The impact of home energy feedback displays and load management devices in a low energy housing development

D.M. Whaley, S.R. Berry, W.Y. Saman

Barbara Hardy Institute, University of South Australia

Abstract

Home energy feedback display and monitoring systems are a key feature of Australia's leading eco-friendly housing development at Lochiel Park in South Australia. The displays comprehensively measure electricity, gas and water usage in real-time, and can manage loads during periods of peak electricity demand. The houses are designed to be near net zero energy homes and incorporate a high performance building envelope, roof-mounted photovoltaic panels, solar water heaters and energy efficient appliances.

The paper describes the display and monitoring systems, summarises samples of delivered energy results for selected households, and the average for Lochiel Park. The results show that despite living in similarly constructed houses, often with the same number of occupants, there are significant monthly and annual variations in net delivered energy.

In addition, This paper draws on a series of in-depth interviews to discuss the residents' attitudes towards, and experiences interacting with, the in-home feedback display and associated energy systems, and describe how feedback displays may assist residents understand their end-use energy behaviour, reduce their net energy use, and assess whether household appliances and energy systems are operating correctly.

The interview responses reveal a mostly positive attitude to the energy feedback displays, but a generally negative attitude towards the load management system. This negative response may be due to the lack of perceived benefits from such a device, and a poor understanding of how to operate this feature. Finally, this paper outlines the residents' suggestions for improving the energy feedback monitoring systems.

Background

Evidence presented by world leading climate scientists is showing that anthropogenic greenhouse gas emissions has reached the level which is altering the global climate, and continued high use of carbon based fuels will further exacerbate the problem [1, 2]. Leading economists have suggested that human impact on the global climate is one of the greatest economic, social, political and environmental challenges facing this generation and our immediate future generations [3, 4].

In most developed nations housing has evolved to the degree that households expect high levels of thermal comfort, the convenience of an almost endless supply of electricity available at the flick of a switch, and hot water on demand, irrespective of the environmental impact of making that energy available [5]. Increasing demand for thermal comfort and other energy services around the world, combined with factors such as increasing population, all contribute to a continuing upward trend in energy demand [6]. Housing expectations and cultural norms, embedded institutional construction practices, regulatory standards and dominant technologies have evolved without due consideration of the resultant ecological footprint [7]. What we build, the appliances we install, and the way we operate our buildings is the result of many social, economic and technical influences, such as the cultural institutions that shape communities, the technology norms applied by industry, the education and training of actors that meet market demand for new housing, and the experience of households that demand and use new residential products [8]. This interaction of actors, institutions, rules and technologies over many years has brought us to the point where housing in many nations has a significant negative impact on the local environment and the global climate [9].

Concern for anthropogenic greenhouse gas emissions has prompted individuals, communities and governments in many countries to consider reducing building energy use and thus lowering the carbon impact of the building sector [6, 10]. Researchers and government agencies alike have suggested that improving the energy and carbon performance of residential buildings will play a key role in delivering substantial and sustainable greenhouse gas emission reductions in developed economies [11-14]. This energy and carbon emission reduction will likely be the result of changes in the technology applied to buildings, changes to the design of buildings, and changes to the way we operate our buildings and appliances [15].

Responding to concern over building energy use and residential greenhouse gas emissions, the South Australian Government chose to showcase the cutting edge of climate relevant sustainable urban development by creating Lochiel Park, a model green village of national and international significance [16].

Creation of Lochiel Park

The Lochiel Park Green Village is a planned estate of 106 residential dwellings, created though the policy initiative of the State Government of South Australia, with estate design and management by a government agency, infrastructure and housing constructed by the private sector, and the majority of dwellings sold to the general public through the local real estate industry.

Located on 15 hectares of surplus government land, approximately eight kilometres North-East of the Adelaide central business district [17], the development was originally intended to be disposed to the property market as a standard broad-acre land sale of 150 residential allotments, but a change of state government introduced new policy objectives including an increased interest in environmental outcomes [18]. This resulted in the Premier of South Australia declaring in 2004 of the project’s new intent [18]:

> “I want South Australia to become a world leader in a new green approach to the way we all live. The Lochiel Park Development will become the nation’s model ‘Green Village’ incorporating Ecologically Sustainable Development (ESD) technologies.”

