Cutting lifetime residential greenhouse gas (GHG) emissions

Summary of residential changes to the National Construction Code 2022 and BASIX

Alan Pears

This summary information includes recent updates to the topic since publication.

The National Construction Code (NCC), applicable to most of Australia, and the Building Sustainability Index (BASIX), used in New South Wales, have incorporated major energy and climate updates during 2022. These mandatory changes are being phased in during 2023 and are substantial for residential buildings. This update provides a broad overview of these changes.

National Construction Code

The major changes relating to residential energy efficiency and climate issues in the NCC 2022 are:

- In most states and territories, a shift from a requirement to meet 6 star thermal energy performance to seven stars under the Nationwide House Energy Rating Scheme (NatHERS) or equivalent under alternative methods (with transition arrangements in place for some states and territories).
- More recent weather data (from 1990 to the end of 2015) to better reflect our changing climate is now used for ratings, so energy values for star rating levels and heating and cooling limits have changed to allow most existing building designs to achieve the same star rating. Refer NatHERS 2022 Climate Files. The reference building Verification Method for use with software other than NatHERS tools has also been revised.
- A new appliance-focused 'whole-of-home' efficiency rating has been introduced that sets an overall annual energy use budget for major fixed appliances and equipment, including space conditioning, water heating, lighting, pools and spas. This includes installation of rooftop solar that can offset appliance energy use.
- A focus on design of dwellings to be 'net zero carbon ready'. This includes measures such as provision for future electric vehicle charging infrastructure in apartment buildings.
- Deemed-to-Satisfy (DTS) Provisions have been updated and some changes to the NCC structure have been made. Most of the DTS Provisions for Class 1 and 10 buildings are now included in the ABCB Housing Provisions Standard, which is referenced in NCC Volume Two. The DTS Provisions now contain what was previously known as Acceptable Construction Manuals (ACM).
- A number of other changes in the NCC 2022 may impact on energy performance aspects of residential building design and operation. These include more comprehensive condensation and mould management measures and basic requirements to manage thermal bridging. Requirements for 'liveable housing design', in recognition of the needs of mobility-limited and older people, have also been introduced, enabling longer-term adaptability of housing stock.

Different states and territories apply varying requirements in a number of areas, and apply different timeframes to adopting some mandatory measures: these are changing in response to factors impacting on the building industry and regulatory agencies. Refer NCC 2022 state and territory adoption dates.

Resources:

- Overview of changes – energy efficiency and condensation
- Understanding NCC 2022

BASIX

The BASIX standards, as used in New South Wales for residential energy efficiency provisions instead of the NCC, have been revised to increase stringency, improve consistency with the NCC and incorporate updates in default appliance efficiencies, ventilation, lifts and water heating. It will continue to use greenhouse gas emissions as its main indicator, but the requirements have been updated to align with the NCC 2022 7 stars, except in the north coast climate zone and apartment buildings up to five storeys. It continues to use a web-based calculator but now incorporates the NatHERS whole-of-home approach adapted to work with BASIX.

A materials index that estimates embodied emissions has been introduced, though no performance standard is mandated.

Increases to the existing BASIX standards will take effect on 1 October 2023. See Increase to BASIX Standards.

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Cover image. Red Zephyr Blue (RZB) House by Carrier and Postmus Architects, WA. Winner of Award for Sustainable Architecture in WA Architecture Awards 2020 (Image: Douglas Mark Black)

Abstract

There is an urgent need to cut greenhouse gas (GHG) emissions to net zero or beyond within the lifetime of buildings constructed today. This note focuses on strategies and measures that help to achieve this goal in relation to residential building design, construction and initial fit-out. Many decisions are made during these phases that have substantial implications for emissions from production and supply of materials, during decades of operation and at end of life. Emissions associated with furniture, plug-in appliances, consumables such as food, and transport are not addressed.

1.0 Introduction

Household greenhouse gas emissions are generated by energy use, organic wastes, and indirect emissions associated with building activity and manufacture, supply and the installation of materials and equipment, as well as land clearing and demolition for development. Emissions from private transport are also influenced by the location of homes relative to the services the occupants use. Carbon dioxide, from the burning of fossil fuels, is the major greenhouse gas produced by household activities. Methane, from the breakdown of wastes in landfill and leakage from fossil fuel production and delivery (eg coal seam gas and gas distribution systems, coal mines, petroleum production), trace amounts of carbon monoxide and oxides of nitrogen created during combustion processes, and leakage of refrigerants from air conditioners and refrigerators also contribute to global warming.

1.1 The climate emergency and buildings

The Paris climate agreement aspires to achieving net-zero emissions by 2050 while limiting global heating to under 2 degrees Celsius, and as near to 1.5 degrees Celsius as possible. This is a short timeframe relative to the lives of buildings. We have a limited cumulative carbon budget available, so substantial emission reduction as quickly as possible is a priority. Slower action eats into this climate budget. This implies that new buildings should either achieve zero-net emissions when built or incorporate features and use energy sources that can deliver zero emissions as soon as possible, as outlined in sections 2.4 and 4.2, and discussed in detail below.

1.2 What designers can do – overview

Figure 1 summarises actions designers can take or influence during design and construction. Passive design forms a key part of the response in these actions. These are discussed in more detail in the paper.

ISSUE	POSSIBLE ACTIONS
Location and site	Consider solar access, natural features influencing shading, ventilation. Encourage client to consider transport options, access to services and employment, solar access (See Trubka et al, 2010 The costs of urban sprawl – predicting transport greenhouse gases from urban form parameters) Manage land clearing impacts (see Wright and Baracco, 2019 Architecture's role in the repair of the natural environment)
Embodied emissions	Minimise building floor area, surface area, complexity of design Design for adaptability, durability/low maintenance, end-of-life resource recovery and use Select low-embodied emission and low environmental-impact materials for building fabric, fit out and site (eg paving) If demolishing an existing building, maximise reuse and high-value recycling
Operational emissions	Design for changing, more extreme climate and potential energy supply failures Provide client with an operating manual for home, appliances and equipment, and detailed list of materials and equipment with supplier details (eg Sanctuary magazine provides this information for each home it reviews) Design building for energy efficiency, minimum peak thermal and electricity demand, comfort, health, safety and resilience Select appliances and equipment for energy efficiency and limited peak energy demand, compatibility with smart management systems, incorporate energy monitoring and data analytics/user feedback Incorporate (or make provision for) on-site renewable energy systems, energy storage, vehicle charging and use of these portable batteries to supply energy Ensure sustainability features are correctly installed
Assurance of quality and performance	Provide documentation and evidence of appropriate installation of materials, equipment, etc. Install monitoring and diagnostic systems to confirm performance and allow occupants to continue to optimise it
End of life	Design for disassembly (see Crowther, 2005 Design for disassembly – themes and principles) Select products and materials likely to have recovery, recycling systems in place
Unavoidable climate impact	Purchase carbon offsets from credible providers

Figure 1. Roles of designer in achieving net-zero emission housing. See section 2.4 for explanation of net-zero emission dwelling.

2.0 Background

2.1 Emissions from Australia's residential sector

The Australian government reports on annual operational emissions by economic sector; data from the latest available report is shown in Figure 2. Residential sector operational emissions in 2017 were 115 Mt CO2e (million tonnes of carbon dioxide equivalent), 39% higher than in 1990. Transport (5.2 tCO2e/household), which is beyond the scope of this paper, and electricity (4.5 tCO2e/household) dominate. Total Australian annual emissions in 2017 were 530.8 Mt CO2e.

