An overview of energy, climate and resource considerations for residential appliances and equipment

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 The Lake House, Tasmania, by biotope architecture.interiors has been designed to be self-sufficient for water and energy with additional energy generated fed back to the grid (Image: Peter Mathew)

Abstract

This Note provides an introductory review of the energy use and climate and resource impacts of appliances in residential buildings and factors that influence their performance. Its main focus is on the design stage, but it may also assist designers when they work with specifiers, contractors and clients. Many decisions made during design, construction and equipment installation have significant climate impacts associated with input materials and services, operation and end of life. The extreme urgency of shifting towards a zero-emission economy and society increases the significance of these decisions, which lock-in immediate and long-term climate impacts and adaptation potential.

This Note complements Cutting lifetime residential greenhouse gas (GHG) emissions by Pears (2020), which provides an overview of lifecycle climate and energy impacts and issues in the residential sector.

1.0 Introduction

Appliances and equipment underpin climate impacts of operational residential energy use, as well as upstream and downstream lifecycle emissions. Figures 1 and 2 show detailed operating emission data for 2014, the latest available at the time this paper was written. Major electric and gas appliances and equipment installed during construction or renovation, typically include water heating, lighting, cooking, pools and common area equipment in apartment buildings. Together, these generated over 40% of the 63.9 Mt of residential operating emissions in 2014 shown in Figure 1. Space conditioning, which is influenced by heating and cooling appliance selection, installation and management as well as building design and climate, contributed an additional 24% of Australian household emissions. Home automation networks and associated equipment such as motorised shading are becoming more popular (Pears and Moore 2019). These increasingly influence energy use.

As well as designers, developers, specifiers and builders may also advise on, supply or influence selection of plug-in appliances that generate a further quarter of household operating emissions. Designers may influence these participants.

Appliances and equipment operate within a context. They are elements in systems that deliver useful services, such as comfort, food storage or cleaning.

They are technological devices that use energy and other inputs, such as detergent and water, and are purchased, installed, managed and maintained by humans or automation.

Evolving building energy regulations and policies increasingly frame the context for appliances and equipment by setting building thermal performance standards. The 2019 National Construction Code (NCC) (ABCB 2019) also sets requirements for water and space heating equipment, ventilation, lighting, pools and spas, and plumbing fitting efficiency. NSW's BASIX scoring system takes into account heating and cooling appliance efficiency, cooker selection and refrigerator ventilation. NABERS rates emissions of common areas for existing and new apartment buildings.

As part of COAG's (2019) agreement regarding trajectories for zero net energy residential buildings, performance requirements for the ratings of major fixed appliances, lighting and on-site renewable energy generation are being considered in the NCC 2022.

At the time of writing, details of methodologies and stringency have not been finalised. COAG's agreement extends to development in the longer term of tools for energy disclosure at time of sale or lease for existing dwellings, and development of minimum standards for rental housing. These are also likely to include consideration of major fixed appliances.

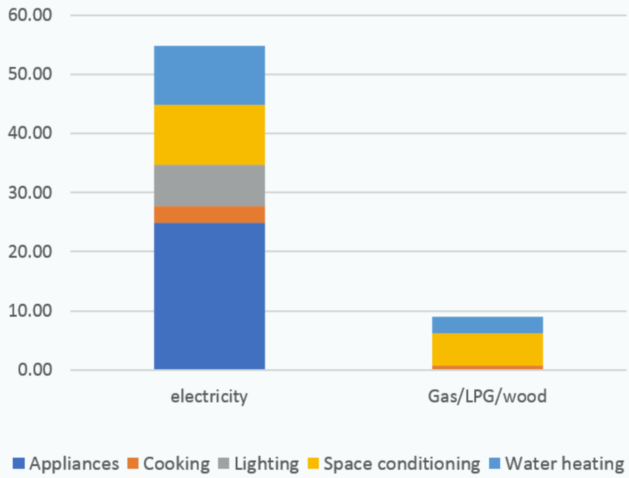

Figure 1. Australian emissions from residential activities in 2014 ($MtCO_2e$). Australian residential greenhouse gas emissions from operating energy by major activity and energy source (total 63.9 $MtCO_2e$). Image: Author, based on data from Energy Rating (2015).

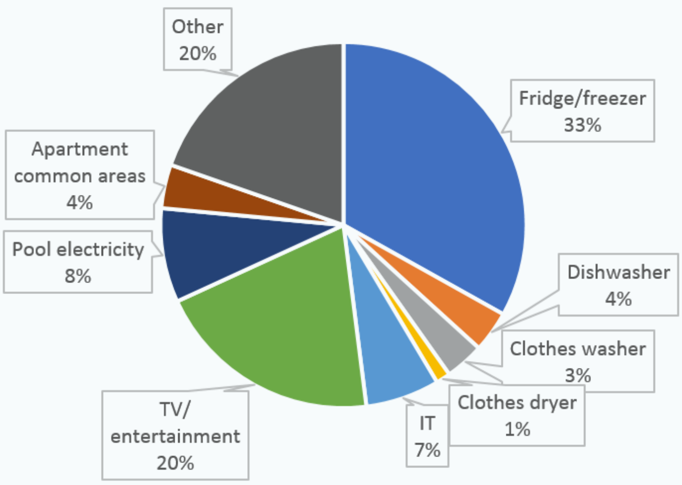

Figure 2. Greenhouse gas emissions from Australian residential electric appliance usage in 2014. The pie chart shows percentages of emissions (25 million tonnes of CO_2e, as shown in Figure 1), comprising 39% of total annual residential operating energy emissions. Image: Author, based on data from Energy Rating (2015).

2.0 Roles of building designers for appliances

Building designers play key roles in the lifecycle impact of appliances and equipment.

Building design influences appliance-related outcomes. It determines allocation of space, aesthetic and noise impacts, locations and lengths of pipes and ducts, and the environmental conditions within which an appliance will operate.

These affect appliance selection and sizing, installation, performance, future user behaviour, access for maintenance and potential to change to a different type of appliance at time of replacement.

