Building Demand Response Capability into Appliances: A-HELP in difficult times

George Wilkenfeld

George Wilkenfeld and Associates

Abstract
Household air conditioner ownership and use in Australia has grown phenomenally since the late 1990s, and is projected to increase even more over the next 10 years. In some States more than half the peak demand from the household sector on extreme summer days is air conditioning load. This is stressing electricity supply infrastructure today and is projected to drive infrastructure investment in the near future.

Although some utilities are moving to time of use pricing, the great majority of air conditioner owners do not face the real costs of supply and are heavily cross-subsidised by other electricity users. Better signalling of prices is necessary but not sufficient – air conditioner owners need to be able to respond to price signals, either manually or automatically.

Many electricity utilities, especially in the USA, have developed demand response programs targeting air conditioner loads. However, these have been limited in scope because of the expense of making the last link between the utility's communication and control system and the appliance, and by reliance on proprietary technology and standards.

The Australian Household Electricity Load Management Platform (A-HELP) project, funded by the Australian Greenhouse Office, involves air conditioner suppliers, the electricity supply industry, government agencies, research groups and others, with the common aim of developing open standards and protocols for communications between electricity suppliers and individual household appliances (with or without smart meters or other intermediate controllers).

The ultimate aim is for demand management response capability to be built in to all air conditioners sold, either as a standard design feature or as an easily-installed option.

The Growth of Household Air Conditioning in Australia

Until recently, Australian households have not been high users of air conditioning. During the 1980s the penetration of refrigerative conditioners (both cooling only and reverse cycle) appeared to plateau at about 25%, while penetration in the USA climbed from about 60% to more than 70% (Figure 1).[1] Penetration rates have historically been higher in the states of Western Australia, South Australia and Victoria, which have hot summers and cold winters, and lower in the more temperate coastal climates of New South Wales and Queensland. Evaporative coolers are also popular in the southern coastal cities, which have lower summer humidity, and in some inland centres.

Sales of refrigerative air conditioners increased dramatically after 1996, from an average of around 400,000 units per year through the early 1990s to over 1 million units in 2003 [1]. Large variations in annual sales have been common in the past, because air conditioners have been to some extent seasonal and impulse purchases, and if the early part of the summer is hot then sales for that year tend to be higher. Some of the recent sales growth was associated with a series of hot summers and also a boom in home-building activity. However, there are signs that the dynamics of the market have now changed permanently, for the following reasons:

- Rising household incomes: Australia has had 15 years of uninterrupted economic growth, enabling households to increase consumption of all services, including thermal comfort;
- Falling real air conditioner prices: as the share of products imported from China and other Asian countries has risen, the real average price of products has fallen;
- Falling real electricity prices (in most States), and the absence of price signals indicating the high marginal cost of supply during summer peak demand periods;

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[1] 'Penetration' rate is the proportion of households possessing at least one unit of that appliance, and cannot be higher than 100%. ' Saturation' rate is the average number of appliances held by owning households, and cannot be lower than 1.

- Decades of promotion of reverse cycle air conditioners by electricity utilities, as a counter to gas heating;
- Increasing noise, air pollution and perceived crime risk in inner city areas, making it less attractive to open windows and to rely on natural ventilation, even in low-rise housing;
- The increasing number of high rise apartments, many with poorly shaded and/or west-facing glazing, and less able to rely on natural ventilation and openable windows due to their layout, safety concerns or wind velocity and exposure problems;
- The increasing tendency for project home builders to install air conditioning (or to provide a 3-phase power outlet to facilitate later installation) as a marketing edge;
- The combination of declining block sizes and increasing house floor areas is reducing the scope to optimise orientation and to retain mature tree cover in new subdivisions. This increases the proportion of new houses that rely on air conditioning for summer comfort because they are poorly orientated and shaded, even if they have reasonable levels of insulation;
- Most of the highest housing growth areas are in the hinterlands of the large coastal cities, where local micro-climates are several degrees hotter than the coastal suburbs of the same cities;
- Changes in home financing, which enable homebuilders to increase their mortgages to cover expenditure on fixed equipment such as air conditioners, whether at the time of construction or later; and
- Global warming: summer average temperatures have been rising in Australia, as in many other parts of the world. After a relatively mild period in the early 1990s, the six hottest years since reliable records began in 1910 have all occurred in the last decade, with 2005 the hottest on record. [2]

Given these drivers it is little wonder that an increasing proportion of existing dwellings are acquiring air conditioning, and more new houses are being equipped with air conditioning at the time of construction. Penetration is projected to reach 60% by 2020.