However, these residential sector emissions do not include annual emissions from material production and supply, and construction activities (often described as 'embodied emissions', because they are generated by activity in supply chains, and incorporated into the building at time of construction). One study (Teh et al, 2019) estimates that residential building activity produced 20.2 MtCO2e of embodied emissions in 2015. These included emissions from upstream supply chains, mining and harvesting materials, financial services, distribution, sales, etc. Road and bridge construction, part of which can be related to residential development, added a further 5.2 Mt CO2e in 2015.

Together, these residential sector operational and embodied emissions now comprise around a quarter of Australia's total annual emissions. The emission intensity of Australian grid electricity is declining as the share of renewable electricity increases. Increasing numbers of households are also installing on-site renewable electricity generation.

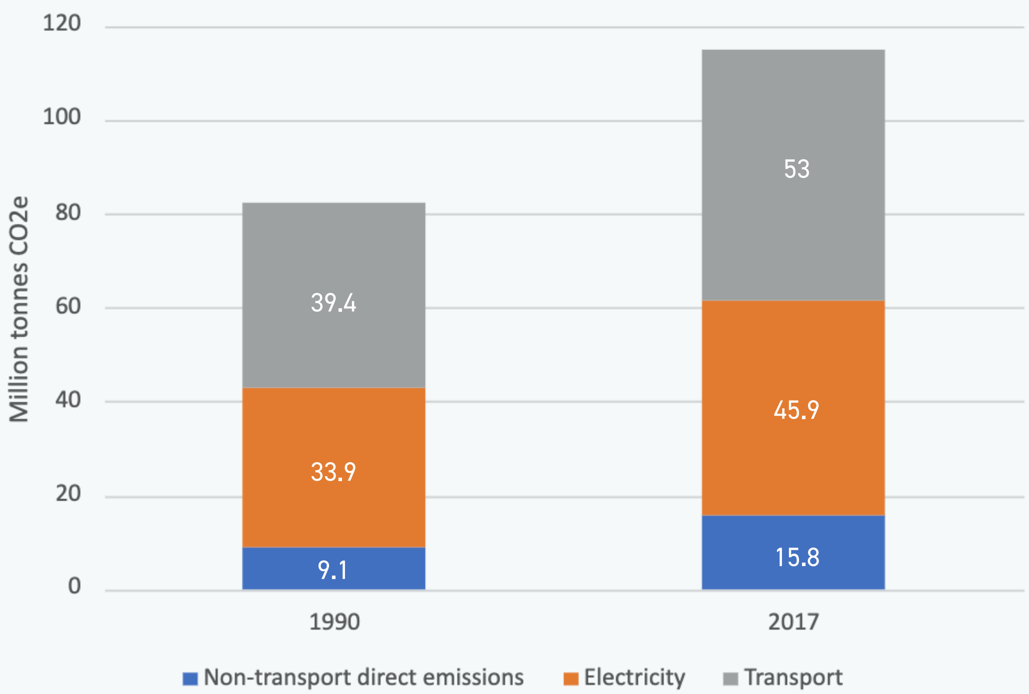

Figure 2. Australian residential sector annual operational greenhouse gas emissions, 1990 and 2017 (Source data: Commonwealth of Australia, 2019). Non-transport direct emissions include combustion of gas (approx. 9.5 Mt CO2e in 2017 and 5.1 Mt in 1990) and non-energy elements including decay of wastes and leakage of refrigerants. See earlier text in this section for data on additional annual emissions associated with residential materials and construction (20.2 MtCO2e) and infrastructure.

2.2 Adapting to climate change and other developments

Our world is heating up. This energises our climate, creating more frequent and intense extreme events, including rainfall, fire, flood, wind and higher sea levels. More subtle outcomes can include higher humidity, hotter nights and changing wind patterns. These changes apply greater stresses to energy supply and other infrastructure, increasing the risk of failures. New buildings must be designed to cope with the consequences of ongoing global heating, or to facilitate affordable adaptation. The Australian government's climate analogues explorer (Figure 3) shows how the climate of a given location might compare with other locations as climate changes.

Safety, health and comfort issues will become more challenging. How will occupants of a high-rise apartment building cope, or evacuate if power fails in hot weather? Can indoor air quality be maintained? How will occupants and building owners respond to more intense and frequent bushfires?

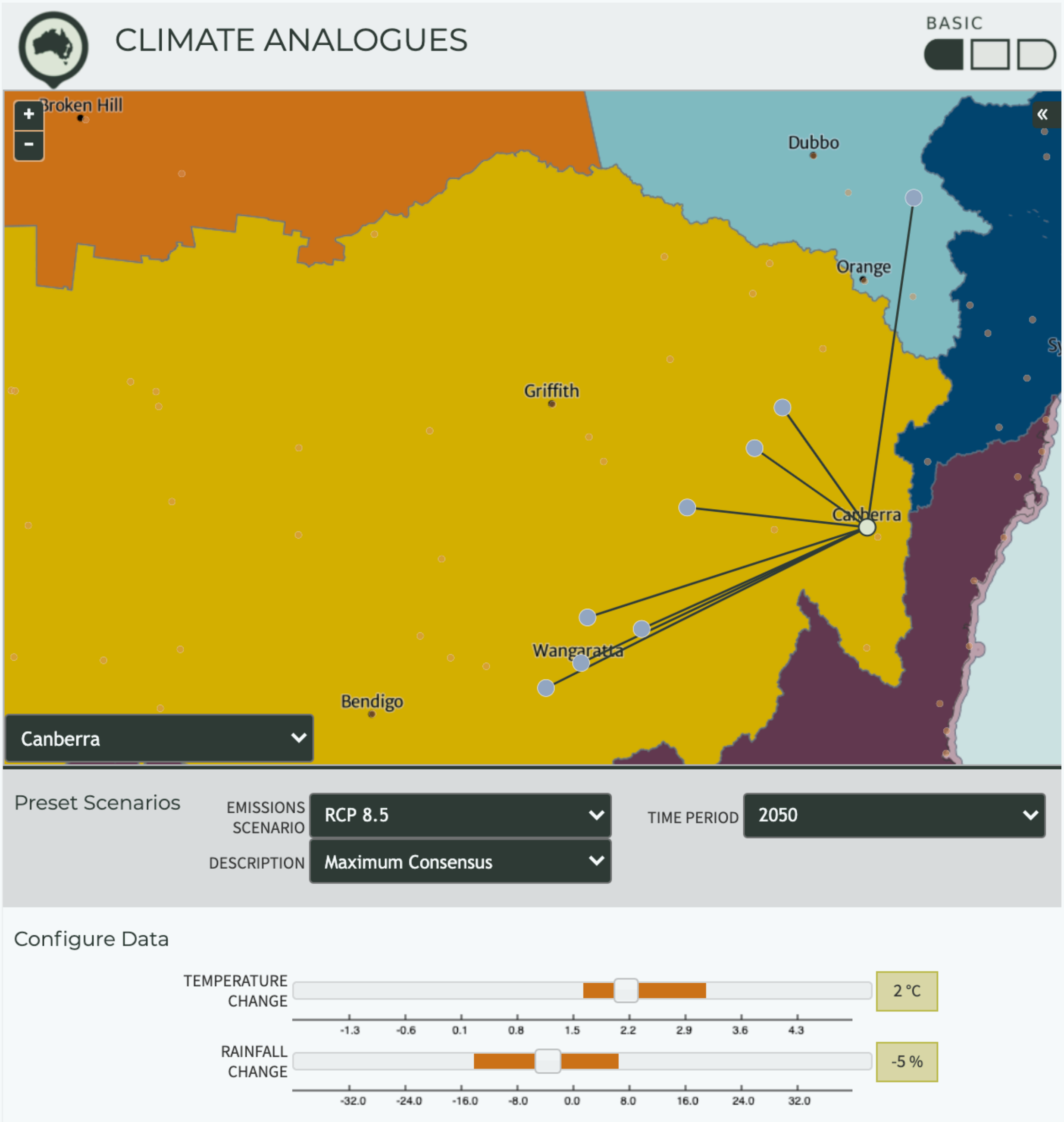

Figure 3. Example of use of climate analogues explorer to show climates similar to what Canberra's could become in 2050 with 2˚C of warming. (Source: CSIRO Australia and Bureau of Meteorology, n.d. © Copyright CSIRO Australia and Bureau of Meteorology).

