SPACE CONDITIONING IN RESIDENTIAL BUILDINGS

Space conditioning: Current situation

Current energy usage. In Australia, space conditioning (i.e. active heating and cooling) is the single largest category of residential energy consumption, accounting for 38% of consumption in 2011 according to EES[77,3]. So reducing residential energy consumption depends critically upon how we heat and cool our homes. This current space conditioning energy usage amounts to about 46 MJ/household/day on average (see Part 2, Section 6.3). In a well-retrofitted house, much of that space conditioning energy demand will be eliminated by the passive measures mentioned elsewhere in this section. Well-designed new homes might substantially eliminate active heating and cooling, however the Plan focuses on retrofitted homes where active heating and cooling, depending on location, may still be required.

Heating vs cooling. Australian homes use about ten times as much energy heating as cooling (see Part 2 Section 6.3). Therefore, at present, a reduction of total space-conditioning energy needs to focus on heating. In Southern states the energy ratio is much higher. Taking into account the efficiency of heating vs cooling (ie heating is generally less efficient), then the ratio of the energy service provided will be less than the amount implied by the direct energy ratio. With climate change it is likely that the heating-to-cooling ratio will lessen further.

Energy sources. The widespread use of fossil methane as a heating fuel is a significant problem. As explained in Part 1, the position of the Zero Carbon Plan is to completely and rapidly phase out the use of fossil methane. Electricity then is the predominant mains energy source for space conditioning in this plan. As discussed in the Stationary Energy Plan [1], Victoria is responsible for over 60% of Australia's total space-heating demand, with most of that supplied by mains gas (60.4 PJ out of 79.2 PJ for the whole of Victoria residential space heating demand). Indeed the winter peak in gas usage across Australia comes almost entirely from Victorian residential demand [1]. PV as an energy source is increasing, but its availability is predominantly in summer.

Wood. Wood fuel accounted for about 43 PJ/annum in Australian homes in 2011 [77]. Because of the low efficiency of wood heating, the amount of heating is lower than this energy number would suggest.

Power vs energy. Although the impact of seasonal heating demand is significant, the summer-time peak powerdemand most often defines the debate on electricity supply. However, summer-time peak power is fleeting. According to AEMO, it is likely that the seasonal peak demand will shift from summer to winter ([78] page 4) as summer demand is reduced by rooftop PV. This mitigates the effect on the grid of summertime air conditioner usage in afternoon but not evening.

Problems with ducted systems. The use of in-roof ducted space conditioning, although widespread in some states, is highly problematic for a number of reasons:

Ducting losses. A typical ducting arrangement in a home's ceiling space has a surface area in the area of many tens of square meters. In summertime the unconditioned space through which these ducts pass would often have temperatures exceeding 50°C. The conductive loss of heating or cooling energy through these ducts is significant. It would not be unusual for 20% to 40% [79] of the cooling energy to be lost in the ducts alone.

Poor air mixing in winter. Warm air entering a room from a ceiling vent is generally too buoyant to mix properly because of the tendency of hot air to rise. If air velocity is increased to give better mixing, then draughts and noise levels can become annoying. As a result the level of comfort can be significantly reduced. This can be especially problematic where a conditioned space adjoins a stairwell.

Poor fan-only operation. In summer there are many hours when a good fan alone gives sufficient comfort. Unlike split systems, ducted systems generally cannot provide well-controlled air movement to create useful fan-type cooling. One key reason is that horizontal air movement from a split system will generally give better cooling comfort than any air movement from ceiling-mounted or floor-mounted vents of a ducted system.

Whole-of-house circulation. Air in a ducted system typically travels around a partly closed circuit with a single return-air vent. This requires an unobstructed air path from every conditioned space back to the return-air point. This can be associated with undesirable draughts in winter since individual rooms cannot be closed off. The other downside is that much more fan energy is required simply to move the air. Split systems, on the other hand, recirculate air within individual rooms, requiring less fan energy and allowing for fewer draughts. Tirdly, this means that circulation areas, such as hallways, end up being conditioned spaces. Thus a side effect is to condition a greater a volume than is really required.

Zoning. Typical installation of ducted systems divides homes into zones comprising more than one room each, whereas split systems are typically handled on a per-room basis. Heating a single bedroom may lead to a second bedroom being heated unnecessarily.

Leaks go un-noticed. Ducting is typically held together with adhesive tape which tends to weaken over time thereby creating leaks. To the home owner, it is generally not obvious if there are small to moderate leaks, accordingly a great deal of energy can be lost through leaks over long periods of time.

Air infiltration. A side effect of duct air leakage is that there can be a significant infiltration of outside air due to pressure imbalances [79].