Given explicit direction from the State Premier to develop a niche green urban estate of world standing, an advisory panel of state and local government officials and community representatives was established to define high level objectives across a relatively broad range of areas including environmental sustainability, social sustainability, urban form, transport, industry development and economics [17]. By benchmarking against major international and national niche green residential developments, performance targets were set covering potable water, open space, water recycling, energy technologies, revegetation, solar passive design, waste reduction and management, designed building life span, local transport use, community interaction, and many other impacts. These detailed targets were refined in consultation with the various expert groups [18], with final design overarching targets set at a reduction of:

- 66% energy used
- 74% greenhouse gas emissions
- 78% potable water use

Expert consultative groups for energy and water were used to translate the original targets into rules and guidance materials that could communicate the desired sustainability principles to be applied to each house. These were published in the Urban Design Guidelines [19], with minimum requirements including:

- 7.5 NatHERS Stars thermal comfort
- Solar water heating, gas boosted
- 1.0kWp photovoltaic system for each 100m^2 of habitable floor area
- High star rated appliances
- Low energy lighting (CFLs & LEDs)
- Ceiling fans in all bedrooms and living spaces
- Rainwater harvesting feeding the hot water system
- Treated storm water feeding toilets, cold laundry taps and irrigation
- An in-home energy use feedback display

The Guidelines established a new set of rules, calling for practices outside existing institutional and professional norms, requiring the application of technologies and systems uncommon to the mainstream building industry, and the consideration of new performance indicators bringing new concepts to building design and construction practices. These Guidelines meant that households were exposed to different technologies and styles of house design compared to new dwellings commonly available in South Australia.

Upon the release of the Guidelines, housing product was offered to the open market in 2007 with construction of the first homes beginning in 2008. The majority of the housing allotments had been sold by mid 2011, and the majority of the homes completed and occupied by late 2012.

This paper provides an insight into the energy performance of this green village, and in particular examines the effectiveness of in-home energy feedback displays in encouraging behaviour change. The paper is structured to provide a short review of the academic literature on the use and effectiveness of energy feedback displays, discuss the methodology and monitoring systems used in Lochiel Park, explore the energy performance of the development, and examine the findings from the in-depth household interviews.

Literature Review

Energy use feedback typically exists in the form of periodic energy bills or through the need to gather and prepare fuel for cooking, heating and cooling or lighting. In developed and many developing countries, energy use feedback is often provided by regular bills based on metered consumption or predicted consumption of electricity, gas or liquid fuels. This feedback process is temporally removed from the day to day energy services that are responsible for the energy use, with billing intervals often monthly, bimonthly or quarterly. Metered bills typically show cumulative consumption over the billing period and are very unlikely to disaggregate consumption by end-use or time, while bills based on estimated consumption prevent households from recognising any relationship between energy services and energy use [20]. More recently, complex real-time of use information, even disaggregated to typical end-use, has become possible via computers, mobile phones, and other portable devices [21].

Readily accessible energy use information for households has been found to facilitate experimentation, encourage learning and support good energy management practices, but while feedback is necessary for the learning process, feedback on its own may not be sufficient to bring about behaviour change [20, 22]. Darby [20] notes that energy use feedback has an educational impact as well as directly impacting behaviour, facilitating a greater consumer understanding of the relationship between energy services and energy use.

Energy feedback is not limited to the provision of energy use information. The recent acceleration in the uptake of domestic rooftop solar photovoltaic panels by the general public has meant a more widespread distribution of electricity generation and household tracking of energy generation data. Evidence is available demonstrating that building-integrated electricity generation with feedback displays can lead to energy demand reduction [23, 24].

A number of studies have identified energy savings associated with the use of in-house energy feedback displays [20, 25-28], with the energy saving impact of feedback technologies varying modestly across the literature. Ueno et al. [27] monitored the energy use of 8 households in Japan pre and post the installation of an in-home interactive feedback display, finding an average 9 per cent energy saving in the first two months after installation. Darby [20] summarised the results of various feedback studies and noted that savings of between 5 to 15 per cent were associated with direct feedback displays. Faruqui et al. [25] examined a dozen North American and international pilot programs and found that energy savings range from 3 to 13 per cent, with an average of 7 per cent. Ehrhardt-Martinez et al. [26] reviewed 23 mostly North American programs and found that energy savings associated with real-time aggregate feedback typically fall somewhere between 0.5 and 18 per cent. Stromback et al. [28] investigated 74 energy feedback trials in Europe, North America, Australia and Japan reporting average savings of 8.68 per cent for in-home displays.