2.3 Policy and action context

There is increasing momentum behind a transition to net-zero emission (or beyond zero) housing, although there are differing interpretations of what this means – see section 2.4. Steps in this direction are being taken, though they fall short of what is really needed.

Australian governments have agreed to develop 'trajectories for low energy' for both new and existing homes (see DISER, 2020 and COAG Energy Council, 2019 for detailed reports). This is a national plan that sets a trajectory towards zero-operational energy and zero-carbon ready buildings for Australia. Commitments were made in early 2019 to incorporate cost-effective measures for new buildings in the 2022 National Construction Code, and beyond. An addendum agreed in November 2019 extended this commitment to existing buildings. This includes development of rating tools, energy disclosure at time of sale or lease, appliance standards and labels, rental property energy standards, mechanisms applying to strata and rental properties and vulnerable households, and enhanced data collection.

State and territory governments are also acting independently. For example, the ACT has proposed removal of a mandatory requirement to connect gas to new developments (ACT Government, 2020). The Victorian government (DELWP 2020) has developed a *Residential Efficiency Scorecard*. This has been trialed around Australia (DISER 2020a). NSW, ACT, SA and Victoria run government-incentive programs that support action to improve energy efficiency.

At the time of writing, over 900 Australian architecture firms have made a public commitment to climate action – see Architects Declare Australia (2020). Many councils, communities and businesses are making commitments, such as Climate Emergency declarations, allocating resources and taking action. A key message here is that building energy and climate policy commitments and action are accelerating and expectations of accountability for delivered performance are rising.

As mandatory energy disclosure schemes evolve and existing home standards are introduced, the resale and rental value of a home will increase if its energy performance is good, its climate impact is low and superior performance on health and comfort is recognised by potential buyers or tenants.

2.4 What is a net-zero emission dwelling?

There is no single definition. At present, Australian government policy focus is on buildings that:

'...have an energy efficient thermal shell and appliances [including space conditioning, hot water, lighting and pool pumps], have sufficiently low-energy use and have the relevant set-up so they are "ready" to achieve net zero energy (and carbon) usage annually, if they are combined with renewable or decarbonised energy systems on-site or off-site'

(COAG Energy Council, 2018, p.2).

This involves achieving annual net-zero energy-related operational emissions through combinations of:

- Reducing energy consumption using efficient building design, appliances and low-emission energy sources
- On-site renewable-energy generation to reduce energy consumption and for export to offset remaining annual energy-related emissions
- Purchase of renewable energy from energy grids or from other sources in local precincts
- Purchase of carbon offsets.

This interpretation falls far short of a comprehensive approach. Other potential elements of a net-zero emission building include:

- Reduction of lifecycle emissions, including embodied energy, maintenance and end-of-life emissions for the building, appliances and equipment
- Building design that factors in changing climate, adaptability to changing occupancy as average household size changes and individual household circumstances evolve, low maintenance and minimal impact at end of life
- High energy efficiency, low peak demand fixed appliances and equipment beyond those listed in the government strategy above, including cooking, smart technologies and plug-in appliances provided by a builder or third party
- Provision of on-site, precinct or other renewable energy, energy storage and management systems
- Provision of smart energy and water monitoring, diagnostic and user-feedback systems to support optimisation of energy use, identification of faults and potential for energy trading and interaction with third parties for energy trading (see, for example, Pears and Moore, 2019)
- Reduction of transport emissions, including provision of vehicle charging and storage facilities and consideration of access to services and employment, and equitable low-carbon transport options such as walking, micro-mobility and public transport infrastructure
- Reduction of non-energy emissions, such as methane from wastes, refrigerant leakage, land-use change
- Purchase of carbon offsets to compensate for unavoidable carbon emissions (see section 4.2)
- Restorative measures that enhance carbon storage, support local food production and improve quality of life. For example, using Living Building Challenge, WELL (International WELL Building Institute) and other rating tools.

3.0 The designer's role in zero-emission housing

The following sections look at specific aspects of zero-carbon housing of relevance to design, construction and commissioning of new and renovated residential buildings. As noted earlier, issues related to location and site, climate impacts, and responses to them, should be considered before detailed design begins.

3.1 Changing house types and sizes – apartments

We are seeing a dramatic increase in the proportion of new housing in the form of high-rise apartments. Apartment share of new housing has increased from less than a fifth to around a third over the past 15 years (Rosewall and Shoory, 2017). The business model for development of many of these buildings, and the energy and climate issues, differ greatly from traditional detached and low-rise housing. Construction techniques and financing models are more closely aligned to office building development. The small external surface area of individual apartments, dominated by glazing, means cooling, humidity/condensation management and noise from adjoining apartments are much more significant issues than in traditional housing. Management when power supplies fail, design and efficiency of centralised services (or alternatives) and access to quality outdoor spaces are also critically important.

Yet each apartment buyer or renter is seeking a home, so they need information about the performance of an individual apartment, as well as about the implications of centralised services and access to facilities. Many apartments are owned by landlords, who may not be focused on these issues – until they impact on the rents they can charge and the difficulty in finding tenants.

Apartment buildings can be surprisingly large GHG emitters, especially high-rise apartments, which tend to have much higher common area and service energy use for lifts, communal pools, carpark ventilation, lighting and central hot water, heating and cooling systems. There is large potential for improvement – see Figure 4.

Some innovative approaches are emerging to support design and construction of more sustainable apartment buildings, such as Nightingale 1, a five-storey multi-residential inner-city Melbourne development by Breathe Architecture. Nightingale 1 is the inaugural project of the Nightingale Model – a triple bottom line (social, environmental and economic sustainability) replicable housing model. Nightingale 1 is the first Australian residential building to be connected under a fossil fuel-free embedded network, incorporating solar PV and heat pump hot water and delivering 100% Green Power to all 20 apartments. Apartments feature cross-flow ventilation, optimised solar orientation, thermal mass, ceiling sweep fans, double glazing and communal laundry facilities – achieving a NatHERS average of 8.2 stars (far exceeding building code requirements). No gas, air conditioning or carparking are included in the project (ArchitectureAU, 2018a and 2018b; Breathe Architecture, nd; Breathe Architecture, 2020). The Nightingale principles, which are being applied across an increasing number of projects (Nightingale Housing, 2020), incorporate use of electric (CO_2) heat pumps for hot water and hydronic heating, as well as energy recovery ventilation and many other sustainability features.