Domestic air conditioning energy consumption and peak load could potentially grow even more rapidly than the number of air conditioners, because of increasing average dwelling size, the tendency to cool the entire house rather than just one or two rooms as in the past, longer hours of operation, increasing average outside temperature and more frequent days of extreme high temperature due to global warming.

Given the combination of high growth rates in ownership and increasing use per air conditioner, it is conceivable that the energy consumption and peak demand of air conditioning in the residential sector could double in the next 10 years.

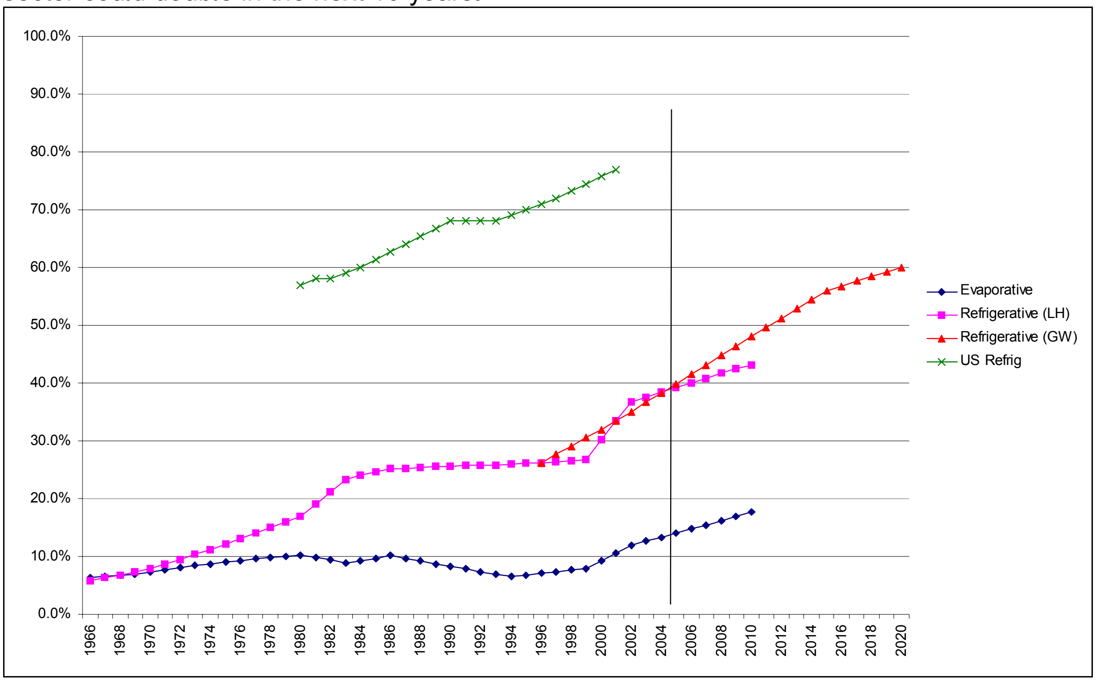

Figure 1 Percentage of households with at least one air conditioner, Australia and USA
Projections to 2010 from [1], projections to 2020 from [3]

Peak Demand

Air conditioner peak demand is one of the major factors driving capital investment in the National Electricity Market (NEM), as well as a mechanism for cross-subsidy between air conditioner users and non-users.[2] During the 1990s the state electricity systems all registered their maximum annual peak demands during winter, but all are now summer peaking. Typically about 30-40% of commercial sector demand and 40%-50% of residential sector demand on extreme summer days is now due to air conditioning, and the two loads are of similar MW magnitude.

Air conditioning load is much less of a problem in commercial buildings. The load factor of commercial air conditioning is similar to other commercial loads, whereas the load factor of residential sector air conditioning is very low – ie its share of annual energy use is far lower than its contribution to peak demand. Much of commercial sector electricity consumption is metered by time of use, so the costs of air conditioning energy and peak load can be signalled and recovered. However, there are no ready means available at present to signal or recover the costs which air conditioner-owning households place on the system.