There is increasing interest in incorporating features that facilitate independent living for people with disabilities and aging at home. For example, Livable Housing Australia (2017) provides detailed guidelines of relevance to appliances for design of kitchens, laundries, lighting and tap fittings, as well as broader aspects such as access and safety. Incorporating these features may extend the useful life of a building, enhance quality of life and reduce healthcare costs. With regard to appliances and related fittings, the guidelines focus on provision of adequate space to move and work, and user-friendly controls for taps, lighting, etc. Emerging home automation solutions could also facilitate independent living.

Designers advise builders and individual clients on appliance and brand selection, and provide specifications that shape contractors' product selection. They can also influence future user behaviour and experience. At brownfield and renovation sites, contract requirements may affect disposal of existing appliances and equipment. Project supervision, contractual clauses, inspections and follow-up can be critically important in ensuring clients and future occupants gain intended outcomes and also recognise their roles and responsibilities. The inclusion and use of ongoing monitoring systems to identify issues and provide evidence for corrective action, and provision of user manuals can support these outcomes.

Tools such as thermal imaging cameras (now available as plug-in options for mobile phones), blower door tests, mobile phone cameras, data analytics using ongoing performance data and Building Information Systems support more rigorous accountability requirements. The building industry's poor record related to product substitution (SOG 2016), workmanship and the failure of inspectors and regulators to enforce requirements, as documented by Shergold and Weir (2018), means that clients place increasing value on design detail, specification and quality control.

As residential markets shift towards apartment buildings, more developers and builders are specifying central energy service systems, as well as providing standard plug-in appliances for increasing numbers of dwellings. These decisions have long term implications for future owners and occupants.

Table 1 lists the major appliances and energy-consuming equipment typically incorporated into new buildings or major renovations, as well as the major portable appliances occupants may use. The focus of this paper is on systems, appliances and equipment likely to involve a building designer's input to key lifecycle impact decisions by influencing building context, selection, installation and energy source.

System or appliance	Separate dwelling	Apartment
Usually provided by developer/builder based on advice or specifications influenced by designer		
Heating cooling (H&C), ventilation	• Major fixed H&C equipment, often dwelling-scale central systems • Exhaust fans, range hoods • Energy recovery ventilation, humidity management	• Whole building HVAC systems with large central sources of heat and cooling and duct or pipe distribution systems. • Potentially district or precinct systems such as low temperature single pipe district heating/cooling systems • Other options as for separate dwellings, but multiple units
Common area lighting	• Outdoor and security lighting	• Security, safety, entrance areas, corridors, etc
Common area facilities and parking	• Scope to adapt parking areas for other uses over building lifecycle	• Car parking (with ventilation, lighting etc), pools, gyms, lighting, etc
Hot water and water	• Hot Water Services, plumbing, shower and tap fittings, energy recovery • Water reuse, recovery, recycling, treatment	• Whole building systems with large central sources of heat and cooling and duct or pipe distribution systems • Other options as for separate dwellings but multiple units
Clothes washing, drying	• Laundry fit out, clothes drying racks and areas, dryer ventilation	• Communal laundries, standard 'package' of appliances • Dryer ventilation, outdoor drying facilities
Electric wiring, gas pipes, telecommunications wiring, security systems, energy management, automation and 'smart' technologies, renewable energy and storage systems	• On-site infrastructure and connection to grids • Provisions to future proof, eg conduits for cables, structural design, spaces for on-site renewable energy and storage, vehicle charging, switch from gas	• As for separate dwellings, but also communal systems • Precinct-scale solutions and partnerships with third parties, eg energy retailers, network operators or energy service providers
Provided by developer/builder or buyer, tenant or occupant based on advice or specifications influenced by designer		
Cooking appliance(s), Dishwasher, Refrigerator, Clothes dryer, beverage storage	Builder may offer package of appliances as an additional feature	Especially in larger developments targeting rental, may include appliances in package
Usually provided by buyer or occupant		
Plug-in electric and electronic appliances and equipment	Designer may advise	Designer may advise

Table 1. Appliance and equipment categories and involvement of supply chain, buyer and occupant in their selection.

3.0 Appliance life cycle

The decision to buy and install an appliance has upstream and downstream implications. It influences the level of energy and emissions embodied in materials, manufacture, transport and services to supply and install the product. It 'locks-in' operating impacts of appliances and associated on-site infrastructure such as ducting, and influences end-of-life disposal as well as some practical and financial aspects regarding investment decisions and replacement options. Some examples put this into context.

A detailed study for refrigerators (JEMA 2014) found that the net embodied emissions for production and transport of an average 2010 model 501 litre refrigerator in several Asian countries were around 415 kg CO_2e for an appliance that consumed 290 kWh annually. Annual operating emissions would be just over 200 kg CO_2e using 2019 Australian grid electricity. These embodied emissions were therefore equivalent to around two years of operation.

Modern LED lamps have much lower life-cycle energy and environmental impacts than incandescent or halogen lamps (refer section 6.3). As LED efficiency and product life has improved, they are now significantly lower than those of fluorescent lamps and older LEDs (Dillon, Ross and Dzombak 2019).

Where a new appliance is significantly more efficient than the one it replaces, energy and emission savings of premature replacement of a major appliance can offset the additional embodied impacts within a few years. Recovery and recycling of the retired appliance can shorten this period. E-waste can contain valuable and toxic materials, so it is particularly important to ensure they are recycled at end of life.

Example

The JEMA report (2014) compared the 2010 refrigerator described above to the life-cycle impacts of a representative 1999 400 litre model. The older product consumed 795 kWh annually, emitting around 600 kg CO_2e (based on the greenhouse intensity of the Australian electricity grid in 2018-19, as reported in DISER 2020), compared with just over 200 kg annual emissions for the newer product. So, the energy and emission payback period to offset the 415 kg CO_2e of embodied emissions of the new replacement product was about a year if the older product was retired from service. Annual savings on energy bills would be over $125. The emissions associated with mining and processing of the materials in the retired appliance, mainly plastics and steel, were 295 kg CO_2e. In principle, much of this material could be recycled at end of life.

Therefore, when a designer specifies or influences selection of a more energy-efficient new appliance, life-cycle energy, emission and financial benefits can be gained.

4.0 Selection of energy sources

For most appliances, electricity is the only energy option. For space and water heating, cooking and pool heating, gas (usually supplied by pipeline, or LPG from tanks) is widely used. Wood is also used for space heating and, in some cases, cooking and hot water. On-site solar energy is often used for hot water, and to produce electricity.

