PV sizes to cover annual energy demands for each of the three modelled scenarios under specified occupancy patterns. This software predicts hour-by-hour PV electricity production based on variables such as house location and associated solar radiation, the size of the PV system and inverter (NREL 2014).

In all four cases, energy efficiency gains were obtained mainly from additional insulation, glazing upgrades and energy efficient appliances (hot water systems and air conditioners in particular). In addition, only a relatively small sized PV system was required to cover the modelled net energy demand, provided that the building envelope was designed appropriately for the climate and the appliances were energy efficient (Byrne et al. 2019a). The Z-Range Display Home by SJD Homes in Officer, south east of Melbourne, is provided here as a working example.

Completed in late 2018, the four bedroom, two bathroom house was designed as a ZEH with relatively minor modifications to the building fabric, specifically additional ceiling and wall insulation, double glazing, thickened slab for increased thermal mass and inclusion of internal sliding doors for conditioned space zoning. Appliance upgrades included split system reverse cycle air conditioning to replace ducted gas heating and a heat pump hot water system and induction cooktop, eliminating the need for reticulated gas and enabling the timed use of appliances with available PV energy. The design modelling indicated a 4 kW PV system would be adequate to make the home ZEH under typical occupancy (Ren et al. 2011).

Costings provided by the builder for the upgrades needed to meet this performance benchmark totalled $19,750, representing an 8% increase in the house price, originally set at A$247,900. The projected payback period is around 10 years based on an estimated savings of $1,780 on energy bills per annum, assuming a 2.5% annual energy price increase and the continuation of the A$0.099/kWh solar feed in tariff as shown in Fig. 8.3.

As well as being an active display home for SJD Homes, visitor surveys are being conducted to gain insights into market interest in high-performance housing. The house also serves as a demonstration site for the New Home Energy Advisory Service program run by the South East Councils Climate Change Alliance (SECCCA) in partnership with Sustainability Victoria. The Townsville display home has also

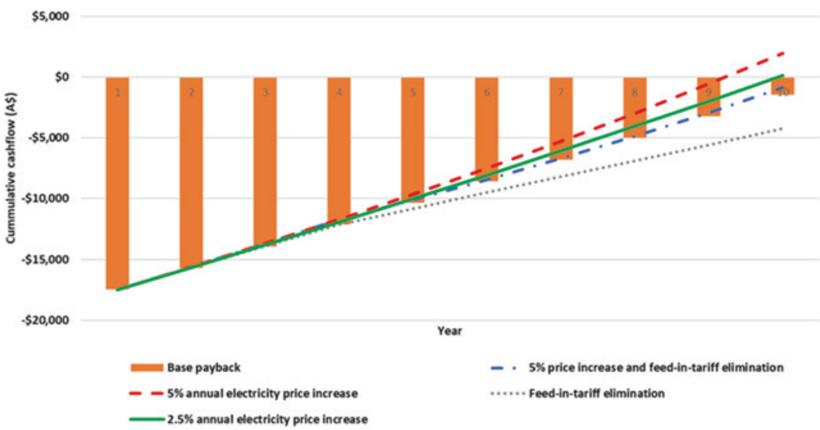

Fig. 8.3 Estimated payback period scenarios for the ZEH upgrades for the Z-Range display home

been completed and is operating as the Stockland's sales office for the display village, whilst also participating in the consumer survey phase. Construction of the Canberra and Perth NZEH display homes are scheduled for early 2019.

Scaling Up: WGV Precinct—Perth, Western Australia

WGV is a 2.2 ha medium density residential infill development in the Fremantle suburb of White Gum Valley led by the Western Australian State Government Development Agency, LandCorp. Located on a former school site, the land availability provided a unique opportunity to take a precinct approach to the design and delivery of the development. WGV accommodates a diverse range of building typologies (detached houses, group houses and apartments) and incorporates climate sensitive planning considerations, innovative water management and creative urban greening strategies (Byrne, Green & Dallas 2018). The precinct will eventually include around 100 dwellings and as of early 2019, is approximately 60% complete.