There is a large and growing cross-subsidy from non-air conditioning households (including those with evaporative coolers) to those with refrigerative air conditioners. It is estimated that in 2004 the cross-subsidy from the 4.1 million non-air conditioner households in the NEM area to the 2.7 million air conditioner-owning households was in the range AU$300-500 million annually, or about $100 per household [3]. Apart from the equity implications, the underpricing of supply costs seriously distorts the economics of the NEM. The household air-conditioning load is in effect driving investment in both distribution and transmission infrastructure and in peaking generation plant, which is used for only a short period each year.

Policy Responses

Australian governments have become acutely aware of the peak load implications of household air conditioning through a number of well-publicised power supply difficulties during the summers of 2003-04 and 2004-05, during which some cities experienced localised blackouts on days of extreme heat (the summer of 2005-06 was relatively trouble free, since the most extreme days fell on weekends or public holidays when the business load was low).

Until recently, however, the policy response has focussed on improving building thermal performance (options 1 and 2 in Figure 2) and on increasing the energy efficiency of new air conditioners sold (option 4). While these are worthwhile measures, they have their limitations.

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[2] Australia has a National Electricity Market (NEM) covering all states except Western Australia and the Northern Territory, which are not interconnected with the main grid covering the southern and eastern States.

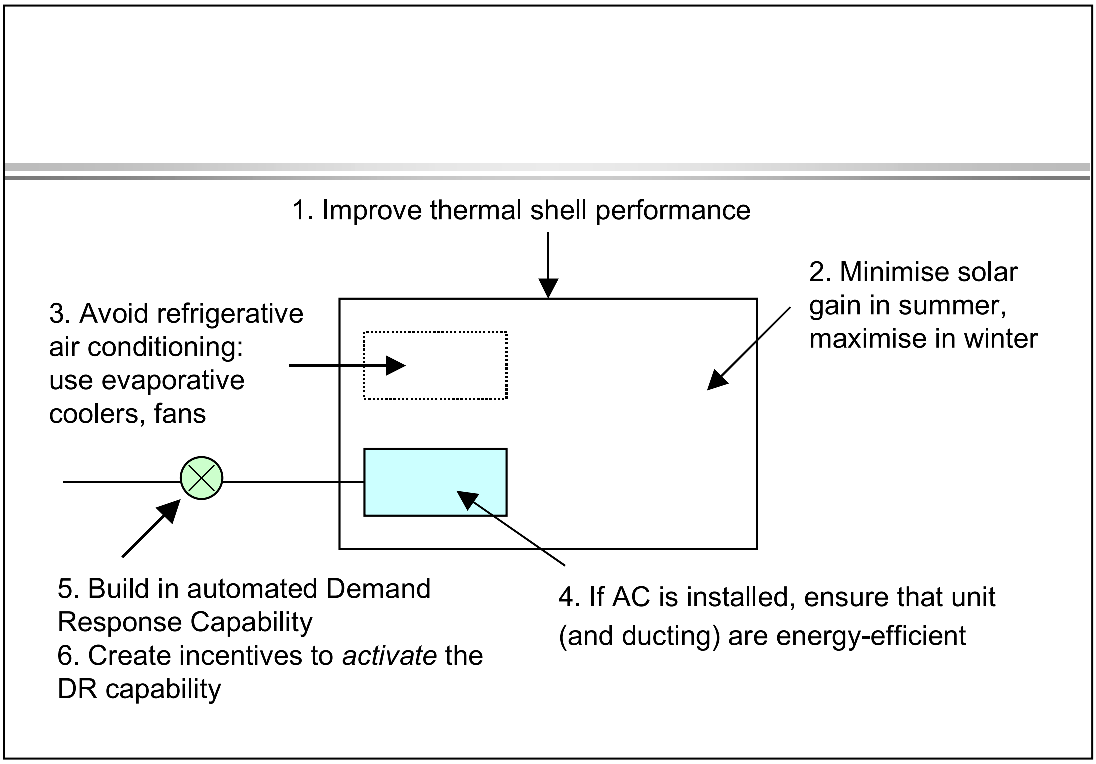

Figure 2. Policy Response Options for Containing Air Conditioner Peak Load

Building thermal performance regulations mainly target steady state heat loss or gain, and the design changes they promote are less effective in limiting the demand for intermittent cooling. Another limitation is that less than 2% of the housing stock is built new or radically refurbished each year, so the rate of improvement in thermal performance is slow. For example, an increase in the thermal performance level of the entire housing stock in the state of Victoria to '5 star' standard from the present 2.2 star average (measured using the AccuRate thermal simulation model) would have reduced the peak load in the residential sector in 2002 by about 530 MW on extreme days [2]. The 5 star level was adopted as a minimum requirement for new homes built after June 2004. At the current stock replacement rate (2%) the peak load reduction from improvements in new dwelling thermal performance standards is only about 10MW per year. In 2005-06, the difference between average summer peak day and extreme day demand in Victoria was already estimated at about 860 MW (NEMMCO 2005). In other words, reliance on this policy option alone would take about 86 years to deal with the *present* level of extreme day peak demand in Victoria, let alone the projected growth. Properly designed 5 star homes should not need air conditioning. If air conditioner installation in new homes were actively discouraged, building thermal performance standards would be a far more effective policy response to containing peak load. However, there are currently no programs aimed at avoiding the installation of air conditioning, even in houses that are designed well enough to not need it (option 3). To be effective, a program of this type would need to based on price – eg by rolling in the peak demand costs into an up-front capital charge payable at the time of air conditioner purchase. Once installed, an air conditioner will almost certainly be used, even if comfort conditions are such that the householder would normally tolerate them.