The climate impacts and economics of energy options are changing fast. This is a complex area, beyond the scope of this paper, but some key issues are:

- High efficiency electric equipment can often generate lower emissions than gas-fired alternatives, and the emission intensity of the electricity grid is declining. Some studies have compared emissions and costs of options, for example see Lombard and Price (2018).
- Many households and businesses are installing on-site renewable energy technologies or buying renewable electricity to reduce emissions from their electricity use. As energy storage costs are declining, there is an opportunity to further incorporate on-site renewable energy utilisation and reduce overall energy bills. Strata titles and high-rise apartments can limit or complicate on-site energy solutions due to factors such as lack of roof space for photovoltaic (PV) panels or ways of allocating energy within the development.
- If connection to gas can be avoided, costs associated with gas plumbing and ongoing fixed gas connection charges and regular safety checks can be avoided. Where a housing development avoids installation of gas infrastructure, development costs may be reduced, though future flexibility of fuel choice may be constrained.

Designers can influence area, orientation, slope and solar access to rooftops, which impacts the potential for on-site renewable energy generation. High efficiency electric, storage and renewable energy equipment may have different area requirements. Safety, fire risk, building energy regulations, noise and micro-climates can all influence suitability of designing for on-site renewable energy generation.

5.0 Appliance operating energy and emissions

5.1 Overview

The rest of this paper focuses on operating emissions, energy use and costs of major appliances and the decisions made during building design, construction and appliance selection that impact on operation. Other aspects of life-cycle emissions, such as selection of plug-in appliances by building occupants, user behaviour and recycling, are beyond the scope of this paper.

Operating energy and emissions vary greatly depending on frequency and intensity of usage, appliance efficiency, durability and emission intensity of the energy source(s). Annual household electricity consumption can vary from 1,000 to over 40,000 kWh each year, while gas use can vary from zero to hundreds of gigajoules for a large home with a gas heated pool.

Figure 3 shows typical annual electricity use by major household appliances in existing stock, compared with the best products on the market in 2020. There is still substantial scope for ongoing improvement in efficiency of appliances. Note that an individual household's usage of an appliance may differ significantly from the values in this graph, for example, the average household in Figure 3 only uses a clothes dryer once every two weeks.

An all-electric home using 10,000 kWh annually may pay around $3000 at 2020 electricity prices depending on the actual electricity tariff, usage and climate. If this household used 'best now' appliances, electricity cost may be around 45% lower.

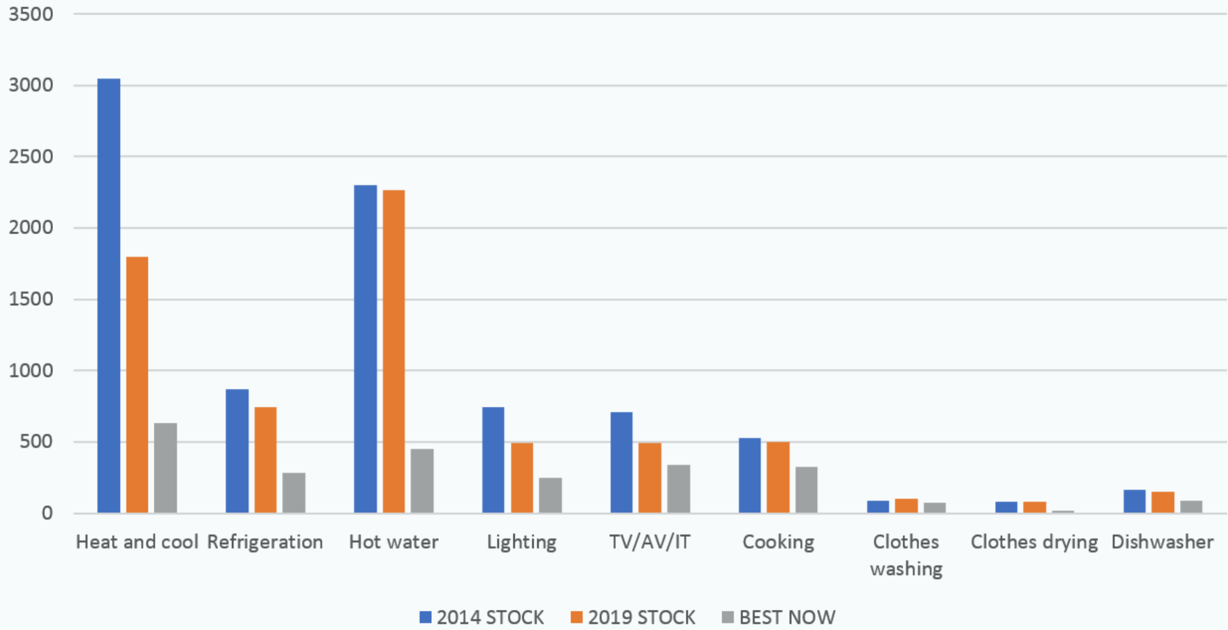

Figure 3. Indicative annual electricity use in a 2 to 3 person home – kWh/year for major activities. Comparison of energy use of average appliance and best efficiency on market stock for a typical 2 to 3 person Australian all-electric household in 2020. Note that the heating and cooling results reflect a combination of improved building envelope and high efficiency reverse cycle air conditioner. Further, the level of heating and cooling energy use varies with climate. Estimates by author based on data from Energy Rating (2015, 2019).

Appliance labelling and Performance Standards

In Australia, a number of major household appliances are required to display energy efficiency labels and/or meet Mandatory Minimum Energy Performance Standards (MEPS). Appliances covered by labels and MEPS are listed at Energy Rating (2020a). Designers can refer to relevant energy labels and MEPS when preparing specifications and advising clients. Spreadsheets of all products on the market and their performance can be downloaded from the Energy Rating website (see Energy Rating - Search the Registration Database, select appliance type to search and, if desired, scroll to the bottom of the page and select 'Download CSV' to download the database.)

This website also has a calculator (at Energy Rating Calculator | Energy Rating) that can estimate the 10-year running costs of labelled appliances as star rating and usage are varied.

Most Australian MEPS are not very stringent, so there is a wide range of performance across products on the market. Energy labels therefore play an important role in informing specifiers and consumers.