As a LandCorp 'Innovation through Demonstration' project, WGV is being used as the basis for several concurrent research programs designed to explore novel approaches to urban densification, affordable housing and sustainable development in 'middle suburb' areas. These include a four year 'living lab' research project supported by the CRC for Low Carbon Living, an ARENA funded study into strata-body operated solar energy storage, and an industry-led initiative that showcases the urban water initiatives.

WGV is targeting 'net zero energy' status, meaning the precinct has been planned with the aim of generating as much energy as is used for operating dwellings, balanced over the year. This will be achieved through a combination of energy efficient building design, coupled with rooftop solar energy generation and battery storage in the multi-residential buildings.

The development model at WGV is one where LandCorp (as the developer) develops the land, including managing development scale planning approvals and undertakes site-wide civil works before offering 'construction ready' lots to the market. The larger lots intended for multi-residential buildings are typically sold following a call for expressions of interest from the market where proponents respond to specific criteria, including any building performance or broader sustainability requirements. Lots designated for detached housing are typically sold directly to the public, who then engage a builder to construct a home. In some instances, an architect may be involved, but often the design is handled by the appointed building company. The use of Design Guidelines as a means of facilitating the construction of energy efficient houses on these lots is the focus of this case study, as an example of how the types of energy efficiency initiatives identified earlier in the chapter can be rolled out at greater scale.

Table 8.3 presents the mandatory energy-related initiatives for the detached lots at WGV. These are known as 'Design Controls' and are seen as the minimum requirement for developer endorsement prior either Planning Approval or Building Licence application to the Local Government Authority. In addition to Design Controls, the Design Guidelines at WGV for detached houses include 'Design Guidance'. This represents advice only and is typically at or above 'good practice', and where the uptake of such initiatives, while desirable from the

Table 8.3 Design guideline design controls & developer incentives

Item	Requirement/incentive support	Review/approval stage
Dwelling design	Over shadowing, orientation, layout and cross ventilation assessed pre development application	Pre-planning approval
Thermal comfort	Minimum 7 star (i.e. <58 MJ/m^2 per annum)	Building licence
Renewable energy	Minimum 1.5 kW Incentive: Upgraded to 3.5 kW via developer contribution	Building licence
Water heating	Solar thermal or heat pump (minimum 5 stars)	Building licence
Air conditioning	Reverse cycle (minimum 3 star)	Building licence
Drying court	Mandatory	Building licence
Landscaping	Space allowance for shade trees Incentive: Advanced shade tree via developer contribution	Building licence

perspective of optimising the performance of a building, may be expensive and therefore be resisted by the market.

In addition to the Design Guidelines at WGV, LandCorp provided a ‘Developer Sustainability Package’ as an incentive and engagement strategy for lot purchasers. The initiatives, which included the upgrading of the minimum required PV system of 1.5 kW to 3.5 kW (the size estimated to make the homes NZEH), as well as the supply of an advanced shade tree of a suitable species (deciduous or evergreen depending on the location of planting in relation to the house design), and a rainwater tank and pump to compliment the mandatory dual plumbing for rainwater to supply the toilets and washing machines. Table 8.3 presents the Design Controls mandated under the WGV Design Guidelines against the relevant stage of dwelling planning and building licence approval, as well as the energy-related incentives provided under the Sustainability Package.