Greater energy efficiency (option 4) can work more rapidly than building standards, since about 6 to 8 times as many air conditioners are installed as homes built each year. Although air conditioner energy-efficiency has improved markedly since the introduction of energy labelling and Minimum Energy Performance Standards (MEPS), and MEPS levels are due to become significantly more stringent in 2008, the effect on peak load is limited. Most manufacturers will achieve higher efficiency by increasing cooling output rather than by reducing motor power. Where the air conditioner is used in a thermally efficient house and is well controlled, this should reduce both energy and peak demand, but if not then the motor demand will be the same, although cooling output will be higher.

The recognition that existing policies are not adequate on their own has led to the serious consideration of programs that directly target the operation of air conditioners at peak times (options 5 and 6 in Figure 2). This means the development of a demand response capability (DRC) in air conditioners, so that householders – or better still, the air conditioners themselves – can respond to price and other signals.

Time of Use Electricity Tariffs and Demand Response

Many electricity utilities, especially in the USA, have experimented with programs in which air conditioner users are invited to surrender some measure of control over the operation of their air conditioner in return for a lower electricity tariff at other times.

In general, these arrangements are an imperfect proxy for time of use pricing. Some rely on the householder to respond manually when advised of high price periods, eg by switching off or setting down appliances, including air conditioners. Others allow the utility to remotely reset the thermostat or interrupt operation altogether for short periods, usually giving the user the option to over-ride the control and accept the high price. The costs of implementing and operating these programs tends to be high, because the utility has to invest heavily in hardware and software, often from a single proprietary source. A large part of the cost is in the last link connecting the utility's control system with the appliance. The costs of recruiting and retaining customers is also high.

The costs of such programs could be reduced very significantly if:

- Time of use pricing became the norm for householders, so they became accustomed to facing the full costs of supply during peak and extreme peak periods, and conversely were offered low rates at other times;
- Response to price signals could be automated rather than manual; householders could preset their preferred response to periods of high price – eg by specifying a priority order for load curtailment – but could always over-ride their preference and accept the higher price;
- Air conditioners could be designed to operate more intelligently and flexibly, eg by pre-cooling in anticipation of pre-signalled high price periods and optimising their operation within power constraints during those periods;
- The communications and switching capability which now has to be installed by the electricity supplier were already installed in the appliance or in a standard household controller, and could be remotely accessed and activated by the electricity supplier via a set of agreed protocols.