Labels have several indicators:

- A star rating that shows the relative efficiency of products in delivering a service. Most labels have a range of up to 6 stars but, where product efficiency has improved rapidly, such as TVs and clothes dryers, products that perform better than 6 stars can show an extra coronet of 4 more stars (Figure 4), giving a rating of up to 10 stars
- Annual energy consumption when tested to an Australian Standard and delivering a specified level of service, eg clothes and dishwashers must clean properly, refrigerators must maintain appropriate internal temperatures and cope with extreme temperatures
- Some labels provide additional information regarding important factors, such as noise levels. A new mandatory label, shown in Figure 5, is being phased in from 2020 for reverse cycle air conditioners, that shows performance across a range of climate zones.

Information on energy performance of some other appliances is available from other sources, including:

- *Choice*, a consumer organisation who carry out comparative tests of many products. Often the detailed energy performance information is presented in the comprehensive data tables accessible only to subscribers. But many public libraries are members.
- *Renew* and many other community groups provide information through web sites, web pages, magazines, events and forums.
- *Topten* is a useful European website that provides energy performance information for a wide range of household and commercial appliances available in Europe. Many of these products are also available in Australia.
- The gas industry publishes a directory of gas water and space heating products and their star ratings under their independent energy labelling scheme.

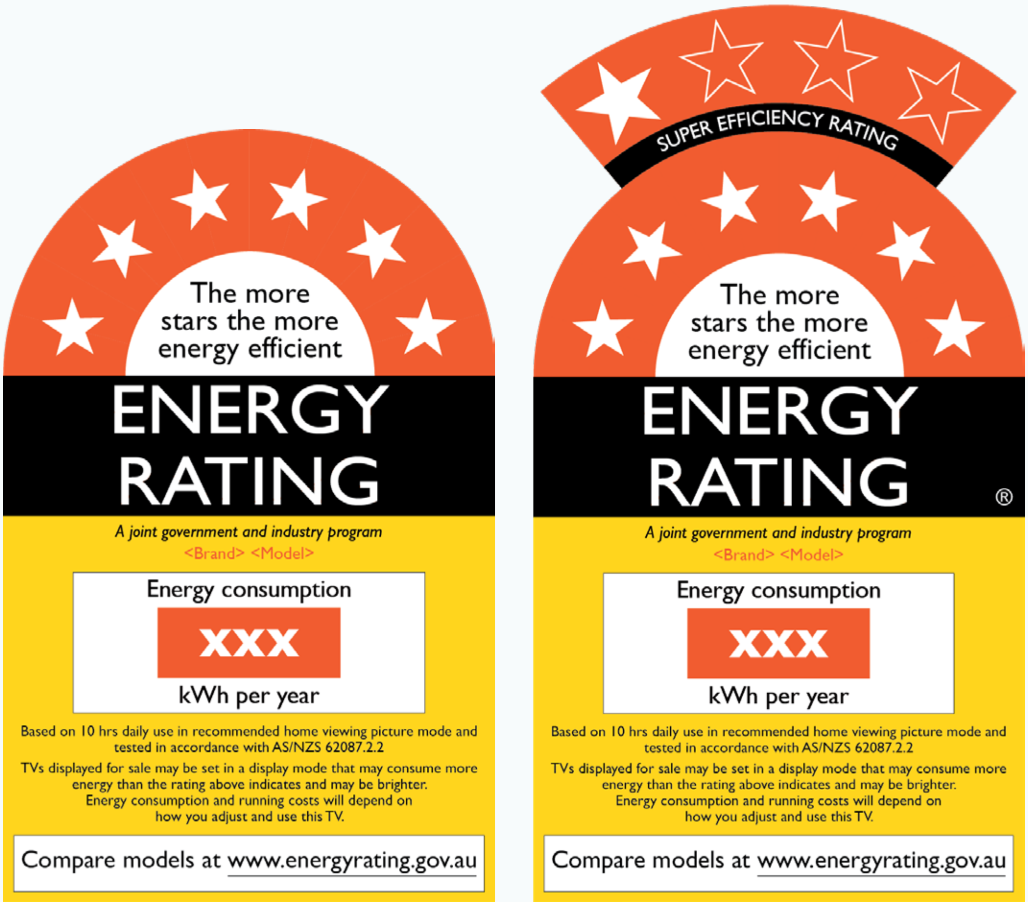

Figure 4. Samples of appliance energy labels. Products rated at 6 stars or less are not required to show the additional coronet that shows up to 10 stars. Source: Energy Rating (2020b).