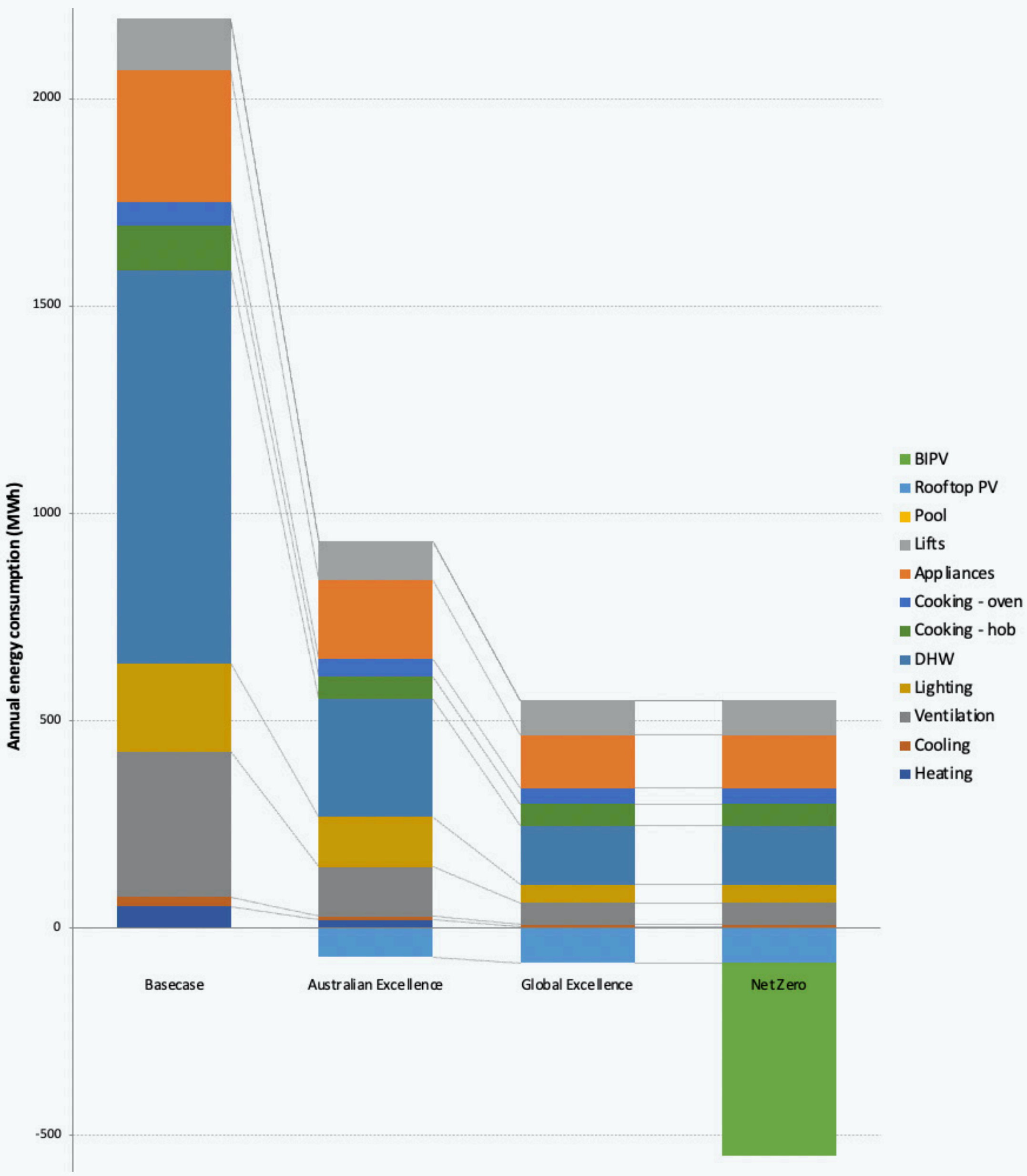

Figure 4. Case study of high-rise apartment building energy use in Sydney. Energy use for provision of central hot water supply is dominant. Graphs show annual energy consumption in Megawatt-hours. (Source: Pitt&Sherry and Ark Resources 2016)

Figure 5. Scarborough and Welkin house, Melbourne by Justin Mallia Architecture (Image. Peter Bennetts). The inner city multi-residential home enables multiple configurations of occupancy.

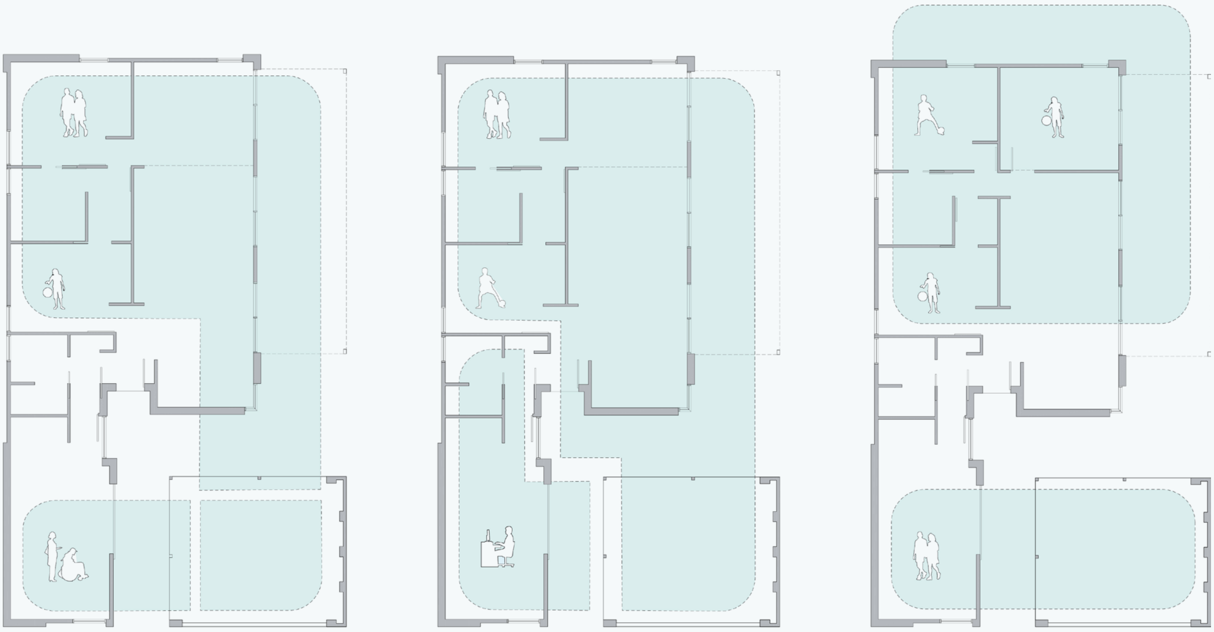

Figure 6. Habitat 21 Adaptable House plans (Image: Monash Architecture Studio, 2020). The planning allows flexible use for different stages of life through spatial adaptation. The Habitat 21 project provided five demonstration suburban fringe homes by VicUrban in partnership with the Department of Planning and Community Development (DPCD) and the Office of the Victorian Government Architect and the collaboration of seven leading architects.

3.2 Flexible design

Technology is changing rapidly, so buildings should be able to adapt. Smart home features may require wiring or space for equipment. Smart monitoring and analysis provide new opportunities for optimisation, identification of faulty or poorly maintained equipment, ensuring accountability of the building supply chain, and replacement of physical products and activities by virtual solutions (see Pears and Moore, 2019). Energy generation, storage and management equipment, vehicle recharging, parking/storage for bikes and personal electric mobility devices may be installed.