Lack of advanced control. Ducted systems typically lack the advanced in-room control features now common on split systems. Advanced control includes, for example, the ability to use occupancy sensors to avoid heating/cooling unoccupied rooms.

Choosing a better way. Any preferred approach for residential space conditioning must:

- not use fossil gas
- (in Southern Australia) prioritise winter-time energy reduction
- be suitable for retrofit
- avoid ducted systems
- be more efficient
- be mindful of summer-time peak power issues.

Much of the demand reduction will arise from passive efficiency measures. For the remaining active space conditioning, the technology best able to achieve these goals is the heat pump which is explained below.

Heat Pumps

The underlying technology used in refrigerators, refrigerative air conditioners, reverse-cycle air conditioners, and even some hot water systems is the heat pump.

Heat pumps can be used to deliver 'coolth', like a refrigerator, or to deliver heat, like a reverse-cycle air conditioner. Heat pumps actually transfer heat energy from or to the ambient environment – usually the air. Usually the electrical energy used to drive them is much less than the heat energy they can deliver.

Basic operation. Heat pumps use a low-boiling-point fluid and pump it continually around a closed circuit of pipes, heat exchangers and valves. On one side of the circuit (the 'condenser') heat is given off, and on the other side (the 'evaporator') heat is absorbed (see 3.19). In a reverse-cycle heat pump, the direction can be reversed and the condenser becomes the evaporator and vice versa, allowing a heater to become a cooler.

Efficiency and emissions. Typical systems operate with a mains-energy efficiency of about 4:1. That is, four units of heat energy are moved for every one unit of electrical energy consumed. This ratio, of thermal energy moved over mains energy in, is called the coefficient of performance (COP) for a heater, or energy efficiency ratio (EER) for a cooler. The COP varies with ambient temperature. For a heat pump acting as a heater the lower the ambient temperature is, the more work the heat pump needs to do to extract heat energy from the environment leading to a lower COP. When the electricity to drive the heat pump comes from a renewable source, and there are no refrigerant leaks, then the space conditioning is effectively free of operational greenhouse emissions.

Other considerations. There are other issues about heat pumps: cold-weather operation, refrigerants, noise and ventilation requirements. These issues are generally the same as for heat-pump hot water systems as described here.

configurations. Various configurations of heat pumps are in common use for space conditioning [80].

Window/Wall Units. These systems have all their components in a single unit mounted permanently in a hole in the wall or window. They are suitable for room sizes up to $70m^2$.

Single-Split Systems. These consist of one unit located indoors and another outdoors connected by pipes. The external units can be mounted in an external wall (1.5m -2.0m above the ground), floor or roof of the building, which makes the system quieter than window/wall units. These are suitable for rooms up to about $100m^2$.

Multi-Split Systems. These consist of one unit outside but two or more (up to seven) indoor units, sometimes with independent control. They are suitable for areas up to about $200m^2$.

Ducted Systems. Designed for central heating, these consist of the heat pump unit on the outside, above ceiling ducts and vents and a return air vent. They are suitable for open-plan buildings and for heating/cooling of most rooms simultaneously up to $200m^2$.

Portable split systems. These use a flexible refrigerant line between the indoor and outdoor units. Their advantage comes from the flexibility of moving to different spaces during the day, and also when permanent installation is not possible. However, they are generally less efficient, and can be more expensive than permanent installations and are suitable for spaces of approximately 35m2 compared to 70m^2 for window/wall units.

Portable non-split systems. A refrigerative portable room cooler can be a single upright unit which vents hot air to outside through a flexible duct.

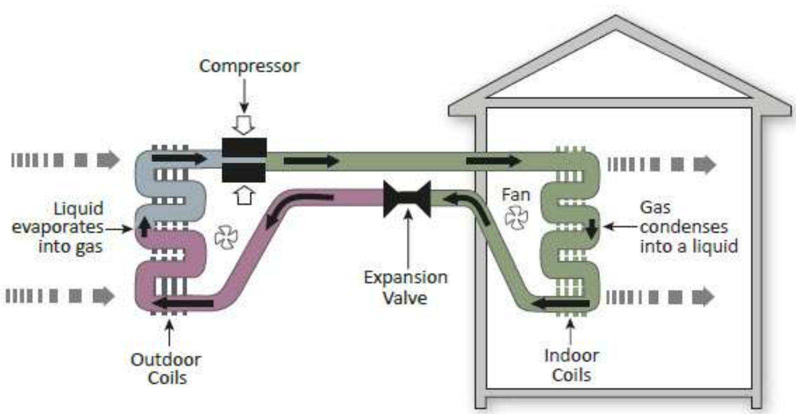

FIGURE 3.19 Heating Cycle of Heat Pump [energy Efficiency & Renewable Energy (US DoE)]

Portable systems are typically less efficient, as they are constrained in the size of the heat exchangers used.