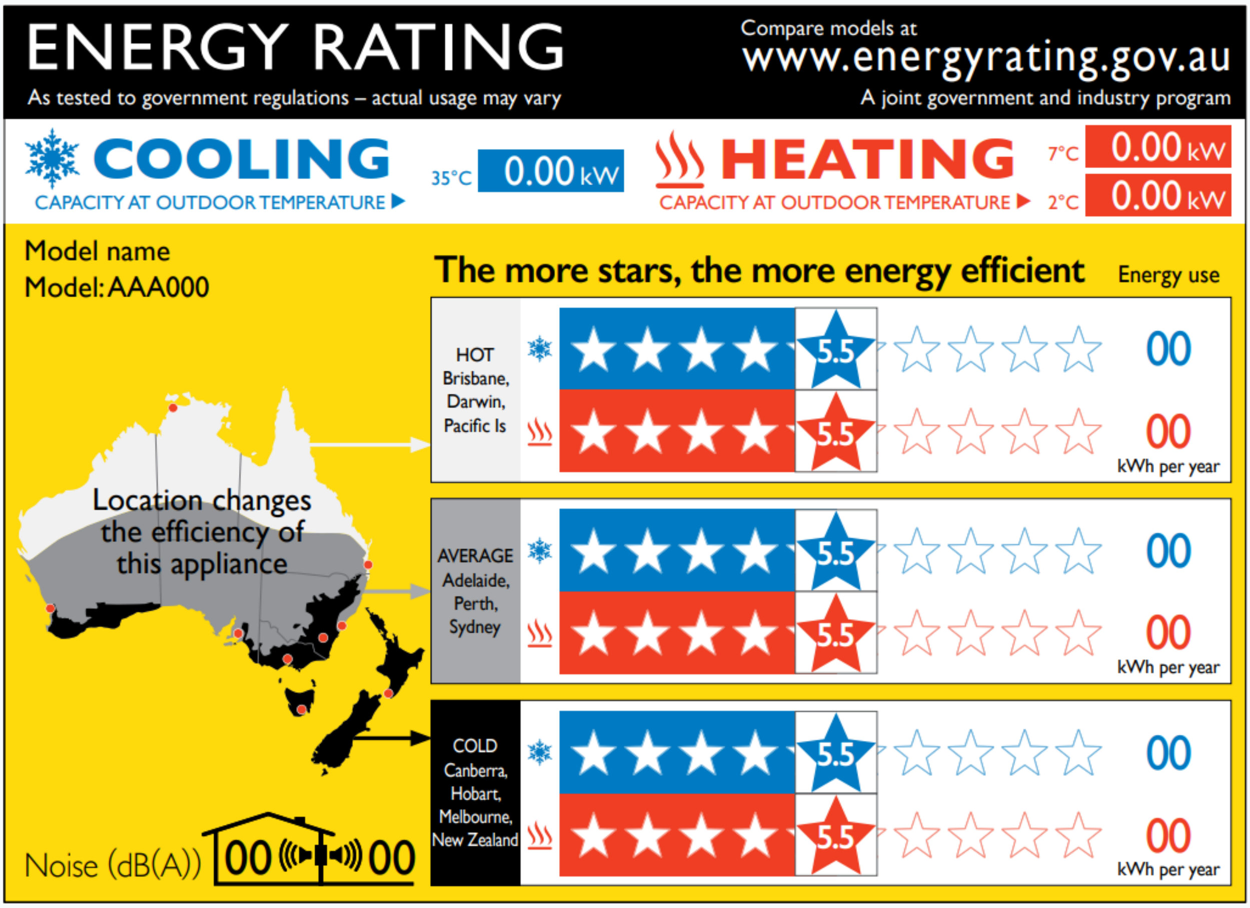

Figure 5. New reverse cycle air conditioner energy label being phased in from 2020. Source: Energy Rating (2020b).

5.2 Appliances in energy systems

Many appliances are really elements in a system, and the overall performance of that system drives the energy and climate impacts – indeed, one inefficient element in a system can have a big impact. For example, an undersized or clogged filter or pipe can dramatically increase energy consumption of a pool pump and undermine pool water quality by reducing the flow rate for filtration. Heat losses or gains from ducts and clogged filters can undermine space conditioning efficiency. A range hood or exhaust fan can increase heating and cooling energy use as it sucks in outdoor air while removing conditioned air. Smart sensors can be incorporated, to detect emerging issues such as blocked filters and other faults.

Installation practices can impact on capacity of future users to manage and maintain equipment. An inaccessible switch may lead to equipment being left on unnecessarily. A filter that is difficult to access and clean, and with no indicator to show it needs cleaning, can undermine efficiency and performance, and reduce equipment life.

User manuals (with clearly labelled photographs of the actual installations and appliance details) and education at time of handover can assist future building occupants to operate and manage equipment efficiently and effectively.

5.3 Modes of operation

Operational modes of an appliance such as standby, start-up and cycling at part load can have significant impacts on emissions and operating costs. For example, a storage hot water service with a pilot light that supplies a small amount of hot water may be very inefficient relative to an instantaneous HWS due to heat loss from the tank. Designers can specify appliances that operate efficiently in the modes most likely to be used. These issues will also be explored in the appliance-specific sections below.

6.0 Key appliances and equipment and the services they deliver

6.1 Comfort and health (heating and cooling)

Appliances that deliver comfort and health include heaters, coolers, fans, ventilation mechanisms and other equipment that maintain comfortable temperatures and humidity and indoor environment quality.

Building thermal performance influences equipment capacity requirements, energy and climate impacts, as well as occupant comfort. These important issues are discussed in Cutting lifetime residential greenhouse gas (GHG) emissions by Pears (2020) and Heat stress resistant residential design in Australia by Hatvani-Kovacs (2019).

High-performance buildings usually require much smaller capacity HVAC systems that will be easier to offset with renewable energy and may also be simpler and cheaper to buy and install. Different rooms in high-performance buildings with variable occupancy may have very different heating and cooling requirements. So traditional central conditioning systems with central thermostats, which only sense temperatures close to them, may not offer the flexibility needed. Energy losses from ductwork or pipes, particularly in a hot roof cavity, and from unnecessary conditioning of rooms that are not in use may be substantial. Ducted systems can dramatically increase air leakage if outdoor air can flow into the return air grille more easily than air from outlets in rooms. Outdoor air can enter through paths such as ventilated utility areas, pet doors or gaps in the building envelope. If internal doors are closed, air from those rooms will not be able to flow to the return air grille unless there is a gap at the bottom, so more outdoor air will replace it or the flow of conditioned air to the room may be reduced.

Apartments and increasingly well-sealed high-performance houses may face condensation and air quality issues, so there is increasing interest in energy recovery ventilation systems. These also offer increasing energy savings and the potential for advanced filtration of particulates such as bushfire smoke in response to a changing climate. Portable sensors that report humidity, carbon dioxide level and other variables are becoming more accessible as they decline in cost.

Heating or cooling sources near single glazed windows and poorly insulated walls can create high localised energy flows due to high temperatures and air movement breaking up the still air film next to the glazing. The inertia of heated concrete slab floors and heat from uninsulated internal hydronic heating pipes can create problems in variable weather.

Reverse cycle air conditioners with high star ratings typically deliver lowest operating cost and lower carbon emissions.

If year-round comfort requires cooling, this option also provides heating at negligible extra capital cost. However, quality of installation is critically important if leakage of refrigerant is to be avoided. Slow refrigerant loss reduces system energy efficiency and peak output; most units still use refrigerants with relatively high global warming impacts, although they do not damage the ozone layer. Ideally, systems with refrigerants should incorporate warning indicators so preventive action can be taken if leakage occurs.

Air movement associated with forced convection heating can reduce comfort, because of cooling from the 'wind chill' effect, so slightly higher thermostat settings may be preferred. Surface temperatures affect perceptions of comfort, as our bodies radiate heat to colder surfaces and absorb radiant heat from warmer surfaces. Well insulated walls, low-emissivity glazing and effective window coverings can improve radiant comfort. Radiant heating equipment and sunshine can also improve comfort at a given temperature.