Occupant circumstances evolve, our population is ageing and an increasing range of disabilities must be accommodated. Flexible design that allows for part of a home to be separated for renting out, operation of a home-based business or multi-generational independent living can reduce total floor area per capita, extend building life, and avoid the environmental and cost impacts and disruption of major renovations (Figures 5 and 6).

Repurposing existing buildings could involve converting a large home or commercial building into apartments (Figure 7). The Tiny House movement is also challenging assumptions about just how much space we really need (Figure 8).

Figure 7. London row housing, with each home divided into three apartments (Image: Author)

Figure 8. The Envi Micro Urban Village, Queensland, by degenhartSHEDD architecture + urban design (Image: Tom Anthony). Ten 'micro' houses developed on the former site of a single house - the smallest house is 38 square metres (ArchitectureAU, 2019).

3.3 Practical approaches to embodied energy

Household energy use is responsible for almost 90% of non-transport operational residential greenhouse gas emissions, and around 2.7 times the annual emissions embodied in materials and construction for the residential sector (see Figure 2 and associated text). As operational energy efficiency improves and energy supply is decarbonised, this gap is closing. Embodied emissions add to emissions at the time of construction, not spread over many years, so they add to global heating sooner. Reducing embodied emissions is becoming more important, while cutting emissions from operational energy use is already crucial.

The energy embodied in our existing buildings and infrastructure is a significant resource. Recovery and utilisation/reprocessing avoids the need to mine and process virgin material. Selection of materials with high proportions of recycled or reused content supports emergence of circular economy models, by creating market demand.

Australian studies of emissions embodied in an individual home vary widely from around 50 to 175 tonnes of emissions, depending on what elements are included, selection of materials, and sources of data (see, for example Carre 2011, Crawford 2012).

Typically cement (in foundations, structures, paving, etc), steel (in reinforced concrete, structural, roofing etc) and ceramics (bricks, tiles etc) are major contributors.

Over a building's lifetime, embodied emissions associated with fit out, appliance and equipment replacement, maintenance and renovation may be comparable with the impact of the basic building fabric.

Many publications provide useful information on reducing embodied energy of buildings, including Clarke (2014), *Your Home* website, *Sanctuary* magazine (Renew). This starts with optimising floor area, structural design, adaptability and durability. Even when a particular material, such as concrete, is chosen, embodied energy can vary significantly from one producer or process to another, as documented in Lord (2018).

A useful and comprehensive guide to minimising building embodied energy is the London Energy Transformation Initiative (LETI, 2017). The Australian EPiC database (The University of Melbourne, n.d.) also includes useful data and resources.

The relationship between incorporation of energy efficiency and renewable energy features and embodied emissions is complex. Many energy efficiency measures offer multiple benefits, for example double glazing reduces condensation and potential mould growth while also reducing noise transmission. Carre (2011) found that the embodied emissions of windows comprised 2.3% of building structure embodied energy, while brick veneer walls comprised 28%. Even if specifying double glazing, the associated embodied energy could be easily offset by selection of lower embodied energy bricks or concrete, or a small reduction in floor area. Rooftop solar systems have been shown to have a relatively short 'energy payback' period. Analysis is complicated by how end of life is managed: recovery for reuse, recycling or reprocessing can offset part of the original embodied emissions.

Data on embodied emissions from production of materials is limited, for many reasons. Averaging of data means that variations between suppliers may be blurred, or data from other countries may be used. Many emission-intensive industries limit release of supplier-specific data because of confidentiality concerns, and it can be difficult to track specific supply chains in global industries. Seeking transparency from suppliers and working with Life Cycle Analysis specialists are practical paths for decision-makers.

When considering use of materials that are usually emission intensive, such as metals and cement, it can be useful to ask specific suppliers to provide evidence of why their products have lower impact than the average.

Factors such as maintenance, durability and impacts on operational energy can also influence life cycle costs and impacts.

A lot more work is required in this area. Techniques such as Life Cycle Analysis (see Hes, 2012 [A practical guide to life cycle assessment of buildings]), and development of circular or 'closed loop' economies will play valuable roles.

3.4 Operational energy – implications of design, selection and installation

Operational energy, in addition to its contribution to emissions, is a significant ongoing cost for households, drives investment in unnecessarily expensive appliances and equipment, and contributes to unnecessary energy supply infrastructure. This means it is also a significant cost for the Australian economy.

Since 2014, the emission intensity of electricity has declined by more than 15% due to increased renewable electricity generation, and this downward trend is expected to continue.

There is wide variation in the level of energy use across households, with the highest 5% of users consuming around 15% of total residential electricity. Appliance and equipment energy use, trends and options will be discussed in a companion note: An overview of energy, climate and resource considerations for residential appliances and equipment.

Retrofitting features such as extra insulation can be costly and difficult in comparison to during initial construction.

So, it is important to specify insulation appropriate to future climate conditions, and to ensure it is installed properly.

Where products such as advanced glazing are specified, it is also important to ensure that the specified items have been installed.

Time and date-stamped photographs of packaging and installations from mobile phones can confirm that correct products have been installed. Thermal imaging and blower door tests can detect gaps and other installation issues. These approaches can also detect poor practices such as failure of electricians or plumbers to maintain thermal integrity when penetrating insulation or membranes.

3.5 Integrated, local and renewable energy solutions

Australia's energy system is transforming rapidly from the simple one-way model in which large power stations and gas fields provide energy that is distributed to many consumers. We are moving to a complex, smart, distributed energy system where end-users may produce, store and manage energy demand while at the same time improving efficiency, which reduces the amount of energy and the supply and storage capacity needed to deliver a given service.

Preferences for various energy sources (such as away from gas) are also shifting as technologies change and environmental priorities evolve.

Designers of new homes and renovations should incorporate, or make provision for, future installation of these developments to futureproof homes and resale prices. Examples of the kinds of changes that may be needed include conduits for renewable energy and electric vehicle cables, fireproof panels where batteries can be installed, space for ducting of ventilation systems, and space where electric cars and bikes can be recharged.

Key elements of this future include:

- Thermally efficient building envelopes that incorporate energy recovery ventilation. As buildings become more airtight and temperatures more extreme, the need for indoor humidity management increases along with air filtering at times of poor outdoor and indoor air quality. The Passivhaus approach applies this model (see Parry, 2017 Passivhaus: the pathway to low energy buildings in Australasia).
- Smart, efficient appliances, lighting and equipment whose performance can be managed and can interact with energy grids (including local micro-grids), so households can participate in demand response programs, limit peak demand and minimise the capacity and cost of renewable energy and storage systems
- On-site renewable energy production, usually rooftop photovoltaic (PV), access to and ability to integrate with local and neighbourhood or regional energy production
- On-site energy storage and capacity to charge electric vehicles (EV) (cars, e-bikes, e-scooters etc) and, in future, use them to supply electricity to the home and electricity grid
- Smart energy monitoring, data analytics, fault diagnostics and alerts, system management, energy trading software (see Figure 9)
- Capability to run the home, or at least essential services (fridge, lights, lifts etc) in island-mode if grid supply fails, using electricity from battery, EV, back-up generator, local micro-grid, etc. The majority of power failures occur within local electricity networks, so local storage can play a valuable role.
- Off-grid housing and micro-grids, especially in remote and disaster-risk areas where powerlines are expensive to maintain, have large electricity losses, and may fail or be shut down during extreme climate events.