Why not evaporative aircon?: Evaporative air conditioning is widely available and well understood. It can be suitable and more efficient than heat pumps in some situations. However the general preference for heat pump systems over evaporative arises from:

Cooling-only. Unlike heat pumps, evaporative systems cannot be used for heating. In climates needing active heating and cooling it is desirable to combine both into a single system.

Limited applicability. The effectiveness of evaporated systems diminishes with rising humidity. As a result they are unsuited to many localities.

Limited cooling. Evaporative systems can only drop the temperature by about 80% of difference between the web-bulb temperature and the dry-bulb temperature. In extremely hot weather, the amount of cooling from evaporative systems will probably not be enough to keep a home comfortable because they cool down the very hot outside air. Heat pump systems, on the other hand, generally operate mostly with re-circulated air.

Water use. Evaporative systems depend upon a continuous supply of water, amounting to about 1L/hr for every 500W of cooling.

Ground-source vs air-source. The most familiar type of heat pumps get their heat energy from the air – they are referred to as 'air-source heat pumps'. Another type of heat pumps exchange their energy with the ground via long underground pipes. These are called 'ground-source heat pumps', and can be more efficient than air-source units when weather is extreme because of the relative stability of the ground temperature. Ground-source heat pumps also have the benefit of being very quiet because they do not have a fan-forced heat exchanger on the outdoor unit.

Generally there is a trade-off between efficiency and cost. Ground-source units have a much higher capital cost than air-source units because of the earthworks involved and the more specialised nature of the equipment.

Star rating. Air conditioners have been subject to star rating rules since 2000. Air conditioner energy consumption is covered by AS/NZS 3823.2-2011. This applies only to systems with capacities less than 65 kW. Evaporative systems are excluded. Ratings are on a star scale of 1 to 10, where the range 7 to 10 stars is considered super-efficient. Devices that both heat and cool have a separate star rating for each mode. The star rating is calculated using a formula ([82] page 3) based on tested annual-average COP (for heating) and EER (for cooling). A 1-Star system is defined as having a minimum annual COP (or EER) of 2.75 [83]. For each increase in COP (or EER) of 0.25, another 0.5 stars is awarded.

MEPS. Air conditioners have been subject to MEPS since 2001 [84] (updated in 2010). The threshold performance level that applies for air conditioners [85] varies according to configuration. As an example, since October 2011, split system heat pump systems (<4 kW) have a minimum annual-average COP of 3.66, which corresponds to a rating of 2.8 stars (rounded down to 2.5). Larger systems (up to 10 kW) have a threshold COP of 3.22 (1.5 stars).

Electricity Demand-Reduction Potential

High-efficiency heat pumps can, when properly chosen and installed, provide heating comfort in homes using much less energy than commonly used alternative technologies. For example, a high-efficiency split system might conceivably replace a ducted gas heater and require about ten times less mains energy to achieve the same level of heating comfort. This is illustrated in Figure 3.20 (based on Perez-Lombard et al 2011 [86]). A more complete explanation of the method and assumptions involved in the generation of this diagram can be found at Appendix 9.

Heat Pumps and Solar Energy

Do heat pumps provide solar energy?

The marketing of some heat pump devices describes them as providing solar energy around the clock. At one level this is clearly incorrect since the devices do not have a solar collector and are not directly dependent upon solar radiation for their operation. However, at a deeper level, claims like this are valid, since:

- the energy extracted comes from the ambient environment, and the mains energy is principally to pump the ambient energy
- the ambient heat is renewable in a very real sense
- that heat ultimately originates from solar energy

The testing and rating regime for heat pump hot water systems, for example, explicitly treats such systems as providing renewable energy and they earn STCs (a type of renewable energy credit) in a way comparable to solar hot water systems.

Costs

Split-system reverse-cycle air conditioners vary greatly in price based on size and performance. The purchase and installation of an individual high-performance system was found to typically cost in the range of $1,200 to $2,400 per room based on a survey of a range of products. For example a high-performance multi-head split system with four indoor units costs could be expected to cost around $7,000 - $8,000 fully installed.

Ceiling Fans

Ceiling fans are a useful complementary technology to reduce cooling requirements of a room in summer and used in reverse rotation to circulate the air in a room and distribute warm air in winter. Fans do not lower air temperature, but the effect of moving air on skin gives a cooling effect of about 3°C. This can allow the aircon thermostat to be set higher, cutting cooling costs. Where split system air conditioning is installed (see above), separate ceiling fans are unlikely to be necessary because the fan-only mode of split systems gives equivalent (or better) behaviour. In Australia, unlike India, there is no MEPS or star rating for fans. The efficiency, and energy requirements, of different fans can vary greatly.