A variety of radiant heating options exist but running costs can vary greatly. For example, a 2 kW plug-in fan heater or radiator costs over 50 cents per hour – 3 to 5 times as much as a reverse cycle air conditioner providing the same amount of heat. Some reverse cycle air conditioners can provide a mix of radiant and convected heat, as well as cooling. Hydronic heating can use gas or heat pump. Resistive radiant electric heating can be effective, especially in well-insulated smaller spaces, but may be expensive if used for long periods.

Operating costs for heating and cooling vary greatly with climate, area conditioned, temperature settings, technology and energy prices. State governments provide useful independent information, and resources such as the Australian Government's Your Home (Commonwealth of Australia 2020) also provide extensive advice.

Reverse cycle air conditioners (see Figure 5) and gas heaters both carry energy labels, however they use different methodologies, so cross-technology comparisons cannot be made based on the labels.

Many apartment buildings provide central heating and cooling systems. Losses from distribution systems can undermine their overall efficiency. Financing and billing arrangements may mean apartment occupants face unavoidable high fixed charges and limited incentives to operate their systems efficiently.

Ceiling fans are an efficient source of cooling, using 20 to 100 watts (Choice 2020). They can significantly improve summer comfort and can also improve the NatHERS star rating. Natural ventilation should be used when possible (see Aynsley 2007).

Evaporative coolers can be effective in less humid climates, though they can consume a lot of water, and they require air outlets or open windows to balance the incoming flow of outdoor air. Poorly sealed evaporative units can increase energy costs by allowing higher air leakage from the building all year.

For apartment buildings and precincts, an emerging option is the 'single pipe low temperature' district heating and cooling solution (see Flexynets). This approach uses a single pipe with water at 15°– 25°C and point of use reverse cycle air conditioners that use this water as a heat source or sink. These have low distribution losses and high operating efficiency, especially in extreme ambient temperatures. Heat pump technologies are also evolving rapidly, as high climate impact refrigerants are phased out and innovation continues.

There is increasing interest in adding smart demand management controls to electric heating and cooling systems, to limit their impact on peak demand and energy costs.

Already many reverse cycle air conditioners can be remotely managed by network operators, typically by switching off the compressor for short periods while leaving the indoor fan running. There is increasing interest in pre-cooling or pre-heating buildings when renewable energy is available at low cost. This strategy is more suited to high mass, thermally efficient homes: in some cases, the increase in energy use due to longer periods of operation can exceed the cost savings. Changes in energy market rules will encourage more demand management over time. Designers should specify these controls to future proof operation.

In response to increasing heatwaves and a heating climate, provision of a 'refuge room' or 'cool retreat' is proposed as an option to maintain conditions for comfort with minimum cooling or heating energy requirements (Hatvani-Kovacs 2019).

Key Points:

- Minimise requirements for space heating and cooling consumption and peak demand by optimising building design and controllable ventilation
- Carefully size HVAC equipment to optimise capital cost and performance and consider including demand management capability for electric equipment
- If ducted systems are installed, ensure good insulation and that effective return air paths exist from rooms to return air register
- Manage condensation and indoor air quality risks
- Select efficient, zoned HVAC equipment and test air conditioners for leaks before charging with refrigerant
- For apartment building shared systems, minimise distribution system heat losses, incorporate consumption-based charging and minimise fixed charges

6.2 Domestic hot water

Most hot water is used for cleaning people, dishes and clothes. However, many clothes and dish washers now heat their own water, and water-efficient showers cut hot water demand. Nevertheless, access to hot water from a central unit for bathrooms, laundries and kitchens is still seen as an essential. Peak hot water demands from multiple bathrooms and large numbers of visitors can be high.

Standby losses from storage tanks can be significant; for example an instantaneous gas HWS can be much more efficient than a storage unit when hot water usage is low. 'Dead water losses' as water cools in long pipes (especially if they are poorly insulated) can waste energy, water and time. Heat losses from circulating ring main hot water systems in apartment buildings can be very high, even when insulated to industry standards.

The situation is complicated by the focus on legionella, which can cause health risks if water is not heated to temperatures of 60° – 70°C, while concerns about scalding create pressure to deliver water at lower temperatures, usually around 50°C. The usual solution is to heat the water above 60°C, then add a tempering valve that mixes cold water with hot water to deliver water at 50°C. These valves can fail.

Long water pipes can lower the actual delivery temperature, so effective insulation is essential.

A storage hot water service (HWS) with a reasonable rate of reheating provides substantial supply while limiting peak demand for electricity or gas. Instantaneous units can require larger capacity wiring or gas pipes. However, storage tanks lose heat on standby. A 5 star gas storage HWS has standby usage of around 15 megajoules per day – equivalent to over 60 litres of hot water. Traditional large electric units that use a resistance heating element have standby losses of 2 to 3 kWh a day, equivalent to 40 litres or more of hot water. Extra insulation and insulated pipes (including drain pipes) can cut this loss for electric units but, for gas storage units with pilot lights, extra insulation may cause overheating.

While solar hot water has been very popular and is well proven, advanced heat pump units, combined with on-site solar electricity generation, are capturing increasing market share. Good quality heat pumps are quiet and produce 4 or more units of heat per unit of electricity, cutting energy use for both standby losses and useful hot water. These are simpler to install than solar, and some can be programmed to heat when rooftop PV output is available. They don't overheat in summer and maintain good performance in winter. If little hot water is being used, excess PV capacity is available to power other appliances or for export.

The Clean Energy Regulator publishes a registry of the number of Small Technology Certificates (STCs) that solar and heat pump HWS units qualify for in up to five climate zones (Register of solar water heaters). The number of STCs provides an indication of the performance of the unit in an Australian Standard test.

Increasing numbers of apartment buildings provide central domestic hot water systems. Where these involve central plant and circulating ring mains, energy losses from the distribution system can be very significant, even when installed to engineers' specifications. Occupants may also face significant fixed charges for provision of hot water. If separate metering is not provided for each user, some occupants may waste hot water, due to lack of a price/usage signal.

Key points:

- Minimise standby energy and 'dead water' losses
- Address legionella and scalding risks
- When selecting solar or air source heat pump HWS units, check performance on the Clean Energy Regulator's registry
- For apartment buildings, minimise HW distribution energy losses, incorporate incentives for efficient hot water use and minimise fixed charges
- Consider heating well-insulated storage HWS units when low cost renewable energy is available, reducing emissions, operating costs and peak energy demand.