The amount and type of displayed information are important factors in the success of achieving energy savings [22, 26, 29]. Darby [22] and Ehrhardt-Martinez et al. [26] have found that 'direct' feedback, such as real-time energy use data, has a significantly larger impact than 'indirect' feedback, such as billing data provided after consumption has occurred. Ehrhardt-Martinez et al. [26] and Fischer [29] argue that greater savings occur when information is more frequent (current) and more detailed (disaggregated).

Ehrhardt-Martinez et al. [26] also noted a relationship between the energy savings impact of the study and the period of householder interaction with feedback information, finding that average energy savings tend to be higher for shorter studies (average 10.1 per cent) than for longer studies (average 7.7 per cent). This raises the issue of sustainability for energy use behaviour change due to direct feedback systems. Ueno et al. [27] found that energy saving behaviour extended beyond the technology associated with the direct feedback information, demonstrating that in-home feedback displays help householders become more energy literate and develop new behaviour patterns. For the small sample of houses in their research, Ueno et al. [27] found that total energy use of the appliances displayed on the feedback system was reduced by about 12 per cent whilst the total consumption of the not-displayed appliances was reduced by about 5 per cent.

The literature also identifies different levels and types of energy savings. Ehrhardt-Martinez et al. [26] found three categories of action: 1) simple changes in routines and habits, 2) infrequent and low-cost energy stocktaking behaviours (i.e. replacing incandescent bulbs with CFLs), and 3) investments in new energy-efficient appliances, devices, and materials. The study noted that most of the energy savings achieved through feedback programs resulted from changes in behaviour rather than investments, although greater savings were achieved by those households that invested in new technology.

The literature shows that households can react quite differently to the availability of energy use feedback data [30]. In a study of various in-home feedback display devices in Sweden, Vassileva et al. [30] found that 47 per cent of the participants interacted with the display quite often, while 19 per cent of the participants never consulted it. This study also found that the use of energy feedback displays with low-energy use households might, in some cases, cause an increase in energy use.

The Australian specific research into the effectiveness of in-home energy feedback displays is reasonably limited with results available from only two small-scale surveys, both of which are limited because the sample households were in the early stages of interaction or had virtually no experience interacting with the newly installed technology [31, 32]. This paper provides an opportunity to survey a larger group of households, most with multi-year experience interacting with in-home energy feedback displays.

Methodology

This research was based on the analysis of quantitative data collected from installed monitoring systems, and the analysis of qualitative data collected from interviewing 10 resident households living in Lochiel Park.

Resident Interviews

To understand the experience and perceptions of residents, primary qualitative data was gathered through a set of 10 in-depth interviews, with residents selected at random from a field of over 60 candidate households who had lived at Lochiel Park for a period not less than 12 months. All volunteer households were owner-occupiers, who represent the largest resident type at Lochiel Park. Where possible all adult owners of the same household were interviewed together, but where this was not possible prompts were used to enquire into any differences likely between the adult residents. For households with children, additional prompts were used to enquire into their likely usage of the energy feedback display.

The semi-structured interviews [33], conducted 'face-to-face' in their home, utilised open-ended questions to provide a replicable focus on the research questions, and were designed to explore the experiences and perceptions of households.

The questions probed the experience of residents during the home buying and construction phases, their perception of thermal comfort and ease of operating a passive solar home, and their experience interacting with new energy technologies such as solar photovoltaics, solar thermal water heaters and the energy feedback displays.

To protect the confidentiality of the interviews, anonymous verbatim quotes are used to illustrate points. Elsewhere the original language used by interviewees has been incorporated into the paper, or paraphrased with a light touch to facilitate the clarity of the message.

The information collected from the interviews was triangulated through a comparison with the experience of the principal authors, who have interacted with almost all potential candidate households at Lochiel Park on related energy use research. The researchers have informally discussed the use of the feedback displays with residents separately, sometimes on multiple occasions. These interactions have been used to test whether the sample survey results are representative of the experiences of the total potential population. Comparisons are also made with the findings of the 2010/2011 series of Lochiel Park residents' interviews and an associated survey [32]. This series of interviews was conducted during the early stages of the development of Lochiel Park when only around a quarter of the homes were occupied, and during a period when many residents were still establishing their household routines and behaviours, but nevertheless these interviews provide a valuable comparison with the more recent series of interviews.