Some of these conditions are now being met in Australia. Several large electricity distributors are planning to roll out 'smart' time of use meters, although their motivation may be more to recover the costs of supply at high price periods rather than to offer customers ways to reduce their price exposure. It will most likely be up to governments and regulators to ensure that the costs of purchasing and operating air conditioners are clearly signalled to customers, and to ensure that customers are given the option to avoid high prices rather than just to pay them. Electricity regulators are becoming increasingly interested in promoting approaches and technologies which can compete with supply in terms of availability and price, and demand response, like energy efficiency, is a direct competitor for investment in electricity supply infrastructure.

Demand response programs in Australia so far have mainly concentrated on business electricity users, who can commit to withdrawing large blocks of load during peak periods. However, the scope for aggregating demand reductions from household users is increasing as technology changes. The need to do so is also increasing: the peak load from household air conditioning is growing so rapidly in Australia that it will soon use up the buffer of load reduction available from large users.

The A-HELP Project

Australia's energy labelling and MEPS program is jointly operated by agencies of the Federal, State and Territory governments.[3] In 2004 the Australian Greenhouse Office (AGO) was requested by governments to investigate the use of the EEEP to address peak load issues in air conditioning. A study commissioned by the AGO was published in late 2004.[3]

The study suggested using the EEEP's existing influence over energy efficiency standards and other aspects of air conditioner performance to develop and promote demand response capability in air conditioners and in other household appliances. Subsequent research indicated that there are already many technical solutions to this.[6] Some capabilities are already embedded in current models, and more are being developed, either by manufacturers working in isolation or by consortia formed for this purpose in several countries.

Indeed, the problem is not technology but standardisation. There are so many different approaches, standards and protocols that product buyers, electricity suppliers and other stakeholders do not have

[3] The program, formerly known as the National Appliance and Equipment Energy Efficiency Program (NAEEEP) was renamed the Equipment Energy Efficiency Program (EEEP) in 2005, when New Zealand formally became a partner.

a simple, consistent way to assess the capabilities of alternative products or compatibility with their own communications and control systems, proposed demand management programs and electricity pricing strategies

In early 2005 the AGO initiated the Australian Household Electricity Load-Management Platform (A-HELP) project. The aim of the project is to build a large scale, reliable and low cost demand response capability (DRC) in the household appliance stock, by standardising the main elements, *starting from the appliance end.* This will enable providers of the upstream elements of DRC systems, including metering and control gear suppliers, to take advantage of the capability at low cost.

A-HELP is not so much a single project as a framework and a point of focus for a range of projects and activities, not all managed by the AGO. In the year since A-HELP was initiated, a large number of organisations have become involved, including the principal manufacturers and importers of air conditioners and their industry association, the largest operators of electricity distribution networks and their industry association, home automation system suppliers, professional organisations, university departments and research organisations.

Many of these stakeholders have of course been aware of and working on peak load management, but have not previously been able to identify or engage with other stakeholders. After a series of informal meetings, the AGO referred the matter to the national standards-setting body, Standards Australia, which provides a forum for taking the concept further through its committee structure.

Demand Response Standards and their Application

In January 2006 Standards Australia formed a new committee (designated EL-054, Remote Demand Management of Electrical Products) and published a draft *Classification code for demand response capabilities of electrical products* to give committee participants an initial focus for discussion.[4]

The primary functional elements defining demand response capability, illustrated in Figure 3, are:

- The mode of signalling from the electricity supplier, demand response aggregator or other external agent to the customer's site (some typical options are listed in Table 1); this indicates the communications services and hardware that the external agent will need to provide or utilise;
- The additional hardware (if any) that must be present on site (options listed in Table 2);
- The level of demand response capability of the end use device (usually but not necessarily an air conditioner) (options listed in Table 3).

The fourth primary element is whether the installation is capable of one-way signalling only, so the utility has no direct verification of response, or two-way (duplex) communications.

The technical pathways for achieving these functions, including the performance requirements for different types of equipment and the rules for interfacing between them, are secondary. In fact there are many existing standards defining these already. It is not the intention to create new technical standards but to identify existing ones, to assess their consistency with the proposed functional classification and, if they are compatible, to reference them from the high-level functional standard.