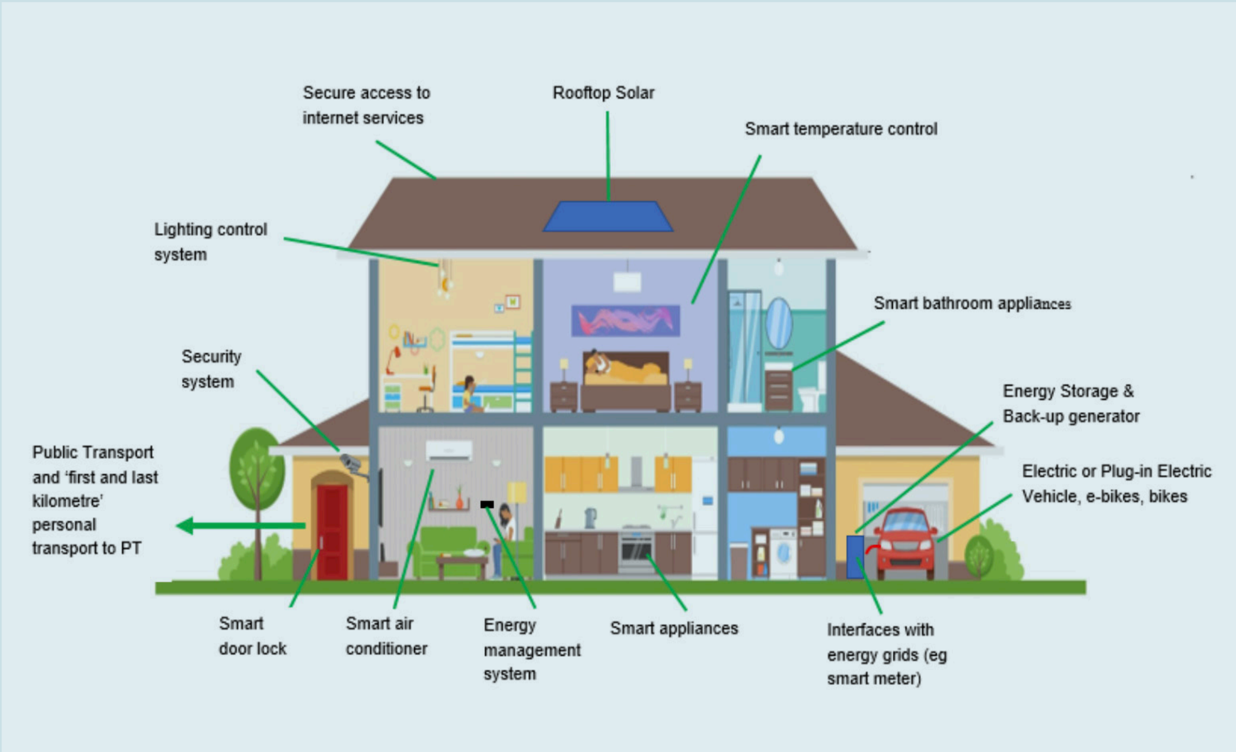

Figure 9. Example of a smart home in a distributed energy system (Source: Pears and Moore 2019).

These technologies are blurring the boundaries between consumers, energy suppliers, stationary and mobile energy. New business models are emerging to implement integrated and distributed systems. It is an exciting and rapidly changing time.

The most practical option for low-carbon residential energy supply at present is generating or buying renewable electricity. On-site renewable generation and storage offers potential to avoid buying electricity, to profit from sale of exports and, if suitable storage is installed, optimise buying and selling costs and reduce exposure to risk of energy supply system failures. Buying renewable electricity is becoming more convenient, as energy retailers, emerging businesses and community groups offer an ever-widening range of green electricity purchasing models and carbon offset schemes.

According to research (Lombard and Price, 2018), an all-electric home using best efficiency equipment is financially preferable to gas for most new homes. Going all-electric means costs of gas pipes and fixed daily gas charges are avoided. Using a reverse-cycle air conditioner purchased primarily for cooling offers heating as well, for negligible additional capital cost.

The gas industry plans to shift to renewable hydrogen by 2050 but, during the transition, it will continue to sell a fossil fuel and, if hydrogen is produced from fossil gas, emissions would increase due to process inefficiencies – unless rapid progress is made in carbon capture and storage.

It is generally cheaper, and often cashflow positive from the time of investment, to invest in energy efficiency and renewable energy using mortgage finance, as the returns on investment often exceed monthly repayment costs.

3.6 Energy efficiency and demand management

The International Energy Agency describes energy efficiency as 'the first fuel' because using less energy delivers multiple benefits such as lower capital and operational costs, improved health and amenity, enhanced resilience and lower environmental impacts than all forms of energy supply. Specific energy efficiency measures related to the building design and construction phase are discussed below.

3.7 Building fabric factors

The building influences the energy and climate impacts of appliances that deliver heating and cooling for comfort and health amenity. Heat flows, through glazing and opaque elements, and air leakage influence the amount of heating or cooling required to achieve temperatures required by occupants – which can vary. The thermal inertia of a building influences the radiant temperature of surfaces and the rate of variation in temperature in response to a given amount of heat flow.

Radiant heat gain or loss through windows and opaque elements affect the temperature at which occupants feel comfortable. Draughts can add to discomfort and trick thermostats, while air movement created by fans can improve summer comfort but adversely affect winter comfort.

Glazing type, area, shading and orientation are critically important. They affect building temperatures and comfort levels when no heating or cooling equipment is being used (free-running mode), temperature extremes, peak heating and cooling loads and appliance sizing.

Design and construction quality influences the impact of air leakage, natural ventilation and active ventilation systems, especially in extreme weather (see Figure 10).

As Australians face periods of more extreme heat and building thermal performance is improved, dwellings become more sensitive to summer heat and solar radiation. Many modern homes could be described as 'solar ovens', as even a small amount of heat can raise the internal temperature significantly. Upper-storey spaces with low thermal mass and high heat flows through glazing, roof and walls, and heat flow from the lower storey can be particularly problematic.

One study (Willand et al, 2016) found that, in Melbourne, 6-star homes were warmer and required more cooling than 4-star homes. High thermal performance dwellings with effective shading and ventilation may require little or no cooling but, if cooling is needed, it should require much less energy and smaller capacity cooling equipment. Hatvani-Kovacs' (2019) Heat stress resistant residential design in Australia provides a useful example of how differently two 6-star rated buildings – one optimised for winter and the other for summer – perform in extreme hot weather.

Experienced users of NatHERS modelling tools can explore the free-running performance of a dwelling room by room and hour by hour, allowing identification at design stage of which rooms or areas may be uncomfortable and when. This facilitates redesign, or consideration of contingency strategies, before construction starts.

The 2019 National Construction Code (NCC) (ABCB, 2019) introduced separate summer and winter thermal standards for many climate zones in addition to annual requirements. This will focus more attention on summer performance. The NSW BASIX scheme has used separate heating and cooling requirements since its inception.