Overview of Lochiel Park Monitoring Systems

The data presented in this study is based on monthly analysis of one minute interval data collected from the in-home displays installed in each Lochiel Park dwelling. Although the systems collect electricity, gas and water use, and electricity generation information, the focus of this paper is on individual household delivered energy, i.e. the difference between the onsite energy consumption and that generated onsite.

Each home is fitted with an 'EcoVision' brand monitoring system, which incorporates an in-home display, a programmable logic controller (PLC), and an array of intelligent meters and sensors [34, 35]. This equipment measures and displays the residents' electricity, water and gas use, plus solar photovoltaic electricity generation, in real-time. This level of monitoring is referred to as *general* in the data reported in this paper. In addition, In addition, other information are monitored in 10 of the houses, such as the indoor air temperature and relative humidity, the electrical consumption of up to eleven energy services (including heating and cooling, lighting, laundry, etc). This is referred to as *detailed* monitoring. Table 1 summarises the data measured by each monitoring system. Detailed information is available in [34].

Table.1: EcoVision measured and calculated parameters for the general and detailed monitoring systems. Note (D) indicates digital, (A) represents analogue sensors [35].

	Electricity (kWh)						Water (L)					Tank Level (%)	Gas (L)		GHG (kg)	Temp / RH
System	Solar (D)	Import (D)	Export (D)	Total*	Net*	Individual appliances (D)	Mains (D)	Recycled (D)	Hot Usage (D)	Mains Hot (D)	Rain*	Volume (A)	Mains (D)	Hot Water (D)	Greenhouse Gas Emissions*	Living , Lounge, Bed rooms (6 A)
General	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	×	✓	×	✓	×
Detailed	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

A detailed monitoring system schematic is shown in Figure 1. The figure identifies the EcoVision touch screen, the PLC, the optical network terminal (ONT), the contactors, the interconnecting cables, and the various analogue and digital sensors. Note that an overview of the general monitoring system can also be seen in the figure, due to the common components (i.e. the 8 digital sensors surrounded by the dashed box). Raw data from each system is collected remotely each month.

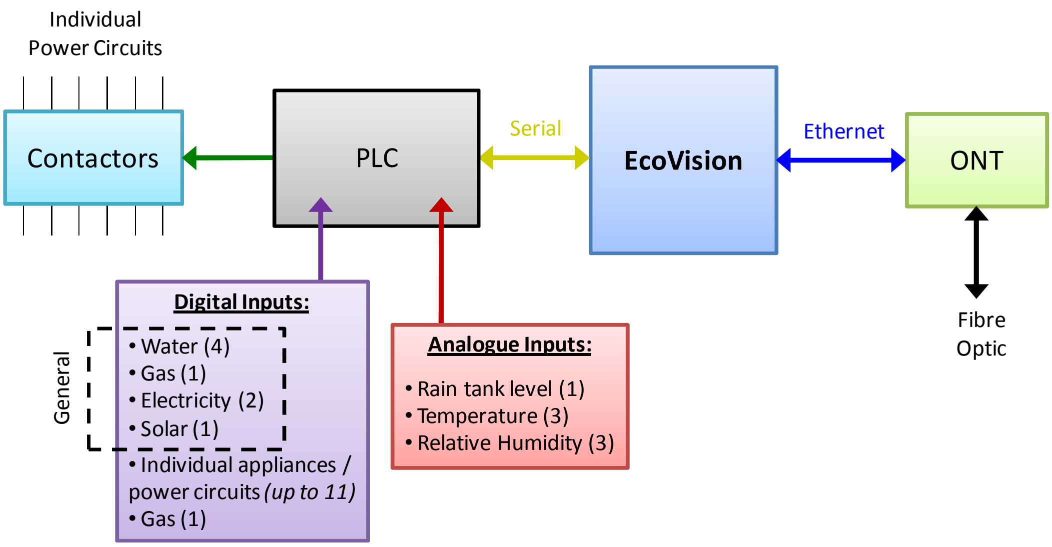

Figure 1: Overview of the detailed monitoring systems, showing various components. The dashed box represents the sensors used in the general monitoring system [35].

The system can also control the peak power demand by limiting it to a preset value. A feature of the EcoVision monitoring system allows peak energy demand events to be managed by interrupting the power supply to up to 6 individual power circuits or appliances by controlling specific contactors. The contactors are typically wired to appliances such as reverse-cycle air conditioners; pool or spa pumps; ovens and dishwashers, and power circuits such as laundry and kitchen. The load limit and the order in which appliances are deactivated are customised by the resident. The feature shuts down nominated appliances until the electricity load falls below the preset limit. Due to safety reasons, deactivated appliances are not automatically re-energised; this must be done by the resident manually. The Load Management feature is voluntary, and to encourage initial uptake the electrical retailer offered a small financial incentive to residents who maintained a 3kW limit at all times, however, this incentive is no longer available.