Some examples of the application of the typology are as follows:

- X0 is the existing (baseline) situation – no communications, no DRC.
- Aa1.1 describes a ripple controller based system needing a receiver external to the appliance.
- Dx4.2 describes an internet based system that communicates (2-way) directly with the appliance, provided the correct modem card is installed.
- Bg3.1 describes an arrangement where a 'Smart' controller receives a power-line internet signal and switches the appliance via a 'dry' contact. If the controller initiates the event in response to a dynamic price signal received by a smart meter, and could signal this response back the utility (by whatever pathway), the configuration would be Bfg3.2.

A classification method of this type (if not like this is in every detail) can be useful in a number of ways. Utilities can clearly specify to product suppliers the types of configurations they require, or wish to promote, to support their demand management objectives and program designs.

Appliance suppliers can indicate the level of DRC built into their products, to assist utilities, demand aggregators or product purchasers who wish to participate in DM programs,. Suppliers of signalling and mediation equipment can indicate which configuration/s their equipment supports.

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[4] At the time of writing the draft was available at http://www.saiglobal.com/shop/Script/Details.asp?DocN=MSWD06011ATCRD. The comment period closed on 17 March 2006, and EL-O54 met for the first time in May 2006. It is likely that there will be significant changes from the Draft, the main concepts from which are summarised in the present paper.

The classification provides a basis for determining compliance, eg the supplier of an air-conditioner with a built-in (or optional) DRC card could state: 'This equipment (or configuration of equipment, if installed together) meets the requirements of Classification Ax5.2. Bx5.2 and Gx5.2 of AS/NZS Standard ZZZZ.200X, *Classification code for demand response capabilities of electrical products*.'