6.3 Lighting

LED lighting now dominates the lighting market, and is far more efficient, flexible and responsive than other options. LED lighting is progressively improving in efficiency (see Dillon et al. 2019). Best technology now approaches 150 lumens of light per watt of electricity, up from 50 to 70 a few years ago. In comparison, halogens produce around 20 lumens per watt. In Australia over the past decade, most incandescent lamps have been phased out, and a halogen lamp phaseout is expected to begin in late 2021 (see Lighting | Energy Rating). The National Construction Code limits installed lighting power density (in watts per square metre) and specifies controls in section 3.12.5.5 of NCC Volume 2 (ABCB 2019).

Key points:

- Adequate but not excessive lighting brightness
- Appropriate zoning and accessible switching, so occupants can manage lighting to suit requirements
- Dimmers and sensors to control lighting
- Avoid or separately switch task lighting and aesthetic lighting
- Avoid recessed lighting that creates potential for air leakage and gaps in insulation.

6.4 Cooking

Cooking is a complex and emotional topic. Many people pay large premiums for name brand equipment and sophisticated technologies. Most kitchens incorporate a cooktop, oven (usually with grilling capability) and microwave oven. Benchtop appliances such as rice cookers, slow cookers, air fryers, toasters and kettles are becoming increasingly common.

Induction cooktops are replacing other electric options: they are fast, very controllable, and more efficient. Costs are falling. Magnetic cookware is required, which is becoming widely available. Rated peak electricity demand can be very high – 10 kW or more in some cases, necessitating wiring upgrades in many existing homes. Manufacturers should be able to design cooktops that have much lower demand ratings, as most people rarely use more than 3 to 5 kW of cooking capacity.

Many homes are switching away from gas for all activities. 'Going off gas' can avoid significant fixed daily gas connection charges.

For each unit of heat that actually cooks food, a gas cooktop dumps 1.5 units of waste heat into the kitchen, while an induction cooker dumps 0.2 units. Burning gas also creates indoor air pollution and water vapour.

Most households now choose electric ovens, the majority of which have moderate peak demand of 2 to 4 kW. Triple glazed doors, effective insulation and relatively low weight (lighter means faster warm up), and fan-forced ovens are most efficient. The website https://www.topten.eu/ provides comparative energy performance information for European ovens, many of which are available in Australia. The best ovens use under 1 kWh, and fan-forced ovens under 0.7 kWh to cook a test load. Provision should be made for microwave and other types of supplementary ovens that are increasingly common additional appliances.

Key points

- Provide adequate space for food preparation, management of dishes and appliances; consider sound absorption or isolation for noisy appliances
- Select efficient, responsive, low peak demand kitchen appliances and rangehoods
- Provide space and electrical wiring capacity for benchtop appliances and fixed appliances. Total rated peak demand in a kitchen can exceed 15 kW even though actual energy consumption may not be high. Smart appliances that manage peak demand could save a lot of money on electrical wiring installation, but are not widely available yet.
- Select a rangehood that is efficient, quiet, has efficient lamps, and can be sealed shut when not in use.

6.5 Cold food storage — refrigeration

Refrigeration is a major contributor to household energy consumption. It need not be. An efficient modern family fridge consumes around 250 kWh per year, costing $75. Older fridges may use more than four times, and low efficiency new models, twice as much energy.

Key points:

- Select appropriately sized, high efficiency models using the energy label's annual kWh number, not just the star rating
- Ensure that the local environment of a refrigerator is as cool as possible by ensuring sufficient space for good ventilation, insulation from outdoor heat and, of less importance because of its intermittency, minimising heat from cooking (see 6.4 Cooking section)
- Do not install an outdoor air supply for 'cool air' – this can significantly undermine building air leakage control and thermal performance. An efficient refrigerator generates only 30 watts of heat, so the adverse impact on space conditioning energy of a vent is likely to far outweigh heat released from the fridge compressor
- Take care if specifying refrigerators with glass doors or commercial equipment, as energy consumption can be high
- Discourage inclusion of additional refrigerators (often old or inefficient ones) in laundries, garages, rumpus rooms or bedrooms, especially thermo-electric and multi-fuel refrigerators and wine cabinets, which can be high energy users.

6.6 Cleaning dishes

Cleaning dishes involves use of hot water, detergent, electricity for a dishwasher and/or human labour. A typical family dishwasher uses 0.6 to 1 kWh per load on the program used for the appliance label. Longer, hotter programs can use 30% to 50% more (see *Choice* for reviews).

Key points:

- Minimise distance between kitchen tap and hot water service and insulate the full length of hot water pipes to reduce time delay and 'dead water' losses (when water in pipes cools, it must be drawn off before hot water is available at the tap, wasting water and energy)
- Select water-efficient kitchen taps that do not encourage 'accidental' use of hot water. Options include separate hot and cold water taps, mixer taps that only begin to supply hot water when the handle is pointing to the left of the centre, and very clearly marked hot and cold markings on mixer taps (see Figure 6) combined with user education to position the control to 100% cold water unless hot water is actually required. LHA (2017) recommend capstan or lever type taps
- Design dishwasher cabinets to allow small or standard sized dishwashers (eg with a removable drawer unit or adjustable strong shelf that a small dishwasher can sit on)
- Specify low energy consumption dishwashers – but note that energy consumption may be higher on programs other than the one used for the energy test
- For smaller households, specify or encourage purchase of an efficient smaller, multi-drawer dishwasher or model with a half wash or smart load sensing feature. Washing full loads saves energy, but leaving dishes in a dishwasher for a long time when trying to accumulate a full load creates odour and hygiene issues, and can allow food to dry on dishes, making cleaning more difficult
- Select a dishwasher with a water leakage control, to avoid the risk of damage to the kitchen
- Design the kitchen so that it is convenient for occupants to dispose of scrapings of food from dishes before washing, and to wash dishes in the sink and drain them.

Figure 6. Can you see which direction for this trendy tap is hot? There is a red dot! (Image: Author)

6.7 Cleaning (washing) and drying clothes

Washing clothes can be done by hand or machine and uses water, detergent and energy (mainly for heating water).