The heart of the EcoVision system is the in-home display which offers residents direct feedback, and real-time monitoring. The touch screen allows users to quickly summarise their consumption by time period and type of fuel / water, for any desired hour, day, week or month. Data is displayed numerically as well as in bar charts. The *detailed* monitored systems also offer a small degree of electrical energy consumption disaggregation, by breaking down how much energy is consumed by specific appliances or power circuits. Figure 2 shows (a) a summary of electricity consumption and generation for one day, and (b) shows the appliances whose power had been interrupted by the load management feature.

Figure 2: EcoVision screens, showing (a) electricity consumption and generation, and (b) appliances deactivated by the load management system, for a period of one day.

The EcoVision system not only provides real-time information, it also allows users to compare their energy use and generation historically by month, week, day or hour. It also has the capability of converting the energy consumption to associated greenhouse gas emissions. Currently the system does not allow residents to directly compare results against other residents' usage or estate averages.

Energy Performance of Lochiel Park Homes

Figure 3 shows the average delivered energy for the entire estate over a 12 month period. The dashed blue line represents the estate's average, and shows the monthly standard deviation as vertical bars, whilst the red dots represent the average of the households interviewed in this study. The close agreement between the two averages indicates that the interviewed households are broadly representative of the estate as a whole. Note the number within the round brackets of the x-axis represents the number of households within the estate for which data is available to calculate the average. This number generally increases over the monitoring period as newly constructed houses are connected to the monitoring system, however, in some instances the number slightly decreases due to intermittent data collection system problems.

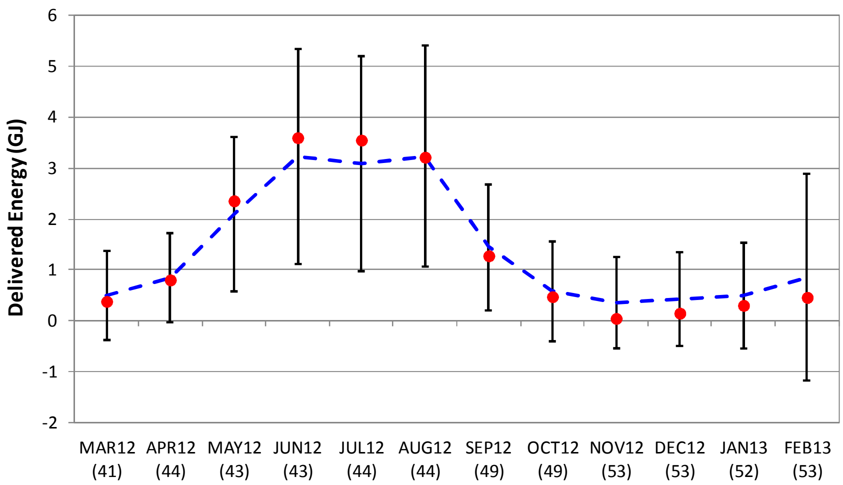

Figure 3: Average monthly delivered energy for Lochiel Park households (blue dashes), and for the subset of interviewed households (red dots).

Figure 3 also highlights three key features. Firstly, some Lochiel Park households are operationally net zero or below zero energy for summer months and those months immediately pre and post summer. Such a result demonstrates the successful application of low energy house design and fitout for temperate Australian conditions. Secondly, the average of the interviewed households is similarly zero or near net zero energy for those months. Thirdly, the large standard deviation span, particularly for winter months and late summer (February), indicates that there is a significant spread in net delivered energy for some households. This is despite the many common design and resident characteristics and energy system fitouts.

Figure 4 below shows the net delivered energy per month per resident for each of the interviewed households. After normalising for the number of residents in each household, the monthly delivered energy varies significantly between households, possibly indicating different energy consumption behaviours and/or the impact of differences in patterns of use and efficiency for particular appliances and equipment. In general, each house follows the same trend of higher delivered energy in winter months, most likely due to a combination of significantly lower solar photovoltaic electricity generation, higher artificial lighting use, and higher heating demand. Note that some of the interviewed households are missing data points, due to intermittent monitoring system faults.