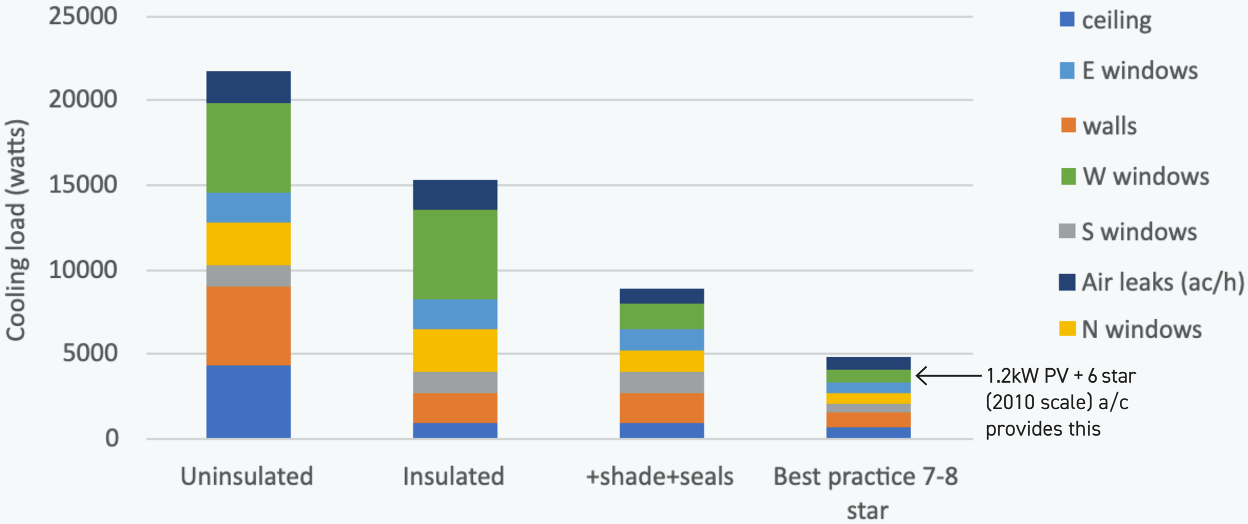

Figure 10. Peak cooling requirements for a house on a hot afternoon. A 7-8-star house with efficient building fabric and cooling equipment can be offset by PV (Image: Author).

3.8 Ventilation

Utilisation of natural ventilation may be affected by noise, security concerns, risk of rain intrusion, low wind speeds and other factors: good design can limit these factors. (See Aynsley, 2014 Natural ventilation in passive design). As buildings become tighter and more thermally efficient, the energy implications of providing fresh air in extreme temperatures becomes relatively more significant. For example, in a bedroom when the temperature difference between the room and outdoors is 12 to 15 degrees Celsius with 0.3 air changes of fresh air per hour, one third of the thermal load is due to conditioning of this fresh air. This example illustrates the significance of ventilation-related thermal loads, even though this example involves low leakage. In windy weather many homes leak like sieves and require much more thermal energy to offset air leakage.

High performance Passivhaus buildings often install mechanical energy recovery ventilation systems. (See Parry, 2017 Passivhaus: the pathway to low energy buildings in Australasia). These ensure adequate fresh, filtered air while dramatically reducing energy waste. But care is needed in equipment selection and maintenance: some older whole home ventilation systems consume 100 watts – almost 900 kilowatt-hours annually if used continuously – adding 30% to total consumption of a high efficiency home. Filters must be kept clean, or air quality will decline and energy consumption increase.

Efficiencies are improving, small units for individual rooms are appearing, and zoning and smart controls improve management. In moderate weather, occupant management of ventilation using openable windows may be preferred. Active ventilation systems can also be integrated with space conditioning.

3.9 Estimation of heating and cooling requirements and equipment sizing

It is difficult to estimate residential building heating and cooling energy use at the design stage. Poor quality construction and installation practices, substitution of materials, location of space conditioning equipment, and external factors such as overshadowing and localised wind effects can all make a big difference to real world performance, as can user behaviour and expectations. Small changes in thermostat settings and assumed hours of space conditioning can lead to very different estimates.

Many designers and system specifiers use sizing rules-of-thumb that were developed for thermally poor buildings or different climates. Equipment may be oversized or undersized, with cost and performance implications. For example, reverse-cycle air conditioner capital cost increases significantly as capacity increases.

Modern homes with high star ratings have much lower thermal energy requirements than older homes (Figure 11).

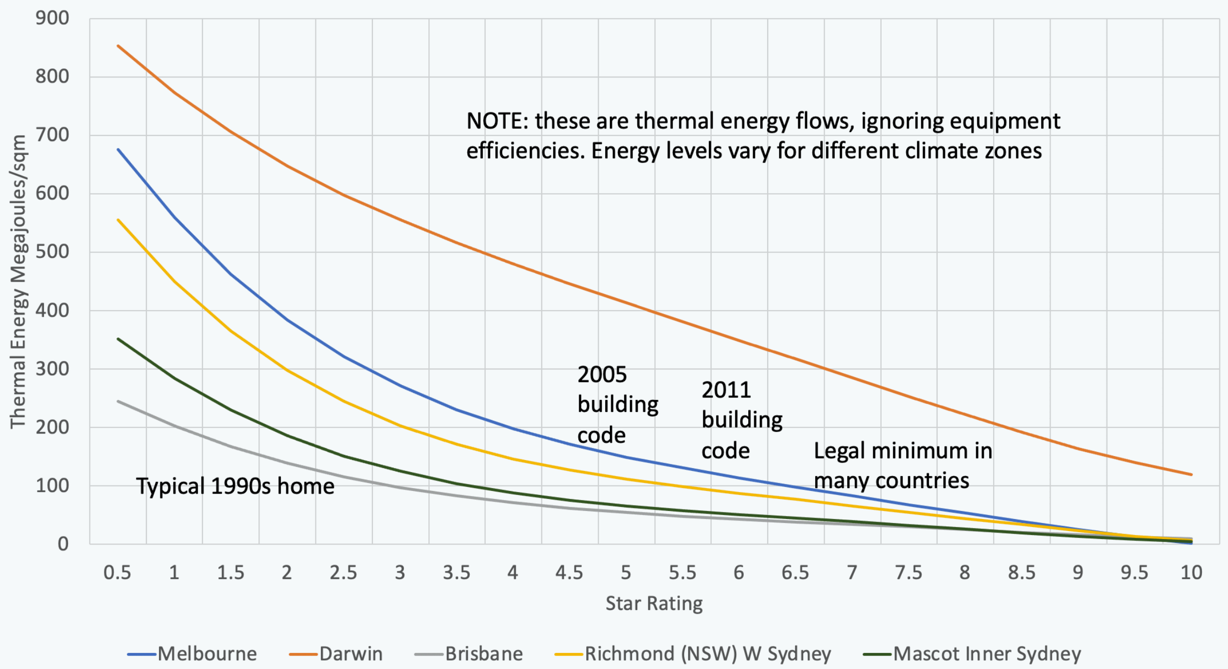

Figure 11. Examples of NatHERS star rating annual thermal energy (megajoules/square metre) for selected climate zones. Note that additional summer and winter requirements apply in many climate zones, as described in text (Source: NatHERS, 2019).

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They need much smaller capacity space conditioning equipment – unless individual rooms have large unprotected glazed areas or other room-specific issues that create high localised thermal loads. High performance homes also tend to remain within a smaller temperature range and respond to energy inputs more quickly. For example, they may not cool down much over a winter night, so occupants may not need to switch on heating the next morning. Highly insulated rooms used at night, or very well protected from sun, can have surprisingly low peak heating and cooling demand.

NatHERS modelling tools can help with appropriate sizing and estimation of ballpark heating and cooling energy use and emissions as can AIRAH's *FairAir* calculator, especially for equipment sizing. These tools can report on performance of zones or rooms, and can also be used to explore the benefits of improved shading, insulation, etc.