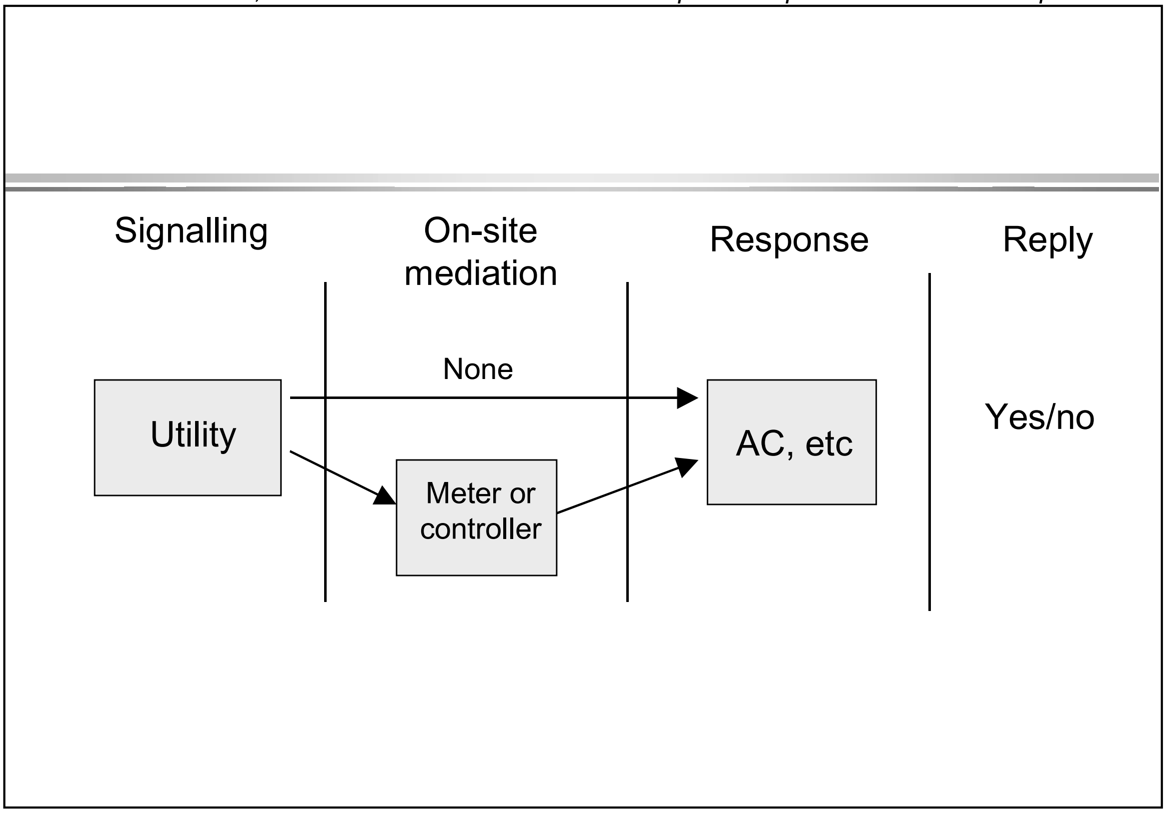

Figure 3. Proposed Standard Demand Response Capability (DRC) Classification

Table 1 Possible Standard Classification for Signalling

Type	**Description**
X	No means of communication, or no means of accessing it
A	Ripple control signal
B	Other powerline-carried signal (eg powerline internet) activation signal
C	Landline dialup internet
D	Landline broadband internet (copper, cable or fibre)
E	Landline other
F	Wireless internet
G	Wireless other (eg GSM, pager)
H	Other

Table 2 Possible Standard Classification for Signal Pathway and Mediation

Type	**Description**
x	No on-site mediation – utility signal goes straight to target appliance
a	Ripple relay receiver (hard wired – separate or built in to meter)
b	Ripple relay receiver (plug-in, for use at appliance power outlet)
c	Modem for internet
d	Wireless receiver
e	Simple interval meter (ie intelligence for price-response DRC resides elsewhere)
f	Smart interval meter (can initiate price-response DRC)
g	Multi-function 'Smart' controller
h	Other

Table 3 Possible Standard Classification for Appliance DRC

Type	Description
0	No known capability (ie either not meeting higher criteria, or not tested)
1	Can only be controlled by external power interrupt, but will restart after power resumes
2	Can be controlled by control circuit interrupt (eg compressor contactor) but no pre-existing contacts for that purpose (so needs on-site modification)
3	Equipped with external control ('dry') contacts (needs on-site cabling, but no modification of equipment itself)
4	Capable of off /on or other responses (eg settings) to external control signal/s, subject to installation setup, but no other on-site modification
5	Capable of off /on or other responses to external control signal/s, irrespective of installation setup (eg multi-function card in all units sold)

Perhaps the most powerful application of the typology will be in the interaction of the energy labelling and MEPS program and electricity utility demand management incentives. Air conditioner suppliers could choose to state whether their products were compatible with specific DRC functions, and buyers who wished to participate in their utility's DM program could identify those products and receive a rebate for purchasing them. Just as energy labelling stimulated the market for energy-efficient appliances, it can also stimulate the market for demand response.

Once there were enough products with DRC available, it would be open to governments to mandate disclosure of the level of DRC on the energy label. A suitable opportunity to do this may be at the proposed rescaling of the air conditioner energy label following the planned introduction of the more stringent MEPS for single phase air conditioners in 2008. Ultimately, meeting a minimum level of DRC could become a mandatory performance requirement, like meeting a minimum level of energy-efficiency. Any mandatory requirements would of course be subject to formal benefit-cost analysis and regulation impact assessment.

Increasing the availability and sales of DRC-compatible air conditioners would lower the costs of implementing load control programs, but would not of itself compel utilities to offer such programs or motivate consumers to participate. However, introducing DRC factors into the purchase process would facilitate other potential measures, such as requiring air conditioner buyers to install smart metering and to go on time of use tariffs. Another option would be to include a 'demand management bond' (say $500-$1,000) in the air conditioner purchase price, to be redeemable on connection to a time of use tariff or after a specified period of participation in a utility load control program.

Measures such as these may appear draconian and politically risky for governments, but they may well be less unattractive than the alternatives. They are justified on equity grounds, to reduce the cross-subsidy burden on non-air conditioner households and other electricity users, and on the grounds of increasing the security of electricity supply in a period where one of the highest risks of supply disruption is from air conditioner load. They would also have the benefit of increasing the competitiveness of demand-side responses in the national electricity market, by enabling the cost-effective aggregation and block demand bidding of air conditioner loads.

Costs and Benefits

The potential benefits of a large scale demand response capability are in some ways easier to quantify than the costs. Unpublished simulation work carried for the A-HELP project suggests that if about a quarter of the household air conditioners in the NEM area in 2004 had participated in DRC programs, the total saving to all electricity users would have been up to AU$ 1,345 million in that year alone. About 92% of this saving would have been from avoiding or reducing the operation of the highest-cost generators, and the rest from deferring network augmentation.