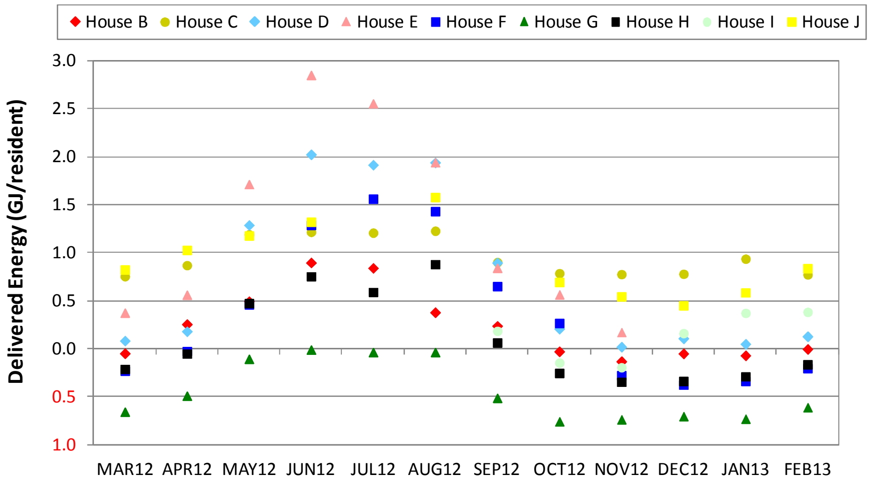

Figure 4: Normalised average monthly delivered energy per resident of the interviewed households.

Figure 4 shows that three of the interviewed households achieve below zero delivered energy for six months of the year, whilst another achieves this for five months. In addition, the figure highlights two key features: firstly, Households D and E require higher amounts of delivered energy in the winter months. This is probably due to use of gas space or underfloor hydronic heating, whilst the remaining households utilise reverse-cycle air conditioners with a high coefficient of performance. Secondly, Household G consistently achieves operationally net or below zero energy performance. This is probably due to the combination of frugal energy use, an all-electric house with high efficiency appliances, and a relatively large solar photovoltaic system to offset expected electrical loads.

Comparison with other Households

Although the results from Figures 3 and 4 demonstrate that some Lochiel Park households require near zero delivered energy for either part or full year periods, the performance of these households should be compared with other existing data sets for similar homes and similar climates to properly gauge their performance. Figure 5 compares the delivered energy of the interviewed houses per habitable floor area, with existing data collected by the research team for a nearby new housing estate (Mawson Lakes, MLK) in 2002/03, and with current state (SA AVG) and Australian (AUS AVG) national averages [34]. Note that the total delivered energy for Houses E, I and J has been extrapolated to correct for incomplete data sets.

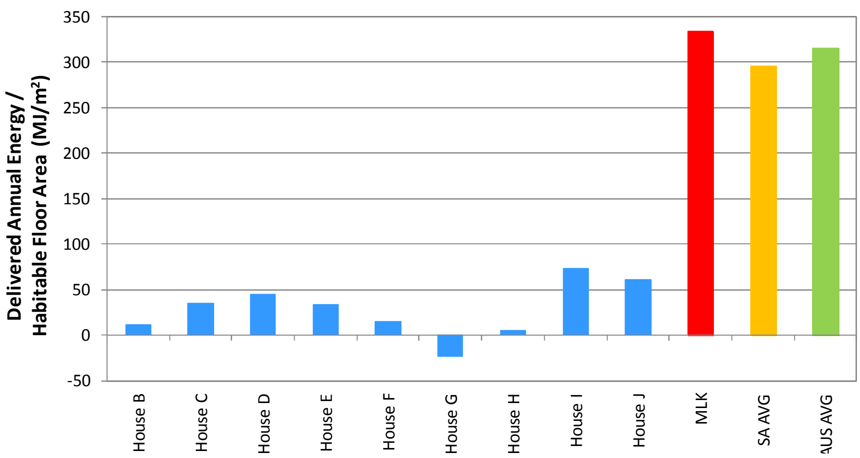

Figure 5: Delivered annual energy per habitable floor area for the interviewed households, a sample of Mawson Lakes households, and both state and national averages.

Figure 5 demonstrates that Lochiel Park households require significantly less delivered energy compared with the monitored sample of new homes from the Mawson Lakes estate, and compared to both the state and national averages for all households (including apartments, units and holiday homes).