Figure 8.4 presents the results of energy demand modelling and estimated GHG emissions for an ‘As Built’ scenario for detached dwellings at WGV, compared with ‘Compliance’ based performance for a new, comparable size dwelling in the same area. The As Built assumptions are based on the implementation of the WGV Design Controls and Sustainability Package initiatives outlined above, adjusted for what has been built on site at the time of modelling (Kinesis 2019). This includes 7 star NatHERS thermal performance (i.e. <58 MJ/m^2 per annum), a mix of mix of hot water systems, including solar thermal (both electric and gas boosted), along with the specified 3 star air conditioner and LED lighting requirements, and an average PV system size of 3.6 kW. The Compliance results are based 6-star NatHERS thermal performance (i.e. <70 MJ/m^2 per annum), gas hot water heating, standard air conditioning (2-star, single phase), and standard lighting. No PV is accounted for.

The estimated annual operational energy demand for the Compliance case on a per dwelling basis is 5362 kWh, made up of 4645 kWh of grid electricity and 717 kWh of natural gas (or 2581 MJ). The resultant calculated GHG emissions is 3753.4 kg CO2-e.

The ‘As Built’ case shows a reduction in overall operational energy demand of 16% from the Compliance case resulting from improved

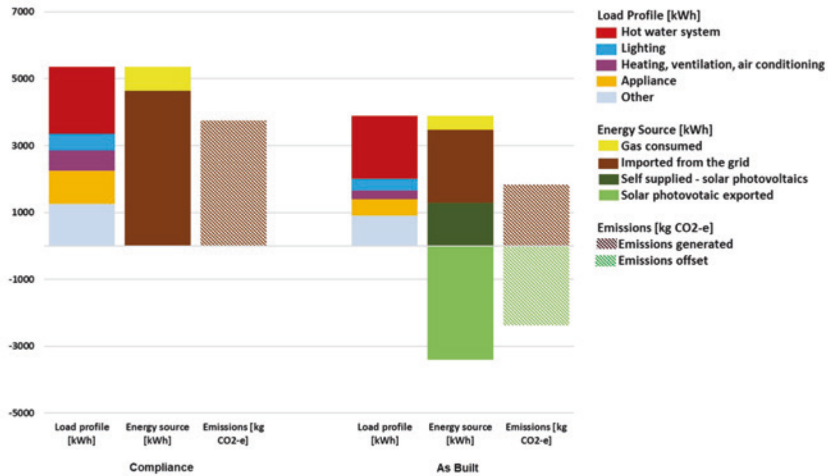

Fig. 8.4 Projected annual dwelling energy demand by load, plus energy sources for the detached lots at WGV, alongside Compliance case. Estimated GHG emissions for each scenario is also provided

performance across hot water heating, space heating and cooling, lighting and appliances. The energy make-up is expected to be 32% self-supply from PV, 56% grid and 11% gas. PV export is expected to average 3402 kWh/year, which equates to 156% of annual import. The calculated GHG emissions is 1531 kg CO2-e offset by 156% by the surplus PV export.

Performance monitoring of individual detached dwellings is now underway at WGV (along with the monitoring of other typologies) with early data supporting the modelling predictions.

Conclusion

The CRC's living laboratories are demonstrating pathways to transition to NZEH. The evidence documented at these highly innovative residential developments is showcasing different technical solutions, identifying a wide range of private and societal benefits, and validating the economic viability of the transition.

Most importantly, these living laboratories have been instrumental in documenting the user experience of NZEH, finding that residents appreciate the improved levels of thermal comfort, lower energy bills, and associated health and well-being benefits.

The ramifications of inaction are exposed by the wealth of documented evidence. The lack of policy action means lost opportunities to improve electricity network security, to reduce the impact of peak energy loads, to improve the resilience of homes to extreme weather events such as heat waves, to improve levels of thermal comfort for occupants, to improve the overall affordability of housing to owners and renters, to improve energy productivity, and reduce global carbon emissions.

These living laboratories have documented the benefits of pushing beyond industry norms, exciting the market for better housing, mainstreaming innovative technologies and scaling up to mass production. Net zero housing is significantly better for the residents, the local economy and energy networks, and can play an important role in helping Australia meet its international climate change commitments. Due to these and other demonstration projects Australia is well placed to transition to a low carbon housing sector.

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