The simulated burden on participating air conditioner households was relatively light: not more than 0.5 hours off in every 4.5 hour period during the ten periods of highest wholesale pool prices. Whether that response were achieved by off—on switching by external agents (DRC Types 1 to 3 in Table 3), or by an average of 11% reduction in average load (Types 4 and 5 in Table 3) is immaterial to the outcome, but important to the program cost and level of customer acceptance.

The value of a demand response capability of this magnitude would be over AU$ 1,000 per annum per participating air conditioner. As the benefits would be distributed across all electricity users (including non-residential customers, households without air conditioners and air conditioner households not participating in the DRC program) the benefit accruing directly to participants would have been much lower. It would be up to regulators, electricity utilities and DRC aggregators to devise arrangements which capture the benefits and offer air conditioner households a high enough share of it so that they have an incentive to participate.

The costs of including a standardised demand response capability in every air conditioner sold cannot yet be known. However, they are certain to be significantly less than trying to add such a capability in the field after the air conditioner is installed. The capability could also be incorporated in other readily curtailable loads such as the controllers for swimming pool pumps (present in about one in ten Australian households), and possibly day rate electric water heaters. (Night rate or off-peak electric water heaters, common in Australia, are already under electricity system control. The scope for demand response in products such as clothes washers, clothes dryers or dishwashers may be limited due to safety concerns such as risk of fire or restart without warning, and the power reductions would be relatively minor).

The technology already exists to enable all the demand response capable appliances in a house (or a street, or an entire neighbourhood) to exchange information during high electricity price events, to optimise the collective response of all participants (within the constraints set by each householder), and to share the resulting cost savings.

International Implications

The great majority of air conditioners sold in Australia are imported and Australia is a relatively small market for air conditioners by world standards. The success of the A-HELP project relies heavily on the participation of global suppliers, who cannot be expected to incorporate DRC features (at however low a cost) without sufficient market demand.

Demand response and time of use electricity pricing in a less regulated utility environment are issues common to most developed economies. Developing economies face even larger problems from air conditioner load, since pricing tend to be even less cost-reflective and the supply systems operate under greater stress. The issue is probably even more pressing for economies at the beginning of the inevitable growth path in air conditioner ownership than for countries such as the USA, where air conditioner ownership and use are fairly mature.

The AGO has taken steps to engage the International Energy Agency (IEA) Demand Side Management Task (15 and 12) and the Asia-Pacific Economic Cooperation (APEC), to ensure that developments in Australia will be consistent with, and possibly become a model for, international standardisation. The AGO, with IEA support, is proposing to sponsor international workshops on the subject, possibly to be held in Europe and in Asia, over the next year.

The AGO has also proposed the inclusion of A-HELP and DRC in general in the scope of its Memoranda of Understanding with government agencies in the USA and in the Republic of Korea (the latter being the source of a large share of the air conditioners sold in Australia). It is proposed that the countries explore the scope for a common approach to direct load control. This will require discussions between government agencies, standards bodies, electricity utility interests and air conditioner manufacturer associations in the two countries.

Conclusions

Continuing growth in air conditioner use is inevitable, in Australia and elsewhere, due to a combination of greater wealth, changes in the built environment and global warming. Extreme day peak demand from household air conditioners is becoming one of the key drivers in electricity system capital investment, and one the main risks to supply system stability.

Energy-efficiency measures and programs have only a limited impact. A combination of time of use pricing and demand response is a more powerful strategy. Efforts to date have suffered from high costs and from limited application geographically. Costs can be radically lowered by standardising the hardware and software of demand response and building it in to all (or most) air conditioners sold. Even if the capability is used in only a fraction of installations, or only for part of the service life of an air conditioner (eg while the local sub-station is constrained) the costs are likely to be so low, and the benefits so high, that the strategy will probably be cost-effective.

This is the focus of the A-HELP project, which focuses on the Australian air conditioner market in the first instance. However, because the problems are common to many countries, and because air conditioners are so widely traded, the solutions must also be international.

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