Interview Findings and Discussions

The level of interaction between the households and their in-home energy feedback display varies widely from no engagement, to occasional use, to multiple daily interactions. Differences can be observed across gender and age, with females less likely to use the display, and older (retired persons) less likely to have high frequency (daily) interaction with the feedback system.

The majority of households (6/10) had daily interaction with the feedback display, 3/10 households had occasional interaction and one household never interacted with the display. These figures hide differences between genders, whereby almost all male adults (9/10) interacted with the feedback display, yet 4/10 female adults stated they had no regular interaction with the display. The response from Household E characterises a reasonably typical level of interaction with the feedback system:

> *I think it's useful, I value having it there, I look at it most days.*

The frequency of interaction is slightly lower than that noted in the previous study [32], which found 80 per cent had daily interaction, but this may be explained by the novelty of the system wearing off with residents. Our research found a perception that use patterns have changed since the initial period of interaction, with half of the households suggesting they use the display less now than in the first 12 months of having the system available. One household felt that they have increased their usage of the display as they have grown more comfortable and confident using the system and the information provided. Household H represents the majority perception of usage changes, stating:

> *Less, a lot of it's the curiosity and learning the patterns of our usage.*

The Edwards and Pocock [32] research was conducted during the first months of occupation for the first tranche of Lochiel Park households, and changes to interaction frequency have most probably occurred as households settle into their new home, lose some of the initial curiosity with the display, and become more familiar and comfortable with the various energy technologies and the pattern of their use.

Very few households (2/10) keep detailed tracking of daily energy use and electricity generation, manually transferring data from the feedback display to separate spreadsheets. Other users more casually track energy use and electricity generation. Household J used the monitored energy data to help predict the size of their next energy bill. Household B represents a high frequency user, revealing:

> *'I love the touch panel. I keep an ongoing spreadsheet of all our daily solar generation and electricity usage.'*

Most higher frequency users asked for Wi-Fi or Bluetooth compatibility to allow data downloads to other devices. Almost all households (9/10) considered some value in having the feedback information available on other devices such as mobile phones, tablet or laptop computers, particularly so data could be checked when residents are away from the house (i.e. at work or on holidays). Some households suggested greater value could be gained from the feedback displays if they could facilitate other activities such as linking to the internet, or allow settings for their solar water heater to be altered. Some users expressed frustration that variables such as energy prices and the time-clock could not be altered by residents, reducing the accuracy and usefulness of the output information.

The feedback displays were most often used for checking electricity usage, electricity generation from the solar photovoltaic system, and to a lesser extent, water usage. The residents of a detailed monitored house also monitored the amount of water available in the rainwater tank, using their display. One household found the gas data confusing. Household B expressed a desire to use the data to track the deterioration of photovoltaic panels over time. The monitored data was also used for fault identification, with five of the households mentioning how the in-home feedback display was helpful in identifying system failures or underperformance. For example: Household F checks the solar generation data on a regular basis to ascertain whether their DC/AC inverter is still operating, as a response to the original inverter burning out.

Several households thought that comparing their energy and water use with others in the Lochiel Park estate would be useful. Household C suggested a creative competition to encourage behaviour change by having an energy use challenge across the estate, with households able to see the energy use patterns of other Lochiel Park households.

Most households (7/10) felt that the system was easy to use, although comments were made from some who felt the software was not intuitive. This finding is similar to that of Edwards and Pocock [32] who found 80 per cent of households perceived the feedback displays to be easy to use. Household C provides a typical response to the question of ease of use:

> *Yeh, not a lot to it really.*

Several households suggested that some of the information provided was confusing, particularly the time axis information which doesn't show the actual time of use. This may limit the user's ability to recognise the relationship between specific technology use and energy use. Household H stated:

> *On the timescale it's not registering the time of day, so I can guess when the graph timescale is. I can see the beginning of the day and end of the day …*

Few (3/10) households had attended a training session, with 6/10 suggesting that either more guide material or training would be useful.