The NCC specifies NatHERS assumptions about thermostat settings and hours of occupancy of different rooms. It can provide useful comparative information on thermal energy flows. An important change in the NCC 2019 requires homes in many climate zones to meet separate summer and winter energy targets, as well as the existing annual star rating energy targets. For example, a 6-star Melbourne home is now required to achieve less than 96 megajoules per square metre for heating and 45 MJ/m2 for cooling, as well as an overall annual target of 114 MJ/m2.

Actual energy use and carbon emissions can be calculated by adjusting these energy flows by the appliance efficiency, occupancy patterns relative to those assumed in NatHERS, energy prices and the emission factor of the energy source.

Residential cooling and other activities are responsible for a large, and increasing, proportion of total summer peak electricity demand. One study, see Figure 12 (Energyconsult 2015), suggests residential cooling is responsible for a quarter to a third of total summer system peak demand and that total residential contributions to state-level summer peak demand can be 30% to 55% of total peak demand. Yet Australia's National Construction Code pays little attention to peak demand, though the 2019 update includes separate requirements for summer and winter thermal energy performance in addition to the existing 6-star annual star rating requirements.

Grid peak demand drives investment in energy supply infrastructure, which is expensive. Higher peak demand encourages energy companies to promote more energy use and increased emissions at other times, so they can recover capital costs and make profits.

3.10 Other built-in equipment

Equipment to provide lighting, cooking, space conditioning and hot water supply is usually installed during building construction and renovation. Designers or builders may specify and arrange installation of this equipment. These topics and others related to appliances will be discussed in the companion note: An overview of energy, climate and resource considerations for residential appliances and equipment.

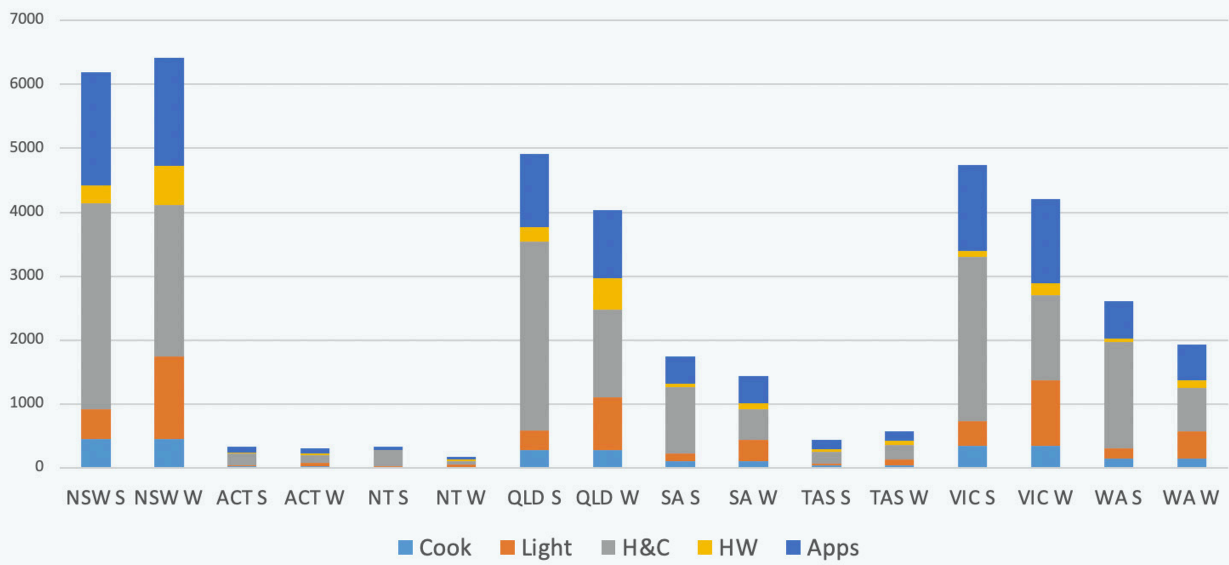

Figure 12. Australian residential sector contributions to system peak electricity demand (MW) by state and activity. Totals 21,320 MW (summer) and 19,086 MW (winter). High peak demand increases equipment costs and vulnerability to power outages, while increasing energy costs and emissions. Energy efficiency measures can be targeted at activities that contribute to peak demand. (Source: Energyconsult 2015).

4.0 Other important issues

4.1 Provision for maintenance, upgrades and end of life

Provision for access for maintenance and equipment replacement can reduce future costs. A focus on durability, especially for difficult-to-access elements such as upper-storey window frames, fascias etc, can avoid future complications and costs.

Ensuring plumbing is compatible with future use of rainwater or recycled water, and electrical wiring (or conduits for future wiring) that allows for future on-site energy options will enhance the adaptability of a building, while avoiding potentially high costs and practical problems for future owners.

Consideration of end-of-life disassembly (see Crowther, 2005, Design for disassembly – themes and principles), including selection of products and materials likely to have recovery and recycling systems in place, can support long-term emission reduction while focusing today's suppliers and installers on this issue.

4.2 Unavoidable climate impact – carbon offsets

The practical realities of industrial production and practices, and the time it takes to change, mean that it is not yet possible to avoid all emissions associated with building construction and operation. Decision-makers may face uncertainties about levels of emissions, so they may wish to take out insurance for possible emissions.

Purchase of carbon offsets involves paying others to take emission-reducing or sequestration actions they would not otherwise pursue, so that your project can claim the credit for the emission reduction.

As global emission reduction targets tighten, it is likely that offsets will become scarcer and more expensive as competition increases. So, they are not a long-term solution. But selection of worthy projects means that investment in capacity to cut emissions, as well as local social, economic and other environmental outcomes, can be captured, while offset buyers manage impacts they cannot reduce.

Australia's *Climate Active* (2020) framework (formerly the National Carbon Offsets Standard) supports voluntary reporting of climate impacts by organisations. The *Climate Active* approach can be voluntarily applied to a building project (or by a household). Products, buildings, events and organisations can be certified to demonstrate their compliance with a government-designed emission accounting system. Other schemes can also be used, such as the Global Reporting Initiative (2020). Carbon offsets can be purchased through a variety of suppliers, including a United Nations (2020) website and suppliers listed on the *Climate Active* website.

Conclusion

Residential building activity and operational emissions comprise around a quarter of Australian annual greenhouse gas emissions. There is an urgent need to cut emissions to near zero. While policy is pursuing a trajectory towards net-zero emission buildings, this is insufficient. Designers play key roles that influence upstream emissions embodied in the materials and services they select, as well as locking-in operational, maintenance and end-of-life impacts for many decades. New residential buildings must be designed to adapt to changing climate, technologies, social factors and policy changes. Net-zero emission buildings that also provide healthy, safe and affordable living can be built today. This can be done using a range of measures to cut emissions, including energy efficiency, renewable energy, energy storage and smart energy management, complemented by purchase of carbon offsets to cover emissions that cannot be avoided.

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Alan Pears AM has worked on building, appliance and equipment energy and environmental issues for over four decades. His work has included policy and program design and implementation, education, field research and involvement in a range of building, local government and community-based projects. He is a well-known commentator, analyst and author on energy, climate and building issues, and has received multiple awards from industry and community groups. Alan is a Senior Industry Fellow at RMIT University and a Fellow at the University of Melbourne. He also works with the Australian Alliance for Energy Productivity on leading edge projects.

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