Operation. In summer, the fan is rotated at a high speed to generate a wind chill effect by creating a strong down draught. The down draught rushes past the skin and causes the human sweat to evaporate causing a perception of a temperature several degrees below the actual reading in a room. This does not lower the temperature in the room as air conditioning does and the effect will be negated if the fan is switched off. It should be noted that "Cooling building occupants by airflow uses less than 10% of the energy needed for air conditioning" [87].

In winter, the fan is made to rotate slowly in the reverse direction which has the effect of drawing the cold air near the floor upwards and making the warm air near the ceiling circulate downwards. This creates a better heat distribution within the room. The fan is rotated at a slower speed to lessen discomfort from draughts.

The prices of ceiling fans vary widely but are generally between $100 and $400 each [88]. They can be installed for approximately $110 per fan [89].

Residential Space Conditioning Implementation Recommendations

Technology. Where active systems are required, the recommended method of achieving high-efficiency heating and cooling in Australian homes is with split-system style heat pumps. Systems with low-GWP refrigerants are strongly preferred.

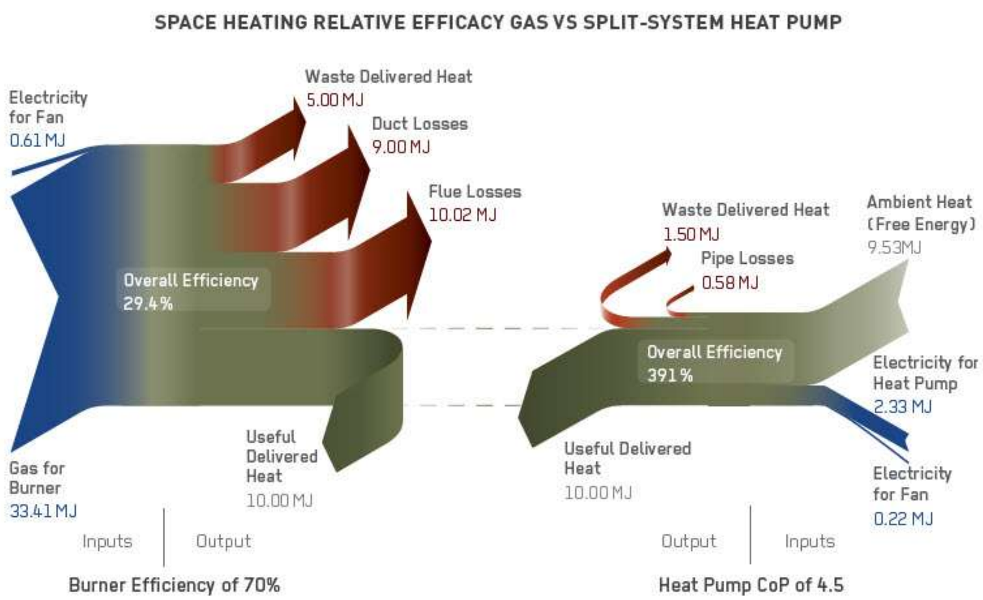

FIGURE 3.20

Useful heat delivered from a split system heat pump is produced 6.4 times more efficiently than a ducted gas burner system.

Appropriate shading comes first. Windows exposed to direct sun in summer should be shaded, if possible, before air conditioning is installed.

Active gas replacement. The Buildings Plan recommends the active replacement of existing gas heating systems with heat pump systems.

Minimum performance. Split systems with a minimum performance rating (heating and cooling) of 4.5 stars are recommended.

Configuration. Multi-split-style heat pumps configurations are recommended for houses that need to service more than about four separate areas.

Installation considerations. Systems should be installed with pipe insulation of a high standard, and with good attention to detail to reduce the risk of thermal bridging.

Operating considerations. In using the split system for heating and cooling, the following good-practices apply:

Fan. The use of the fan-only mode is encouraged for temperatures up to about 28°C to reduce the number of hours of active cooling.

Doors and windows closed. Close doors and windows in rooms which are conditioned to reduce draughts and to constrain the conditioned space. Windows exposed to direct sun should be shaded.

Cool-climate performance. Be mindful that the heating performance in cold weather can vary greatly between models. Choose carefully.

Sizing. Typical ranges of sizes would be ~2 kW(t) for each bedroom and 4-5 kW(t) for living rooms . Smaller heat pumps tend to be more efficient than larger capacity units within the range of sizes suitable for building air conditioning. For post-retrofitted thermally efficient building envelopes, the actual heating and cooling demand will be lower than for typical current building practice. In cold regions, heat pumps that perform well at lower temperatures should be selected.

Source: http://decarboni.se/publications/zero-carbon-australia-buildings-plan/3-building-space-conditioning