The Load Management feature of the system was not being used by any of the households. Many households thought that feature was no longer operating, others thought the feature was of little value to them for they were already very energy efficient. Household B did not use this feature because they wanted to maintain control of all electrical appliances and equipment. Household E had used the feature but found it 'useless' after it turned the washing machine off when they needed the clothes washed. Household G attempted to use the feature without success. Household I thought it was 'conceptually fantastic, but not a good feature at the moment', and referred to a negative experience of another Lochiel Park household that was not interviewed in this study. Household F was typical of responses to this feature:

> *[person's name] did mentioned that and explained it somewhat, but we haven't sort of run into that territory where we've been motivated to need to do it, …*

The majority of households (7/10) believe they have modified their behaviour due to their interaction with the feedback system. And although the quantum of behaviour change could not be determined with any confidence through the interview process, two of the households suggested their behaviour changes were relatively small, but others have achieved larger savings. Household D noted that they disposed of an old second refrigerator because it used too much electricity for the pleasure of providing cold drinks. When asked about behaviour change Household J felt the feedback system had been instrumental in helping them alter their energy use behaviour:

> *Yeh, definitely; the last two billing periods we have really examined what we using and how we are using it and have made some significant changes.*

Other households were not as positive about the affect of the feedback display of their energy use behaviour. Similarly Edwards and Pocock [32] found that some households considered their behaviour to be reasonably energy efficient and suggested that their behaviour would not be greatly affected by the feedback display. This type of response was identified in our interview series, with Householder I stating:

> *'We're here because we already were wary of our behaviours, we had already taught ourselves to conserve power .... Our behaviours had already changed, and they go on changing as we read more and we live in our house, but the screen is not part of that.*

The displays provided a variety of other benefits. Several households noted they use the feedback data to maximize their economic return from the local solar feed-in tariff, by reducing electricity use during photovoltaic generation hours and maximising export to the grid when electricity is at its highest value. Household C has used the feedback display to determine the energy use change associated with installing standby-load reduction technology.

The display was also being used as an educational tool, both to other members of the household and to visitors. Both Households D and G noted the value of showing the display to visitors.

An issue expressed by many households was the importance of service to maintain and repair the in-house feedback system. Several households talked about sensor faults, poor levels of response from the display provider, the slow process for software upgrades, and the lack of technical support. Household J raised the question of whether the system will be maintained for the life of the house.

Overall the value of the in-home energy feedback system is reflected in the number of households that wish to have a system in their next home. Six out of ten households suggested they would like a feedback system in their next home, although not all wanted the same brand of monitoring system, and one household qualified the response with concern about the system's affordability. On the whole there was sufficient interest to suggest the majority of households valued having live energy use and electricity generation monitoring in their home.

A larger sample of Lochiel Park households will be interviewed or surveyed to gain further understanding and insight into the experiences of residents and their in-home energy feedback displays. The larger sample size will facilitate a broader range of both quantitative and qualitative analysis investigating relationships between energy usage and other factors, such as demographics, frequency of interaction with displays, perceived need for energy services, and perceived energy use behaviour change.

Conclusions

The paper has provided integrated technical and social research on the outcomes of a world class model green village which demonstrates how building design and practices, energy efficient appliances, renewable energy technologies, and household behaviours may lead to a more environmentally sustainable lifestyle. The Lochiel Park development includes the first large-scale residential development in South Australia with in-home energy feedback displays.

Detailed energy use and electricity generation monitoring has demonstrated that households in the Lochiel Park Green Village use substantially less delivered energy than others residing in new homes in the same climate.

A series of ten household interviews, backed by informal discussions with over fifty households, provides a new insight into the interaction of residents with in-home energy feedback displays. This new research is compared with data collected from the first tranche of households arriving at the same housing estate.

The research has found that the majority of households interact regularly with the feedback displays to examine their energy use and solar generation, but a small number of households have little or no interest in drawing on the available energy use information. Most households, even some who rarely use the displays, find the system easy to use.

Households perceive that the frequency of use has lessened over time as the curiosity wanes and they establish more regular patterns of energy technology use, but many households maintain daily interaction.

The load management feature of the system is not being used by any interviewed household, and few considered the feature useful. This is not surprising as there is no current financial incentive for limiting the peak demand.

The evidence from the interviewee perceptions is that the energy feedback displays assist households to reduce their energy use and identify energy system faults, although the quantum of energy saving is difficult to ascertain. Most households considered the feedback displays to be valuable tools and indicated they would most likely install similar technology in a future home.

The research has found that in-home energy feedback displays may play a useful role in supporting and encouraging energy use behaviour change, leading to lower energy use.

Acknowledgements

The authors wish to acknowledge the funding and support provided by the CSIRO's Intelligent Grid Cluster. They would also like to thank the support and information provided by Renewal SA, in particular Andrew Bishop and Phil Donaldson. Finally, the authors wish to thank Dr Anne Sharp for her valuable advice and assistance in shaping the Lochiel Park residents' interview design.

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