Key points for clothes washing:

- Provide adequate facilities for hand washing, pre-treatment and management of dry and wet items
- Make provision for front loader requirements, which can be heavy, but are typically more water and energy-efficient than top loaders, and their high spin speed can remove more water from clothes, reducing drying time and energy
- Consider provision of flexible cabinetry so that front loaders can be mounted above floor level, such as on top of a drawer unit, to make loading and unloading easier for users
- Minimise length of insulated hot water pipe to hot water service. Most front-loading washers heat their own water, but some models with dual water connections, especially top loaders, import hot water. In future, adapters may become available so single connection models can import hot water for the warm or hot part of the wash program. Where a dwelling has a heat pump or solar HWS, this could significantly reduce washer energy consumption when warm or hot wash is used
- Consider potential noise impacts on neighbouring rooms
- Where a rainwater storage tank and/or waste-water recovery and treatment may be installed, ensure appropriate water and drainage pipes are installed
- See below for clothes drying issues.

There is substantial variation in energy performance of clothes washers in standard tests, which use a wash cycle that complies with a cleaning performance test. Manufacturers may include a voluntary energy rating for cold wash. The energy rating includes a small bonus for washing machines that extract more water from clothes (usually using a high spin speed) in recognition of the benefits regarding clothes drying.

Using traditional electric clothes dryers is an energy intensive activity: removing just one kilogram of water from wet clothes consumes around 0.8 kWh – costing over 20 cents.

Unvented dryers can create condensation and mould problems, while vented dryers can remove a lot of conditioned air from a home both during operation and at other times if the outlet is not sealed shut. Drying clothes on a clothes rack in a heated area also increases heating consumption and adds to the risk of condensation.

Heat pump dryers are far more efficient than other options, typically using a third or less energy than traditional dryers and rating 7 to 10 stars on the energy labels. They extract heat from the humid exhaust air and reuse it, while condensing the water from the air. This water must be drained or removed from the appliance, but can be used to water gardens or for other purposes. Take care when using the Energy Rating website (Energy Rating Calculator | Energy Rating) to select a dryer. The website describes both efficient (7 to 10 star) heat pump and inefficient (2 star) condensing dryers that use running cold water as a source of cooling to condense water vapour from exhaust air (and waste both energy and water) using the same term 'condensing dryers'.

Key points for clothes drying:

- Incorporate clothes drying racks outdoors (preferably with rain protection) or in utility areas that can be closed off from conditioned spaces and separately ventilated
- Encourage purchase of high star-rated heat pump clothes dryers by providing cabinetry capable of holding their weight and convenient means of draining away water condensed from clothes
- Make provision for venting of conventional clothes dryers to outdoors – this doesn't save energy but it reduces risk of condensation and mould growth. Vents should seal shut when the dryer is not in use
- Recommend or specify a high efficiency clothes washer with high spin speed, to minimise the amount of water to be removed during drying.

6.8 Pool pumps and heating

Energy use by a pool can include filtering, salt-water chlorination, heating and indirect energy use to manufacture pool chemicals.

Pool energy use generates almost 5% of Australian household energy-related carbon emissions, even though only about a tenth of homes have them.

Electricity use, dominated by pool filter pumps, can add 20% or more to electricity bills. Energy labels are mandatory for pool pumps from 2021 and the most efficient models can cut running costs by two-thirds or more, though they may run for longer at a lower flow rate. Each additional star on the label saves 25 percent of energy use. Pool pumps are well suited to participation in demand response programs because the time of operation is not critical.

Key points:

- Design pool pipes and filtering systems to minimise flow resistance and select an energy efficient pump. A larger capacity filter and short, wide pipes with no sharp corners or bends can deliver large energy savings by reducing resistance to water flow. Regular filter cleaning is also critically important so an alert sensor is useful
- Minimise heat loss from outdoor pools. Use a pool blanket or anti-evaporation film. Design pool surroundings to block wind as heat loss is very sensitive to wind speed, which also increases evaporation
- Use solar thermal heating or a PV-powered heat pump for lower emissions than gas heating
- For indoor pools, ensure the building is well insulated with a minimum area of glazing, use of high-performance glazing and shading, and effective heat recovery from hot, humid exhaust air to reheat pool water and recondense water vapour to top up the pool.

6.9 Apartment common services

Common area and security lighting, central space conditioning and domestic hot water systems, central laundries and pools are provided in many apartment developments. Aspects of these features have been discussed earlier.

Additional services may include active ventilation of carparks, lifts, and recreational facilities. A report by Pitt&Sherry and Ark Resources (2016) (see Cutting lifetime residential greenhouse gas (GHG) emissions) shows high levels of energy use by common service activities in Australian high-rise apartment buildings, and the potential for savings.

Key points:

- Carefully design and specify equipment for maximum efficiency
- Ensure quality assurance regarding installation
- Install appropriate management, monitoring and reporting systems, as these play crucial roles in ensuring building occupants and owners corporations have lower, affordable energy costs and a reduced environmental impact.

6.10 Energy and water management and supply systems

Increasing numbers of individual households and apartment developments are installing technologies such as rooftop or on-site solar electricity generation, battery storage, smart energy, automation and building management systems (see Pears and Moore 2019), rainwater tanks and composting systems.

Home automation and advanced communications technologies are developing rapidly. They can enhance convenience and comfort, optimise energy use, and facilitate independent living. If suitably designed and operated, they can significantly reduce greenhouse gas emissions, despite using some electricity.

These can be complex, and both technologies and service provider business models are evolving rapidly. Distributed energy, water and materials solutions are transformative ways of cutting environmental impacts and energy and water costs. However they are beyond the scope of this paper.

Conclusion

Building designers play a crucial role in shaping and influencing the life-cycle costs, energy use, carbon emissions and environmental impacts of appliances and equipment installed in buildings. When selecting and specifying appliances and equipment, and designing the context within which they will operate, it is important to consider the fundamental services being provided.

Decisions that influence the context in which an appliance is located, and the characteristics of the appliance itself, impact user behaviour and an occupant's health and quality of life. These decisions also impact capital cost, operating and maintenance costs over the life of the appliance, and that of future replacement appliances.

Technologies, materials, user expectations and needs, climate, regulatory standards and voluntary rating schemes are changing rapidly, so it is important for designers to keep up to date with evolving developments in this area.

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